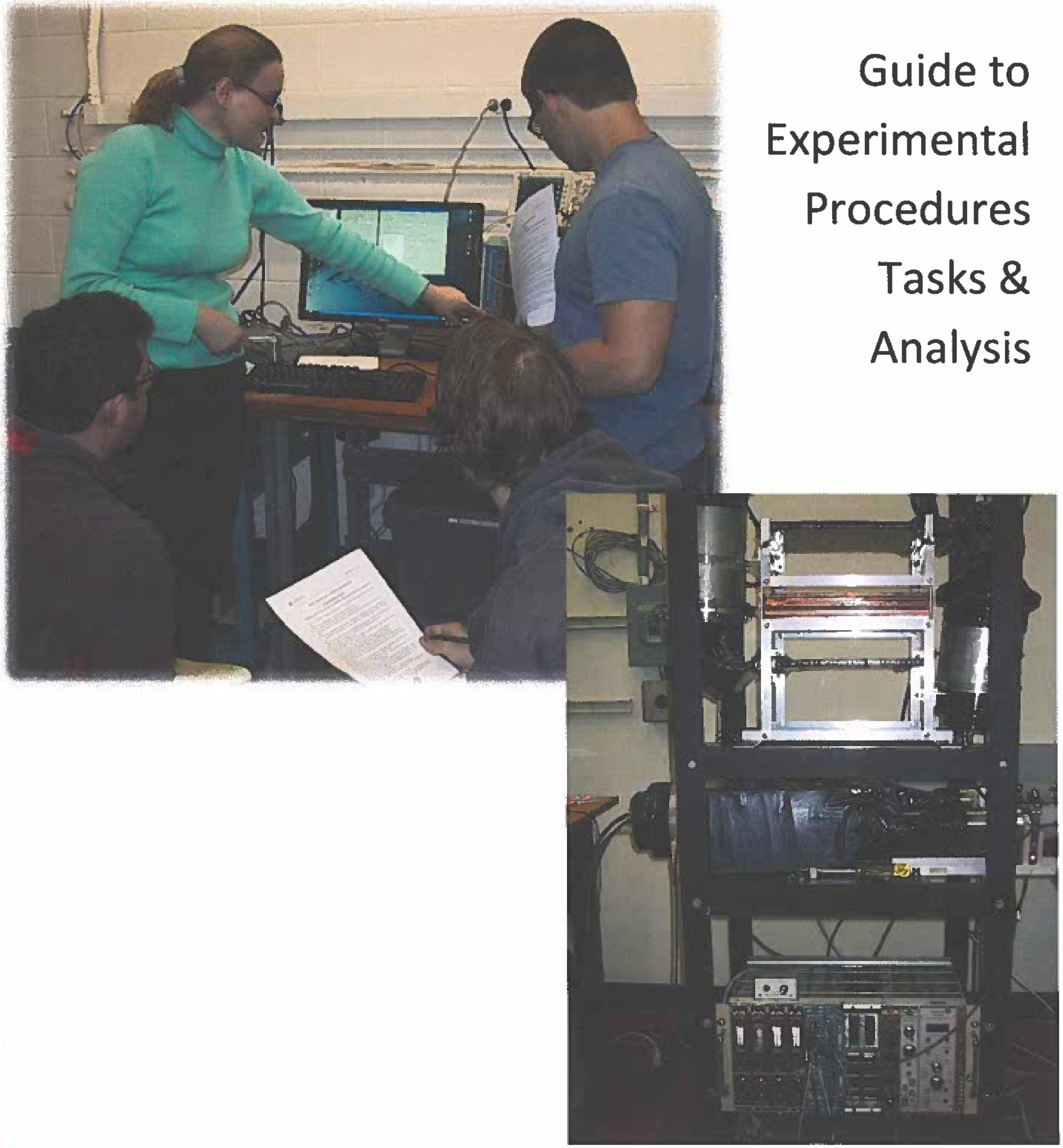
UNIVERSITY of ROCHESTER

ANSEL

ADVANCED NUCLEAR SCIENCE EDUCATION LAB



Guide to
Experimental
Procedures
Tasks &
Analysis

PHY 245W/445W

CHM 244W/444W

LABORATORY MANUAL

FOR THE
ADVANCED NUCLEAR SCIENCE EDUCATION LAB

Guide to Experimental Procedures, Tasks and Analysis

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University of Rochester, January 2020

I. Introduction to the ANSEL Manual

The Advanced Nuclear Education Laboratory (ANSEL) course at the University of Rochester has been designed to provide students with hands-on experience in detection and handling of various types of radiation occurring in our natural environment or produced artificially. In a series of accompanying classroom lectures, presentations and practical demonstrations, this 1-semester course also gives a brief introduction to the basic functionality of common detection instruments and methods of electronic signal processing and to data and error analysis. It also demonstrates principles of applications of radiation in science and technology, e.g. in radiological imaging. To develop a deeper understanding of the theoretical background of relevant physical phenomena and instrumental technology, students are expected to consult more extensive scientific textbooks and technical manuals.

This ANSEL manual concentrates on defining the actual tasks to be accomplished in the ANSEL experiments to be performed by each student or team. The information is presented in terms of minimal lists of steps in setup and tests that, if satisfied in sequence, should guarantee acceptable success of experiments. However, it should be realized that often several different setups can accomplish the main goals of an experiment. In addition, experimenters in ANSEL, as in the field, may occasionally face unexpected breakdown or malfunctioning of equipment, requiring quick response and implementation of alternative solutions "on the fly."

This ANSEL manual also contains auxiliary information in diagrams and data sheets for use in specific experiments. Furthermore, hints and suggestions about the expected aspects of analysis and interpretation of data are provided. The finding should be communicated in written reports following the scientific journal format defined in an ANSEL Report template included in this document. It should be emphasized that considerations of experimental uncertainties form an important part of experimental papers in all physical sciences and are thus required for an acceptable report.

The present ANSEL Data Acquisition System is based on an 8-channel digital signal processing unit (DDC-8). Instructions for basic setup and use are collected as a checklist in a special section of this manual. For the numerical analysis of data obtained in the ANSEL experiments, THE powerful software package Igor has been made available via the ANSEL TWiki web utility, whose basic operations are defined in a checklist copied in A special section near the end of this manual.

The next section gives a coarse technical overview over the present set of experiments offered in the ANSEL lab and their educational goals. It is followed by brief outline of obvious safety rules to be followed by everyone in the ANSEL lab rooms.

Most of the rest pf the manual contains a series of brief sets of "task sheets" describing student activities and suggesting discussion points to be covered in the written accounts of experiment and data analysis.

II. Summary of ANSEL Experiments

Most participants in the ANSEL course are expected to have used modern oscilloscopes in their prior training. Nevertheless, in an Experiment 0, this manual suggests some initial exercises to help in familiarization with the characteristics of the different types of digital oscilloscopes used in the ANSEL. In particular, menu and function buttons on the scope front panels should be tested, as they select different available modes of operation and display.

The first few main experiments focusing on γ-ray spectroscopy utilize sodium-iodide (NaI(*Tl*)) detectors, because of their utility, robustness, and widespread use in the field. These detectors have been the mainstay of many of the initial studies of nuclear structure. However, even now, long after the advent of solid-state detector technology in the 1960s, which provided significantly higher resolution, NaI(*Tl*) detectors continue to be used extensively, e.g. as multiplicity filter systems, in basic nuclear science experiments. These detectors have also played important roles in nuclear-medicine imaging and, more recently, in nuclear forensic applications.

The initial ANSEL experiments with NaI(*Tl*) detectors of different sizes introduce students to the processes involving interactions of photons with electrons in solids and the interpretation of complex detector response to such radiation. They introduce students to safe and proper practices in handling radioactive sources and detecting low-level radiation. Students learn to set up and calibrate electronic chains for signal processing and to perform low-precision spectroscopic data analysis. They acquire practical understanding of radio-active decay processes, construction and time dependent activity of γ sources. As an important educational benefit of these experiments, experimenters demonstrate by their own study that our natural environment contains a broad spectrum of energetic electromagnetic radiation, including γ-rays of energies in the MeV range.

Modern developments of solid-state detectors allow high-resolution spectroscopy to be conducted for photons and charged particles. The ANSEL high-resolution γ-spectroscopy experiment employs cooled hyper-pure germanium detector setups. Silicon solid-state detectors are used to detect charged particles with good resolution. In the ANSEL α-particle experiment, such detectors are employed in a vacuum chamber to measure, with ^{241}Am sources of α particles, some properties of thin metallic foils. This is an example of destruction-free testing of materials with nuclear interrogation techniques. Detector response in this application is modeled with the Bethe-Bloch theory of energy loss of charged particles in matter.

Conventional detectors of charged particles and of low-energy photons (X rays or γ-rays) have often been based on Townsend gas amplification processes. This type includes the venerable Geiger counter, but also proportional and ionization chambers, which are all still in use, both in the applied field and in basic science experiments. Such detectors are employed in several ANSEL experiments. Specifically, a proportional gas amplification counter is used for counting X rays and low-energy γ-rays. The low density of the detector counting gas gives rise to a complex instrument response function, even for mono-energetic photons. Challenges for the calibration of such gas detectors are mitigated by application of specific absorption techniques for photons.

Many procedures in basic science studies and technological applications involve multiple radiation detectors, e.g., for the purpose of disentangling and identifying complex multi-photon emission pattern. Directional correlations between photons emitted in a sequential cascade from the same microscopic system are quantum mechanically expected and provide information about the quantum numbers involved in the transitions (selection rules). In the ANSEL, experimenters are introduced to the underlying coincidence methodology in $\gamma-\gamma$ correlation experiments involving two γ-ray detectors. A radioactive isotope decaying by emitting a positron is used a source of two simultaneously emitted, directionally correlated 511-keV γ-rays. These γ-rays are produced in the annihilation of the positron with an electron in the environment. Two ANSEL detectors are electronically tuned to selectively accept the correlated γ-rays. Varying the relative orientation of the detectors allows one to spatially locate the source of positrons in a process simulating the powerful method of positron emission tomography (PET) used in diagnostic medicine. In a further, optional part of this experiment, the method is employed to the measurement of a nuclear $\gamma-\gamma$ cascade populated in the beta decay of a radioactive bismuth isotope and compared to quantitative predictions.

The ANSEL cosmic-muon experiment introduces students to an additional, modern imaging technique, demonstrating at the same time existence and properties of our cosmic radiation environment. In that experiment, several large plastic-scintillator detectors are used to select a flux direction of "tagged" positively or negatively charged muons. The method is equivalent to defining a beam of cosmic muons. The interaction of the fast cosmic muons with organic materials is then measured in the experiment. For a fraction of the negative muons coming to rest in a stopping material, the lifetime is measured for the decay into electron and neutrinos.

With the ANSEL Mössbauer experiment, students are introduced to one of the most precise spectroscopic tools available, which is at the heart of applications in nuclear and solid-state physics research, in chemistry and even in remotely controlled planetary investigations. Students are introduced to effects of resonance absorption processes. Their detection requires a specific use and setup of electronic chains and data acquisition. Specific goals of the ANSEL experiment are demonstrations of effects of nuclear deformation and electric field of crystal lattices on the hyperfine structure of electromagnetic transitions of iron atoms, as well as measurement of magnetic hyperfine structures of nuclear transitions occurring in different chemical compounds involving iron-57.

Finally, ANSEL experimenters will be able to produce and demonstrate radioisotopes via neutron activation of stable materials such as aluminum and copper. The identification of the radioisotopes is performed using the characteristic radiation emitted and the associated lifetimes for their beta-decay. One useful practical application of the method consists in the elemental and isotopic identification of unknown materials exposed to intense fluxes of neutrons. Such high neutron intensities can be produced by the strong Am-Be neutron sources and the ANSEL DT-neutron generator.

The laboratory experience is completed with a written report on each experiment complying with accepted standards of professional publications of scientific results. The expected format is defined by a template document copied in this manual. The contents of each report are accordingly organized and should reference the general background of the experiment, observations made during the measurements, explain the data reduction applied, as well as offer conclusions derived from the experiment. It should contain enough detail (sketches of setup, electronics circuit diagrams, signal shapes, figures of raw spectra, functional fits, etc.) to allow another researcher with corresponding professional background to repeat the measurements described.

III. Laboratory Rules

1. ANSEL experiments use mostly closed radioactive sources of very low activities. Nevertheless, ANSEL experimenters are expected to follow the general rules conveyed in the official training in radiation safety hazards and protection, which they must have passed.
2. Wearing lab coats and protective gloves are required for work with open (un-sealed) samples containing radioactive material.
3. Wearing lab coats and protective gloves are not required for work with low-level sealed radioactive sources.
4. If not in use in a running experiment, radioactive sources must be stored in a shielded safe in the respective B&L or HH rooms.
5. User and location of any source taken out of the safe must be listed in the logbook/sheet usually placed on top of the safe. This task is usually performed by the Teaching Associate.
6. Minimize the time spent handling radioactivity and maximize the distance from a source, both within reason. Caution should be exercised with the stronger of the two Mössbauer sources, which will be delivered by UR RadSafety specifically for the production runs.
7. Distance yourself appropriately from the strong Mössbauer source and stay behind the lead-glass shield.
8. Follow the plausible rules and safe ways of working. Do not eat, drink, smoke or apply cosmetics in an area where radioactive substances are handled.

ANSEL students are required to take a radiation safety course and pass the associated completion test within the first two weeks of the lab course.

