LabVIEW DAQ for NE213 Neutron Detector

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ABSTRACT

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A neutron spectroscopy system, based on a NE213 liquid scintillation detector, to be placed at the Stanford Linear Accelerator Center to measure neutron spectra from a few MeV up to 800 MeV, beyond shielding. The NE 213 scintillator, coupled with a Photomultiplier Tube (PMT), detects and converts radiation into current for signal processing. Signals are processed through Nuclear Instrument Modules (NIM) and Computer Automated Measurement and Control (CAMAC) modules. CAMAC is a computer automated data acquisition and handling system. Pulses are properly prepared and fed into an analog to digital converter (ADC), a standard CAMAC module. The ADC classifies the incoming analog pulses into 1 of 2048 digital channels. Data acquisition (DAQ) software based on LabVIEW, version 7.0, acquires and organizes data from the CAMAC ADC. The DAQ system presents a spectrum showing a relationship between pulse events and respective charge (digital channel number). Various photon sources, such as Co-60, Y-88, and AmBe-241, are used to calibrate the NE213 detector. For each source, a Compton edge and reference energy [units of MeVee\(^1\)] is obtained. A complete calibration curve results (at a given applied voltage to the PMT and pre-amplification gain) when the Compton edge and reference energy for each source is plotted.

This project is focused to development of a DAQ system and control setup to collect and process information from a NE213 liquid scintillation detector. A manual is created to document the process of the development and interpretation of the LabVIEW-based DAQ system. Future high-energy neutron measurements can be referenced and normalized according to this calibration curve.

1- MeVee: Unit used to equivocate electron absorption energy to other absorbed particles.
INTRODUCTION

Emission of neutrons at the Stanford Linear Accelerator Center (SLAC) is a result of linear interactions with targets. The spectroscopy system is used to measure neutron spectra for a range of a few MeV to 800 MeV. Project entails the creation of a data acquisition system to detect and process information, from neutron sources, at high speeds and for multiple detectors.

The NE213 liquid scintillator is sensitive to both photon and neutron radiation. The liquid is composed of hydrocarbon groups. Photon radiation interacts with the detector either by Compton Scattering, the Photoelectric Effect, or absorption. Compton Scattering is the predominant occurrence in the NE213. As photons scatter off electrons, the electrons are excited into higher energy states. The atoms become unstable, causing electrons to drop back to their stable energy state. The electron’s lost energy results in photon emission. Neutron radiation acts differently. Incoming neutrons bombard the nuclei of the hydrogen or carbon atoms, by reaction eject a proton. The proton may either excite orbiting electrons or decelerate causing photon emission [1]. Both types of radiation result in the emission of photons.

Emitted photons are however too weak for detection. A Photomultiplier Tube as well as an amplifier are attached to the end of the scintillator to strengthen the signal. In the PMT, a photocathode wall converts photon energy to electron energy. Electrons then multiply through a series of dynodes, resulting into a strong pulse [2].

NIM and CAMAC systems process incoming signals in preparation of data acquisition by a PC. The NIM modules trigger off of incoming pulses and generate respective gates. Gates are square pulses that designate the start and ending period for integration of the pulses. The ADC integrates the pulses to convert the analog signal into digital signals/channels. Two methods have been developed to acquire the information from the ADC. They are the Look-At-Me
(LAM) and Digital I/O Trigger systems. The LAM system employs the use of the LAM register. The ADC sets the register every time a signal is integrated and converted into a digital channel, i.e. the register is set when the module is ready with information, hence Look-At-Me. When the ADC is read the LAM register is cleared and the process continues a search for the LAM to be set once more. The second method, Digital I/O Trigger, traffics the flow of data in the control layout with use of a Digital Input/Output Board, a standard PCI card. It traffics information in and out of the ADC.

LabVIEW-based DAQ begins communications between the PC and control system to plot data onto a histogram providing a relationship of pulse events to ADC digital channel numbers. The NE213 system is calibrated by various photon sources such as Cobalt-60, Yttrium-88, and AmBe-241. AmBe is also a photon as well as a neutron source. The calibration curve represents both photon and neutron energies. By taking plots of any radioactive environments and referring to the calibration curve one may determine the energy of the surrounding.

A manual is also developed to document the techniques and background information to achieving the desired results. The PC used for experimentation runs a Pentium II processor at 600MHz with 130KB RAM. Windows NT operating system is run by the system.

**METHODOLOGY**

Signal processing and LabVIEW data acquisition are the two major compositions of the project. Signal processing is done via CAMAC and NIM modules. The most important part of signal processing is gate generation. The idea behind the gate is providing the CAMAC ADC with the proper period of time for pulse integration, time is specified by gate width. The ADC converts analog pulses into digital signals/channels using charge integration. The integrated
charge is classified into 1 of 2048 channels [3]. The LabVIEW DAQ program is responsible for acquiring and analyzing the data.

