AN ABSTRACT ON THE THESIS OF

David C. Vasquez for the degree of Master of Science in Radiation Health Physics presented on February 26, 2010.

Title: The Design, Use and Implementation of Digital Radiation Detection and Measurement Equipment for the Purpose of Distance Instruction.

Abstract Approved:

David M. Hamby

Digital Instrumentation and Detection is becoming the future of radiation detection and measurement. Computers are able to perform digitally what before would have taken an extensive array of analog equipment. The art of teaching radiation detection and measurement is following this same pattern of a shift from purely analog to digital, computer-based equipment.

This thesis will involve designing software composed of digital equipment that will allow for distance students to learn the fundamentals of radiation detection and measurement. It will do so by using LabVIEW to create three detectors including the GM tube, Proportional Counter and Scintillator. The other associated instrumentation equipment that will be modeled includes a pre-amplifier, amplifier, SCA, MCA, and dual-counter/timer

The end goal is that distance students can successfully learn the same fundamental principles of radiation detection as their on-campus counterparts.

The Design, Use and Implementation of Digital Radiation Detection and Measurement Equipment for the Purpose of Distance Instruction

by
David C. Vasquez

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presented on February 26, 2010.

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

David C. Vasquez, Author

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1 INTRODUCTION

1 Introduction

1.1 Overview

As with most other electronic devices, nuclear instrumentation began as purely analog equipment used to detect and quantify ionizing radiation. The first instruments were rather rudimentary and did not always provide the most accurate picture of the radiation's energy or type. With the progression of technology, increasingly more accurate ways of measuring radiation came into play and many kinds of detectors have been developed. Today, many different types of detectors, such as the Geiger Muller Tube, Proportional Detector, and Scintillators, are all used to detect radiation.

With the need to teach students the fundamentals of radiation detection, comes the need for a lab full of costly detectors and supporting equipment. Also, with the progression of technology, comes the use of computers to the field of radiation detection.

Computers shaped and defined this thesis in two direct ways. First, computers and the internet have resulted in the creation of distance education programs across the country. A problem that occurs when students receive their education from a distance is that the off-campus students do not have access to the necessary lab equipment that is available to the on-campus students. Another major revolution in the field of radiation detection is that computers have brought about an ability to analyze pulses in the digital realm even though they originate from analog equipment. By processing signals digitally we have the ability to extract more information and therefore provide better detection capability.

In this work we create a software program that allows distance students to carry out laboratory exercises intended to teach the fundamentals of analog detection equipment that would be taught in an advanced radiation detection class. Through the use of this software, distance students will take part in radiation detection labs through a virtual classroom with virtual detection equipment.

1.2 Goals and Objectives

The overarching goal of this project is to complete a body of work that covers, in detail, the theory and processes necessary to create a virtual detection lab with multiple equipment modules. The behavior of the analog equipment being simulated in the virtual realm follows distinct mathematical models; these models will be programmed into LabVIEW for the virtual equipment to follow all of the behaviors of real equipment, as closely as possible.

The objectives of the work include modeling the following equipment:

- Geiger Muller Tube
- Proportional Counter
- Scintillation Detector
- Signal Splitter
- Pre-amplifier
- Amplifier
- Oscilloscope
- Dual Counter/Timer.

Radioactive sources will also be modeled so that the student can analyze radioactive decay and its subsequent detection.

Another key objective is to review the literature dealing with teaching digital labs and digital instrumentation in order to determine how to combine the methods of teaching and learning in this new style. When this aspect is successfully completed the distance students will have been exposed to nuclear instrumentation through these virtual labs similar to those who completed the labs on-campus. The final objective is to carry out a lab for NE/RHP 536 with the program created in LabVIEW and compare this to the same lab carried out with real detection equipment.

The application of this program is to be a virtual lab for distance-education students to learn about radiation detection. This will include explanation of the process, application, and equipment involved. The work will also familiarize students with digital detection which, in the future, will become more and more blended with analog detectors. In the near term, students will have some form of physical detector that detects radiation and then feeds this information into a computer for processing and analyzing (Ellis & He, 1993).

2 BACKGROUND

2. Background

2.1 Distance Education and Virtual Labs

2.1.1 Virtual Labs

Distance education is quickly becoming a very popular method employed by high schools, colleges, and universities to provide instruction to students who otherwise might not be able to attain higher education. Conducting virtual classes is done by recording the class and allowing access to distance students by streaming the lecture via the internet. Conducting labs this way is more difficult because the students often need to have physical access to detection equipment. For distance classes involving labs, there are two main options; the students physically travel to the university and undertake the course, or the lab equipment and materials are provided virtually. There are many key benefits to having a virtual laboratory. For students, the benefits that this project will provide are accessibility to both equipment and virtual training.

There are five key questions that need to be addressed when establishing a distance lab and teaching virtual labs (Hatherly, Jordan & Cayless, 2008):

- Will the distance student be able to successfully conduct the labs and learn the required concepts;
- Should a lab manual be developed specifically for distance students;
- Are there any flaws or bugs present in the software;

- What is the students perception and reaction to the program; and
- Does the program achieve its goal of allowing students to successfully complete the distance labs.

The first three points will be addressed herein by undertaking the labs and adding instructional information to the manual as the distance labs are developed. As an example, one of these labs will be presented in Section 5, and discussed in detail. The remaining two points outlined above will constitute future work and will be implemented as changes are needed, and as student feedback is received.

2.1.2 LabVIEW as a Design Interface for Virtual Labs

Using a computer interface to create virtual labs for students is a relatively new concept made easier through the use of LabVIEW, designed specifically for digital instrumentation. One of the key aspects, in addition to creating digital equipment, is that the end user will see and control all instrumentation in a virtual environment. Initially, LabVIEW could only be run on computers that had LabVIEW installed. Now, LabVIEW allows for remote monitoring and remote control through web-based browsers (Swain 2009). This means that students conducting these labs can run the program from a remote server through their browser at home.

Currently, South Carolina State University uses a simple remote LabVIEW interface to allow students to control SMILEY, a virtual satellite completely designed in LabVIEW. The program allows those outside the University to control SMILEY through any supported internet browser. Key to their research are some important limitations examined and pointed out that could crash a virtual program. These included system failure when the network is down, virus problems, information theft, and remote access failure through system firewalls (Swain, Anderson & Singh, 2003). The only two of these anticipated to be problematic for our purposes includes system failure when the network is down and remote access failure through system firewalls. Student users will be given instructions on properly setting the security of their firewall. A network outage, however, is something outside the control of these virtual labs, but it is not expected to be a problem of significance.

2.2 Software

2.2.1 LabVIEW

LabVIEW is a software program designed to mimic real laboratory instruments. For instance, LabVIEW can be programmed to perform the same functions as an analog NIM Bin amplifier, except that it would do so digitally without the user having to physically touch the equipment. The programs that run in LabVIEW are known as VIs because they are Virtual Instruments. LabVIEW has three key interfaces that the programmer uses;

- Front Panel;
- Block Diagram; and
- Icon and Connector Panel.

The front panel is what the student will see and use to control the LabVIEW program as it runs. The student will only have access to the Front Panel. The panel shown in Fig. 2.1 is a very basic program where the student would have access to a gain dial that adjusts the amplitude of the sin function being displayed in the graph; the height of the sin function is dependent on the level of gain being applied.

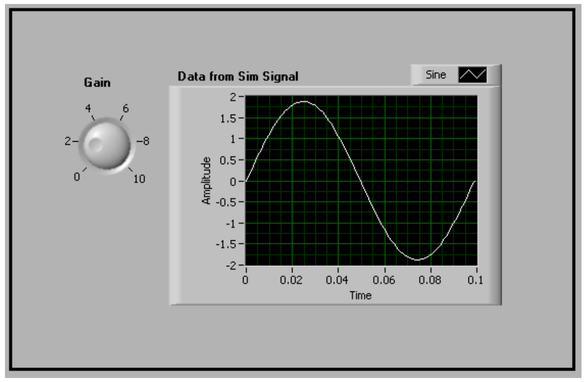

Figure 2.1: Example of a LabVIEW Front Panel

The block panel is that which is designed by the programmer to control the front panel. It contains the graphical source code which enables the user to operate the front panel. Figure 2.2 is the simple program module used to run the front panel of Figure 2.1. It is composed of various Graphical User Interfaces (GUIs). These program functions execute bits of code that would normally be typed out in a specific programming language. In this example, the gain GUI is used to adjust the gain and is wired into the amplitude of the Simulate Signal Function which is producing the Sin Wave. Finally, a GUI is placed at the output as a display so that the user can visualize the output.

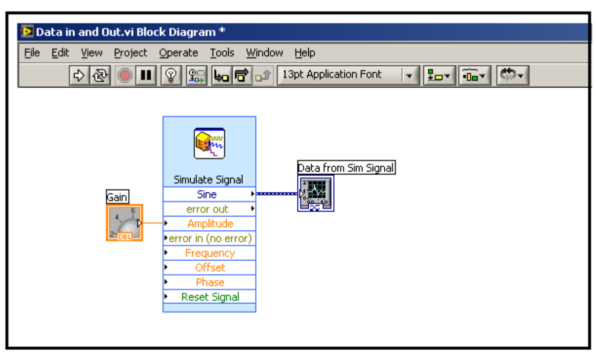

Figure 2.2: LabVIEW Block Diagram

The icon and connector panel is used when the programmer places one VI inside of another VI. The embedded VI then becomes the subVI and is quite useful for larger programs that can become complex. These subVIs are indicated with a specific icon in the larger program indicating that there are multiple smaller programs (subVI) running inside of the larger program (VI). Figure 2.3 demonstrates an icon on the left. The actual program this icon executes can be seen on the right of Figure 2.3 and contains the code that will be executed. Being able to utilize these sub VIs keeps the main program from becoming too complex (LabVIEW 2009).

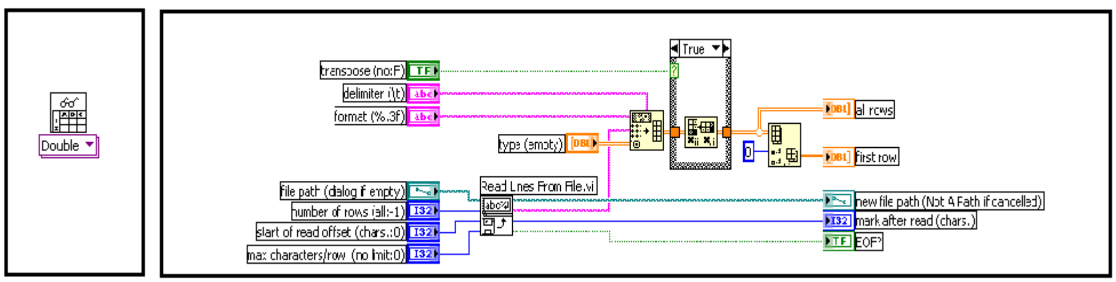

Figure 2.3: Icon and Connector Panel

2.3 Radioactive Decay

Radioactivity is the spontaneous transformation of an unstable nucleus. When an unstable nucleus needs to become stable it does so through the spontaneous release of energy. It can give off particulate and also non-particulate radiation. Non-particulate radiation generally has no mass whereas particulate radiation has mass. There are different types of decay particles that can be emitted; some of the major ones of interest are alpha particles, gamma rays, and beta particles. Often after the parent nuclide has undergone radioactive decay it will lose mass and be converted into a different isotope, known as the progeny.

It is not known exactly when a particular atom will undergo decay, but given enough atoms their rate of decay then can be predicted. Activity is a measure of this transformation rate and is usually specified in units of decays per second (dps) which is equivalent to Becquerel. Another from which is often used when there are higher rates of decay is the Curie; one Curie (Ci) is defined as 3.7×10^{10} decays per second.

The derivation of the activity equation is presented below. Equation 2.1 shows the activity as a function of time, in relation to its decay constant, λ. Integrating Equation 2.2 we have the activity with its associated constant of integration. Finally, the solution gives us Equation 2.4 which allows for the activity of a source after a specific period of time to be calculated in relation to its decay constant (Cember 2009).

$$\frac{dA(t)}{A(t)}=-\lambda(t) \tag{2.1}$$

$$\ln A(t)=-\lambda t+C \tag{2.2}$$

$$A(t)=e^{t}\,{}^{\lambda t}e^{-} \tag{2.3}$$

$$A(t)=A_0e^{-\lambda t} \tag{2.4}$$

2.4 Particulate Radiation

2.4.1 Alpha Particles

Alpha particles are heavy charged particles that directly ionize along their path length. They can be directly detected as opposed to gamma rays which must first undergo a reaction with the detection material. They are easily shielded and can be completely stopped with something as thin as a piece of paper. Generally, alpha particles have a short path length and are stopped within centimeters as they traverse air.

Alpha particles transfer a high amount of energy over a short distance. They are made up of 2 protons and 2 neutrons and are orders of magnitude larger than beta radiation (Martin 2000). Detecting alpha particles can be carried out through a number of techniques to be discussed later.

2.5 Electromagnetic Radiation and Photon Interactions

Gamma rays and x-rays are high energy photons. A photon is in essence a "packet" of energy. The photon is unique in that it can behave as both a wave and a particle. These wavelengths, that differ in the distance between the crests of the wave, make up the electromagnetic spectrum, which contains everything from radio waves, visible light, and at high energies, gamma and x-rays which are capable of ionizing matter.

Gamma and x-rays are uncharged and do not directly ionize in the medium through which they are passing. A heavily charged particle will create many ionizations along its path which can be detected by turning these ionizations into an electric charge. Gamma ray detection is more of a delicate task because the gamma ray does not ionize along its path length, but must undergo an interaction in the medium through which it is traveling to be detected (Martin 2000).

Generally, a photon will undergo one of three different interactions with the material through which it travels. For low-energy photons, the dominant mechanism is photoelectric absorption, for mid-level energy the major method of interaction is Compton scattering and finally, high-energy photons generally initiate pair production.

The significance of these interactions is that the resulting particle, which is usually an electron, is used for spectroscopy and detection purposes.

2.5.1 Photoelectric Absorption

The process of photoelectric absorption is one in which an incident photon interacts with an orbital electron transferring its full energy and ejecting that electron from the atom. Generally, the electrons rearrange themselves and as they fill more tightly bound shells a characteristic x-ray is emitted.

2.5.2 Compton Scatter

Compton scattering involves an incident photon which interacts with an electron. The photon scatters after transferring part of this energy to the recoil electron which is kicked out of its orbital shell. The energy transferred by the incident photon varies as a function of the recoil electron scatter angle and ranges from zero to some maximum resulting from complete 180^{o} scatter.

2.5.3 Pair Production

Pair production dominates as the interaction for high-energy photons. Essentially, a photon is converted into a positron and electron pair. A minimum photon energy of 1.02 MeV is required for the process to occur, and is more prevalent as energy increases. The positron will ultimately annihilate and combine with a free electron. When this occurs, two 511 keV photons are emitted in opposite directions. These energies relate to the rest masses of the two annihilating particles.