IV. Experiment Task Sheets, DAQ and Igor Checklists, auxiliary data

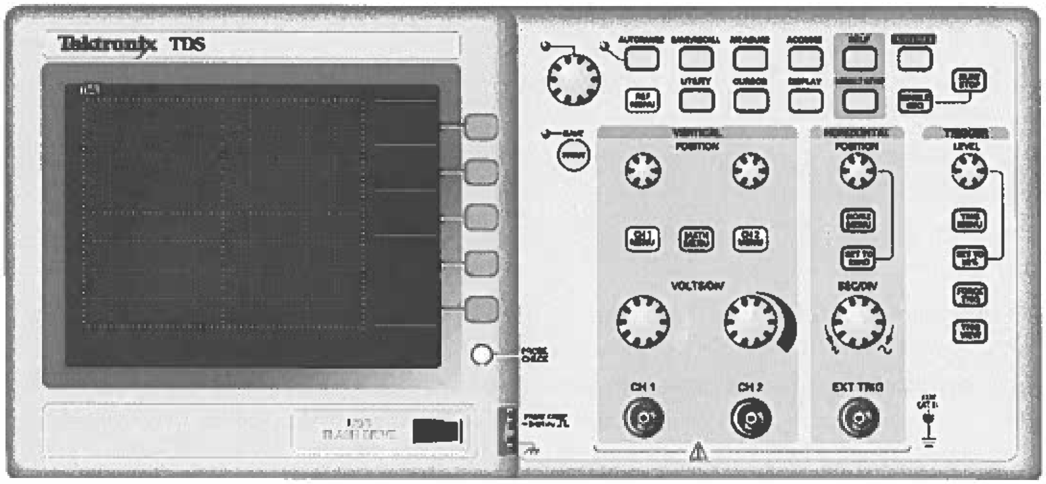
ANSEL Experiment Analog & Digital Electronics

Experimental Tasks (2 Periods)

I. Digital oscilloscope, practice basic operations.
II. Analog electronics, practice spectroscopic applications.
III. Run the Data Acquisition, pulser calibration.
IV. Digital electronics, cables and terminators, set up logic operations.

I. The digital oscilloscope

1. Ascertain that the Teaching Associate (TA) has set up for your use an analog (spectroscopy) pulse generator ("pulser"), for example, an ORTEC model 419 pulser with 50-Ω BNC cable(s) to use with scope operations. **Assign 2 identical cables (same type, same length) as your scope test cables.**



2. *Familiarize yourself with the layout of the front panel of the Tektronix oscilloscope ("scope"). The scope has a display area with variable function buttons and a control area. Properly set up, the display screen will image signal amplitude (vertical ordinate) vs. time (horizontal, abscissa). It will also display numerical values for vertical (V) and horizontal sensitivity (s) per scale division. The control area contains BNC type signal inputs, as well as control knobs for vertical and horizontal position and sensitivity, separately for each of the color coded scope "channels." Menu and function buttons are used to select the desired modes of operation and display. The knob "Trigger Level" is used to control the minimum signal amplitude displayed by the scope. In operation, the value of the trigger level is indicated by an arrow on the right side of the display area and by its numerical value on the bottom of the screen.*

If at any time during the lab the scope appears to be malfunctioning, press the "*Autoset*" button, which will reestablish scope default settings.

3. Without cables connected to any of the scope inputs, switch on the scope power by pressing a button on the top of the front panel and press Default Setup. The screen may, or may not, display one or several traces as colored horizontal lines.
4. Press the various menu buttons (Trigger and Channel menus) and note the available options.
5. Select one channel (Ch 1, yellow) and deselect the other channels by pressing the corresponding menu buttons. Press the Trigger Menu button for Ch 1 and select ground (GND) for Ch 1 coupling. Trace 1 should appear vertically centered. It may indicate some electronic noise fluctuations.
6. Move the trace across the screen by operating horizontal and vertical position controls. Change horizontal and vertical scales and note the values displayed on the screen for sensitivities and offsets.
7. Adjust the scope trace to the left and vertical center of the screen. Choose 1 V/division and 1 μs/division for vertical and horizontal sensitivities, respectively. For the trigger level choose DC coupling, positive signal slope, and 1 MΩ for the Ch1 input coupling.
8. Connect the pulser (direct) output to Ch 1 input with a BNC cable and observe the signal trace on the scope screen.
9. Determine presence or absence of a DC level on the pulser output by changing the trigger mode between AC to DC. Measure the signal amplitude, as well as rise and decay times of the pulser signal.
10. With BNC cables connect the direct output of the pulser to scope Ch 1 and the attenuated output to Ch 2 display both Ch 1 and Ch 2 traces on the screen.
11. From the trigger menu select trigger source Ch 1.
12. Change amplitude and decay times of the pulser signals and observe the corresponding changes of the signal images on the scope screen.
13. Calibrate approximately the pulser control dial and attenuator switches in terms of the voltage indicated on the scope screen.

This completes the scope tests. Following should be tests of a pulse shaping with main amplifiers. Document all control settings of all modules used.

II. Analog electronics, use a spectroscopic signal amplifier and single-channel analyzer.

1. Produce a low-amplitude pulser signal from the attenuated output. Record signal pulse shape (rise and decay times) and amplitude. Insert this pulser signal into an ORTEC 571 or 572 Spectroscopy Amplifier (or similar). Set the amplifier to lowest coarse and fine gains. Select the appropriate input polarity and set the amplifier base line restorer toggle switch (BLR) to automatic (AUTO). Select No Delay on the toggle switch at the unipolar output.
2. Select a 3-μs shaping time (to be varied later).
3. View the unipolar output of the amplifier on the scope.
4. Set the pulser signal amplitude such that the amplified (unipolar) signal is of the order of 1 V.
5. With the scope (DC, 1MΩ) check for a DC level on the amplifier output. If necessary, correct it to zero level by turning the DC screw driver potentiometer on the front panel.
6. On the scope inspect the trailing slope of the amplifier unipolar output signal for under or overshoot. Observe the response of the signal shape to turns of the pole-zero adjust screw driver potentiometer (PZ). Optimize for fastest signal return to base line with no crossing.
7. Observe (and record) the response of the amplifier output signal to different shaping time constants selected with the Shaping Time selector varied from 0.5-10 μs.
8. On the scope channels 1 and 2, triggered on Ch 1, inspect the bipolar amplifier output signals and their relation to the unipolar signals. Note that the unipolar signal can be delayed by a preset time, depending on the position of the toggle switch DELAY.
9. Set up an ORTEC 551 Timing Single Channel Analyzer (TSCA) or 590A amplifier-plus-TSCA in integral mode, to trigger on amplifier output signals of minimum amplitude ("threshold").
10. Feed the bipolar amp output into the TSCA input. Display the TSCA output signal on scope Ch 1 (trigger on Ch1, note polarity). Display the delayed unipolar amplifier output signal on scope trace Ch 2. An amp signal will appear on CH 2 only when a corresponding TSCA signal has triggered Ch 1.
11. Varying the lower threshold of the TSCA will restrict the pulse height amplitude of signals that are displayed on the coincidence trace Ch 2.
12. Demonstrate similarly the function of a TSCA in windows (E-DE) mode.

This completes the analog electronics tests. Following should be a measurement of a pulse generator output signal using the DDC-8 based data acquisition module. Document well in your log book all control settings used by all modules used.

III. Run the Data Acquisition, perform a DDC-8 pulser calibration.

1. Confirm with a TA that you are producing proper Signal and Trigger from the amplifier and TSCA output.
2. Follow the procedure in the *DDC-8/Blackbox Quickstart User's Guide* to initialize hardware and software for measuring pulser signals in histogram mode.
3. Set the pulser output to DDC-8 mid acceptance range (+1 V amplitude) using pulser attenuators and fine adjust knob. Check signal amplitude with scope.
4. Connect the pulser output to DDC-8 channel CH_0 and the trigger signal to NIM_IN_0.
5. Start the measurement and let signals be accumulated for a few minutes.
6. Stop the measurement and view the acquired data on the computer monitor.
7. Measure the linearity of pulser and DDC-8 by acquiring pulser signals for 10 different amplitudes, each checked on the scope and acquired for 1-2 minutes ("pulser fence"). Start and stop each measurement by connecting and disconnecting the trigger signal to and from the DDC-8.
8. Determine the range of the DDC-8 analyzer which ideally should be 0-2 V. Plot signal amplitude in volts vs. DDC-8 channel number (bin #).

This completes the DAQ test runs with a pulse generator. Following should be tests with NIM logics and cables.

IV. Generate and process digital signals, set up logical requirements. Before further processing check signals on scope. Note that Delay-Gate Generators have the functions of delaying a signal and/or converting it to a wide "gate" signal.

1. Confirm that you have two identical scope cables.
2. Feed an amplified pulser signal into a discriminator (TSCA) and its output to a logical/linear FAN IN/FAN OUT (FIFO) module.
3. Inspect the various FIFO NIM output signals on the scope with **DC** and **50Ω** trigger mode. Note the signal levels.
4. Observe changes in scope response when changing the trigger mode, first to **AC**, then to **1MΩ**.
5. Observe signal reflections on open cables by connecting an additional, loose cable with one end and a BNC/LEMO Tee to the scope input.
6. Terminate the loose cable with a 50Ω terminator and a barrel.
7. Connect one FIFO NIM output signal to scope Ch 1 (AC, 50Ω). Trigger on Ch 1. Feed another FIFO NIM output signal to a (ORTEC or LeCroy) Gate/Delay-Gate Generator (GG). Observe the GG output signal(s) on Ch 2 of the scope.
8. Connect one FIFO NIM output signal to a Gate Generator (GG) to produce a 100-200 ns wide "gate" signal. Connect the other to a Delay Generator (DG) to produce a delayed signal.

9. Observe the two signals on scope channels 1 and 2, respectively, triggering with the gate pulse.
10. Insert the two signals into inputs of a coincidence unit. Select two-fold coincidence mode. Observe the coincidence unit output on the scope.
11. Varying the delay of the delayed signal, measure the coincidence resolution time. Compare it to the sum of the widths of gate and delay pulses.
12. Insert the wide gate pulse into the Veto input of the coincidence unit. Select single-fold (or) mode of the unit. Observe the coincidence unit output on the scope.
13. Varying the delay of the delayed signal, measure the anticoincidence efficiency and resolution time. Compare the latter to the coincidence resolution time.

Experiment	
Oscilloscope Practice, Electronics	Osc
Photon Spectroscopy w. NaI Detectors	NaI
Spectroscopy w. Solid-State Detectors	GeSi
Radiation Measurements w. Gas Detectors	GPC
Coincidence/Imaging Experiments	PET
Interactions of Cosmic Radiation (τ_μ)	Mu
Mössbauer Spectroscopy	MB
Neutron Activation (β-Decay)	NA
Data Acquisition	DAQ
Data Analysis	IGOR
Template Laboratory Report	Rep
Auxiliary Documents	Aux

ANSEL Experiment Photon Spectroscopy

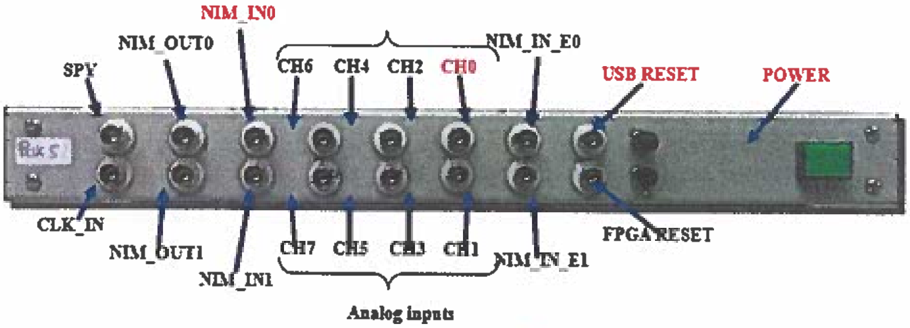
Experimental Tasks

With the help of the TA set up detector, electronics and data acquisition:

1. Power up the NaI detector (HV polarity and level) and the electronics NIM bins and/or specific power supply units.
2. Place a ^{22}Na γ source close (5 cm) to the face of the NaI.
3. On the scope, follow the analog pulse along the slow circuit.

a. Check the effects of the settings of gain and time constant controls at the main amplifier.

4. On the scope, inspect the output of the fast (lower) part of the main amp and feed it to a discriminator used to derive a digital signal for strobing the ADC(→DDC-8).
5. Trigger the scope Ch 1 with the discriminator output signal, view on Ch 2 the analog signal and ascertain a proper (low) setting of the discriminator threshold.
6. Feed analog signal to the DDC-8 analog input (Ch 0).
7. Feed the digital signal to the DDC-8 digital input NIM_IN0.



+/- 1V (maximum amplitude = 2V !!)

Figure: Front panel of data acquisition/signal processing unit (DDC-8).

8. Check on the scope the proper relative timing of analog and strobe signals.
9. Start the data acquisition according to the quick setup checklist.
10. Accumulate, display and save a ^{22}Na γ energy spectrum in histogram form.
11. Check the appearance of the NaI spectrum for the ^{22}Na g source and place the dominant structure in the middle of the spectrum by adjusting fine and coarse gain of the main amplifier.
12. After the above choice of gain (and previous integration) parameters, do not change the amplifier settings for any of the additional measurements.
13. Take a final measurement for the Na source (5 min). Then remove this source and place it far away from the detector (in the cabinet).
14. Based on the ^{22}Na γ energy spectrum, perform a coarse calibration of the ADC channel numbers in γ-ray energy. In this task utilize the well measured channel # posi-

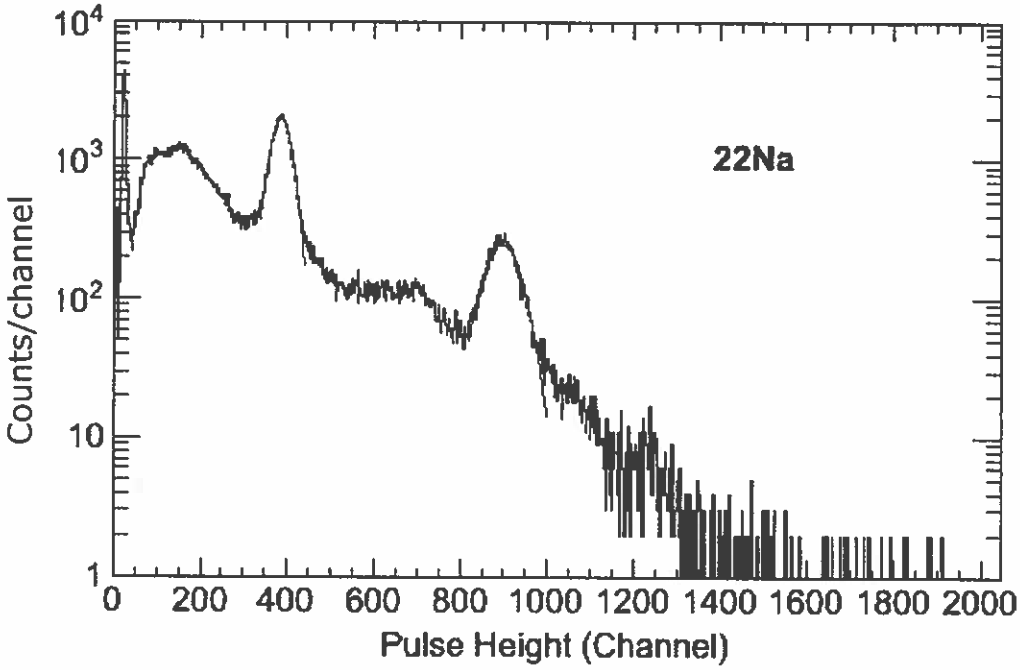
positions of the full-energy peak (1.275 MeV), of the associated Compton edge (E_{CE} = ?? MeV) and of the 0.511 MeV annihilation peak.