The function of the NE213 liquid scintillator is to scintillate upon incident radiation. Generated photons by the NE213 are converted into electronic pulses through a PMT. ~1000 Volts is applied to the PMT. The electronic pulses are fed into an amplifier of gain 10. The signal from the amplifier is routed to both a LeCroy 623D Octal NIM Discriminator and a LeCroy 2249W ADC. The discriminator triggers off of incoming pulses to create a gate. The gate width is set at 120 nsec to assure that the scintillator’s pulse is fully represented. A threshold is adjusted on the discriminator to exclude noise; this parameter is set to 0.0302 Volts. The gate is a standard NIM pulse, ~0.7 Volts. Another standard often dealt with in control circuitry is the 3-5 Volt TTL signal. One must take care not to cross NIM and TTL signals.

From this point forward, the circuitry is characteristic to the employed DAQ method, LAM or Digital I/O Trigger. The LAM system hires the LAM register as the determining factor to perform the next read; the other system acquaints the Digital I/O Board to control the traffic of information, defining when the ADC is ready with new information, synchronizing data flow.

**Look-At-Me System**

One of the outputs of the discriminator is sent to a CAMAC LeCroy 2323 Duel Gate Generator. The gate generator is manually preset to generate a one-millisecond gate each time a signal or trigger comes in. This gate is sent back into the discriminator’s inhibit terminal. The inhibit terminal functions to veto all output signals from the discriminator while an inhibit signal exists. Thus, in the setup the discriminator is inhibited for one-millisecond after the discriminator detects an event. This is to allow time for the ADC to digitize the existing analog
signals at its terminals. This period of inhibition is also accounting for other module delays, wire delays, and computer processing time. Circuit diagram shown on figure 1.

The pulses routed to the ADC from the amplifier are delayed by 20 nsec. This is to assure that the gate and pulse arrive at the terminals of the ADC simultaneously. Note that the gate arrives 8 nsec before the pulse, to assure the ADC is prepared to digitize the incoming signal.

Digital I/O Trigger System

The Digital I/O Trigger method, although more complicated, is a much more beautiful system by virtue of its synchronization. The circuitry setup continues as follows. From the discriminator, a gate flows into a Phillips Scientific Quad Four-Fold Logic Unit model 754 set to operate as a Fan-out module. Fan-out is designed to reproduce multiple of the same signal. Of these signals, one is routed to the LeCroy 2323 Gate Generator, set to latch mode. In latch mode the module produces high signals when its input (start) terminal receives a high signal. If the stop terminal is high then the outputs of the Gate Generator are off. One of the outputs of the Gate Generator is routed to the veto terminal of the Fan-out unit. If the veto receives a high signal all outputs of the unit are vetoed. If the latch is set (stop is high), the veto exists, and according to the circuitry gates no longer flow to the ADC. Gates remain vetoed until the latch is removed.

The Digital I/O Board is a PC to control interface. It is a terminal of communication, empowering computer software to set conditions to the control setup.

Event-by-event Description of the Digital I/O Trigger

The first pulse from the scintillator latches the Gate Generator, thereby vetoing the fan-out. Before the fan-out is vetoed, the gate that is generated from the first pulse has already flown
through the discriminators, reaching the ADC. The Digital I/O Board then registers that the ADC is ready to be read and proceeds with the execution of an ADC read. The first event has been recorded. The Digital I/O Board momentarily sets the stop terminal of the Gate Generator, allowing for a brief flow of gates and the process repeats. Circuit diagram shown on figure 2.

**LabVIEW Data Acquisition**

The LabVIEW data acquisition file begins performing a set algorithm of initializations on the CAMAC GPIB crate controller and the CAMAC system. Figure 3 shows a programmers view of the GPIB being initialized through a sub VI (sub-program). Sub VI’s are provided in the LabVIEW DAQ library. After initialization a CAMAC crate controller clear register operation is performed, to stop initialization of the crate controller. To clear the registers the CAMAC crate controller four parameters are specified: the slot number ($n = 30$), the sub-address ($a = 0$), the function code ($f = 17$), and the control register bit ($64$) [4]. The slot number refers to the module’s station number in the CAMAC crate. The sub-address refers to a particular connection within a particular instrument/module. The CAMAC crate has 25 slots; slots 24-25 are reserved for the crate controller, leaving 23 slots for other modules. The function code indicates what kind of operation is to be performed (read, write, or control command). All three parameters are defined in the GUI interface of LabVIEW, to execute the CAMAC clear operation, as shown in the figure 4. After configurations and initializations, the program then proceeds to open a file and appends headers. Data collection occurs through one of two methods: Look-At-Me or Digital I/O Trigger.