2.6 Detectors Modeled

2.6.1 Proportional Counter

The Proportional Counter is a detector that has been in use since the late 1940's. It functions on the basis of gas multiplication. It is essentially a gas filled chamber that multiplies the number of charge carriers created in the original interaction to an amount easily detectable by standard electronics. The basis for the proportional counter's amplification is a phenomenon known as the Townshend avalanche. It occurs when free electrons created by the incident radiation are accelerated toward the anode through an electric potential to create more free electrons through collisions with other gas atoms, creating a cascading process. The secondary ionizations result in a collected charge that is proportional to the initial energy deposited by the incident radiation.

Thus, the amplitude of the resulting signal pulse will be proportional to the incident energy of the incoming radiation such that the energy of the particles or photons entering the detector can be determined. Proportional counters are desired when some kind of spectroscopy is of interest. If the only application is detection, then a GM tube would be the preferred detection method (Cember 2000).

2.6.1.1 High Voltage Plateau

The proportional counter is beneficial in that it maintains information about the energy deposited by the initial radiation entity. Depending on the type of radiation, the proportional counter has specific operating regions where the applied voltage creates a region of stability such that small fluctuations in the voltage do not have a significant effect on the recorded count rate. Alpha particles generally deposit most of their energy over a short distance. The equipment being modeled generally will only need around 600 to 800 volts to detect most of the particles incident upon the detector.

Beta particles have a longer path length than alpha particles; this means that they deposit less energy per unit path length. A counting curve is created by taking numerous counts at increasing levels of voltage. Depending on the type of radiation a region of stability will exist where the counts over a range of voltages will plateau. This area indicates the preferred voltage for that detector and radiation type such that small fluctuations in voltage will not greatly affect the counts. When creating a counting curve for beta radiation the proportional counter generally functions best at a higher region of voltage starting around 1000 volts and ranging up to 1600 volts for the detection equipment we are interested in modeling..

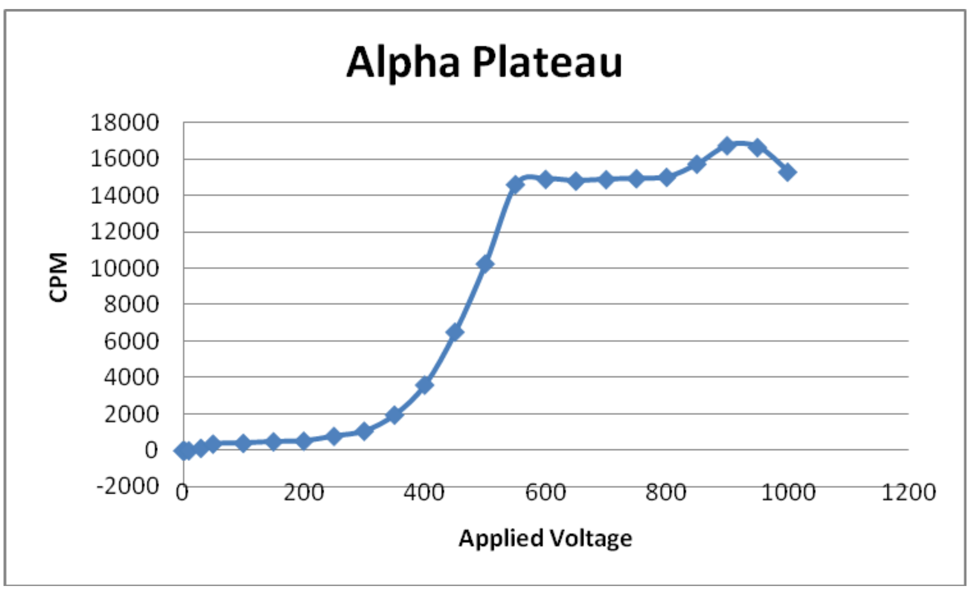

Figure 2.4: Proportional Counter Alpha Plateau

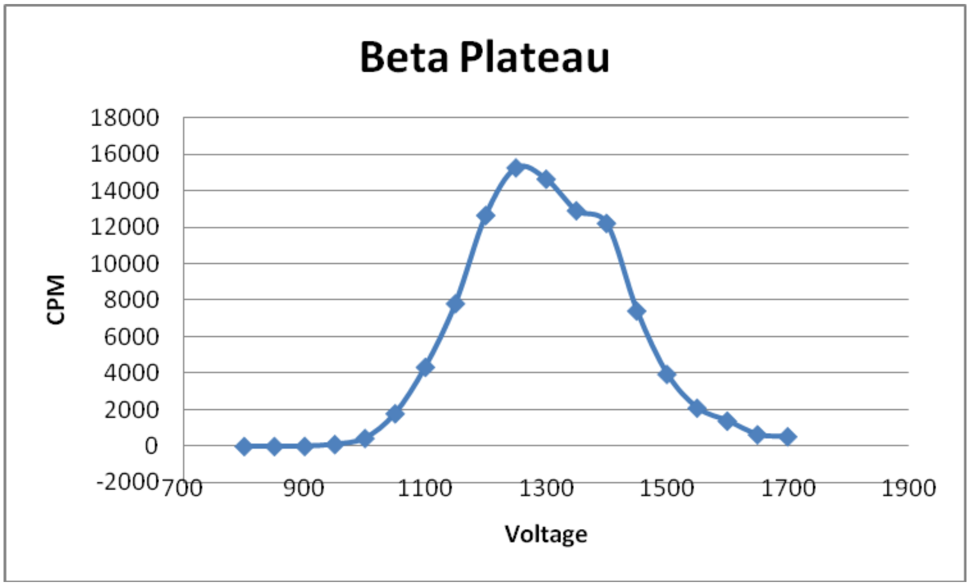

Figure 2.5: Proportional Counter Beta Plateau

Figures 2.4 and 2.5 demonstrate the alpha and beta plateaus for the proportional detector. The beta plateau drops off at 1400 volts because at this region the pulse amplitude is too large for the associated electronics to record. This phenomenon is something that is key to modeling the associated digital equipment, even though digital equipment would allow for detecting up to a very high range of output voltage pulses (Knoll 2000).

2.6.1.2 Proportional Detector Pulse Output and Operating Range

The maximum amplitude of the voltage pulse is a function of the original number of ion pairs, n_o, and the capacitance, C, of the detector system; where e is the charge on a single electron (1.6×10^{-19}C).

$$V_{max} = \frac{n_o e}{C} \tag{2.5}$$

Equally important for the proportional counter is that integrated charge, Q, varies in proportion to the original number of ion pairs and the gas multiplication factor, M.

$$Q = n_o e M \tag{2.6}$$

The gas multiplication factor varies with detector and gas type, and is experimentally determined (Knoll 2000). For the purpose of this project, P-10 gas was used to create the beta and alpha curves and the associated characteristics of P-10 will be used in creating the virtual proportional counter.

2.6.2 GM Detector

2.6.2.1 GM Detector Theoretical Properties

The GM detector is one of the oldest detectors in existence. It was first used in 1928 and is a simple gas filled detector that uses gas multiplication to greatly amplify the original charge created by the interaction of ionizing radiation with the detector gas (Knoll 2000).

One of the most important characteristics of the GM detector is that its output voltage pulse will always be of the same amplitude due to its nature of creating a "cloud" of electrons through the Townshend avalanche. As an incident radioactive particle enters the GM detector it creates any number of ionizations. These ionizations will then rapidly fill the tube with electrons via the Townsend avalanche process until a signal pulse is sent and the detector resets itself. This process occurs for any type or energy radiation that enters, meaning that the detector only registers the number of quanta entering and does not record other aspects such as initial energy deposition. The pulse leaving the detector is typically large enough to be analyzed without using a pre-amplifier or even an amplifier (Martin 2000).

Thus, the pulse amplitude from a GM is essentially the same regardless of the initial event and is dependent on the detector capacitance (constant) and bias voltage (variable) applied to the detector. The pulse amplitude increases roughly in proportion to the over-voltage, the difference between the applied voltage and the minimum voltage needed for a Geiger discharge. The pulse amplitude is therefore independent of the incident radiation energy and pulses serve only to count incident radiation.

The GM detector usually has a fill gas and also a quench gas. The quench gas is used to prevent additional unwanted discharges. The dead time of the GM tube is generally on the order of 50 to 100 μs and represents the time the tube needs to reset before being able to count another pulse, thus limiting its maximum count rate (Knoll 2000).

2.6.2.2 GM Detector Pulse Output and Operating Range

Figure 2.4 shows a standard pulse output from a GM tube, with a bias of 900 volts. The radiation source was Cs-137, but any other source placed at the GM window would have produced a similar pulse height and shape. Some key aspects of this output critical in designing a virtual instrument are the pulse height, which is approximately 500 mV, and also that the pulse is unshaped and negative. These aspects will be modeled and discussed further in Section 3.

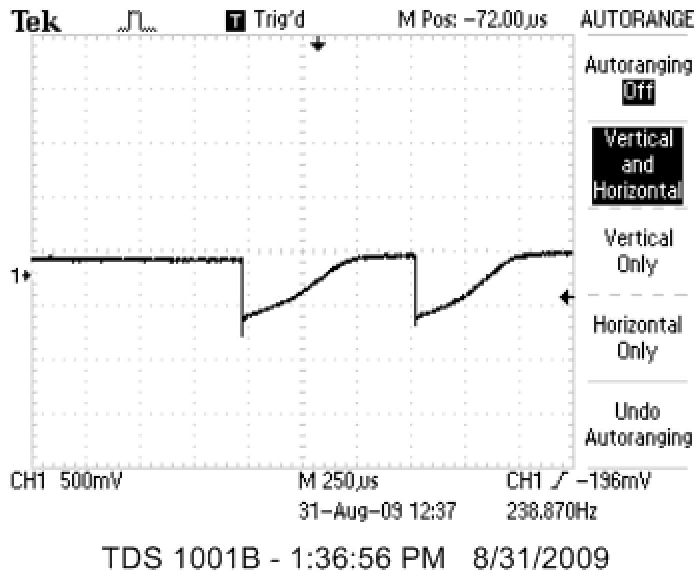

Figure 2.6: Raw pulses from a GM Tube

The GM tube in our lab generally operates best at around 900 volts. Below 600 volts the electric field is generally not strong enough and recombination of the ion pairs occurs. At higher bias voltages equipment damage can occur. Also, as you get to these levels of bias voltage a phenomenon will occur where the detector undergoes continuous discharge, which means that you know longer get accurate data.

2.6.3 Scintillation Detector

The scintillation detector is used to detect ionizing radiation by the light generated when ionizing radiation interacts in the active volume. Spectroscopy is a means of looking at a visual picture of radiation counts as a function of energy. This will create raised peaks at energy levels where specific nuclides are depositing the most energy. The scintillation detector provides a very clear and accurate picture of the radiation and its associated decay energy. Scintillation detectors are used most frequently when looking at photons and provide a very accurate picture of the energy range of the photons of interest (Knoll 2000).

For the purpose of radiation spectroscopy involving a NaI detector, there are multiple steps the incident radiation goes through before being converted to a pulse. First the photon strikes the scintillation material. The incident photons excite the electrons out of the valence band and into the conduction band. This excited state will then de-excite back to the valence band. By adding an impurity, a new band gap can be created that will cause the electron to emit a visible photon when it de-excites. Generally, a good scintillation material will have an efficiency of about 20% (Knoll 2000).

2.6.3.1 Photomultiplier Tube

The photomultiplier (PM) tube has a photocathode that converts the incident light coming from the scintillator material into a photoelectron. These photoelectrons are then guided through the PM tube to reach the electron multiplier region of the tube. This process occurs by using a series of dynodes that create an additional number of proportional electrons.

2.6.3.2 Spectroscopy

Gamma ray spectroscopy involves looking at the output of a radioactive source. Energy deposition is plotted against the number of radiation counts falling at numerous energy ranges; as more and more photons are deposited at specific energies a visual picture is developed that is useful for determining the behavior of the isotope or isotopes of interest.

Some key prominent factors in spectroscopy are the result of gamma ray interactions (Fig 2.5). The Compton Edge is a direct result of Compton Scattering and is the place where the recoil energy of the electron is at a maximum. Pair Production occurs at higher energies and is responsible for the single and double escape peaks. The single escape peak occurs at energies greater than .512 MeV and comes from the positron slowing down in the detector medium and annihilating into two .511 MeV photons. When one escapes there is a corresponding single escape peak and when both photons escape there is a double escape peak.

Some other interactions occurring inside the detector will also lead to peaks in the output. A key one of these is the Characteristic X-ray escape peak which occurs after photoelectric absorption when the excited nucleus de-excites through the emission of an x-ray. The peak usually occurs behind the full energy peak a distance of the x-ray energy away.

Another key aspect of spectroscopy is the fact that some gamma rays will interact in the shielding surrounding the detector and create peaks in the response function. These include annihilation photons from pair production, backscattering in the lead due to Compton scattering, and finally x-rays from the lead.

Figure 2.5 shows an ideal spectrum of a higher energy isotopes and its resulting output. The prominent full energy peak is where the isotopes primary decay energy is. The Compton continuum occurs over a range of energies where deposition at all scatter angles occurs. This can be seen by the sweeping semi-circle of energy deposition. Finally, at energies above 1.022 MeV single and double escape peaks are produced due to the phenomenon of pair production.

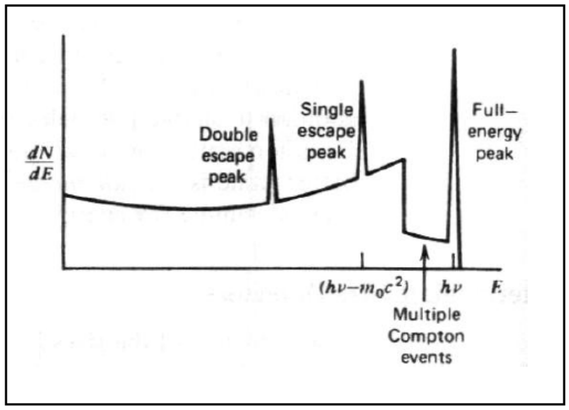

Figure 2.7: Ideal Energy Deposition Spectrum Showing Full-Energy Peak

Figure 2.6 shows an actual spectrum collected with Gamma Vision, a program specifically designed for the purpose of spectroscopy. The isotope of interest is Co-60 which emits two gammas at 1,172 and 1,332 keV each with 100% yield. The behavior and output of the scintillator through an MCA is critical to designing a digital scintillator capable of analyzing these types of output pulses (Knoll 2000).