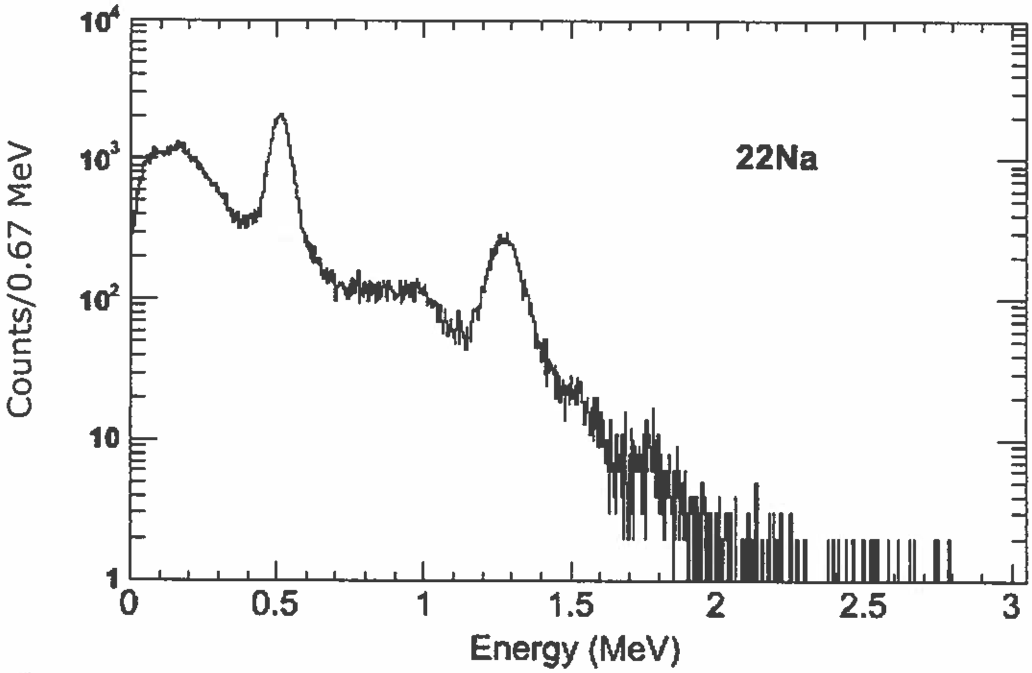
17. Perform similar, individual measurements for the ^{60}Co and ^{54}Mn sources.
18. Verify that the main γ lines for these sources appear in the spectrum approximately at the expected locations. Record observations in logbook.
19. Measure the γ-ray energy spectrum for the unknown source.
20. Remove all sources from the vicinity of the NaI detector and perform a measurement of γ-ray energy spectrum of the room background. To accumulate sufficient intensity, accumulate data for at least several hours (possibly overnight).

Data Analysis

1. Compare measured count rates with expectations based on source half lives.
2. Identify in the measured spectra for the three known sources the prominent spectral features and correlate their channel positions (ch#) with the known energies (E_γ or E_{CE}). Perform IGOR fits of main γ lines, keeping track of experimental errors. Use Gaussians for γ lines and half-Gaussians for Compton edges.
3. Generate a calibration table and a plot of energies of the positively identified prominent spectral features from the three known sources (^{22}Na, ^{60}Co, ^{54}Mn) *vs.* the experimental channel numbers for these features.
4. Perform a least-squares fit for the calibration data E_γ(ch#) and include the best-fit line in the calibration table and plot.
5. Generate plots of all measured energy spectra as Counts/keV *vs.* Energy/keV.
6. Identify the γ-ray energies of prominent features in the spectrum for the unknown source. Based on the provided search table, suggest the identity of the unknown source (or source mix).
7. Identify the γ-ray energies of prominent features in the spectrum for the room background. Based on the tables (provided in the ANSEL Twiki pages) of known γ-rays, suggest the identities of the various spectral components.
8. Measure the peak-to-Compton ratio of the detector for a high-energy γ-ray.
9. Determine the energy resolution of the detector as function of E_γ.

Data Graphs for γ-ray sources





Experiment	
Oscilloscope Practice, Electronics	Osc
Photon Spectroscopy w. NaI Detectors	NaI
Spectroscopy w. Solid-State Detectors	GeSi
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Mössbauer Spectroscopy	MB
Neutron Activation (β-Decay)	NA
Data Acquisition	DAQ
Data Analysis	IGOR
Template Laboratory Report	Rep
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ANSEL Experiment High-Resolution Photon Spectroscopy with a Hyper Pure Ge Detector

Experimental Tasks

With the help of the TA set up detector, electronics and data acquisition, a procedure similar to that followed in the experiment with a NaI detector.

However, HPGe detectors much more fragile and expensive than NAIs!

1. **Slowly** power up the HPGe detector (HV polarity and level are noted on each detector) and the NIM electronics. (ANSEL HPGe detectors are of the coaxial type). **Observe trace movement on scope (DC, Line trigger).**
2. Place a ^{22}Na (or a ^{60}Co) γ-ray source close (1 - 5 cm) to the face of the HPGe detector.
3. On the scope, follow the analog signal along the slow circuit (from preamp to main amp). Record the signal shapes in the log book. Draw a block diagram of the electronics.
4. Select a long enough integration/differentiation time for the main amp.
5. On the scope, inspect the output signals of the main amplifier, if necessary, adjust BLR and pole-zero pot.
6. Feed one of the amp outputs into a discriminator and derive a digital signal for triggering the DDC-8 data acquisition (DAQ).
7. Trigger scope Ch.1 with the discriminator output signal; view on Ch.2 the analog signal and ascertain a proper (low) setting of the lower discriminator threshold and of the discriminator window.
8. Check on the scope the proper relative timing of analog and trigger signals.
9. Feed the analog signal to analog input Ch.0 of the DAQ. Feed the digital signal to the trigger input NIM IN 0 of the DAQ.
10. Start the DAQ according to the DAQ quick setup checklist.
11. Accumulate, display and save a γ energy spectrum in histogram form. Adjust the main amplifier gain controls, such that the energy $E_\gamma = 1$ MeV corresponds to approximately 2/3 of the DDC-8 full scale.
12. Normalize a pulser to an identified high-energy γ line, e.g., the 1.275-MeV line from the ^{22}Na source. Run a "pulser-fence" as linearity check.

Perform the following HPGe detector energy resolution tests for two gamma energy regions, a low energy (LE) region of E_γ =(300-600) keV and the high-energy (HE) region, E_γ = (1-2) MeV. Use several different γ sources (^{22}Na, ^{60}Co, ^{54}Mn, ^{133}Ba, ^{137}Cs) in sequence, in order to sample these regions.

Keep accurate account of running times!

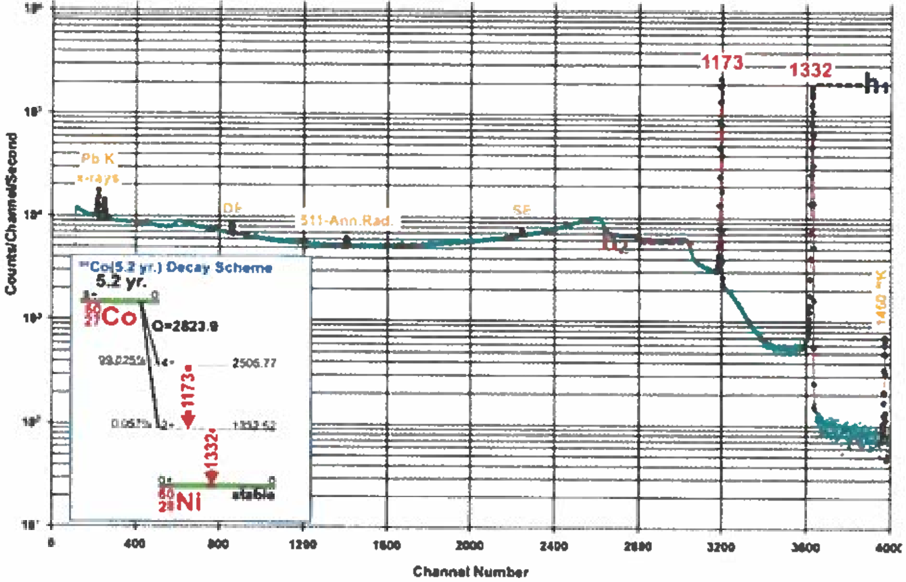


Figure 1: Spectrum of a ^{60}Co γ source. The peak-to-Compton ratio is defined by PC=h_1/h_2, where h_1 is the height of the 1.33-MeV line and h_2 is the average height of the Compton distribution in the range (1040-1090) keV.

13. For each of the following measurements, perform a quick, approximate resolution analysis for a chosen HE line and the pulser line.
14. For the initially selected and 2 additional amplifier shaping times, record the γ energy spectra, in order to measure the dependence of HE resolution on this parameter.
15. Select the minimum shaping time consistent with the best observed energy resolution for the HE line.
16. Take a spectrum for both, the ^{22}Na and the ^{60}Co source, with sufficiently high statistics to allow for a later, off-line, accurate determination of energy resolution and peak-to-Compton ratio.
17. Measure the γ-ray energy spectrum for the unknown γ source (standard disc).
18. Place a ^{133}Ba γ source, which emits low-energy γ-rays, on the face of the NaI and make a good measurement that can serve as reference for the following measurements with absorbers. Note the accumulation time and determine the approximate number of counts collected for a chosen low-energy γ line.
19. Perform a sequence of measurements of the γ energy spectrum for the chosen (in 18.) low-energy γ source with different absorber foils between source and detector face. Use two different thicknesses each of Al and Pb absorbers from the absorber set (wooden box). Base your selection of absorber thicknesses and running time on a prediction based on the table/plot of attenuation coefficients.
20. Perform a high-statistics measurement of the γ-rays emitted from an unknown sample (not a standard γ source).
21. Measure a room background spectrum overnight.

Data Analysis

1. Identify in the measured spectra for the three known sources the prominent spectral features and correlate their channel positions (ch#) with the known energies (E_γ or E_{CE}). In the data analyses, keep track of experimental errors. Use Gaussians for γ lines and half-Gaussians for Compton edges.

2. Produce a plot for the y energy spectrum for each of the known sources (^{22}Na, ^{60}Co, ^{54}Mn, ^{133}Ba, ^{137}Cs). Generate a calibration table of the positively identified prominent spectral features from these sources, i.e., list energy (E_γ) vs. experimental channel number (ch#) for these features.

3. Perform a least-squares fit for the calibration data E_γ (ch#) and include the best-fit line in the calibration table and plot. Keep track of uncertainties.

4. Compare the above calibration with that corresponding to the linearity pulser test.

5. Generate plots of all measured energy spectra dN/dE_γ vs. E_γ as **counts/keV** *vs.* Energy (MeV) or *vs.* Energy (keV).

6. Determine the peak-to-Compton ratio for the chosen HE γ-rays for HPGe detector. Compare this ratio to the value quoted by the vendor.

7. Identify the γ-ray energies (full energy peaks) of prominent features in the spectrum of γ-rays from the unknown source. Based on the provided search table, suggest the identity of the unknown source (or source mix). Compare with the corresponding γ spectrum measured earlier with a NaI(Tl) detector.

8. From the absorption measurements determine the linear absorption coefficient μ and the half-value thickness $x_{1/2} = 0.693/\mu$ for the chosen low-energy γ line. Explain which of γ-ray interaction processes is mainly responsible for the absorption of this line.

9. Compare the resolution obtained for the 511-keV line of the ^{22}Na spectrum and explain different resolutions observed for other, nearby γ lines (possibly of other sources).

10. Identify the γ-ray energies of some prominent features in the spectrum for unknown sample (not standard source).

11. Perform a similar identification of prominent γ lines in the room background spectrum. Based on the provided search table, suggest the identities of the various components.

Reading Assignments: Knoll, (Ch 3 IV, Ch 10 II); Ch 12; Ch 18 V

ANSEL Experiment α Spectroscopy
Experimental Tasks

With the help of the TA set up chamber, detector, electronics, and DAQ according to the block diagram shown in Fig. 1:

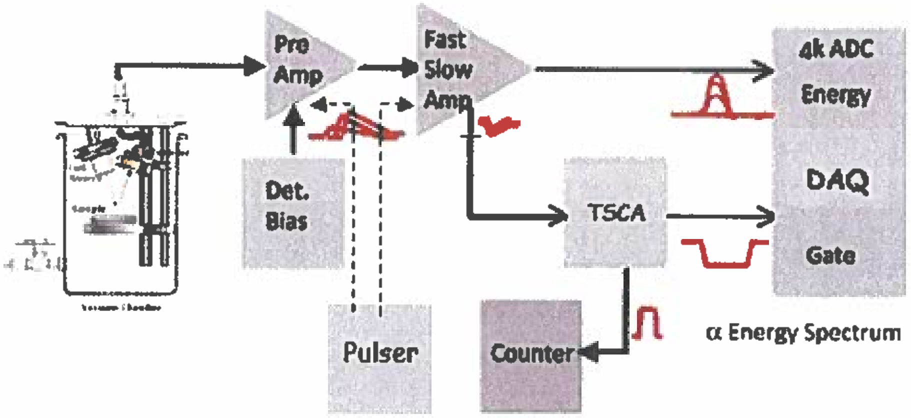


Figure 1: Block diagram for the setup of ANSEL experiment α spectroscopy. Note that the pulser can be fed either into preamp test input or into main amp input.