**LAM Method**

To use the LAM register is must be enabled through the program. The ADC sets the LAM register when it has finished digitizing one analog pulse. The LAM Request Register is 24
bits wide; containing the LAM status of all 24 stations of the CAMAC crate, note that the rate controller does not use a LAM register. The 25th station of the crate does not have an allocated LAM register.

Once the ADC's LAM is set, data is read from the ADC. To read the ADC one must execute a 16 bit read function with the following information: slot number \( n = 22 \), sub-address \( a = 0 \), and function code \( f = 2 \) [3]. However, if the LAM is not set then the DAQ idles, awaiting a set LAM. If the LAM is not set after 20 attempts of checking the LAM, the crate controller is defined to be "hung up" and in need of a jump-start. The program essentially freezes, unable to collect any more data. To jump-start the system the GPIB registers are initialized and then cleared, figures 3 and 4. Between each attempt of checking the LAM, the program waits one millisecond to allow time for the ADC to digitize the analog pulse. With every successfully collected event the histogram is updated, plotting the number of events against channel number. Once enough data is collected, the information is stored into a file.

**Digital I/O Trigger**

The LabVIEW data acquisition system initially orders the Digital I/O Board to send a low signal to the stop terminal of the gate generator. Stopping the flow of gates to the ADC. The gate and pulse already at the terminals of the ADC then wait to be read. The program checks through the Digital I/O Board whether the circuitry is vetoed, i.e. checks if flow has stopped. As soon as the program registers that the circuitry is vetoed, the read function as described in the LAM method above is executed. The program then uses the Digital I/O Board to allow the circuitry to flow briefly, to allow the next gate and pulse to arrive to the ADC.
Calibration Curve

Data is taken from the three sources: Co-60, AmBe-241, and Y-88. The affect of background radiation is removed from the data set of each source. Figure 5 is the result of the data set taken from a Co-60 source with the affects of background radiation extracted. Two humps are present. The peak of the hump corresponding to the largest channel number is known as the Compton Peak. The region just to the lower right to the Compton Peak is referred to as the Compton Edge. The Compton Edge is unique to every characteristic source. The Compton Edge is calculated by multiplying the number of counts at the Compton Peak to the Compton Edge Factor. The Compton Edge Factor is tabulated for the different sources on table 1.

RESULTS

The Digital I/O Trigger system works much more efficiently than the LAM system. The LAM system clocked to collects events from a Co-60 source at 131 particles per second (pps) while the Digital I/O Trigger at 470 pps. Depending on the size and type of source present, the total particles recorded per second vary. Larger sources produce larger rates of detected particles.

One of the limiting factors to the speed of the system is the internal delays of the modules and also the speed of the PC. If a faster PC is applied to this system the number of particles recorded per unit time will surely increase.

The LAM system has a problem of freezing at random intervals of data gathering; a jump-start feature is developed to break out of the frozen or “hung up” system and continue data collection. The “hang up” is caused by improper timing of inhibit and read commands. The system freezes at points in which an overwhelming flow of data is directed to the ADC. To read data from the ADC at such a critical moment freezes the ADC. Once this boundary is crossed the issue cannot be resolved unless initialization is reestablished in the CAMAC system.
jump-start feature reinitializes the registers of the CAMAC system. The Digital I/O Trigger system does not have any problems with an overflow of data to the ADC. It is designed to traffic the flow of data, therefore the ADC would never experience a "hang up."

The data acquisition systems, whether LAM or Digital I/O Trigger, create spectra representing number events of incident particles at corresponding energies. The spectra for Co-60, Y-88, and AmBe-241 are plotted with two curves, refer to figures 6-8. The pink curves represent the sources spectra including affects of background radiation. The blue curves show spectra of solely the source. To achieve a plot without the affects of background radiation, a long sample of background radiation is taken. Dividing the counts, along the y-axis, by the period of time to collect the total data set, one achieves a plot representing counts per second vs. channel number. Applying this to the plot of background radiation and the plot of the source including the affects of background radiation, one may subtract the two plots and conclude with a plot representing solely the source.

The calibration curve of NE213 liquid scintillator, figure 9, results using the following parameters, -1000 Volts applied to the PMT and an amplifier of gain 10 placed at the outgoing signal from the PMT. If these parameters are modified then a calibration curve of a different slope results. The plot is derived from the three photon sources. The linear regression of the curve below is 0.9999. The curve is nearly linear. This reflects the quality of the control systems, wires, scintillator and program.

**STATISTICAL UNCERTAINTY**

The calibration curve is based on one data set of each source, figures 6-8. Radiation is a random process, a source radiates differently from data set to data set. Thereby the result of our
calibration curve is subject to statistical uncertainty. Calculating the statistical uncertainty is as follows.