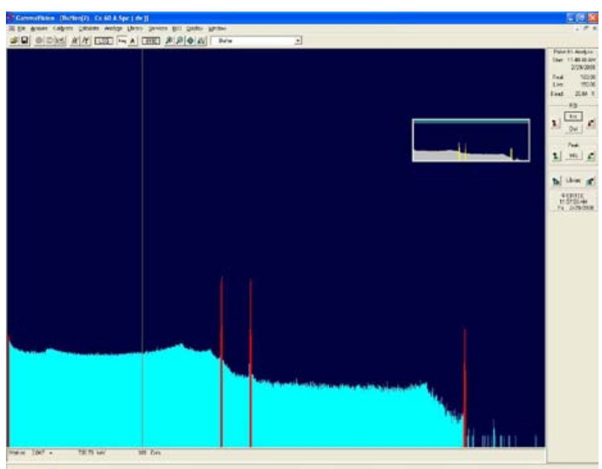

Figure 2.8: Co-60 Spectrum Collected using a NaI Detector

2.7 Detector Physics

2.7.1 Detection Efficiency

The efficiency of any detection system is a measure of its ability to detect incoming radiation. Absolute efficiency refers to the total radiation quanta being emitted by a source compared to those actually counted by the detection system. Intrinsic efficiency is defined as the number of counts recorded from divided by the number of incident radiation quanta.

$$E_{abs} = \frac{\text{Number of pulses recorded}}{\text{Number of radiation quanta emitted by source}} \tag{2.7}$$

$$E_{int} = \frac{\text{Number of pulses recorded}}{\text{Number of radiation quanta incident on detector}} \tag{2.8}$$

Absolute efficiency is affected by source detector geometry. Absolute and intrinsic efficiency are related by Eq. 2.9 which accounts for system geometry given that the distance, d, between detector and source is large compared to detector surface area, A. The solid angle (Ω) is approximated using Eq. 2.10 (Knoll 2000).

$$E_{int} = E_{abs}\left(\frac{4\pi}{\Omega}\right) \tag{2.9}$$

$$\Omega = \frac{A}{d^2} \tag{2.10}$$

2.7.2 Dead Time

Dead time refers to the time it takes for a detector to "recover" after responding to an incident quanta of radiation. Dead time is essentially the time the detector is recovering before it can respond to a new quantum of radiation. Eq. 2.11 shows the dead time relationship for a non-paralyzable system and Eq. 2.12 for a paralyzable model. A paralyzable detector system means that the radiation hits upon the detector can build up under high activities. Essentially, as more radiation interacts in the detector it registers less and less and is in fact frozen or paralyzed. A non-paraylzable system is one in which that the detector misses the counts of radiation it detects while it is recovering, but that these quanta of radiation do not cause the detector to stay down for longer periods of time (Knoll 2000).

$$n = \frac{m}{(1 - m\tau)} \tag{2.11}$$

$$m = ne^{(-n\tau)} \tag{2.12}$$

Eq. 2.12 is used to experimentally determine the dead time of a detector system. It is accomplished by taking three counts with a split source. Each half of the source is counted separately as R1 and R2. Both of the sources are then placed on the detector as RT and counted together. These outputs are then placed in Eq. 2.13 which is used to determine system dead time.

$$Dead\ Time = \frac{[R1 + R2 - RT]}{[2 * R1 * R2]} \tag{2.13}$$

2.8 Equipment Modeled

2.8.1 Signal Splitter

The signal splitter is designed to separate the signal and high voltage, which are both on the same line. The reason for this is so that the HV does not damage the rest of the equipment.

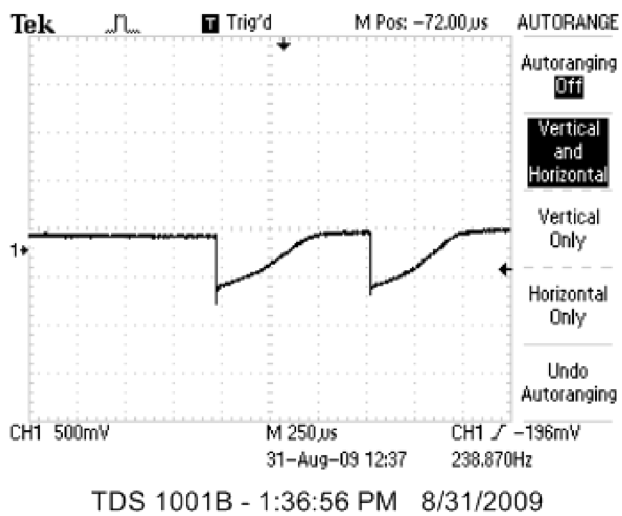

Figure 2.9: Signal taken directly from GM through the Splitter at 900 volts

An important characteristic shown in Fig. 2.6 is the negative pulse which arises from the fact that the charge being generated from electrons is negative. The pulse is around 500mV which is relatively small. The applied voltage is what will directly affect the pulse height from the signal splitter.

2.8.2 Pre-amplifier

A preamplifier's main purpose is to terminate capacitance. Another function of the preamp is that it works as a signal splitter and can provide initial amplification of the signal. In detecting gamma rays through the use of a scintillation detector, the preamp is crucial to the signal chain. Detectors such as the GM tube do not need a pre-amplifier because they generate a large enough charge to be fed straight into an amplifier (Knoll 2000).

2.8.3 Amplifier

The amplifier increases the voltage and signal pulse from the pre-amp or straight from the detector, and it does so in a linear fashion. The amplifier can increase the amplitude of the signal pulse by up to several orders of magnitude. It is also responsible for shaping the signal pulse such that the output pulse height is proportional to the input and the rise and fall times are roughly equivalent. The user has the ability to adjust and change some of the following settings on most amplifiers:

- Gain: Amplification factor;
- Shaping: Controls rise and fall time of the output pulse; and
- Polarity: Tells the amplifier to look for a positive or negative pulse.

The amplifier output signal is critical to radiation detection. Some of the key characteristics of an output pulse are discussed below.

2.8.3.1 Amplifier Uni-polar output

The amplifier input (from the GM) is a stream of electrons with a negative charge. The amplifier has a polarity switch which specifies if the input is positive or negative in nature. As seen in Fig. 2.7 the amplifier is set to negative which means that it is expecting an incoming pulse that is negative. When it sees this pulse it inverts it and the output can be seen below.

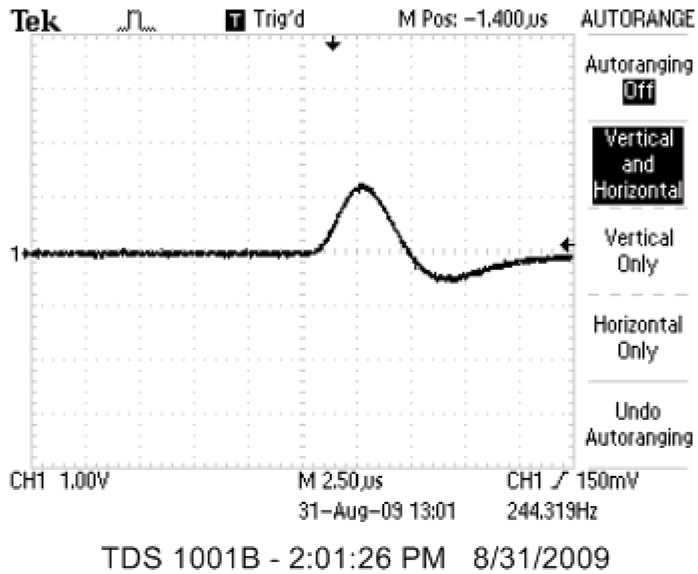

Figure 2.10 Uni-polar Negative Polarity

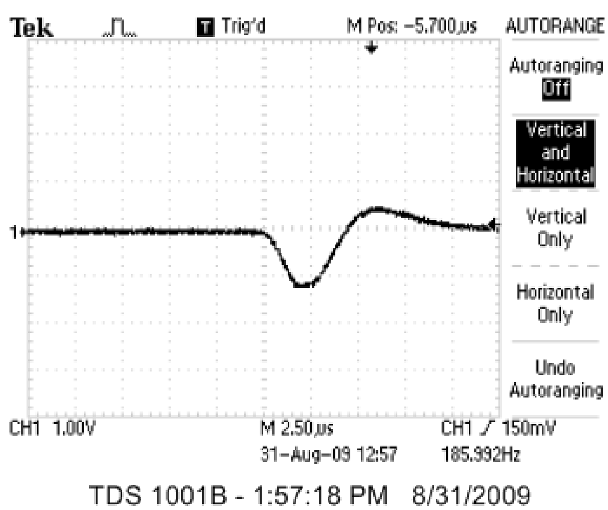

Figure 2.11 Uni-polar Positive Polarity

Figures 2.7 and 2.8 are examples of uni-polar output. They are produced by a GM tube operating at 900 volts with the amplifier gain set to two (2). The pulse has a Gaussian shape, is amplified by the gain, and is shown to have significant undershoot.

2.8.3.2 Amplifier Bi-polar output

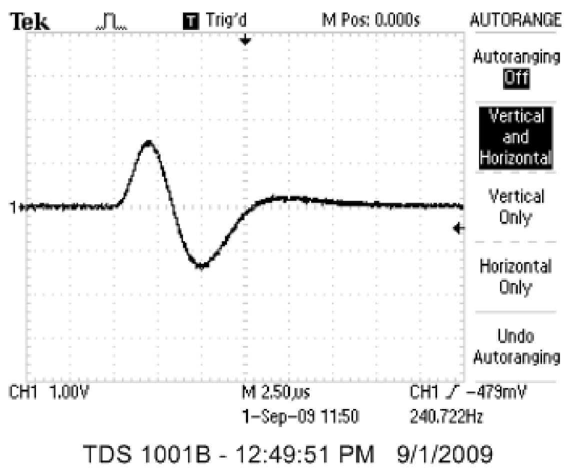

Figure 2.12 Bi-polar Negative Polarity

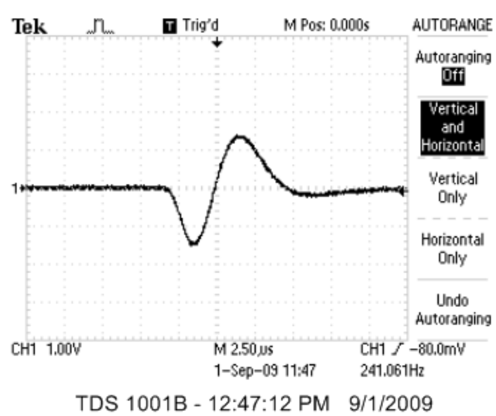

Figure 2.13 Bi-polar Positive Polarity

Figures 2.9 and 2.10 show a bipolar output and demonstrate how the pulse changes when the amplifier polarity is switched. The pulse retains the same shaping and height but is inverted by the amplifier. The input into the amplifier is a negative signal composed of electrons. The polarity switch indicates to the amplifier which signal to expect that have a negative polarity pulse is inverted to display a positive pulse. By switching the amplifier setting to positive the amplifier shows an inverted pulse shape.

2.8.4 Single-Channel Analyzer

The Single Channel Analyzer is used to analyze signals which fall into a particular range of voltage pulse heights. By setting a voltage window to only view pulse heights of a specific value, one can narrow the analysis to specific energy deposition events. A channel is generally set up in the following manner.

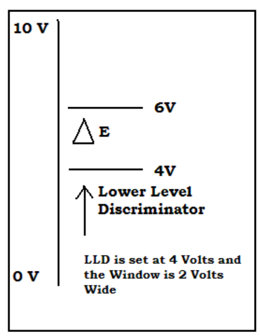

Figure 2.14: Single Channel Analyzer Window

Fig 2.11 shows a discriminator set to view pulse heights above 4 volts and below 6 volts. There is a lower level discriminator (LLD) that tells the SCA when to start recognizing pulses. The SCA also has a discriminator that tells what size of a window to set. In this case the window is 2 volts, which created an upper level discriminator (ULD) to be at 6 volts. The more channels created utilizing this method allows for a more accurate picture of the characteristics of the incident radiation. Generally the LLD is set to eliminate noise being created that is not giving an accurate picture of the charge being deposited from the source.

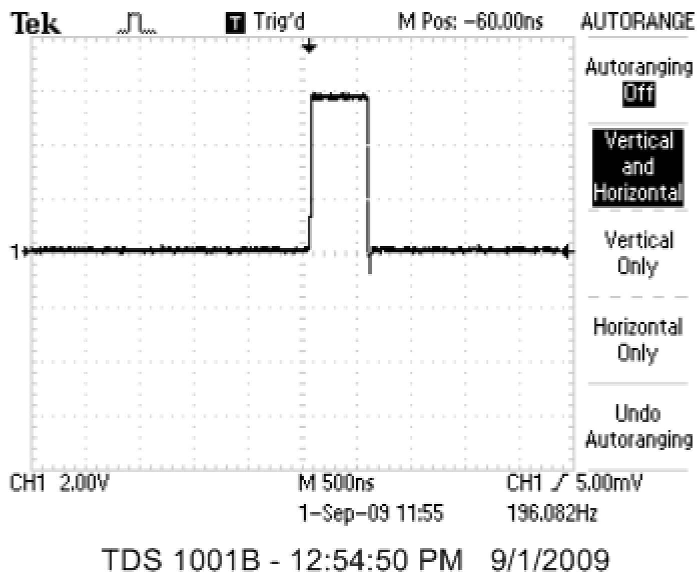

Figure 2.15 Logic Pulse from an SCA

The SCA output consists of uniform logic pulses that do not give information about the kind of radiation being analyzed nor the energy of the initiating event. These pulses generally trigger a yes (square wave) or no (flat line) response for input into the dual counter/timer (Knoll).

2.8.5 Multi-Channel Analyzer

For photon spectroscopy, a clear picture of the energy deposition of the incident radiation must be examined. The multichannel analyzer is essentially a large group of single channel analyzers tied together to create an energy deposition spectrum.

The basic operation of the MCA is to convert the pulse amplitude (analog signal) into a digital representation. This digitized information is then recorded to produce the pulse height spectrum. Since the analog-to-digital converter (ADC) is responsible for this, it is an important part of the MCA's functioning. The ADC is affected by its conversion speed, the linearity of the conversion, and the resolution of the conversion (Knoll 2000).

2.8.6 Dual Counter/Timer

The Dual Counter and Timer is used simply to convert the number of interactions in the detector over a specified length of time. Different modes and preset programs allow the user to measure activity over finite periods of time accurately, and also create programs for running multiple tests.

3 MATERIALS AND METHODS

3. Materials and Methods

3.1 Integrating LabVIEW as a Design Tool

LabVIEW was used to design the digital equipment that will populate this virtual lab. The process used to make sure the digital equipment behaves in a fashion similar to that of real detection equipment is discussed below:

- Real equipment is analyzed to determine operating characteristics;
- Research is conducted to find all applicable mathematical equations and properties of this equipment;
- If needed, real data is collected and converted into usable data to be placed into LabVIEW;
- A hand written model is developed; and
- The equations are placed into LabVIEW and the digital piece of equipment is developed.

3.2 Detectors Modeled

3.2.1 GM Detector

LabVIEW was used to model all aspects of the GM detector. Pulse height, source detector geometry, and dead time were modeled through data collected in the laboratory and by consideration of operational theory (see Section 2).