1. Check the cable hookup of the Si surface barrier detector within the ORTEC 808 vacuum chamber to the ORTEC 141 preamplifier input.
2. Check the hookup of the preamplifier multi-pole supply cable to the connector on the back panel of the ORTEC main amplifier.
3. Check the hookup of the detector bias supply to the preamplifier bias input.

Operate the vacuum chamber only while detector bias is turned off.

4. Let the vacuum chamber up to air and check that there is a Si detector with its connector properly hooked up to the recessed connector in the center of the top wall.
5. Check proper attachment of an ^{241}Am α source at the underside of a tray.
6. Insert the tray into the rack, about 2-3 cm below, and laterally aligned with, the Si detector.
7. Close the chamber and pump down to vacuum (See procedure below).
8. Bias the silicon detector (See procedure below).
9. Observe the detector signals and follow the slow signal path from preamplifier to main amplifier and ADC.
10. Set the shaping and gain controls of the main amplifier according to the ADC requirements.
11. Connect the bipolar output of the main amplifier to the ORTEC single channel analyzer (SCA, TSCA) used to define a lower energy threshold for acceptable signals and a Strobe signal for the ADC.

12. Trigger the scope with the digital output of the SCA and observe the analog signal on another scope channel. Observe the effect of lowering and increasing the threshold level.
13. Connect the unipolar output of the main amp to the ADC (input 7) and the DGG output to the ADC Strobe input.
14. Start the DDC-8 data acquisition and measure the spectrum of ^{241}Am α particles for a few minutes to ascertain proper functioning of the detector and setup and position of the α line in the spectrum, before proceeding with a calibration measurement.
15. Note the position channel of the α line(s) in the spectrum. The known α energies and intensities are given in Table 1.
16. Stop the data accumulation by disconnecting the ADC input to hook up the precision pulse generator.

Use an ORTEC Precision Pulse Generator to check linearity and calibrate the signal pulse height spectrum as below.

17. Hook up the ORTEC 448 or 419 Pulser to the ***Test input of the preamplifier***.
18. Set the large pulser dials to indicate the numerical values of the α energy in keV.
19. On the scope check for proper polarity and approximate pulse height of the pulser signals from the preamp output.
20. On the scope view the unipolar output of the spectroscopy amplifier, which should show a superposition of slightly different particle and pulser signals. Try to produce approximately equal amplitudes using attenuator toggle switches and normalization potentiometer dial of the pulser.
21. Hook back up the ADC input signal cable to accumulate particle and pulser signals concurrently.
22. Fine adjust the pulser signal amplitude until it matches that of the α particle signals. Choosing a sufficiently high pulser frequency facilitates a recognition of pulser signals in the spectrum.
23. By changing the large pulser dials, determine the spectral range accessible to the pulser signals.
24. Start a new run with a series of measurements with several different pulser amplitudes (dial settings) covering the accessible range in a few (app. 10) steps. For each setting, take data for a few minutes.
25. Then disconnect the DAQ input, choose a different pulser dial setting, reconnect the ADC input and run again.
26. Repeat the above two steps, until the desired spectral range is covered by pulser signals.
27. Switch pulse generator off.
28. Stop the run and view the accumulated spectrum. In addition to the α line, a "pulser fence" should be visible with equally spaced lines corresponding to different energies dialed up on the pulse generator.

29. The pulser fence provides an energy calibration of the pulse height scale.

Measure the energy loss of α particles in materials.

1. **Unbias** detector and let chamber up to air (See procedure below).
2. Take out tray with a source and place on top a 1″ rectangular frame with a metallic or mylar absorber foil handed out by the TA.
3. Reinsert tray and realign with the silicon detector. The α particles have to penetrate the absorber foil to reach the detector.
4. Pump down chamber (See procedure below).
5. **Bias** the detector (See procedure below).
6. Start a new run and accumulate a spectrum with the absorber.
7. Observe the shifted position of the α line.
8. Close the run and repeat Steps 1-7 for additional measurements.

Measure the energy spectrum of α particles emitted from a piece of rock.

1. **Unbias** detector, let chamber up to air (See procedure below).
2. After TA has inserted rock material on a tray, close chamber, pump, bias detector.
3. Measure spectrum of a particles emitted from the rock.

Table 1: Energies and intensities of α particles emitted from selected radio-isotopes.

Radionuclide	Alpha particle energy [MeV]	Intensity [%]
Np-237	4.640	6.2
	4.766	8.0
	4.772	25.0
	4.788	47.0
Pu-239	5.105	11.5
	5.143	15.1
	5.155	73.4
Am-241	5.388	1.4
	5.443	12.8
	5.486	85.2
Pu-238	5.456	28.3
	5.499	71.6
Cm-244	5.763	23.3
	5.805	76.7

Data Analysis

1. Perform an energy calibration of the experimental setup.
2. Describe the actual response (resolution) function of the α detector, compare it to the electronic resolution tested with the precision pulse generator. Describe physical effects that could affect the resolution.
3. Compare the measured ^{241}Am α spectrum to expectations based on the information given in Table 1 and measured resolution of the experimental setup.
4. Analyze the measured shifts in the energy spectra (dN/dE_α) of α particles transmitted through absorber films in terms of absorber element composition (Z) or thickness (x). Use the Bethe-Bloch formula formula for theoretical estimates of the specific energy loss, (dE_α/dx).
5. Interpret the spectrum of α particles emitted from the unknown sample (rock).
6. From the known mean ionization energy of I = 32.5 eV of α particles in air, calculate their specific ionization (ion pairs/mm) and their range in air.
7. From your data, illustrate the (statistical) fluctuation-dissipation theorem for the energy loss mechanism.

Letting the ORTEC 808 Vacuum Chamber up to air

Check that the bias supply is turned off.

1. *At the front panel of the vacuum chamber, turn the three-way valve to **Vent**.*
2. *Check the vacuum gauge to ascertain that the chamber is up to air.*
3. *Open the front panel of the chamber and inspect the inside. Perform required manipulations.*

Pumping down the ORTEC 808 Vacuum Chamber

Check that the bias supply is turned off.

1. *At the front panel of the vacuum chamber, turn the three-way valve to **Pump**.*
2. Turn on the vacuum pump and pump for 3-5 minutes, until the vacuum gauge shows vacuum, before continuing with the next step.
3. Leave the pump running to sustain sufficiently high vacuum. Under such conditions, the pumping noise should be low.
4. Now manipulations with the detector, including biasing, are permitted.

Detector biasing and unbiasing

Hook up the oscilloscope to the output of the preamplifier directly and without terminator.

1. *Trigger the scope with line signal (auto)* and choose DC at the input. Choose 100-μs scale. Position the continuous track in the middle of the display.
2. Check that the bias supply potentiometer dial is turned to zero.
3. Switch on detector bias supply to proper output polarity and range (<100V).
4. Switch on detector bias supply to V(olts) and ascertain that the meter indicates zero volts.
5. Ramp up slowly the bias to operating voltage (app. 60 V, or as indicated on detector container box) by turning the pot on the bias supply. Observe the level trace on the scope respond to each turn briefly and then return to zero.
6. At operating bias, turn indicator to A(mperes) and note the magnitude I of the reverse current. For a detector in good operating conditions, the reverse current should be lower than a few μA.

   If that is not the case, or if the supply shows that it has tripped, return the bias dial down to zero and inform the TA.
7. Assuming a preamp input resistor of $R=1M\Omega$ in series with the intrinsic resistance of the detector, calculate the bias correction and apply it, in order to achieve full detector depletion.
8. Trigger the scope normally to observe detector preamplifier signals, which have long (several 10s μsec) decay times.
9. The detector is now ready to be used in spectroscopic measurements.

   After measurements are completed, turn down bias slowly to zero and switch bias supply off.

Experiment	
Oscilloscope Practice, Electronics	**Osc**
Photon Spectroscopy w. NaI Detectors	**NaI**
Spectroscopy w. Solid-State Detectors	**GeSi**
Radiation Measurements w. Gas Detectors	**GPC**
Coincidence/Imaging Experiments	**PET**
Interactions of Cosmic Radiation (τ_μ)	**Mu**
Mössbauer Spectroscopy	**MB**
Neutron Activation (β-Decay)	**NA**
Data Acquisition	**DAQ**
Data Analysis	**IGOR**
Template Laboratory Report	**Rep**
Auxiliary Documents	**Aux**

ANSEL Experiment Geiger-Müller Counter

Experimental Tasks

1. **Determine the characteristic response curve of the GM counter.**
2. **Measure the resolving/dead time of the GM counter.**

With the help of the TA set up GM detector on stand, electronics and data acquisition to measure the GM characteristic response ("plateau") curve and the counting dead time:

1. Remove carefully the protective rubber cap on the end of the cylindrical GM counter tube and place the tube window down into the stand.
   Attention: Do not touch the fragile end window.
2. Check the cable hookup of the GM counter to the aluminum decoupling box. The BNC cable should be hooked up to the box input "DET."
3. Verify that the Tennelec TC 652 high voltage power supply is turned off, with all dials turned down to zero.
4. On the TC 252 select positive HV output polarity.
5. Connect the HV output of the TC 652 HV supply with the "HV" input of the aluminum decoupler box.
6. Connect the "E" output of the aluminum decoupler box with an oscilloscope channel set to DC and line (automatic) trigger.
7. Place a ^{60}Co γ source on the plastic tray in the second shelf from the top of the GM holder.
8. Turn on the TC HV supply. Check polarity LED.
9. While slowly turning the voltage level supplied by the TC up to U=+800 V, observe the scope trace respond and move back to the zero DC level.
10. At U=+800 V negative signals caused by the ^{60}Co γ rays should be visible on the scope.
11. Turn slowly down the HV, until the signals disappear from the scope trace. Note this voltage as the "starting voltage."
12. Turn the HV up slowly to levels slightly above U=+1000 V while watching the scope trace.
13. Stop at a high voltage, when the character of the signals changes drastically, indicating that the GM "breakdown voltage" has been reached.
14. Set the TC output voltage back to slightly above the starting voltage, where GM pulses become visible on the scope.

The GM is now ready for counting. Set up electronics and EZDAQ.

15. Observe the detector signals and follow the slow signal path from decoupler box to main amplifier and ADC.
16. Set the shaping and gain controls of the main amplifier according to the ADC requirements.
17. Connect the bipolar output of the main amplifier to the ORTEC single channel analyzer (SCA) used to define a lower energy threshold for acceptable signals and a Strobe signal for the ADC.
18. Trigger the scope with the digital output of the SCA and observe the analog signal on another scope channel. Observe the effect of lowering and increasing the threshold level.
19. With an ORTEC delay and gate generator (DGG) generate a Strobe signal from the SCA output signal. Adjust for proper relative timing of analog and Strobe signals.
20. Connect the unipolar output of the main amp to the ADC (input 7) and the DGG output to the ADC Strobe input.
21. Start the EZDAQ data acquisition and measure the spectrum of ^{60}Co γ-rays for a few minutes to ascertain proper functioning of the detector.
22. For a fixed time of 1-2 minutes per measurement accumulate data successively for U= 750, 800,....., 1000 V. Note the increases in mean signal amplitude and count rate, which define the GM (plateau) response curve.

Use the split ^{204}Tl source for the measurement of the GM counter resolution ("dead") time.

23. Place one half (#1) of the ^{204}Tl source together with the dummy half on the plastic tray on the second shelf of the GM tube holder. Remember the geometry.
24. Measure for 5-10 minutes the spectrum and note the total number of counts accumulated.
25. Change the geometry and use the other half (#2) of the split ^{204}Tl source together with the dummy half.
26. Repeat the above measurement for this geometry.
27. Change the geometry and place both halves (#1 next to #2) of the split ^{204}Tl source on the tray to make one full disc source (no dummy source).
28. Repeat the above measurement in this geometry.
29. The decrement of the count rate m_{1+2} as compared to $m = m_1 + m_2$ is due to the finite dead time τ of the counting setup (cf. Knoll Ch. 4.VII).

30. Slowly turn down the HV and switch off the TC HV power supply.

ANSEL Experiment Gas Proportional Counter (PC)

Experimental Tasks

With the help of the TA set up detector, electronics and data acquisition, a procedure similar to that followed in previous experiments with other detectors. The counting gas used in this encapsulated detector is Kr. Note that the detector response to photons is complex.

1. **Slowly** power up the PC (+1800V as noted on detector), as well as the NIM electronics.
2. Place a ^{133}Ba (or a ^{57}Co) γ/X-ray source close into or onto the holder between detector and velocity drive.
3. On the scope, follow the analog pulse along the slow circuit (from Tennelec preamp to ORTEC 572 main amp). Record the signal shapes in the log book. Draw a block diagram of the electronics.
4. Select a long enough integration/differentiation time for the main amp.
5. On the scope, inspect the output signals of the main amp. If necessary, adjust BLR and pole-zero.
6. Set up a NIM trigger signal for the data acquisition (DAQ) and check proper relative timing on the scope. Use a very low threshold on the discriminator used for the purpose.
7. For the source used (^{133}Ba) check the provided decay scheme for expected main X-ray line(s). Attempt to discover them on the scope screen. Change the main amp gain to cover approximately the DDC-8 (0 - 2) V acceptance range.
   (Use this gain for a first exploratory spectrum measurement.)
8. Feed the analog signal to analog input (Ch_0) of the DAQ. Feed the NIM signal to the trigger input (NIM_IN_0) of the DAQ.
9. Start the DAQ according to the DDC-8 quick setup checklist.
10. Determine the "zero bin" of the DDC-8 amplitude scale by disconnecting the analog input temporarily.
11. Accumulate, display and save a γ/X ray energy spectrum in histogram form.
12. Adjust the main amplifier gain controls such that an estimated photon energy of E = (30-50) keV corresponds to approximately the middle of the DDC-8 full scale.
13. Perform a measurement with the ^{57}Co source, which should give rise to the 14.4-keV γ-ray from the daughter ^{57}Fe.