From the results in figures 6-8 it is evident that every ADC channel corresponds to a particular number of counts. The number of counts for each channel contains an uncertainty.

\[
\sigma = \text{uncertainty} \\
\sigma \equiv \sqrt{\text{counts}}
\]

For randomly distributed events, the uncertainty is calculated to be the square root of the number of counts [6]. In addition, the propagation of error must be accounted for when background radiation is extracted from a data set. The resulting statistical uncertainty pertaining to the source is the square root of the sum of the squares of the uncertainties of the source with affects of background radiation and the background radiation.

\[
\sigma_{\text{source}} = \sqrt{(\sigma_{\text{background}})^2 + (\sigma_{\text{source with background}})^2}
\]

The uncertainty is calculated for each channel in a plot. The uncertainty of the counts results in an uncertainty in the Compton Peak of each data set. The error propagation of the Compton Peak mirrors to that of the Compton Edge. Thus concluding in a statistical uncertainty in the calibration curve. Refer to figure 10 for statistical uncertainty, represented by error bars.

CONCLUSION

The calibration curve is nearly linear and presented by the equation, \( y = 0.0042x + 0.177 \). Using this equation, the neutron spectroscopy system is capable to map neutron energy levels from a few MeV to 800 MeV. The spectroscopy system is sensitive to photons and neutrons. The calibration curve represents photon and neutron sources although our primary concerns are neutron sources.
The calibration curve resulted with a $R^2$ value of 0.9999 – practically linear. This reflects on the quality of the data acquisition system, the circuitry, modules and the scintillation detector. The calibration curve can be used as a reference for future readings. Placing this data acquisition system in a particular environment, one may determine the energy existing in the setting.

Two routes were taken in the developing of the data acquisition system, one advantages of the Look-At-Me register and the other using the Digital Input/Output Board to traffic data flow through the circuitry. The Digital I/O Trigger method has a speed of approximately four times greater than the speed of the LAM method. The Digital I/O Trigger is more stable and one may depend on it for as long as the hardware is functioning.

This project is a phase of a larger series of experiments and phases. In the future, the calibration curve will also include cosmic muons; this will increase the range of the curve drastically. Ongoing phases are implementing a system for the calculation of live and dead time of the data acquisition system, and a system that can differentiate the energies of different particles, such as photons and neutrons.
REFERENCES


Circuit Diagram – Look-At-Me

Power Supply
Ortec 556
System: NIM
-1000V

Scintillator
NE213

Pre-AMP
x10

4ns

Discriminator
LeCroy 623B
System: NIM
In
Out

Inhibit

4ns

Dual Gate Gen.
LeCroy 2323
System: CAMAC
Ch. A
Ch. B
Start
NIM
Gate width: 1msec
Gate delay: 10ns

ADC
LeCroy 2249W
System: CAMAC
Gate
Analog

Crate Controller
GPIB 3988
KineticSystems
System: CAMAC
Request
Grant
1ns

PC

Figure 1.
Figure 2.
Figure 3. Programmer's view of the GUI interface of LabVIEW. The function above reinitializes all CAMAC registers

Figure 4. Programmer's view of the GUI interface of LabVIEW. The function above clears all CAMAC registers

Figure 5. A sample data set of a Co-60 source without affects of background radiation. Note the Compton Peak and Edge
Figure 6. Data set of Cobalt-60 source. DAQ for 1060 seconds. 200,000 events collected of Co-60 and background radiation.

Figure 7. Data set of Yttrium-88 source. DAQ for 1060 seconds. 138,588 events collected of Y-88 and background radiation.
Figure 8. Data set of AmBe-241 source. DAQ for 1060 seconds. 148,924 events collected of AmBe-241 and background radiation

Calibration Curve for NE 213 Scintillator
-1000 V - 10 Gain

Figure 9. Calibration Curve. -1000 Volts applied to PMT and an amplifier place immediately after PMT with gain of 10
Figure 10. Calibration Curve. -1000 Volts applied to PMT and an amplifier placed immediately after PMT with gain of 10. Error bars pertain to the channel number.

**TABLES**

<table>
<thead>
<tr>
<th>Source</th>
<th>Compton Edge Factor</th>
<th>Source Energy [MeVee]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{241}$AmBe</td>
<td>0.664</td>
<td>4.2</td>
</tr>
<tr>
<td>$^{88}$Y</td>
<td>0.642</td>
<td>1.61</td>
</tr>
<tr>
<td>$^{60}$Co</td>
<td>0.303</td>
<td>1.15</td>
</tr>
</tbody>
</table>

Table 1. Three sources used to find the calibration curve their Compton Edge Factor, and characteristic Source Energies. [5]