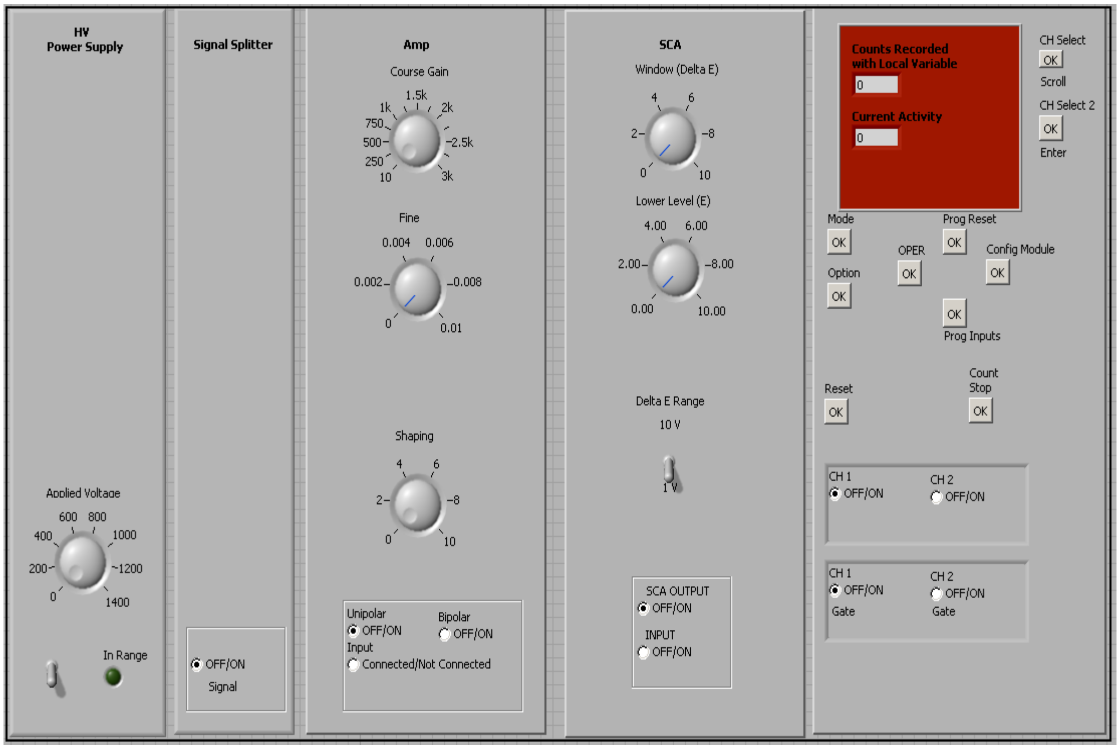

Figure 3.1 GM Tube and associated operating equipment

Figure 3.1 shows the equipment associated with the GM tube as seen from the front panel of LabVIEW. The user will have access to all of these controls for each of the detectors to be simulated.

3.2.1.1 Pulse Output

The pulse amplitude from a GM tube (prior to the amplifier) is always the same and, other than small equipment fluctuations, it is only dependent on the bias voltage applied to the detector. Figure 2.4 demonstrates raw pulses coming from the GM tube at 900 volts. These pulses, as seen from an oscilloscope, are about 0.5 volts at their maximum. If more bias voltage was applied to the GM, the pulse height would increase and if the bias voltage were lowered, the pulse height would fall (Knoll 2000).

The first key aspect of modeling the GM tube was to be able to have LabVIEW accurately model the pulse output as seen from the signal splitter. As the user specifies different equipment, the resulting output as seen from the digital oscilloscope will be a pulse corresponding to the equipment and settings selected. Three different methods were looked at to best re-create the GM pulses.

The first involved using LabView's signal express program which digitally captures pulses straight from the equipment by running them through a special DAQ board designed for LabVIEW. This route was not undertaken due to the cost associated with these boards. The second method involved fitting functions to the signal pulse shape coming from the detector. These functions could then be programmed into LabVIEW and recalled while the program runs. This method was not used due to the complexity of the functions needed to model the pulses. The final method, which was employed, involved using LabVIEW's ability to recall plots based on XY graphs (Bishop 2005).

The following procedure was used to allow LabVIEW to store and recall real pulses:

- A Cs-137 source was placed in front of the GM tube and 900 volts were applied;
- Data were collected from the output of the signal splitter and routed into a Tektronix TDS1000B digital oscilloscope;
- Data were converted to digital data and fed into USB port of the computer;
- Open Choice Software was used to convert this to an X,Y plot and put into Excel;

- Data were simplified due to the large nature of the pulses coming from the oscilloscope and the need to store many data points for multiple pulses;
- Data were converted to tab delimited .lvm files which are specific to LabVIEW; and
- A LabVIEW VI was programmed that would recall this real-time data and display in the running program.

The data gathered from all of the different equipment were used to construct the standard GM pulse. When LabVIEW is modeling the output of a GM, it is displaying the actual pulses one would see from an oscilloscope by recalling stored pulses for these instruments. Some equipment, such as the amplifier, can generate different pulses based on operating parameters of the equipment; an example of this would be the uni-polar and bi-polar settings. In cases like this the data had to be stored in LabVIEW and depending on the output selected by the user, such as a uni-polar pulse, that specific function had to be accessed from the stored data. This was done by using case structures, which allow for switches on the front panel to recall different "outputs."

For the GM tube, all of the possible output pulses were stored in LabVIEW and case structures initiated to allow for the switches on the front panel to select which pulse to recall and display.

These data are then run through the digital instruments and can then be shaped by adjusting the gain or any other function available on standard NIM bin equipment. The pulse being viewed through LabVIEW is the real output of analog equipment that has been manipulated with digital equipment causing it to respond in a fashion similar to that of the real instruments (Bishop 2005).

3.2.1.2 Pulse Height as a Function of High Voltage

One of the key aspects of adjusting pulse height is how the pulse is affected by adjustments to the bias voltage. To accurately model this behavior, an equation for pulse height as a function of applied voltage was created from experimental data collected in the lab. After these data were collected, an equation was derived and placed into LabVIEW to allow the user to adjust HV and have the pulse height rise and fall according to how this behavior occurs when a GM is subject to changes in applied voltage. These changes to applied voltage do not have a directly linear relationship on pulse output. Equation 3.1 is applied to account for this relationship. The relation is fundamental is fundamental to how the digital GM responds to fluctuations in applied voltage. In this equation, y represents the pulse amplitude in volts, and x represents the applied bias voltage to the operating equipment.

$$y = .0071 * x - 4 \tag{3.1}$$

Equation 3.1 was modeled by collecting data in the lab and plotted as pulse height versus applied voltage. After a relationship was established, a curve was fitted and an equation developed to allow for LabVIEW to model this behavior.

The first step in modeling Equation 3.1 was to develop a theoretical model of what is occurring. This model is shown in Figure 3.2 and discusses the logic behind how the pulses are plotted in LabVIEW. Step 1 is that the initial pulse height is determined through Equation 3.1. The pulse is then passed through a discriminator that eliminates pulses when the bias is less than 600 volts or above 1200 volts. This is due to the fact that most GM tubes have a threshold below 600 volts where most of the pulses are lost due to recombination, and above 1200 volts where the GM begins to arc. Finally, this is applied to real pulse data being recalled by LabVIEW so that the virtual equipment is behaving in a fashion similar to that of real equipment.

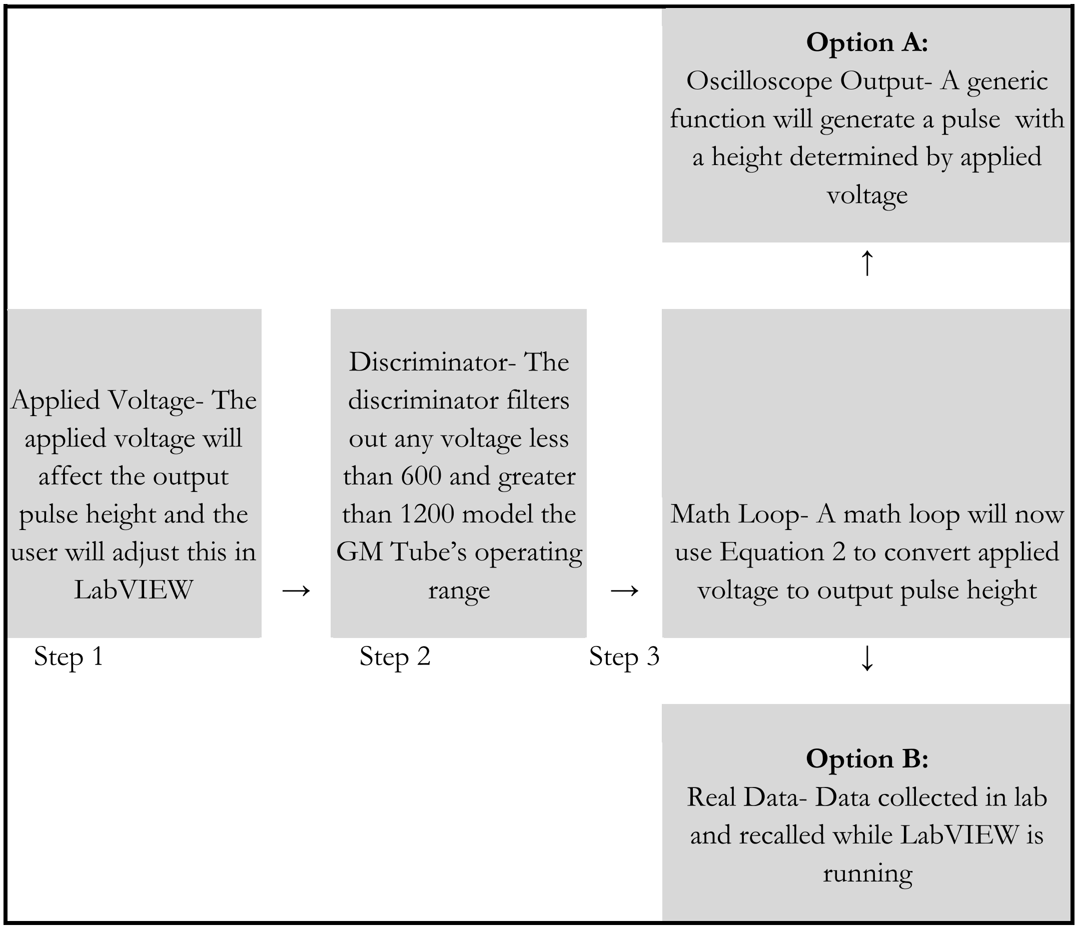

Figure 3.2: Theoretical Diagram of the Instrument Properties

The outcome of how LabVIEW will mimic rises and falls in bias voltage to the output pulse height is displayed in Figure 3.3. The LabVIEW program shown in Figure 3.3 operates from left to right. The Applied Voltage is adjusted by the user and directed through a filter that creates a range where bias voltage is too high or too low for the GM to output an accurate pulse. The filter settings are shown wired into the discriminator at 600 volts for the lower level discriminator (LLD) and 1200 volts for the upper level discriminator (ULD). The reason for this discriminator is because a real GM has too much recombination to see pulse outputs when the applied voltage falls below around 600 volts, and at higher bias voltage a continuous discharge forms which also prevents accurate output.

If the operating voltage set by the user is in range, it is passed into a math loop that converts the applied voltage to an appropriate output pulse amplitude. This can be seen in Figure 3.3 as X being the input value to the equation and the adjusted pulse height passing out of the math loop as Y.

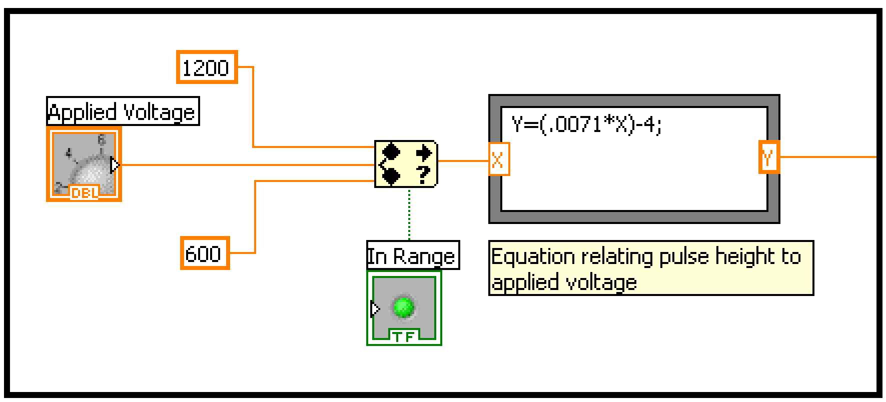

Figure 3.3: Applied Voltage as seen from LabVIEW

3.2.1.3 Source Detector Geometry

As the radiation source is moved farther away from the detector, the detection count rate will decrease since the radiation is emitted isotropically, thus decreasing the flux at the detector (Knoll 2000). This property was accounted for in the digital lab by allowing the user to specify a distance from the source. The mathematical properties of source detector geometry needed to be modeled so that LabVIEW would record the correct amount of activity reaching the detector face as a virtual source is placed at different distances from the detector face. This behavior follows the behavior set forth in Equation 3.3 (Knoll 2000).

$$S = N * \left[\frac{4\pi}{E_{ip}\Omega} \right] \tag{3.2}$$

$$\mathrm{N} = \mathrm{S} * \left[\frac{\mathrm{E_{ip}}\Omega}{4\pi} \right] \tag{3.3}$$

In this equation, S represents the number of radiation quanta emitted by the source, N the number of recorded events, and E_{ip}, the intrinsic efficiency.

The first step in allowing the digital equipment to follow this behavior was to create a logical pattern of what is occurring. Figure 3.4 shows this theory of how Equation 3.3 will be programmed into LabVIEW. The surface area and the intrinsic efficiency of the GM detector are both constants; the distance between source and detector is the only geometric parameter that can be modified by the user.

Surface Area of GM				**Detected Activity (dps)**
	The surface area of the GM is divided by the distance from the source			This correction factor will calculate N (Detected Activity)
Distance from Source		→	This is divided by 4* π	↑
	Intrinsic Efficiency is multiplied by the result of the surface area divided by distance		↑	
Intrinsic Efficiency			**12.5664**	

Figure 3.4: Equations Pre-LabVIEW

Figure 3.5 is what was written into LabVIEW to perform the adjustment for source detector geometry. This takes Equation 3.3 and allows it to run continually based on the changing distance of the source. The VI takes an input activity and runs it through a "while loop" that calculates source activity while enough bias voltage is applied to the detector. All of the bias voltage will be linked to the one input voltage specified by the operator. This was done by implementing a "global variable." A global variable is a single variable that can be placed into all of the different operating loops of the program and access one single input, in this case the bias voltage specified by the user.