Next, perform a series of measurements of the X-ray spectra for ^{133}Ba and ^{57}Co sources with several thin absorbers between source and detector. These measurements will ascertain, or modify, tentative assignments made in the preceding measurements. For the following measurements, keep accurate record of the running time.

14. With the gain settings determined in the previous measurements, accumulate a ^{133}Ba X-ray "Master" spectrum with good statistics. Record accurately the running time of this measurement.
15. With an external ORTEC counter/scaler measure the mean number of counts/s during the previous Master and each of the following data taking runs.
16. Perform a measurement with a thick Pb absorber from the absorber set, in order to determine the counter background.
17. From the absorber set choose two thin absorbers for which a substantial absorption can be expected for the low-energy γ- and X rays.
    Base your absorber choice on the expected transmission deduced from the provided catalog of transmission coefficients for various materials. Include Al and Pb absorbers.
18. (Optional) Normalize a precision pulser to a tentatively identified γ– or X-ray line, e.g., the 14.4-keV line associated with the ^{57}Co source (see provided level scheme).

Report/Data Analysis

1. Discuss *briefly* the functionality of the counter. For example, explain what advantages Kr offers as a counter gas, as opposed to the more commonly used Ar or organic vapors? What is the purpose of the detector Be entrance window?

2. Identify in the measured spectra for the ^{133}Ba and ^{57}Co sources the prominent spectral features and correlate their channel positions (ch#) with the known energies. In the data analyses keep **track of experimental errors.**

3. Generate a calibration table of the positively identified prominent spectral features from these sources, i.e., list energy (E_X or E_γ) *vs.* experimental channel number (ch#) for these features.

4. Perform a least-squares fit for the calibration data E (ch#) and include the best-fit line in calibration table and plot. Keep track of uncertainties.

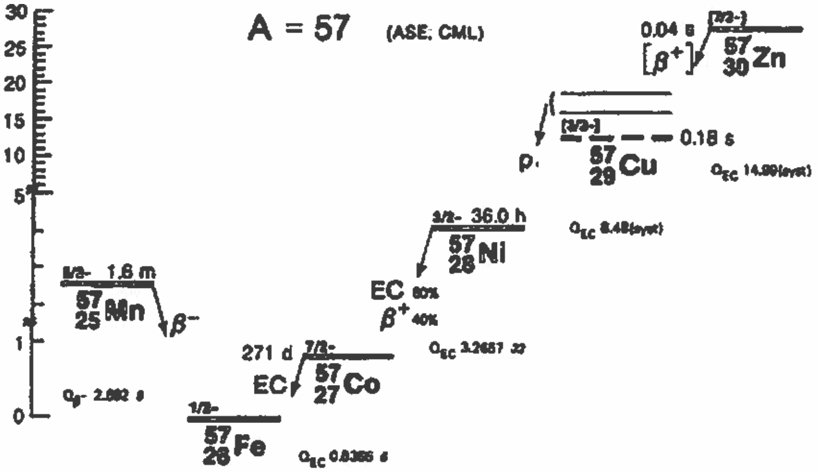
5. Compare the above calibration with that corresponding to the pulser linearity test.

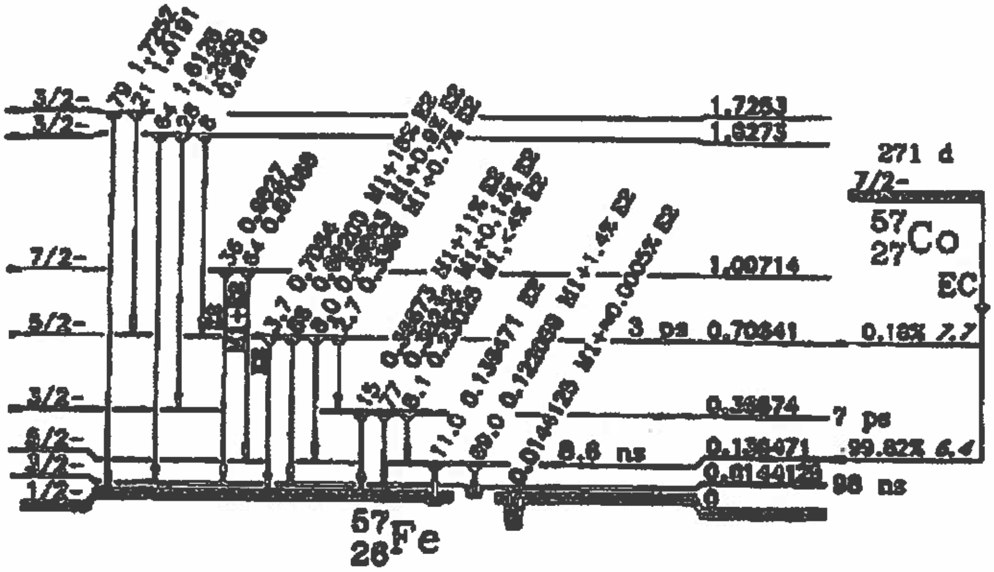
6. Explain the different attenuations of spectral lines obtained with absorbers placed between source and detector. Identify the origin of the dominant low-energy structure in the spectrum.

7. From the count rates measured with the counter/scaler, argue for which, if any, of the runs with absorbers dead time effects need to be considered. Obtain from the TA the fixed DDC-8 dead/busy time per event, which is the dominant component.

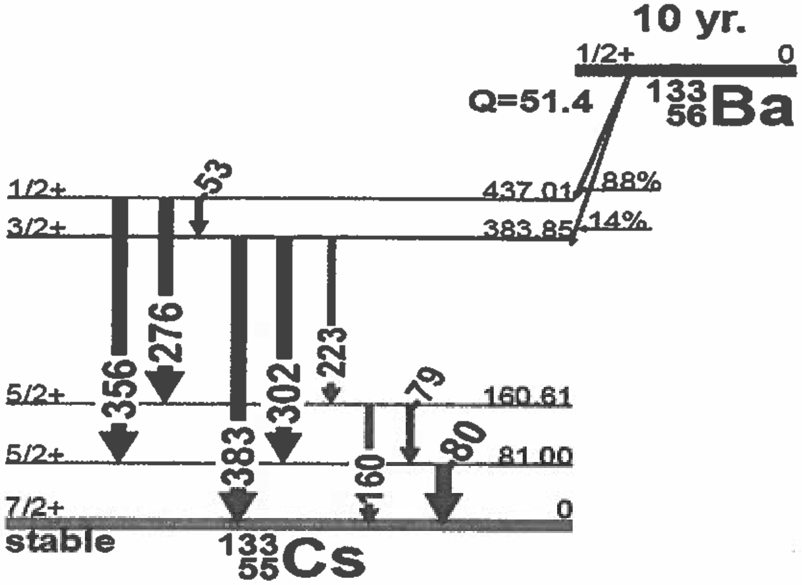
Reading Assignments: Knoll, Ch 6 I-IV; Ch 4 VIIA-C; Tables of X-ray energies.

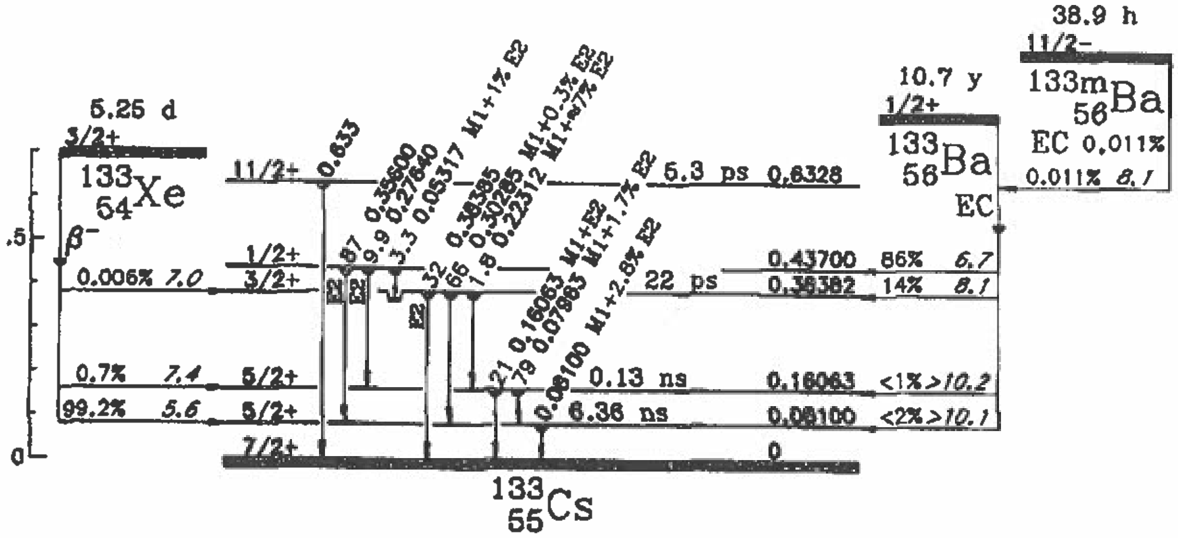
Data Graphs for γ-and X ray sources





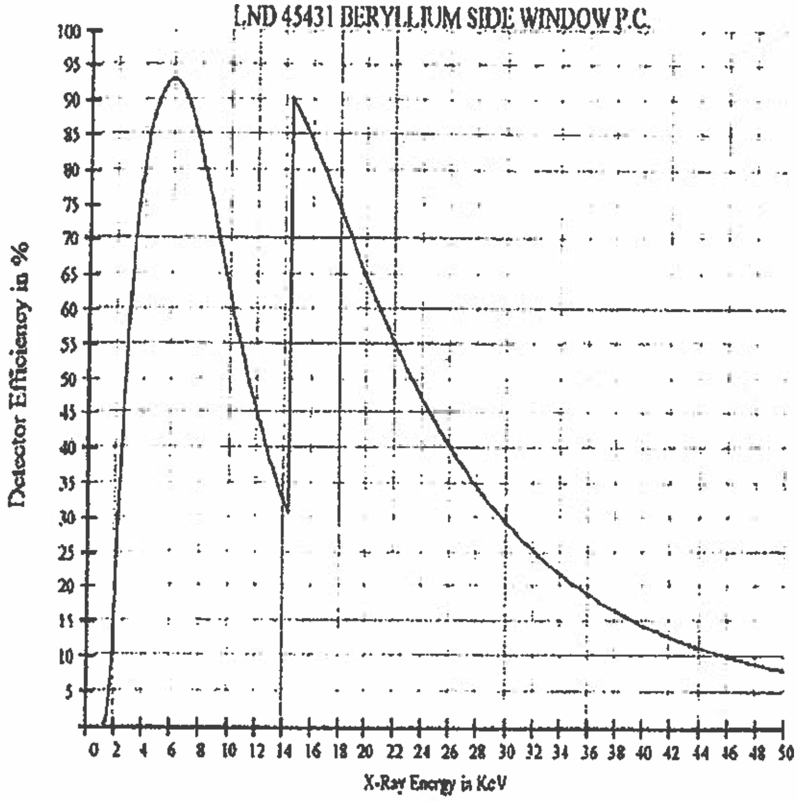
^{133}Ba(10 yr.) Decay Scheme





$^{133}_{56}$Ba

Detector window: 23 mg/cm² Be



$^{133}_{56}\mathrm{Ba}_{77}$

1 Decay Scheme

Ba-133 disintegrates by electron capture to Cs-133 via the excited states of 437 keV and of 383 keV .

Le baryum 133 se désintègre par capture électronique vers des niveaux excités de 437 et 383 keV du césium 133.

2 Nuclear Data

$T_{1/2}(^{133}\mathrm{Ba})$: 10,540 (6) a
$Q^{+}(^{133}\mathrm{Ba})$: 517,4 (10) keV

2.1 Electron Capture Transitions

	Energy keV	Probability × 100	Nature	lg ft	P_K	P_L	P_M
$\epsilon_{0,4}$	80,4 (10)	86,2 (5)	Allowed	6,68	0,672 (5)	0,252 (4)	0,0612 (13)
$\epsilon_{0,3}$	133,6 (10)	13,7 (4)	Allowed	8,07	0,7734 (21)	0,1761 (15)	0,0408 (8)
$\epsilon_{0,2}$	356,8 (10)	< 0,3	2nd Forbidden	> 10,6	0,79 (3)		
$\epsilon_{0,1}$	436,4 (10)	< 0,7	2nd Forbidden	> 10,6	0,88 (4)		
$\epsilon_{0,0}$	517,4 (10)	< 0,0005	Uniq. 2ndForbidden	> 13,9			

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ × 100	Multipolarity	α_K	α_L	α_{MNO}	α_T
$\gamma_{4,3}$(Cs)	53,1622 (6)	15,0 (4)	M1+2,2(13)%E2	4,93 (10)	0,86 (3)	0,226 (8)	6,02 (18)
$\gamma_{2,1}$(Cs)	79,6142 (12)	7,34 (17)	M1+0,09(9)%E2	1,515 (30)	0,204 (5)	0,0530 (11)	1,77 (4)
$\gamma_{1,0}$(Cs)	80,9979 (11)	90,1 (16)	M1+2,23(4)%E2	1,46 (3)	0,220 (5)	0,0570 (14)	1,74 (4)
$\gamma_{2,0}$(Cs)	160,6121 (16)	0,84 (3)	M1+62(12)%E2	0,24 (3)	0,054 (7)	0,014 (3)	0,31 (4)

	Energy keV	$P_{\gamma+ce}$ × 100	Multipolarity	α_K	α_L	α_{MNO}	α_T
$\gamma_{3,2}$(Cs)	223,2370 (13)	0,498 (6)	M1+1,3(2)%E2	0,0853 (20)	0,0113 (3)	0,00292 (6)	0,0995 (30)
$\gamma_{4,2}$(Cs)	276,3992 (12)	7,57 (5)	E2	0,0461 (9)	0,00855 (17)	0,00225 (5)	0,0569 (12)
$\gamma_{3,1}$(Cs)	302,8512 (5)	19,15 (14)	M1+0,05(6)%E2	0,0381 (8)	0,00496 (10)	0,00128 (3)	0,0443 (9)
$\gamma_{4,1}$(Cs)	356,0134 (7)	63,64 (20)	E2	0,0211 (4)	0,00351 (7)	0,00092 (30)	0,0256 (5)
$\gamma_{3,0}$(Cs)	383,8491 (12)	9,12 (6)	E2	0,0169 (3)	0,00273 (5)	0,00071 (2)	0,0203 (4)

3 Atomic Data

3.1 Cs

ω_K : 0,894 (4)
$\bar{\omega}_L$: 0,104 (5)
n_{KL} : 0,895 (4)

3.1.1 X Radiations

		Energy keV	Relative probability
X_K			
	Kα_2	30,625	54,13
	Kα_1	30,973	100
	Kβ_3	34,92 }	
	Kβ_1	34,987 }	
	Kβ_5''	35,245 }	29
	Kβ_5'	35,259 }	
	Kβ_2	35,818 }	
	Kβ_4	35,907 }	7,33
	KO$_{2,3}$	35,972 }	
X_L			
	Lℓ	3,8	
	Lγ	– 5,7	

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	24,41 – 25,80	100
KLX	29,00 – 30,96	47,2
KXY	33,51 – 35,95	5,56
Auger L	2,5 – 5,6	

4 Electron Emissions

		Energy keV		Electrons per 100 disint.
e_{AL}	(Cs)	2,5 - 5,6		138,0 (15)
e_{AK}	(Cs)			14,2 (6)
	KLL	24,41 - 25,80	}	
	KLX	29,00 - 30,96	}	
	KXY	33,51 - 35,95	}	
$ec_{4,3}$ K	(Cs)	17,1776 (6)		10,6 (3)
$ec_{2,1}$ K	(Cs)	43,6296 (12)		4,01 (9)
$ec_{1,0}$ K	(Cs)	45,0133 (11)		48,1 (11)
$ec_{4,3}$ L	(Cs)	47,45 - 48,15		1,84 (7)
$ec_{4,3}$ MNO	(Cs)	51,94 - 53,08		0,484 (18)
$ec_{2,1}$ L	(Cs)	73,9 - 74,6		0,541 (17)
$ec_{1,0}$ L	(Cs)	75,29 - 75,79		7,25 (18)
$ec_{2,1}$ MNO	(Cs)	78,40 - 79,53		0,140 (5)
$ec_{1,0}$ MNO	(Cs)	79,78 - 80,92		1,88 (5)
$ec_{2,0}$ K	(Cs)	124,6274 (16)		0,15 (2)
$ec_{4,2}$ K	(Cs)	240,4143 (12)		0,330 (7)
$ec_{3,1}$ K	(Cs)	266,8862 (5)		0,70 (2)
$ec_{4,2}$ L	(Cs)	270,69 - 271,39		0,0612 (13)
$ec_{3,1}$ L	(Cs)	297,14 - 297,85		0,091 (2)
$ec_{4,1}$ K	(Cs)	320,0283 (7)		1,31 (3)
$ec_{3,0}$ K	(Cs)	347,8639 (12)		0,151 (3)
$ec_{4,1}$ L	(Cs)	350,30 - 351,01		0,218 (4)
$ec_{4,1}$ MNO	(Cs)	354,80 - 355,93		0,57 (1)

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV		Photons per 100 disint.	
XL	(Cs)	3,8 — 5,7		16,0 (8)	
$XK\alpha_2$	(Cs)	30,625		34,0 (4)	} $K\alpha$
$XK\alpha_1$	(Cs)	30,973		62,8 (7)	}
$XK\beta_3$	(Cs)	34,92	}		
$XK\beta_1$	(Cs)	34,987	}	18,2 (2)	$K'\beta_1$
$XK\beta_5''$	(Cs)	35,245	}		
$XK\beta_5'$	(Cs)	35,259	}		

		Energy keV	Photons per 100 disint.	
$XK\beta_2$	(Cs)	35,818	4,6 (1)	$K'\beta_2$
$XK\beta_4$	(Cs)	35,907		
$XKO_{2,3}$	(Cs)	35,972		

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{4,3}$(Cs)	53,1622 (6)	2,14 (3)
$\gamma_{2,1}$(Cs)	79,6142 (12)	2,65 (5)
$\gamma_{1,0}$(Cs)	80,9979 (11)	32,9 (3)
$\gamma_{2,0}$(Cs)	160,6121 (16)	0,638 (4)
$\gamma_{3,2}$(Cs)	223,2368 (13)	0,453 (3)
$\gamma_{4,2}$(Cs)	276,3989 (12)	7,16 (5)
$\gamma_{3,1}$(Cs)	302,8508 (5)	18,34 (13)
$\gamma_{4,1}$(Cs)	356,0129 (7)	62,05 (19)
$\gamma_{3,0}$(Cs)	383,8485 (12)	8,94 (6)

6 Main Production Modes

$$\left\{\begin{array}{l}\mathrm{Ba}-132(\mathrm{n},\gamma)\mathrm{Ba}-133 \qquad \sigma : 6{,}5\ (8)\ \mathrm{barns}\\ \text{Possible impurities : } \mathrm{Ba}-131, \mathrm{Ba}-140\end{array}\right.$$

$$\left\{\begin{array}{l}\mathrm{Ba}-132(\mathrm{n},\gamma)\mathrm{Ba}-133\mathrm{m} \qquad \sigma : 0{,}5\ \ \mathrm{barns}\\ \text{Possible impurities : } \mathrm{Ba}-131, \mathrm{Ba}-140\end{array}\right.$$

$$\left\{\begin{array}{l}\mathrm{Cs}-133(\mathrm{p},\mathrm{n})\mathrm{Ba}-133\\ \text{Possible impurities : } \mathrm{Cs}-132\end{array}\right.$$

7 References

- E. I. WYATT, S. A. Reynolds, T. H. Handley, W. S. Lyon, H. A. Parker. Nucl. Sci. Eng. 11 (1961) 74 (Half-life)
- P. BLASI, M. Bocciolini, P. R. Maurenzig, P. Sona, N. Taccetti. Nuovo Cim. 50B (1967) 298 (Gamma-ray emission intensities)
- J. A. Bearden. Rev. Mod. Phys. 39 (1967) 78 (X-ray energies)
- F. LAGOUTINE, Y. Le.Gallic, J. Legrand. Int. J. Appl. Radiat. Isotop. 19 (1968) 475 (Half-life)
- A. NOTEA, Y. Gurfinkel. Nucl. Phys. A107 (1968) 193 (Gamma-ray emission intensities)

$^{57}_{27}\mathrm{Co}_{30}$

1 Decay Scheme

Co-57 disintegrates by 100% electron capture to the excited levels of 706.42 keV (0.18%), and 136.47 keV (99.82%) in Fe-57.

Le cobalt 57 se désintègre à 100 % par capture électronique principalement vers les niveaux excités de 706 et 136 keV du fer 57.

2 Nuclear Data

$T_{1/2}(^{57}\mathrm{Co})$: 271,80 (5) d
$Q^{+}(^{57}\mathrm{Co})$: 836,0 (4) keV

2.1 Electron Capture Transitions

	Energy keV	Probability × 100	Nature	lg ft	P_K	P_L	P_M
$\epsilon_{0,4}$	129,6 (4)	0,183 (7)	Allowed	7,69	0,8789 (17)	0,1035 (14)	0,0168 (6)
$\epsilon_{0,3}$	469,2 (4)	< 0,002	2nd forbidden	> 10,8			
$\epsilon_{0,2}$	699,5 (4)	99,82 (20)	Allowed	6,45	0,8875 (16)	0,0963 (13)	0,0154 (5)
$\epsilon_{0,1}$	821,6 (4)	< 0,003	2nd forbidden	> 11,1			
$\epsilon_{0,0}$	836,0 (4)	< 0,00035	2nd forbidden unique	> 12,9			

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ × 100	Multipolarity	α_K	α_L	α_M (10^{-3})	α_T
$\gamma_{1,0}$(Fe)	14,41295 (31)	87,69 (7)	M1+0,0005%E2	7,69 (16)	0,782 (16)	113 (3)	8,58 (18)
$\gamma_{2,1}$(Fe)	122,06079 (12)	87,53 (8)	M1+1,4%E2	0,0212 (5)	0,00208 (5)	0,303 (7)	0,0236 (5)
$\gamma_{2,0}$(Fe)	136,47374 (29)	12,30 (18)	E2	0,133 (3)	0,0136 (3)	1,96 (4)	0,148 (3)
$\gamma_{3,2}$(Fe)	230,27 (3)	0,0004 (4)	M1+0,04%E2	0,00374 (8)	0,000356 (8)	0,0524 (11)	0,00415 (9)

	Energy keV	$P_{\gamma+ce}$ × 100	Multipolarity	α_K	α_L	α_M (10^{-3})	α_T
$\gamma_{4,3}$(Fe)	339,67 (3)	0,0039 (4)	M1+0,7%E2	0,00149 (3)	0,000142 (3)	0,0208 (5)	0,00165 (4)
$\gamma_{3,1}$(Fe)	352,34 (2)	0,0032 (4)	M1+0,06%E2	0,00135 (3)	0,000129 (3)	0,0188 (4)	0,00150 (3)
$\gamma_{3,0}$(Fe)	366,74 (3)	0,0013 (4)	M1+17%E2	0,00160 (5)	0,000153 (5)	0,0223 (7)	0,00178 (6)
$\gamma_{4,2}$(Fe)	569,94 (4)	0,015 (2)	M1+0,94%E2	0,000458 (10)	0,0000434 (9)	0,00631 (14)	0,000508 (12)
$\gamma_{4,1}$(Fe)	692,01 (2)	0,159 (6)	M1+17,8%E2	0,000328 (10)	0,000031 (1)	0,00452 (14)	0,000364 (12)
$\gamma_{4,0}$(Fe)	706,42 (2)	0,0050 (5)	(E2)				

3 Atomic Data

3.1 Fe

ω_K : 0,352 (4)
$\bar{\omega}_L$: 0,0061 (5)
n_{KL} : 1,456 (12)

3.1.1 X Radiations

		Energy keV	Relative probability
X_K			
	$K\alpha_2$	6,39084	50,7
	$K\alpha_1$	6,40384	100
	$K\beta_3$	7,05798 }	
	$K\beta_5''$	7,1081 }	21,4
X_L			
	$L\ell$	0,61	
	$L\beta$	~ 0,79	

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	5,37 – 5,64	100
KLX	6,16 – 6,40	23,9
KXY	6,91 – 7,10	2,2
Auger L	0,6 – 0,7	302

4 Electron Emissions

		Energy keV		Electrons per 100 disint.
e_{AL}	(Fe)	0,6 - 0,7		252 (3)
e_{AK}	(Fe)			105,2 (13)
	KLL	5,37 - 5,64	}	
	KLX	6,16 - 6,40	}	
	KXY	6,91 - 7,10	}	
$ec_{1,0\ K}$	(Fe)	7,3009 (3)		70,4 (20)
$ec_{1,0\ L}$	(Fe)	13,567 - 13,705		7,16 (20)
$ec_{1,0\ M}$	(Fe)	14,312 - 14,409		1,03 (3)
$ec_{2,1\ K}$	(Fe)	114,9486 (1)		1,81 (4)
$ec_{2,1\ L}$	(Fe)	121,215 - 121,353		0,178 (4)
$ec_{2,1\ M}$	(Fe)	121,968 - 122,057		0,0259 (6)
$ec_{2,0\ K}$	(Fe)	129,3616 (3)		1,42 (4)
$ec_{2,0\ L}$	(Fe)	135,628 - 135,766		0,146 (4)
$ec_{2,0\ M}$	(Fe)	136,381 - 136,470		0,0210 (5)

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV		Photons per 100 disint.	
XL	(Fe)	0,61 — 0,79		1,55 (13)	
$XK\alpha_2$	(Fe)	6,39084		16,8 (3)	} $K\alpha$
$XK\alpha_1$	(Fe)	6,40384		33,2 (5)	}
$XK\beta_3$	(Fe)	7,05798	}		
$XK\beta_1$	(Fe)		}	7,1 (2)	$K'\beta_1$
$XK\beta''_5$	(Fe)	7,1081	}		
$XK\beta_4$	(Fe)		}		$K'\beta_2$

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{1,0}$(Fe)	14,41295 (31)	9,15 (17)
$\gamma_{2,1}$(Fe)	122,06065 (12)	85,51 (6)
$\gamma_{2,0}$(Fe)	136,47356 (29)	10,71 (15)

Experiment	
Oscilloscope Practice, Electronics	**Osc**
Photon Spectroscopy w. NaI Detectors	**NaI**
Spectroscopy w. Solid-State Detectors	**GeSi**
Radiation Measurements w. Gas Detectors	**GPC**
Coincidence/Imaging Experiments	**PET**
Interactions of Cosmic Radiation (τ_μ)	**Mu**
Mössbauer Spectroscopy	**MB**
Neutron Activation (β-Decay)	**NA**
Data Acquisition	**DAQ**
Data Analysis	**IGOR**
Template Laboratory Report	**Rep**
Auxiliary Documents	**Aux**

ANSEL Experiment PET Scan/γ–γ Angular Correlations

Experimental Tasks (2 experiment stations)

Station A (Periods 1&2)