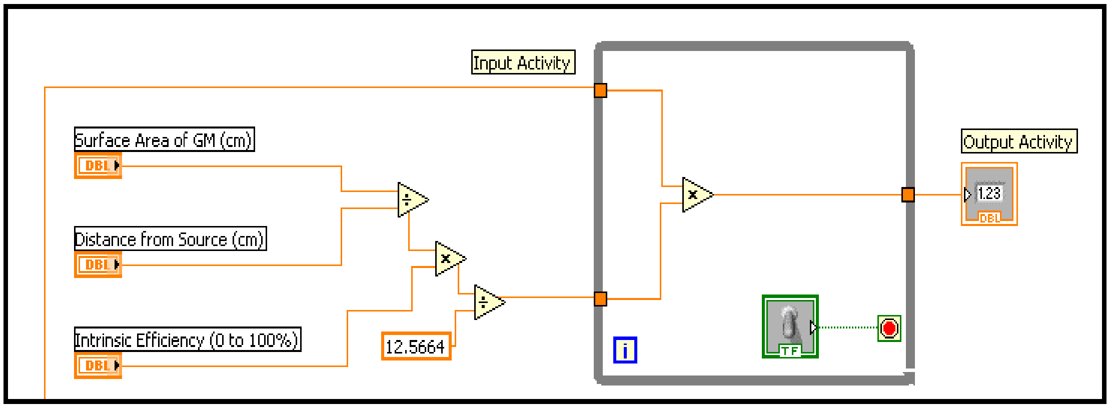

Figure 3.5: Source Detector Geometry

The only input parameter the user will adjust regarding source detector geometry is the distance between the source and the detector. Once the distance from the source has been selected, the LabVIEW program will determine an input correction factor. This factor is applied to the activity of the source to determine the rate at which radiation is striking the detector face. This equation runs inside of the "while loop" as long as sufficient voltage is applied. The digital program will output a detected activity based on what a real detector would see as a source is moved closer or farther from the detector face.

3.2.1.4 Counts as a Function of Applied Voltage

To determine count rate as a function of applied voltage, real data were collected and plotted in Excel. These data were then fit with a 2nd order polynomial equation. This equation takes an input voltage, x, and outputs a correction factor, y, that will adjust for the activity output at different voltages.

$$y = -0.0166X^2 + 32.413X - 15154 \quad (3.5)$$

In LabVIEW, Equation 3.5 is adjusted for an average voltage and used to create a ratio of counts detected at specific voltages. This ratio is used to adjust the count rate being emitted by the LabVIEW source and a corrected counts as a function of voltage outputted.

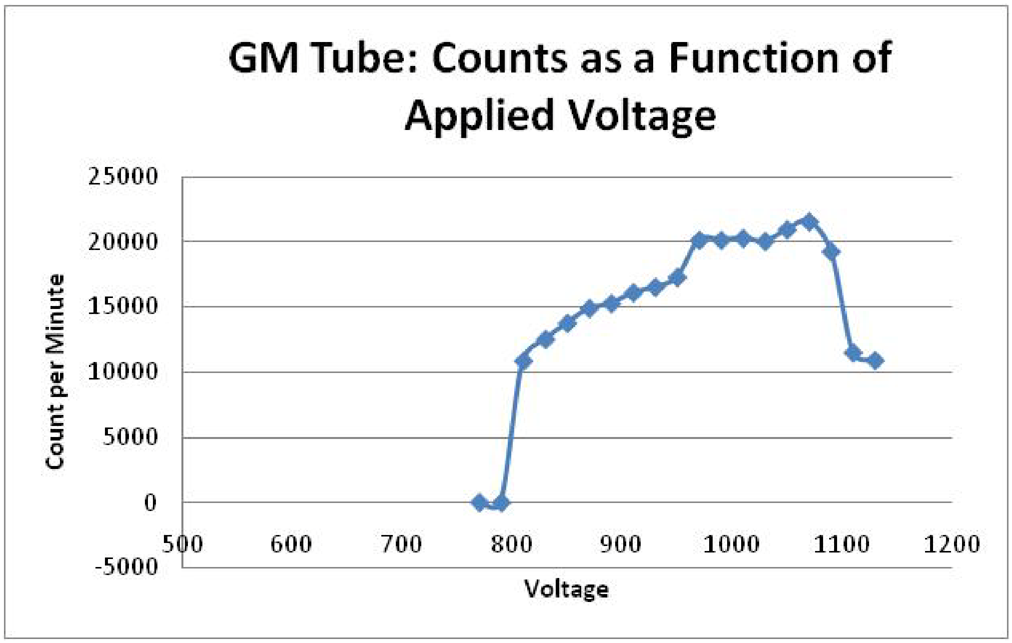

Figure 3.6: Counts as a Function of Applied Voltage

3.2.1.5 Dead Time

Detector dead time plays a major role in the ability to quantify high-activity sources. Whereas source-detector geometry is affected by the distance from a source, dead time could be problematic once the radiation strikes the detector. The detector registers less counts than would normally be counted, if dead time did not play a role. A fraction of counts is lost from multiple radiation quanta hitting the detector at essentially the same time; the higher the activity of a source, the more loss that will be experienced due to dead time. The dead time of the GM detector generally varies between 50 and 100 μs (Knoll 2000). The digital detector designed in LabVIEW is simulated with a dead time of 75 μs. The fraction of counts lost as a function of source activity was modeled through Equation 3.6 which models a paralyzable system. In this equation m represents detected counts, n actual counts and τ represents dead time (0.75 μs).

$$m = ne^{-n\tau} \tag{3.6}$$

This was performed in LabVIEW with the addition of a math loop, as shown in Figure 3.7. This loop takes an input activity, x, and runs it through Equation 3.6. As activity is raised, the loop will create more dead time losses in accordance with a paralyzable detection system.

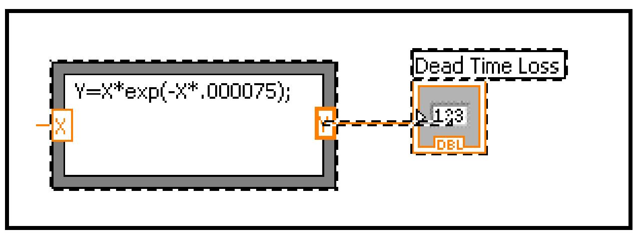

Figure 3.7: Dead Time in LabVIEW

LabVIEW executes this math loop which then outputs the activity the detector is registering after dead time losses are considered.

3.2.1.6 Detected Activity

The activity detected by any detector is dependent on a number of variables, but the most important variable is the actual activity present. In a real detection lab students are given samples with decaying isotopes, each having certain unchanging characteristics such as its half-life. As time progresses, the activity diminishes exponentially as a function of half-life.

For LabVIEW to simulate the detection of radiation, the program must run in real time and virtual nuclides created that decay and result in “hits” on the detector. The user can choose one of two methods for creating digital isotopes. The first method allows manual choice of nuclide characteristics; the half-life and activity of any source can be specified and placed into the program before conducting an experiment. The second option has the user select preset nuclides such as CS-137 and Co-60; these are then programmed into the virtual detector system.

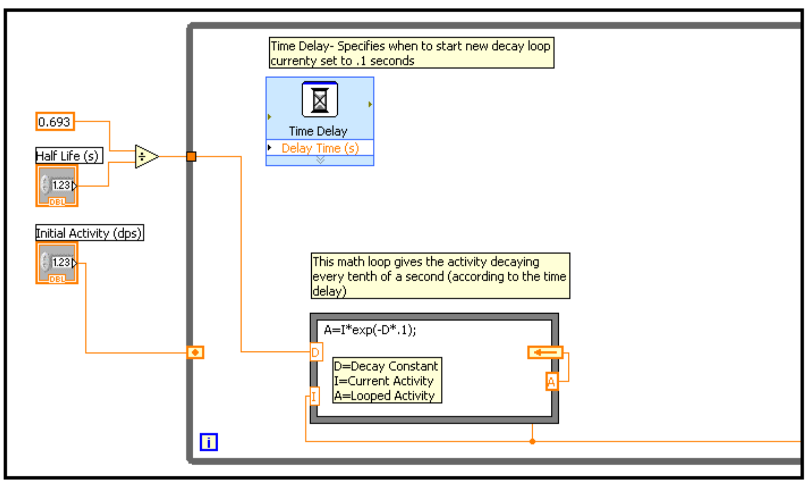

Figure 3.8: Source Activity in a Time Delayed While Loop

These behaviors are modeled in LabVIEW as shown in Figure 3.8. The user input, unless a pre-programmed nuclide is selected, will be the half life and activity needed for the experiment. LabVIEW then runs these through a math loop to calculate count rate. This math loop uses a modified version of Equation 2.2 which is the activity equation.

One of the key aspects of calculating count rate is that, as the source decays, less and less activity will be present with the passing of time. Mathematically, this was accounted for in LabVIEW by having the count rate placed inside a timed loop. This loop runs every tenth of a second and determines an output count activity based on the amount that has decayed in this short period of time. The reason for the time chosen, a tenth of a second, is that at higher values of time the program would not accurately model real equipment with the same level of accuracy, and if a lower time chosen for executing the program it could have adverse affects of slowing the computer.

Once a loop is complete, an output count activity will be sent to the rest of the program. The loop will pass the activity back, through a shift register, into the loop again so that a new activity can be calculated after accounting for decay. The outcome being that as the program is run the detector sees a real activity that is also growing less as a function of the half-life, just as would be seen in a real lab. This aspect of the virtual equipment does not affect lab results for very long-lived nuclides, but it greatly changes the outcome of short lived nuclides.

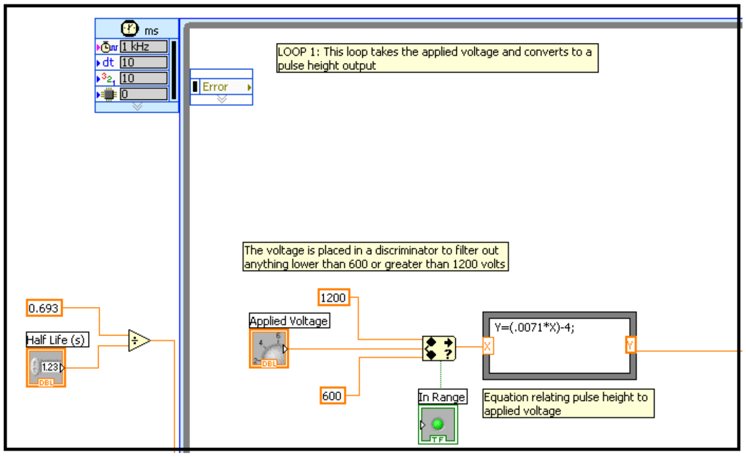

Figure 3.9: Integrated LabVIEW Program

Figure 3.9 displays the time delay which allows for the selected nuclide to decay according to a specific time frame. The time delay can be seen in the upper left corner this is what control the frequency of activity loops. Since the half-life and activity do not vary, they are placed outside the loop so that they are not affected as the program runs. The math loop calculates the new activity and also pulls out the activity being given off by the source.

3.2.2 Proportional Counter

Modeling the proportional counter in LabVIEW was executed in a similar manner to that of the GM tube. Some of the key differences that had to be accounted for include the following:

- The output of the pulse had to be proportional to the incident energy of the incoming radiation;
- The type of incident radiation had to be accounted for (Beta, Gamma or Alpha);

- A way to specify nuclide decay energy(s) had to be initiated into the program; and
- A preamplifier had to be added to the digital equipment (Knoll 2000).

Applied Voltage- The applied voltage will affect the output pulse height and the user will adjust this in LabVIEW → **Discriminator-** The discriminator filters out any voltage less than 600 and greater than 2000 to accurately model the Proportional Counter → **Gas Multiplication Factor-** Based on the user selected setting for voltage it will be ran through Equation 3.7 to determine the Gas multiplication factor as a function of voltage

Step 1 Step 2 Step 3

Original Ion Pairs- LabVIEW adjusts for incident particle energy to account for the number of original ion pairs → **Voltage Pulse Height-** Finally, LabVIEW uses this input information to solve for voltage pulse height. V=Q/C

Step 4 Step 5

Figure 3.10: Proportional Counter Theoretical Properties

Figure 3.10 shows the steps that LabVIEW will go through to determine the output from the proportional counter. The program will initialize with applied voltage and also the energy of the decay products of the radioactive nuclides being analyzed. The first step will be to adjust the high voltage which will then be processed through a discriminator to filter out voltages that are too high or too low. In Step 3, LabVIEW will adjust for the gas multiplication factor inherent in proportional counters. The final part of the program being performed in LabVIEW is the adjustment for the initial energy of the radiation particles. These processes will be explained in the following sections.

3.2.2.1 Pulse Height

The output pulse height of the proportional counter output is dependent on the incident radiation's energy, the fill gas, and also the applied voltage. The pulse height of the proportional counter is modeled by Equation 3.7, which is a combination of Equations 2.9 and 2.10. Equation 3.7 uses 10E-10 farads as the capacitance of the detector system and 26 eV per ion pair as the average energy per ionization event.

$$V = \frac{\left[\left(\frac{\text{Incident Radiation Energy}}{\text{26 eV per ion pair}}\right) * \left(1.6\text{E}-19\text{C}\right)\text{M}\right]}{\left[10\text{E}-10\text{ farads}\right]} \tag{3.6}$$

$$\text{V=Incident Radiation Energy*M*4.57E-12} \tag{3.7}$$

For the voltage pulse of the detector system to be usable in LabVIEW, Equation 3.6 was reduced and was programmed in as Equation 3.7.

The gas multiplication factor for P-10 fill gas was taken from Knoll and plotted in Figure 3.11. This was then used to plot a semi-exponential equation that models the rise in multiplication as applied voltage is increased. This is given in Equation 3.9 and was coded into LabVIEW through the use of a math loop that constantly calculates the multiplication factor with rising voltage (Knoll 2000).

$$M = .0049e^{.0077V} \tag{3.9}$$

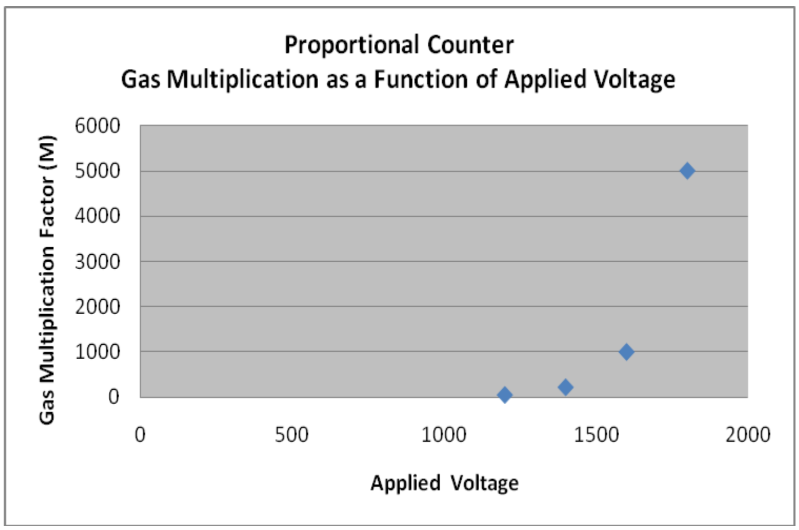

Figure 3.11: Gas Multiplication and Applied Voltage

To create the voltage pulse, LabVIEW follows the pattern in Figure 3.12 so that the output pulse is dependent on the gas multiplication factor, particle energy, and finally the applied voltage.