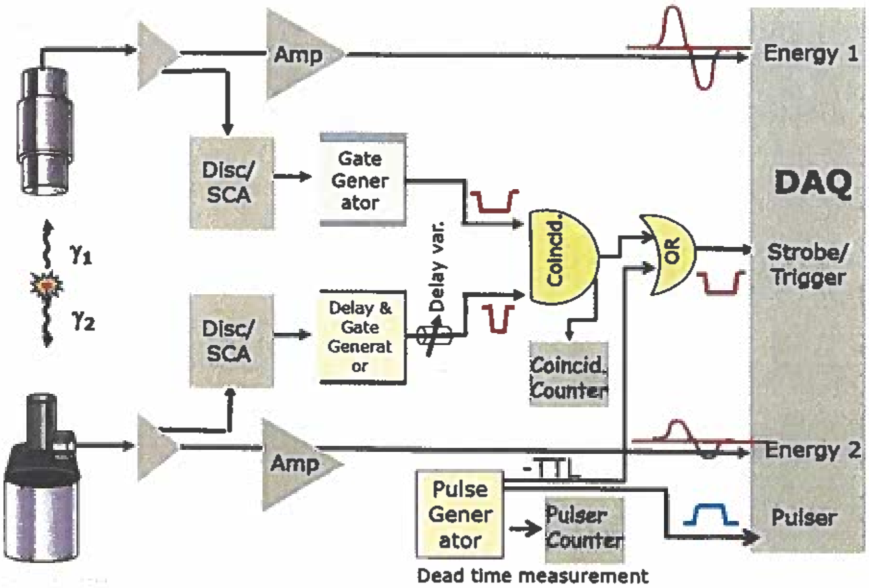
- **I.** **Set up the electronics for 2-detector singles and coincidence experiments and calibrate the detector energy responses.**
- **II.** **Measure the angular correlation of two 511-keV annihilation γ-rays.**
- **III.** **In a PET measurement with two γ detectors, determine the location of a concealed positron emitter.**

Station B (Period 3)

- **IV.** **Repeat I. above, but for detectors of Station B**
- **V.** **Measure the angular anisotropy $A_{\gamma\gamma}$ for the ^{60}Ni (E*=2.507MeV) de-excitation γ cascade.**
- **VI.** **Determine the absolute activity of a γ source.**

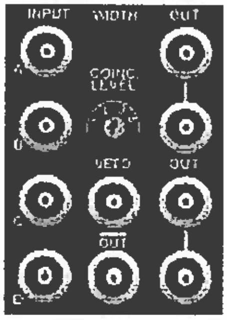
For either Station A or B (periods 1&2):

I. With the help of the TA set up two NaI (γ_1 and γ_2) detectors, or one 2"x2" NaI and one HPGe detector, on respective correlation tables. Set up and tune NIM coincidence electronics and data acquisition system, approximately according to the circuit diagram below. Calibrate the detectors in gamma energy.



Attention: Take precautions to avoid damage to fragile detectors by securing detector signal and power cables.

1. Verify that detector HV bias supply is switched off.
2. Place γ_1 and γ_2 detectors *at minimum distance* (next to one another, if needed) on the angular correlation table.
3. Place a ^{22}Na γ source between the two detectors in closest proximity.
4. Connect γ_1 and γ_2 detector HV cables to bias supply.
5. Connect signal output cables from γ_1 and γ_2 detectors to scope inputs (AC, 50Ω).
6. Switch on HV bias supplies and verify proper detector pulse responses on scope.
7. Verify on the scope that there are ***some*** γ_2 signals coincident with (having a fixed relative time difference to) γ_1 signal triggers, *when detectors are in proximity*.
8. Set up the slow and fast circuits for both γ detectors. Use the available amplifier/discriminator combinations for the detectors. Choose signal shaping times and amplitudes appropriate for DDC-8 input.
9. **Optional:** Set up pulse generator PG slow/fast circuit for the dead time measurement. (Analog: HPGe preamp input, or PG analog or TTL out direct to DDC-8).
10. Provide a scaler for counting externally (independently of the DAQ) the number of pulser triggers sent to the DAQ.
11. Set up two channels of a fast digital logics unit to produce the conditional **master trigger**/strobe signal for the DDC-8 ADC. Design it such that a quick change is possible between the two trigger conditions
    a) for independent (**singles**) counting of detectors γ_1 and γ_2 and the (optional) pulse generator (PG): **(γ_1.OR.γ_2).OR.PG**, and
    b) for **coincidence** counting: **(γ_1.AND.γ_2).OR.PG**.



12. Set up proper width and timing of the logical master trigger signal relative to the various analog signals (γ_1, γ_2, PG).
13. Hook up the analog (energy) signals to the DDC-8 (γ_1 to Ch.0, γ_2 to Ch.1, Pulse generator, attenuated TTL out, to Ch.3). Connect the master trigger to the DDC-8 Strobe input NIM_IN0.
14. Set up the DDC-8 for individual histogramming of γ_1, γ_2, and PG pulse height spectra.

The setup is now ready to simultaneously take γ_1, γ_2, and PG singles data.

15. Calibrate and measure the pulse height spectra for both γ detectors with ^{22}Na source.
16. Verify the location of the PG line approximately in the middle visible spectrum.
17. Start the DDC-8 for a 5-10 minutes singles measurement simultaneously with the external PG scaler.
18. Note the resolutions provided by the γ detectors and estimate the dead time (from the intensity of the PG line compared to the external PG scaler count).
19. Set the window discriminators for the detectors, each to bracket the corresponding 511-keV γ line.

II. Measure the resolution in angular correlation provided by the 2-detector setup, using the two annihilation γ-rays from the ^{22}Na β^+ decay. Total coincidence rate N_{12} per time (or N_{PG}) (in DDC-8) is the main observable, energy spectra are for data quality control.

1. Place the ^{22}Na β^+ source in the middle of the angular correlation table.
2. Place the γ detectors facing each other *at distance*, with $\theta_{12}=180^0$ angular separation. Plan for a $\pm 20^0$ variation in angle θ_{12} of detector γ_1 with respect to γ_2, the fixed detector.
3. Set the window discriminators for the detectors to each accept the corresponding 511-keV γ line. **Record the widths $\Delta\tau$ of the discriminator NIM output signals.**
4. Set the master trigger logic unit set to the **OR** condition (**γ_1.OR.γ_2.OR.PG**).
5. Measure the singles pulse height spectra for both γ detectors simultaneously, to verify the proper discriminator settings. If insufficient, change window(s) and repeat Steps 3 & 4.
6. Set the master trigger logic unit set to the **AND** condition [**(γ_1.AND.γ_2).OR.PG**].
7. Measure for a period of 5-10 minutes the coincident pulse height spectra for both γ detectors and the PG for a $\theta_{12}=180^0$ correlation angle.
   Always start DDC-8 DAQ simultaneously with the external PG scaler.
8. Repeat (in 10^0 steps) the measurement in 7, but for 2-4 larger and 2-4 smaller angles θ_{12}, covering the range $160^0 \le \theta_{12} \le 200^0$. Move only one detector.
9. Check on the dead time in each measurement.

III. In a PET measurement with two γ detectors, determine the location of a concealed positron emitter. Total number $N_{12}(\theta_{12})$ of coincidences (in DDC-8) per time (or N_{PG}) is main observable, spectra are for data quality control.

Discuss and decide upon an *effective scan pattern*. Record steps in logbook. Repeat measurement Steps 6.-8. above but with conveniently chosen detector angle(s).

Switch to the other Experiment Station (last of 3 periods)

IV. Measure the $90^0/180^0$ angular anisotropy $A_{\gamma\gamma}$ for the ^{60}Ni(E*=2.507MeV) de-excitation γ cascade.

Set up detector and electronics in the Station. Set the γ1 discriminator for the 1.17-MeV γ-line, the γ2 discriminator for the 1.33-MeV γ-line.
Perform coincidence measurements for $\theta_{12}=90^0$ and 180^0.

V. Measure with the two γ detectors in this station the absolute activity A of a γ source of your choice.

Data Analysis/Report

1. Sketch electronics block circuit diagram, provide timing diagram approximately to scale.
2. Calibrate γ_1 and γ_2 detectors in energy
3. Determine angular resolution of correlation setup (plot distribution $N_{12}(\theta_{12})/N_1$)
4. Determine DAQ dead time from N_{PG} measured vs. number of PG triggers (scaler).
5. Plot and discuss γ_1 and γ_2 singles energy spectra.
6. Plot and discuss γ_1 and γ_2 coincidence energy spectra, for different angles θ_{12}, including θ_{12} near 90^0 and near 180^0. Discuss potential effects of the 1.275-MeV γ-line on the correlation measurements.
7. Explain strategy for PET scan patterns.
8. Report position coordinates for hidden γ source. Estimate uncertainties.
9. Report $90^0/180^0$ angular anisotropy $A_{\gamma\gamma}$ for the ^{60}Co γ-rays.
10. Report absolute activity of γ source with estimate of uncertainty. Discuss the effect of the finite widths $\Delta\tau$ of the discriminator NIM output signals on the coincidence rates.

Experiment	
Oscilloscope Practice, Electronics	Osc
Photon Spectroscopy w. NaI Detectors	NaI
Spectroscopy w. Solid-State Detectors	GeSi
Radiation Measurements w. Gas Detectors	GPC
Coincidence/Imaging Experiments	PET
Interactions of Cosmic Radiation (τ_μ)	Mu
Mössbauer Spectroscopy	MB
Neutron Activation (β-Decay)	NA
Data Acquisition	DAQ
Data Analysis	IGOR
Template Laboratory Report	Rep
Auxiliary Documents	Aux

ANSEL Experiment Cosmic Muon Interactions

Experimental Tasks

Activities (3 weeks) with active target counter (AT)

1. **Setup of muon telescope and active target counters.**
2. **Counter calibration with γ sources (^{22}Na,^{137}Cs) and muons.**
3. **Setup of electronic logics for energy (and time) measurements.**
4. **Set up Data Acquisition System.**
5. **Measure flux of incoming muons per minute.**
6. **(Optional) Measurement of the muon range curve.**

---

7. **Measure energy loss/light output spectrum with active target counter (AT) (run time > 1 day).**
8. **Perform data conversion and treatment.**

---

9. **Measure mean lifetimes for μ^+ and μ^- decay (run time 1-7 days), and (optional) μ^- capture rate (run time ~ 1 week).**

Note: Please, for scientific and technical background on this experiment and issues to be discussed in the lab report, refer to the special ANSEL report "ACMUT Manual" found in the ANSEL Twiki under "Experiment Manuals"
http://teacher.pas.rochester.edu:8080/wiki/pub/ANSEL/ExperimentManuals/ACMUT_Manual.pdf

Below, brief descriptions of counter and electronics setup are given, followed by step-by-step procedures for the measurements. For more in-depth explanations, graphs, timing diagrams, and images, refer to the above report. Note that the earlier Data Acquisition System EZDAQ has been replaced by the DDC-8 now used throughout the ANSEL.

1. Electronics setups for muon flux, energy loss, decay and capture measurements

The electronic circuitry serving the muon telescope consists of components whose operational principles have already been encountered in an earlier experiment series. Before measurements can be started, several preparatory tasks have to be accomplished.

Electronics modules:

PM HV power supplies (note polarities).
24 V DC power outlet for AT base.
Octal fast discriminator module
Quad logic unit
Fast/slow amplifier
For EZDAQ data acquisition:
ADC and TAC
CAMAC crate with CC-USB controller

Table 1: Power supply settings

Detector	Voltage
Detector #1	+1500
Detector #2	+1500
Detector #3	+1500
Detector #4	+1500
Active Target	-1900
Active Target Base	±24

Energy loss and time measurements require nearly identical setups.

1. Set the HV and supply voltage polarities and values to operate the photo multipliers for all counters at nominal conditions.
2. Check for proper signal pulse shapes and amplitudes obtained from each counter with ^{22}Na γ-ray sources and cosmic muons.
3. According to the electronics diagram in Fig. 1, set up an amplifier for the measurement of calibration pulse height spectra for all scintillation counters (AT & "paddles").
4. Set the fast discriminator thresholds; use the oscilloscope probe if necessary. Make use of the fact that cosmic muons are *mips* and therefore deposit a specific energy of $\Delta E/d \approx 2$ MeV/cm in thin plastic absorbers. The telescope detectors ("paddles") have approximate thicknesses of $d = 1$ cm, the AT has a thickness of $d = 12$ cm.
5. Set and check proper widths of the logic (fast discriminator) signals.
6. Search for coincident signals for all adjacent pairs of telescope counters. If needed, measure a TAC spectrum for each pair of detectors.
7. According to the electronics diagram in Fig. 1, set up the coincidence logic circuitry such that it can be adopted easily to provide either a prompt muon transmission trigger or a muon-stop trigger signal.
8. **For the muon decay and/or capture measurements only:** Set up coincidence logic for the delayed electron/positron signal (Fig. 2). Pay attention to the fact that the latter signal may appear from time-zero to several μs after a muon stop. The AT timing NIM signal is used twice. To minimize dead time, it should be as short as possible for the decay time measurement.
9. ***Measure the flux of muons traversing the telescope per unit time.***

10. Produce respective start, stop and master trigger signals for the DDC-8 and TAC units to record energy and time information with the DAQ.
11. Initialize and start the data acquisition BlackBox/DDC-8 software utilities.