Figure 3.12 shows the above mentioned process as it looks when programmed into LabVIEW. The particle energy can either be manually entered or else will be automatically placed into the program when the user selects a nuclide with a known decay energy. The sequence runs from left to right and starts with an applied voltage placed through a discriminator with a lower limit of 600 volts and an upper limit of 2,000 volts.

If the value falls in range, it is passed into the math loop seen in the center of Figure 3.12. This adjusts the input, V, and converts it to the appropriate output multiplication factor, M. This is then adjusted for incident particle energy and an appropriate output pulse based on all of the factors sent to the front panel.

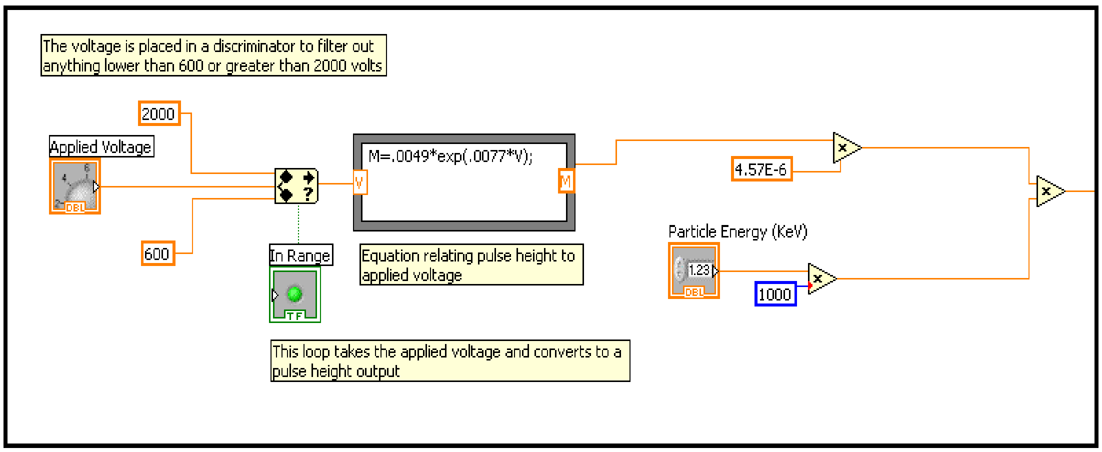

Figure 3.12: Pulse Height in LabVIEW

3.2.2.2 Alpha and Beta Plateaus

Figures 2.4 and 2.5 demonstrate the areas where there are alpha and beta plateaus at specific voltage ranges. The method used to allow LabVIEW to mimic this behavior was the same as detailed in Section 3.2.1.4; which discussed in detail the theory of how the GM detector creates a counting plateau as a function of applied voltage.

$$\text{Count Rate} = -9\text{E-}05 * X^3 + 0.1231 * X^2 - 22.707 * X + 495.41 \qquad (3.10)$$

$$\text{Beta Count Rate} = -0.6474 * X^2 + 1656.3 * X - 958508 \tag{3.11}$$

The difference for the proportional counter is that the alpha plateau appears at a lower voltage and the beta plateau can be seen at a higher voltage. Equations 3.10 and 3.11 were programmed into LabVIEW to allow for the input voltage (X) to create a proportionality factor which was multiplied by the current activity to adjust counts for the operating voltage region. This is seen in Figure 3.13. The switch in the upper left corner allows the user to specify an alpha or beta plateau. The outer loop is an event structure that allows for a given plateau equation to run when the switch is set to that radiation type.

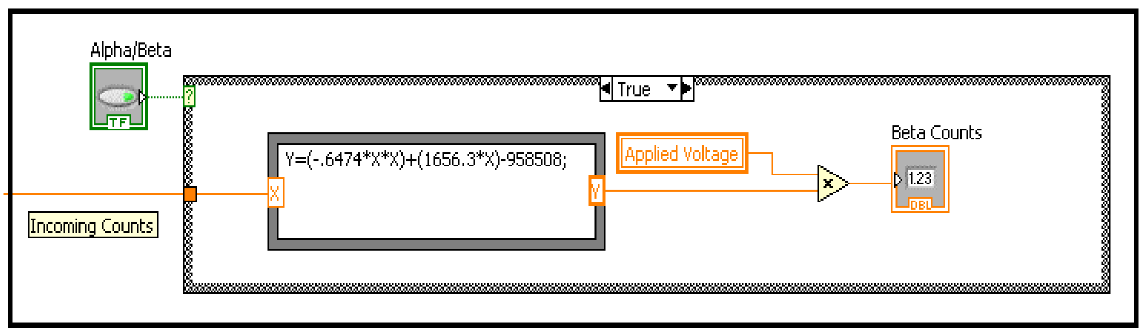

Figure 3.13: Alpha and Beta Plateau in LabVIEW

When programming the proportional counter adjustments for dead time, activity, and source detector geometry were put in place similar to that of a GM tube as outlined in Section 3.2.1.

The proportional detector designed in LabVIEW was designed to have a dead time of 75 μs which was taken from Knoll. The fraction of activity lost as a function of source activity was modeled through Equation 3.4 which models a paralyzable model. It was performed the same way as that of the GM tube with the addition of a math loop as shown in Figure 3.14.

The activity of the system was calculated in the same manner as Figure 3.6 and passed through a while loop that outputs a running detector activity. The activity is corrected for source detector geometry similar to that of the GM tube.

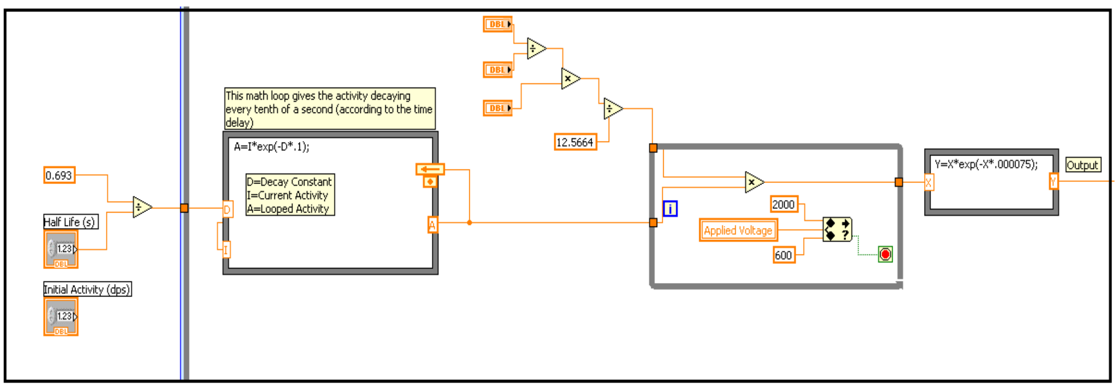

Figure 3.14: Proportional Counter Operating Parameters

3.2.3 Scintillator

For the purpose of instruction, the main output of the scintillator is the different spectra needed for lab and their associated output. In lab, a specific source is placed next to the scintillator and as it decays a resulting spectrum is created. This process and utilizing the output is known as spectroscopy. The two nuclides of interest, for this program, are Cs-137 and also Co-60. The user will be given the ability to select an isotope from the front panel of LabVIEW. The nuclide selected will then be displayed and it will also contain the information needed about the spectrum, such as decay energies. These data can be used to learn about the output spectrum and its dependence on the three gamma ray interactions.

Figure 3.15 shows an example of how this will look in LabVIEW. The picture is a combined Co-60 and Cs-137 output as taken from Gamma Vision. These types of displays will be placed in a database and the user can look at specific desired spectra.

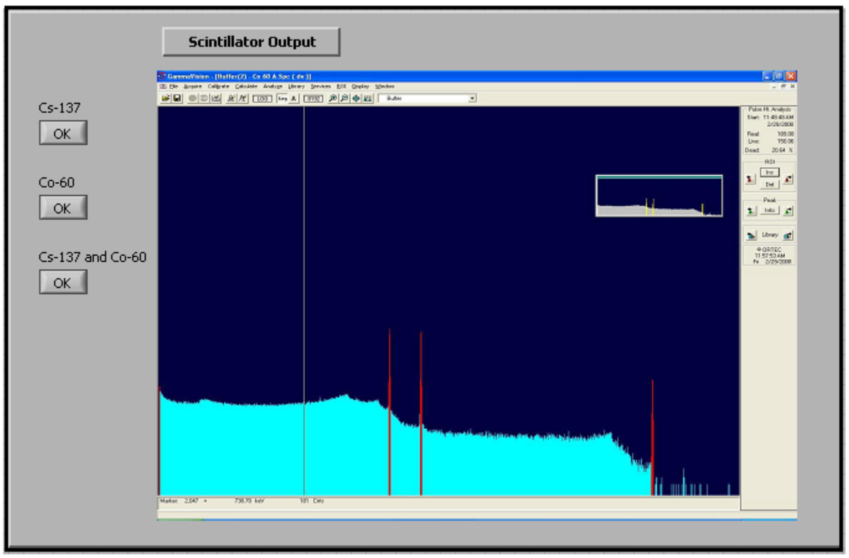

Figure 3.15: Cs-137 and Co-60 Output from Scintillator

3.3 Equipment Modeled

Due to the nature of LabVIEW, all of the NIM bin instruments associated with detection had to be wired into a single cohesive program in order to make the program run correctly. For this reason, each detector was pre-wired with a specific set of equipment that it would normally need to run. The user can select which equipment is needed to perform the experiment, and the other equipment will remain on the display panel but will not output or affect the product.

One of the key factors in detection is that the output of different equipment varies greatly from other equipment. For example the pulse from an amplifier is generally larger than that of a signal splitter. This variation is programmed into each piece of equipment, and then the different equipment is hard wired into each "set" of detectors. The detector and its available associated electronics are given below.

- GM Detector;
  - Signal Splitter, Amplifier, SCA, Dual Counter Timer, and Oscilloscope
- Proportional Counter;
  - Signal Splitter, Pre-amplifier, SCA, Dual Counter Timer, and Oscilloscope
- Scintillator.
  - Sources and resulting output spectrum

Depending on which detector is selected, the corresponding equipment will open up along with this detector. The output can then be analyzed from each piece of equipment by selecting the desired instrument, such as the signal splitter or amplifier.

3.3.1 Signal Splitter

Since LabVIEW is not dealing with the need to actually split the high voltage from the signal the main function the signal splitter will perform in LabVIEW is recalling actual pulses taken from an oscilloscope. Depending on what detector is selected and what high voltage is applied, the user will then be able to view these actual raw pulses from the GM tube or the Proportional Counter as they fluctuate with changing settings.

The process used to allow LabVIEW to do this was initiated by taking pulses directly from a real signal splitter and placing them into a Tektronix Oscilloscope for viewing. The process used to take them from the Oscilloscope and convert them to digital data that would be used by LabVIEW is detailed in Figure 3.11. The first step, is the generation of a real pulse taken from analog equipment and transferred to Open-Source, a software program compatible with the oscilloscope. The data are taken and saved in a standard XY plot. Next they are copied into Excel and a function of the data plotted. These data can then be saved and read by LabVIEW. LabVIEW reads this type of data when it has been saved as a .lvm file, a type of file associated only with this program. LabVIEW is then able to recall these mathematical models that describe the output of a pulse from the NIM Bin equipment (Bishop 2005).

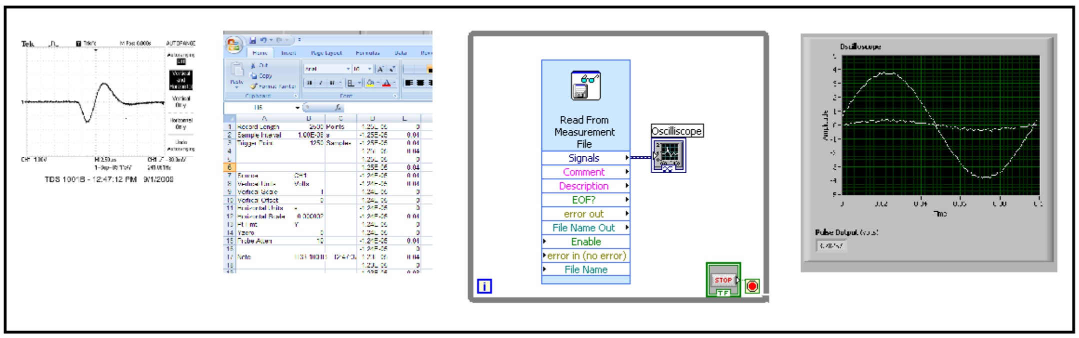

Figure 3.16 Data Flow in LabVIEW

3.3.2 Pre-amplifier

Due to the nature of the pre-amplifier it will only function in LabVIEW in the Proportional Counter section of the labs. In the actual lab, the pre-amplifier does not have any settings the user can adjust and simply is there to integrate and shape the pulse. For this reason, it will be included in the program and initiated with the Proportional Counter, but will simply function for amplifying and shaping the initial pulse from the virtual detector. It will not have any direct controls adjustable while the program is running.

3.3.3 Amplifier

The amplifier's specific function is to allow the user the ability to amplify and shape the pulse. The amplification of the pulse can affect the total number of counts detected by raising the pulse height over the level set by the SCA so that the dual counter timer is not actually detecting all of the pulses being generated.

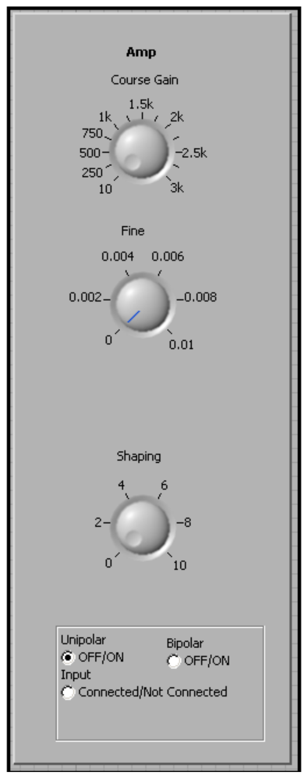

Figure 3.17: Amplifier as Seen from Front Panel of LabVIEW

Figure 3.18 demonstrates how the input signal travels across the wire and can be adjusted with the fine gain and course gain. Another function allows for the shaping of the signal, which is programmed in the same way in LabVIEW but the shaping affects the timing of the pulse, which affects the Y axis of the output display.

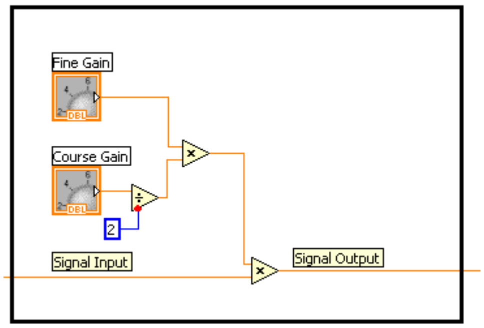

Figure 3.18: The Amplifier and Course and Fine Gain

The output of the amplifier can be chosen as either a uni-polar or bi-polar output. Depending on the input of the user LabVIEW will recall these pulses in binary form and then capture them from the oscilloscope. Figure 3.19 displays a basic case structure that allows for the uni-polar output to be the result of a "true" input and the bi-polar output to be the result of a "false" input.

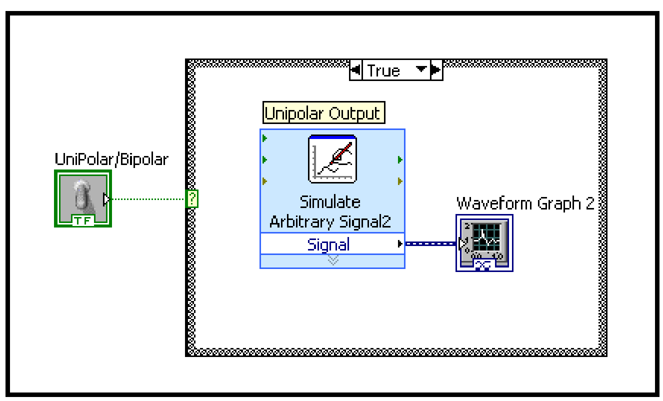

Figure 3.19: Basic Case Structure for Uni-Polar and Bi-Polar Output

In the final program, case structures were set up to allow for all four of the outputs of the amplifier which include the following:

- Bi-polar positive polarity;
- Bi-polar Negative polarity;
- Uni-polar positive polarity; and
- Uni-polar Negative polarity.

3.3.4 Single-Channel Analyzer

The single-channel analyzer's (SCA) main purpose is to create a channel viewing range for pulses falling at specific energies. The result of the SCA output is the logic pulse when the pulse height is in range; it also returns activity when the pulse is in range. The activity is detected by the Dual/Counter Timer which will be discussed later. Figure 3.20 shows the front panel view that will be used to adjust the SCA.

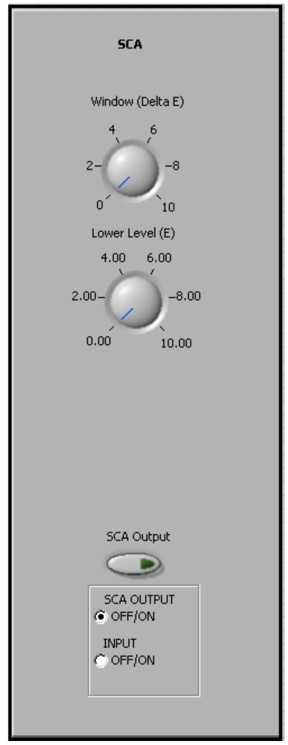

Figure 3.20: Amplifier as Seen from Front Panel of LabVIEW

The SCA has two controls; the Window (Delta E) control adjusts the size of the window, and the Lower Level (E) raises the lower threshold above which pulses are counted. Figure 3.21 demonstrates a simple discriminator that only allows pulses that fall in the specified window range to be passed through. This is then wired to a true/false function; when this function registers a true (in range) pulse it allows the SCA to count that pulse. LabVIEW performs two things when this occurs. The first is that it passes the true value to the while loop that will detect activity as long as it continues to be “true”. The second, is that it passes this same value to a while loop that allows for the logic pulse to be displayed on the virtual oscilloscope.

Discriminator- The discriminator will either return a true or false value based on if the voltage pulse falls in range of the window →

True- LabVIEW allows for the activity to be past to the Dual/Counter Timer and a logic pulse to be displayed on the oscilloscope

↓

False- The SCA does not return activity or a logic pulse

Figure 3.21: Theory behind SCA

Figure 3.21 shows the logic involved in the SCA discriminator. This was then programmed into LabVIEW. A simple diagram of the SCA is shown in Figure 3.22. The output is connected to the discriminators that accept the incoming pulse and output it only while it is in range of the settings specified.

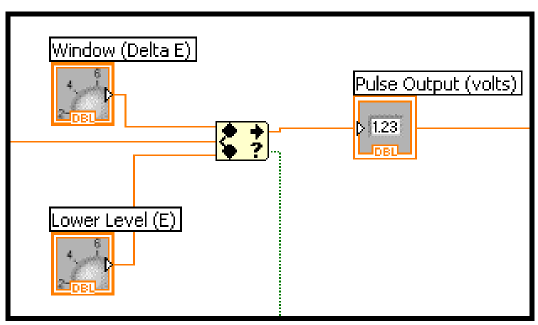

Figure 3.22: SCA in LabVIEW

3.3.5 Multi-Channel Analyzer

The multi-channel analyzer essentially is a string of single-channel analyzers put together to count the radiation "hits" falling into many smaller energy windows. This is similar to an SCA, but the MCA has many more windows to accurately collect and determine the energy of each "hit." The MCA is controlled through a computer software program that is connected to the detection equipment. Gamma-vision is one example of this type of software and is what is used by many instrumentation labs. Since the MCA is normally only used with a scintillator for gamma spectroscopy it was not specifically designed in LabVIEW. The Scintillator in LabVIEW will only be used as a program to recall stored spectra for nuclides of interest.

3.3.6 Dual Counter/Timer

The Dual Counter/Timer's main function is to allow for the equipment to be able to measure and record counts of radiation over very specific functions of time. This was done by creating a timer that functioned when turned on and stopped when turned off.

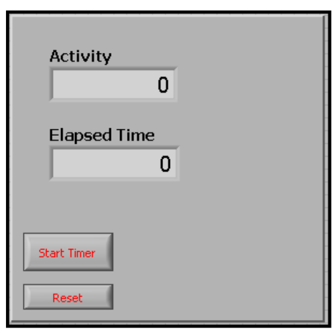

Figure 3.23: Dual Counter/Timer Front Panel

While the dual counter and timer is rather simple on the Front Panel as seen in Figure 3.23, it is actually rather complex when ran executed in LabVIEW. The time as seen in Figure 3.24 executes the while loop which runs continually until stopped. When it is turned off the associated activity is stopped by putting a global variable inside of the loop that only executes when the timer is functioning.

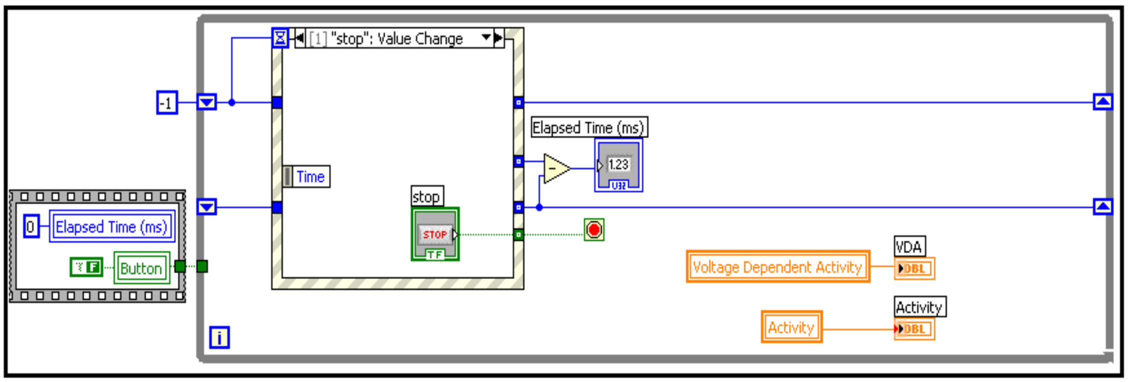

Figure 3.24: Dual Counter/Timer Back Panel

4 RESULTS

4. Results

4.1 Introduction to the Lab

In the following sections data will be taken from real detection equipment and also from the virtual software designed. These data will be analyzed and compared for similarities and discrepancies in Section 5.

4.2 GM Results

4.2.1 Calculating Dead Time with a GM

The dead time of the detector system was calculated with a GM detector running through an amplifier, SCA, and dual/counter timer. The real data from radioactive Ti-204 was calculated by placing a radioactive source close to the detector face. The source used was a split source which means that there were two identical half sources with identical levels of activity. Source 1, as seen in Table 4.1, was one of these sources counted for a minute. Source 2, was the other half and was counted for one minute. Following this, both sources were placed on the detector at the same time to determine the detected activity with losses from dead time.

LabVIEW was then used to conduct the same experiment following the same procedures. A digital source of identical activity was placed on the detector and counts recorded in Table 4.1 under Source 1 and 2. Finally, these two sources were placed on the digital detector and the new activity detected. The bottom column, which is dead time, was calculated using Equation 2.17.

Table 4.1: GM Tube Dead Time Counts

	Real Data Ti-204 (CPM)	Labview (CPM)
Source 1	17449	14980
Source 2	17318	13975
Source 1 and 2	20475	15075
Dead Time	2.4 μsec	33 μsec

4.2.2 Calculating Source Detector Geometry with a GM

Source detector geometry relates to how the detector counts drop exponentially as the source is moved further from the detector. This follows the principles set forth in Section 2.8.1. The real data were collected by placing a Cs-137 source on different shelves at various heights away from the detector. Figure 4.1 was plotted by tabulating the counts at various distances as the source was moved further from the detector, in increments of 1 cm.

Table 4.2: Source Detector Geometry

	Distance From Detector (Cm)	Real Data (CPM)	Labview (CPM)
Shelf 1	1	16385	19987
Shelf 2	2	11702	10069
Shelf 3	3	6927	6643
Shelf 4	4	4292	5054
Shelf 5	5	2782	4017
Shelf 6	6	2013	3333

Table 4.2 compares the real data and the data taken from LabVIEW; which is plotted in Figure 4.1.

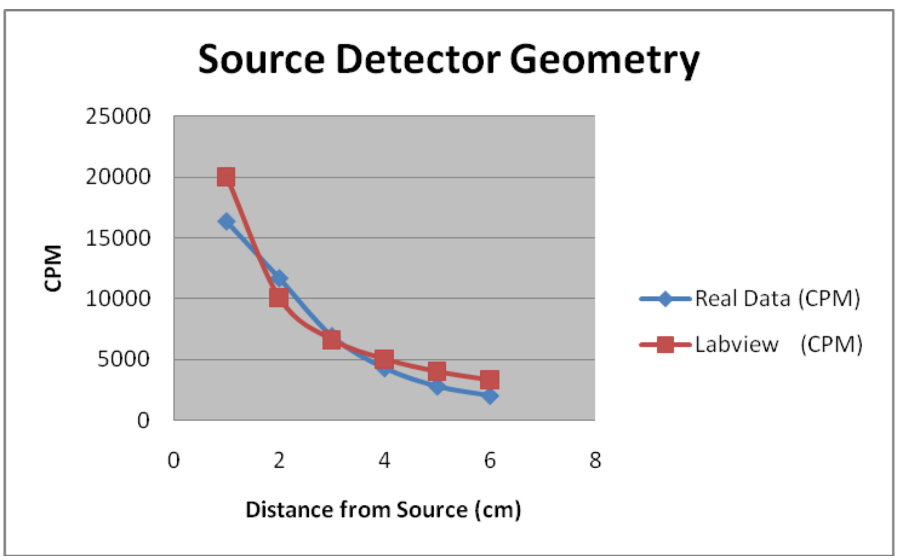

Figure 4.1: Source Detector Geometry of LabVIEW and GM Data

4.3 Analyzing Pulses from the GM Detector

4.3.1 Signal Splitter

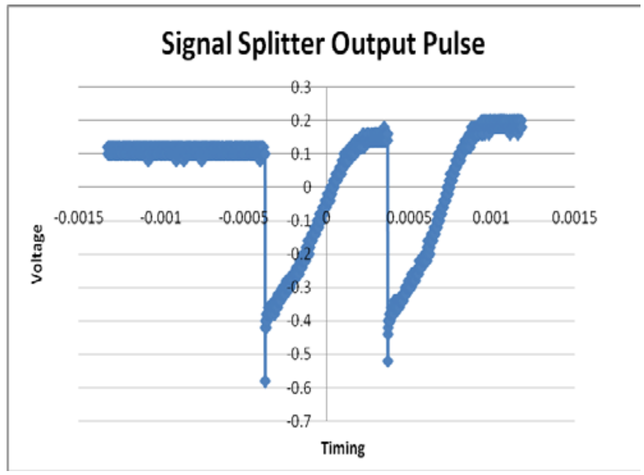

Figure 4.2: Output Pulse from Signal Splitter

4.3.2 Single-Channel Analyzer

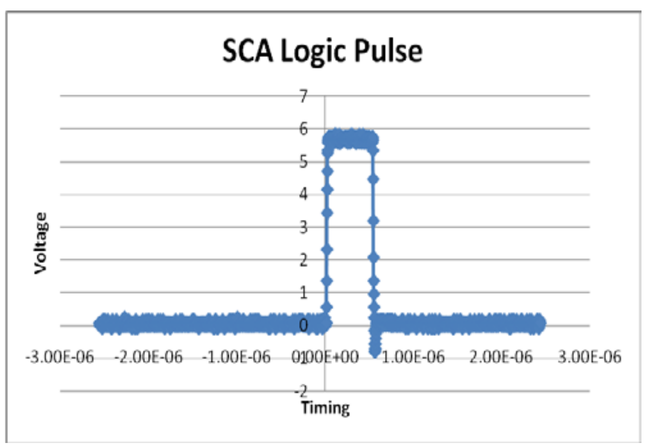

Figure 4.3: SCA Logic Pulse

4.4 Calculating a High Voltage Operating Plateau with a GM Detector

This experiment was done through taking numerous counts of data at a wide range of voltages. The data from LabVIEW and from the real detector equipment were listed in Table 4.3 and shown in Figure 4.3 plotted against each other. The reason the pulses fall off at rising voltage levels is because they are rising above the SCA's channel height and not being recorded.

Table 4.3: HV Plateaus

Voltage	Real Data	Labview Data
770	0	0
790	0	0
810	10873	4335
830	12534	10005
850	13771	10950
870	14919	12645
890	15298	13800
910	16127	14550
930	16551	14850
950	17300	16425
970	20161	16515
990	20165	16440
1010	20309	16050
1030	20078	14550
1050	20971	13950
1070	21583	12450
1090	19287	11550
1110	11509	9450
1130	10916	6885
1150	HV Clicking	
1170	HV Clicking	
1190	HV Clicking	

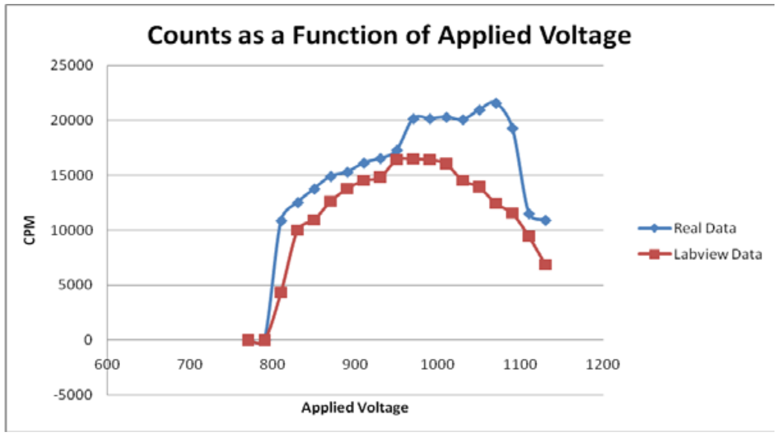

Figure 4.4: HV Plateaus

4.5 Determining Dead Time with a Proportional Counter

The dead time of the proportional counter system was calculated the same way as that of the GM tube with the setup being a proportional counter, instead of a GM tube, running through a pre-amplifier, amplifier, SCA and dual counter/timer.

Table 4.4: Dead Time of a Proportional Counter

	Real Data (CPM)	Labview (CPM)
Source 1	57831	48710
Source 2	61723	49864
Source 1 and 2	124580	39232
Dead Time	70 µs	12 µs

5 DISCUSSION

5. Discussion

The outcomes of the experiments conducted showed data from the LabVIEW equipment similar to that of real detector equipment. Experiments were performed examining dead time, source detector geometry, HV operating plateaus and also signal pulses as viewed from an oscilloscope.

One of the key aspects of this virtual program that does not work the same as real equipment is the fluctuations in results and outcomes due to anomalies in the equipment. Every real piece of equipment may have something about it that causes its output to be slightly different from an experiment on another piece of identical equipment. These changes were accounted for, within reason, by the addition variables causing slight statistical fluctuations to the outcomes that cause some variation each time an experiment is undertaken. The results and outcomes of the experiments are outlined below.

5.1 Experiments

5.1.1 Dead Time

The dead time of the real and virtual detector systems were determined to be within 7.1% of each other, with the dead time of the GM being 23 μs and that of the LabVIEW GM being 33 μs. The LabVIEW program will always register a dead time around this time and will only vary depending on the activity of the source present. At higher activities the system registers lower counts than would have been expected from the activity present. This behavior is somewhat expected and shows that the virtual GM tube is behaving in the same manner as that of the real GM tube.

5.1.2 Source Detector Geometry

The source/detector geometry was investigated. The results shown in Table 4.1 indicate that the GM tube and the LabVIEW GM tube matching up almost perfectly. As the source was moved further from the detector face the counts dropped off exponentially according to the equations put forth in Section 2, which describe this decrease. In future experiments the distance from the source will directly affect the outcome of the total counts detected.

5.1.3 High Voltage Operating Plateaus

Figure 4.3 shows the HV plateau as a function of counts at specific ranges of applied voltage. The curves both fall off at higher voltages where the pulse height is exceeding the range of the SCA. When students conduct this lab they will generate curves similar to the LabVIEW data but with slight variations due to a random number generator that will affect all the data generated in the lab.

The GM tubes operating characteristics are all tied together. As can be shown from Section 4, when any of the operating parameters is varied all of the other operating parameters change in the same fashion as expected in the actual lab.

5.1.4 Determining Dead Time with a Proportional Counter

The dead time of the proportional counter was determined using the same methods and equations as of that of the GM Tube. The real data taken from the proportional counter resulted in a dead time of around 70μs, and that of the LabVIEW program determined to be 12μs. This is the dead time of the system, and the total losses from dead time will vary depending on the count rate recorded by the detector. At higher levels of activity the digital equipment will observe less counts than are incident upon the detector face. When the activity drops the detector will observe a higher percentage of counts. The data collected show this change.

6 CONCLUSION

6. Conclusion

6.1 Brief Summary of the Outcomes of the Experiment

6.1.1 Detectors

6.1.1.1 GM Tube

Figure 6.1 shows the user interface that the end user will control. All of the front panel objects will be tied to the back panel VIs that will control the entire system.

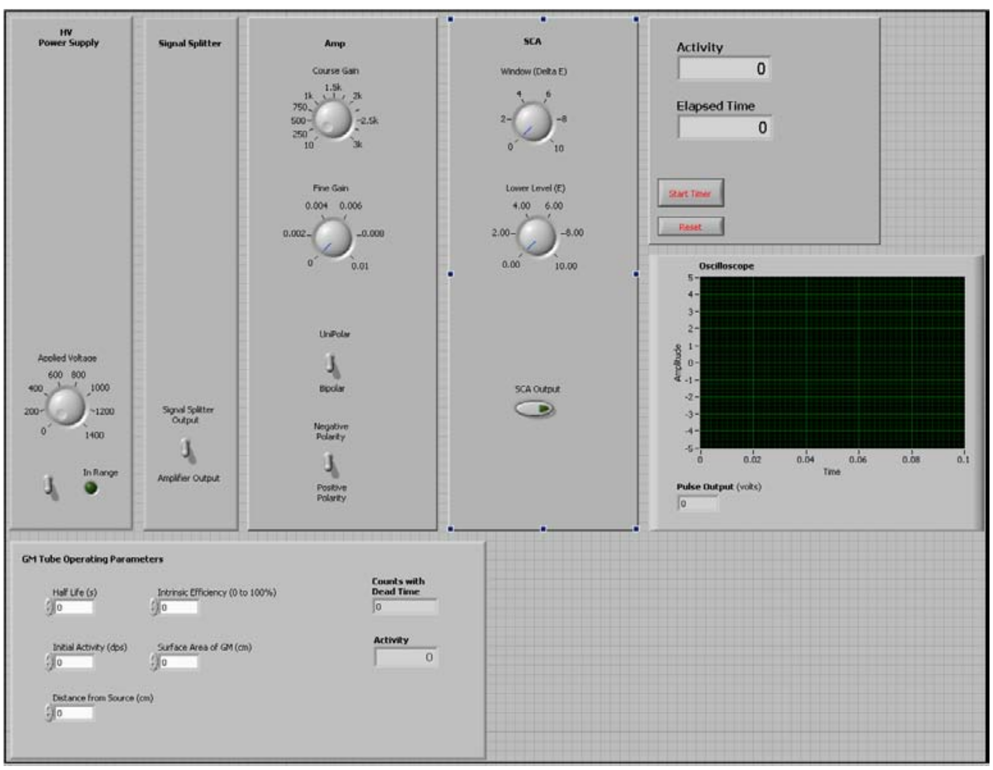

Figure 6.1: GM Tube Front Panel

6.1.1.2 Proportional Counter

The proportional counter is shown in Figure 6.2. It will have the same functionality as that of the GM Tube, but with added controls as shown below.

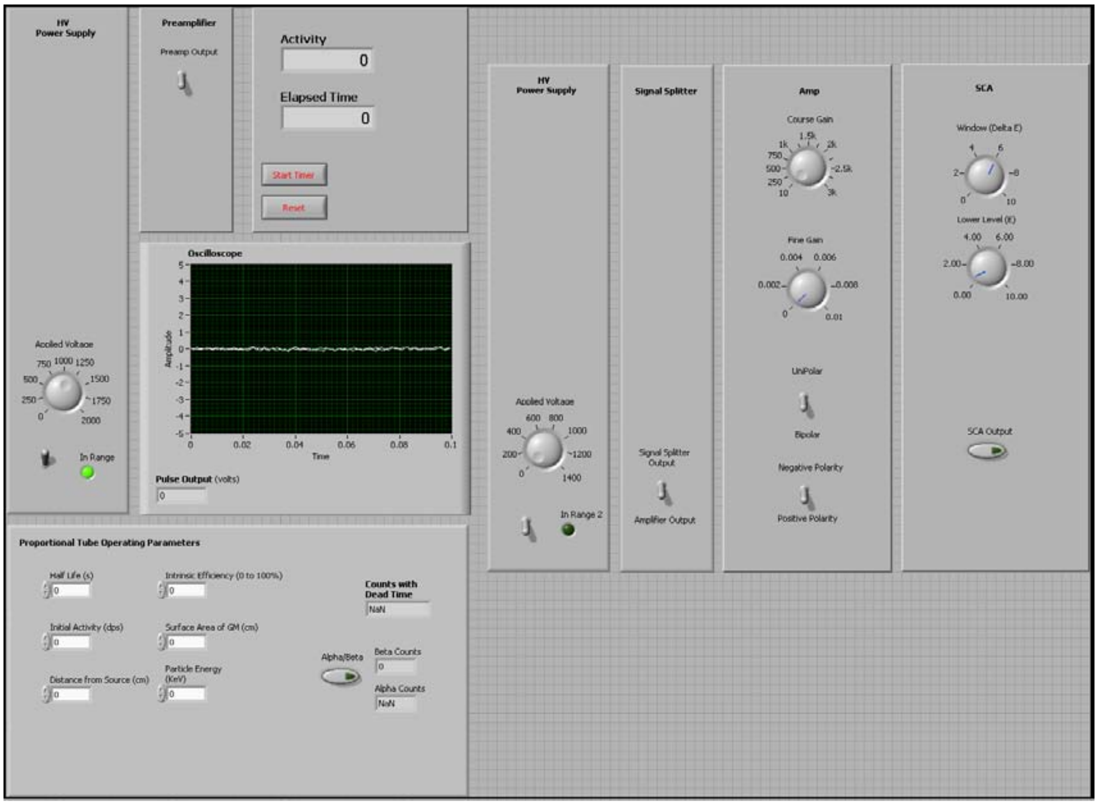

Figure 6.2: Proportional Counter Front Panel

6.1.1.3 Scintillator

The scintillator is pictured in Figure 6.3 and is shown loaded with a working spectrum. The end user will have access to the functionality controls to the left of the generated spectrum.

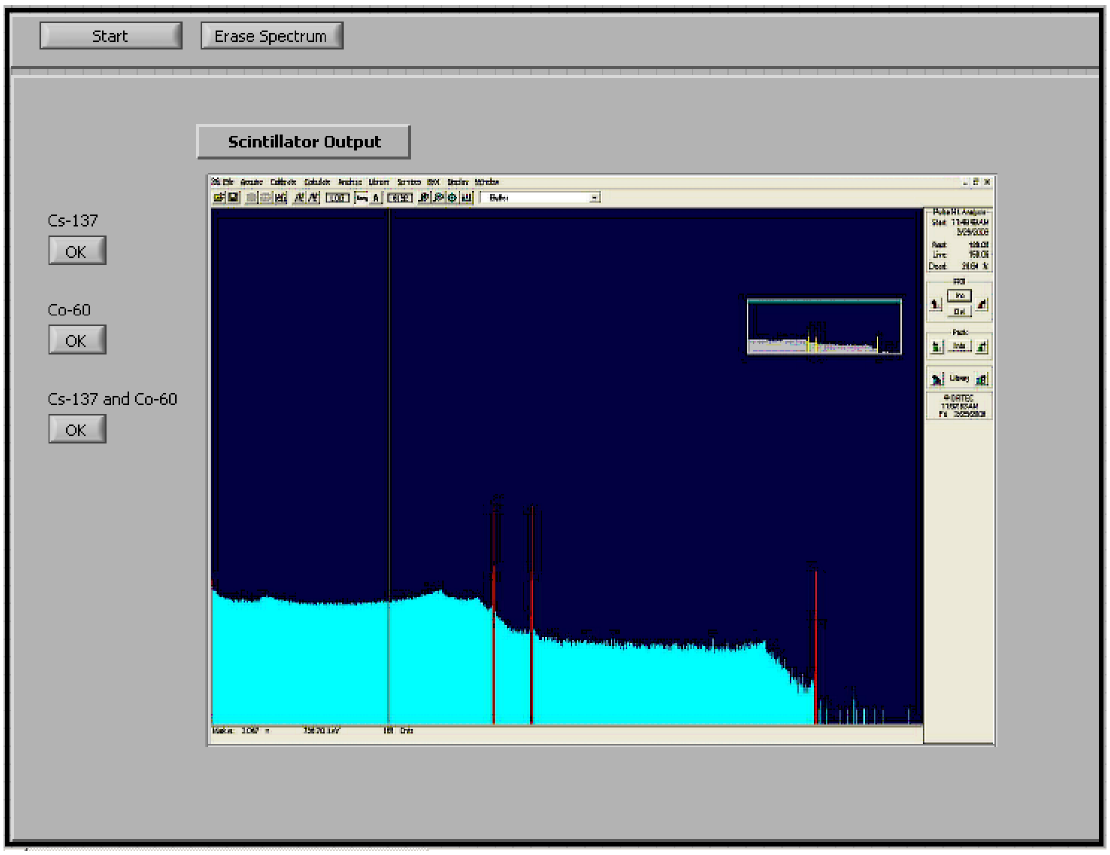

Figure 6.3: Scintillator Front Panel

6.1.2 Detector Functionality

In conclusion it was determined that the detectors functioned properly and modeled the equipment in a desired manner. Future research could improve the scintillator by improving the LabVIEW created detector and enabling it to digitally produce the output spectrum that would be expected from different radio-nuclides. Virtual signal pulses could be digitally transferred to Gamma Vision, or a similar software program, to generate the gamma spectrum for the nuclide of interest. This would allow for outputs that vary as opposed to the static pre-generated gamma spectra that are currently used.

Another issue that could improve the overall experience is to program in more of the anomalies that cause the equipment to malfunction. Students in real labs suffer from many mistakes, including issues like not being able to program the timing capabilities for the timer or placing a source upside down and not registering counts. Future research could be devoted to determining typical errors made by students and placing functions into the equipment so that when students do not set up the digital experiment correctly they encounter similar errors as that which students in lab would encounter.

6.1.3 Equipment

The equipment functions mathematically in the manner in which it was designed. The output shown in the Results Section followed the same expected results that are seen from real data.

Once again, the problem is encountered of the equipment working “too well.” The distance students never have to worry about the kinds of problems encountered by real students of faulty equipment, equipment not being set up correctly or output that does not make logical sense and which needs further discussion and research to determine the source of the errors.

Another area of future research involves creating a better way to view pulse outputs. Currently the LabVIEW program only has a certain number of output pulses from different sources such as Cs-137. This is due to the fact that for each source the output of different equipment and settings produces a range of new pulses. It is difficult to capture every possibility from the equipment and program it into LabVIEW. Future research could be carried out to allow for multiple pulses to be stored and recalled so that distance students see a range of outputs.

Finally, there is some detriment that occurs from not being able to actually physically touch the equipment. Students are at a loss for not having to deal with such issues as the "clicking" noise caused when too much voltage is applied to a GM. This can break the real equipment, which is never a good thing, but students often learn much more from trial and error and problems than they do from an experiment that goes smoothly. A final recommendation for future research in a humanitarian field could be undertaken to determine the level of learning of on-campus students to those of their off-campus counterparts.

6.2 Recommendations for Implementation

It is recommended that the virtual experiments to be undertaken first be performed by students on campus so that the problems they encounter can be explored and solved prior to distance students encountering problems that may not be easily dealt with from afar. It is also recommended that the LabVIEW-based Software be set up on an Oregon State University web server so that it is available at an Oregon State website and accessible from a distance. This site should also be checked from various remote sites and browsers to ensure compatibility. If these recommendations are followed, the software should adequately allow for students to experience and learn at the same pace as the labs being run on-campus.

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