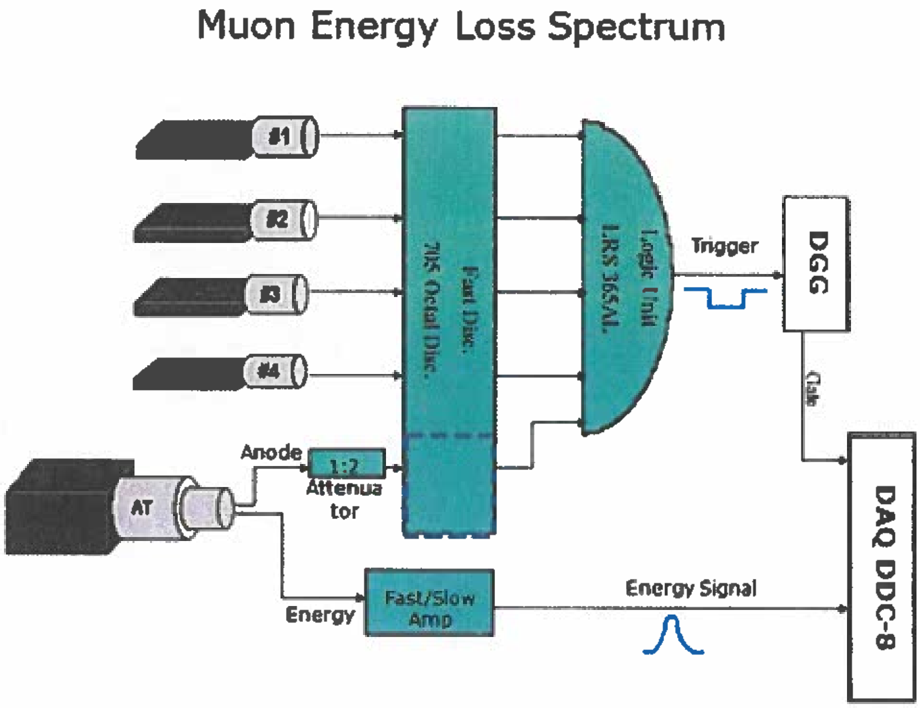


Figure 1
Note: De

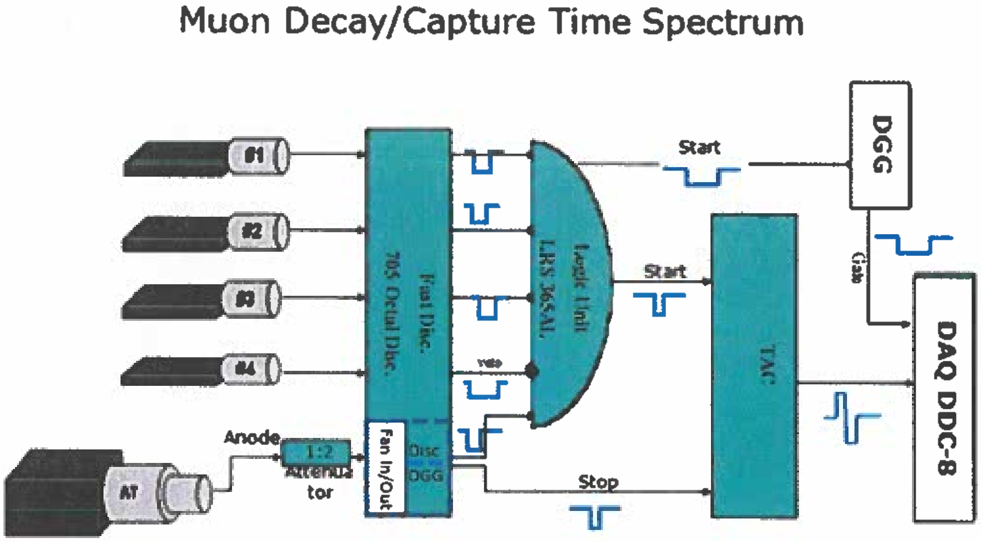


Figure 2: Electronic logic for muon decay and capture time spectra with the AT. Note that the AT timing signal is used twice.

2. AT light output calibration and energy loss measurement

To measure the energy deposited in the AT by muons traversing or stopping in the AT counter, the AT energy-to-light output response should be calibrated with both, ^{137}Cs and ^{22}Na sources, which emit γ-rays of known energies. This can be accomplished using the procedure described below.

Note: *Once the calibration has been performed, the "slow" analog energy circuitry should not be changed in any way. If that should turn out to be necessary for any reason, a new calibration should be performed with the new settings.*

Calibration Procedure

1. The AT has a built-in integrating preamplifier in its base which is optimized for energy measurements. The base requires ±24V supply voltage, which can be provided by two cables to the ±24V power supply in the NIM crate for this experiment. Attention: Connect the cables to the outputs with the correct polarities.
2. Verify that the HV power supply voltage for the AT has negative polarity, before turning it on, and then ramp it up cautiously to its nominal value.
3. Place the γ source on top of the AT in its center (One source at a time).
4. Adjust the AT trigger threshold. The γ-rays are of low energy, so the threshold must be set at its low limit.
5. The logic signal combining a muon traversal (or muon stop) signal with the AT discriminator signal should be used as trigger to generate a DDC-8 gate signal.
6. Adjust the settings to generate a proper ADC trigger for the AT energy signal.
7. Connect energy and trigger signals to the appropriate DDC-8 inputs.

Repeat measurement for the other γ source(s).

Lab Report

Show and discuss responses of all detectors to γ-rays.

Show responses of all detectors to muons. Give measured count rates (cts/min, cts/min·m^2).

Show timing diagrams for electronic signals, include screenshots.

Answer the following questions posed in the ACMUT Manual

Muon interactions with matter: questions on p. 10
Muon weak decay: questions on p. 18

For further topics to be discussed in the lab report, refer to the special ANSEL report "ACMUT Manual" found in the ANSEL Twiki under "Experiment Manuals" http://teacher.pas.rochester.edu:8080/wiki/pub/ANSEL/ExperimentManuals/ACMUT_Manual.pdf

Experiment	
Oscilloscope Practice, Electronics	Osc
Photon Spectroscopy w. NaI Detectors	NaI
Spectroscopy w. Solid-State Detectors	GeSi
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Coincidence/Imaging Experiments	PET
Interactions of Cosmic Radiation (τ_μ)	Mu
Mössbauer Spectroscopy	MB
Neutron Activation (β-Decay)	NA
Data Acquisition	DAQ
Data Analysis	IGOR
Template Laboratory Report	Rep
Auxiliary Documents	Aux

ANSEL Experiment Möβbauer Spectroscopy

Experimental Tasks

Activities (2 weeks) with gas proportional counter and velocity drive

1. **Mount a ^{133}Ba source to calibrate the Kr gas proportional counter (PC)**
2. **Set up bias supply and electronic logics for the PC energy measurement (Ch_0)**
3. **Set up Data Acquisition System (DDC-8)**
4. **Measure and calibrate the PC for the range of energies below 50 keV. Identify the characteristic ^{133}Ba X ray and γ-ray spectra using absorbers**

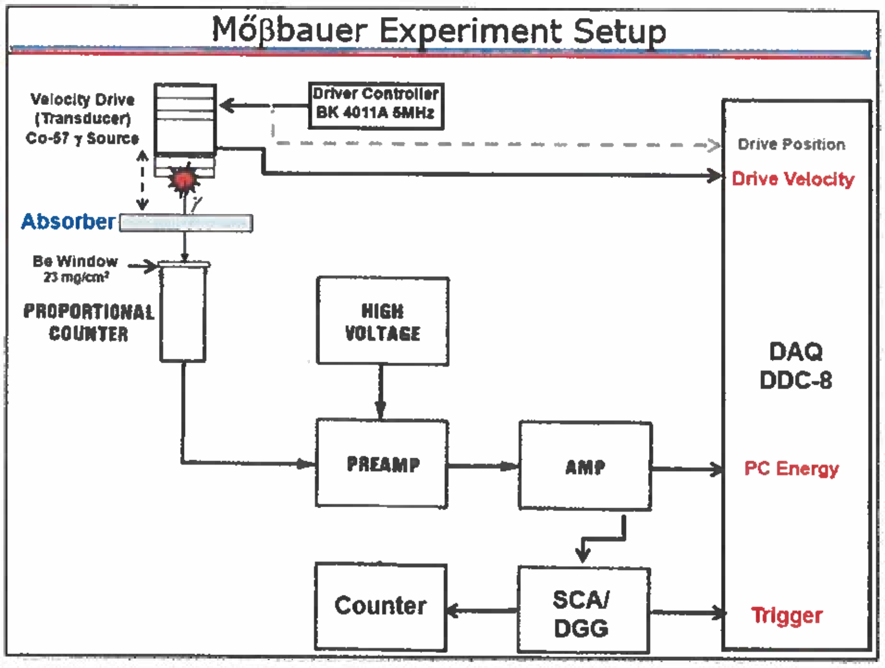

***Figure 1:** Schematic Block Diagram of Electronics*

5. **Measure and identify the PC ^{57}Co X ray and γ-ray spectra using calibrated absorbers (in wooden box).**
6. **Set the SCA window at your discretion, to accept enough counts for the following adjustments and calibration measurements.**

7. **View on the scope and optimize the frequency (≈ 30Hz) of the sinusoidal signal from the function generator driving the velocity transducer (VT400), an electro-mechanical oscillator moving the Möβbauer source in direction of the PC.** (The actual velocity of the drive (and mounted source) is reflected by the response by a "pickup coil." See VT400 Specs for sensitivity (mV/mm·s^{-1}).
8. **Connect the transducer pickup signal to Ch_1 on the DDC-8.** (PC energy should be on CH_0).

9. **With no absorber between source and PC, measure and calibrate the velocity spectrum dN/dv with the DDC-8. Amplify the velocity signal to use a good part of the ADC range.**
10. **With the final setting of the velocity range on the ADC and no absorber between ^{57}Co source and PC, measure a background velocity spectrum.**

---

11. **Set the SCA window narrowly enough to capture just the 14.4-keV Mößbauer line.** (Alternatively, this "gating" can be done off-line, during the analysis of data taken with only a lower SCA threshold.)
12. **Place the absorber holder of the Mößbauer setup at a reasonable position between source and PC.**
13. **Perform transmission measurements of velocity spectra for 3 different ^{57}Fe containing absorber materials: Fe_2O_3, $K_2MgFe(CN)_6$, $FeC_2O_4{\cdot}H_2O$.**
14. **Optional: Measure temperature dependence of transmission line shape for one absorber.**

Data Analysis

1. **Analyze measured X-ray and γ-ray energy spectra using IGOR**
2. **Calibrate DDC-8 energy ADC (Ch_0)**
3. **Calibrate DDC-8 velocity ADC (Ch_1)**
4. **Correct measured velocity spectra for background**
5. **Analyze position and shape of transmission "dips" in velocity spectra for different absorbers with IGOR**
6. **Deduce energies (keV) of electromagnetic transitions between ground and 14.4-keV state of ^{57}Fe in the various absorbers studied.**

Report

1. **Theory: Electric and magnetic hyperfine spectroscopy of nuclear γ-rays, isomer shift, ground and first excited state energy levels of ^{57}Fe embedded in crystal lattices.**
   Conditions for recoilless emission, resonant vs. normal absorption of photons
2. **Experimental method: Use of Doppler effect for scanning transmission of photons through ^{57}Fe containing matter,**
   Explain two-dimensional transmission spectroscopy $T_\gamma = T_\gamma$ (E_γ, source velocity v)
3. **Measurements: Describe function and observed performance of PC**
   Explain strategy for line identification using absorbers
   Display raw ADC spectrum for ^{133}Ba, energy spectrum for ^{57}Co
4. **Explain optimization of function generator with transducer response**
5. **Explain shape of velocity spectra, explain method of background correction**
6. **Determine hyperfine transition energies for the 14.4-keV transition in ^{57}Fe**
7. **Deduce isomer shift (in eV) and magnetic g-factor of the 14.4-keV ^{57}Fe level.**
8. **...**

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Designers & Manufacturers of Nuclear Radiation Detectors
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1-516-678-6141 Fax: 1-516-678-6704

45431 Beryllium Side Window Proportional Counter

GENERAL SPECIFICATIONS

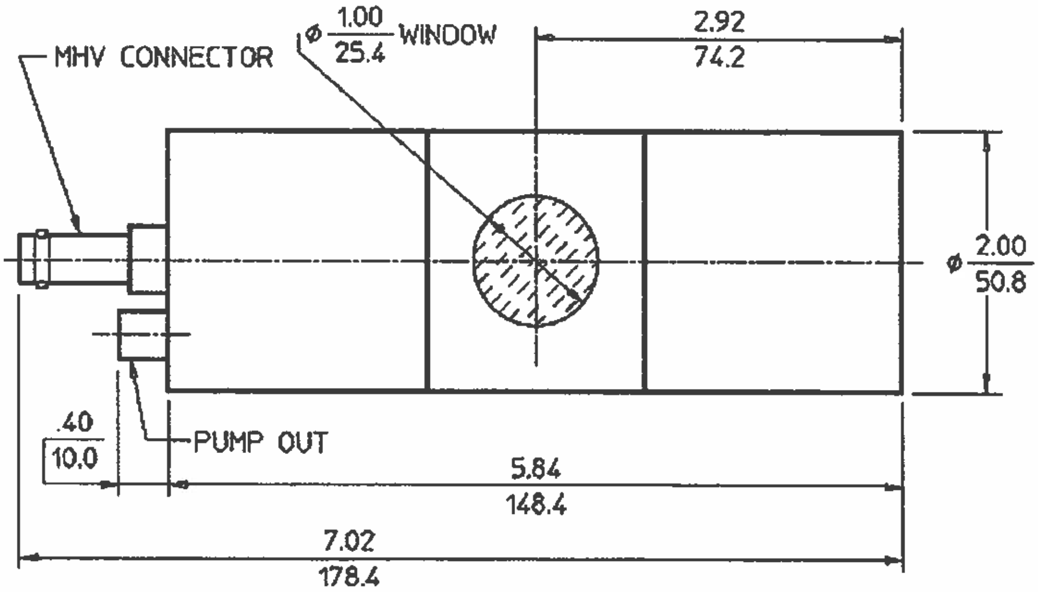
Gas filling	Krypton
Gas pressure (torr)	800
Path length (inch/mm)	1.88/47.8
Cathode material	Aluminum
Maximum length (inch/mm)	7.02/178.4
Effective length (inch/mm)	4.5/114.3
Maximum diameter (inch/mm)	2.00/50.8
Effective diameter (inch/mm)	1.88/47.8
Connector	MHV
Operating temperature range °C	-40 to +75

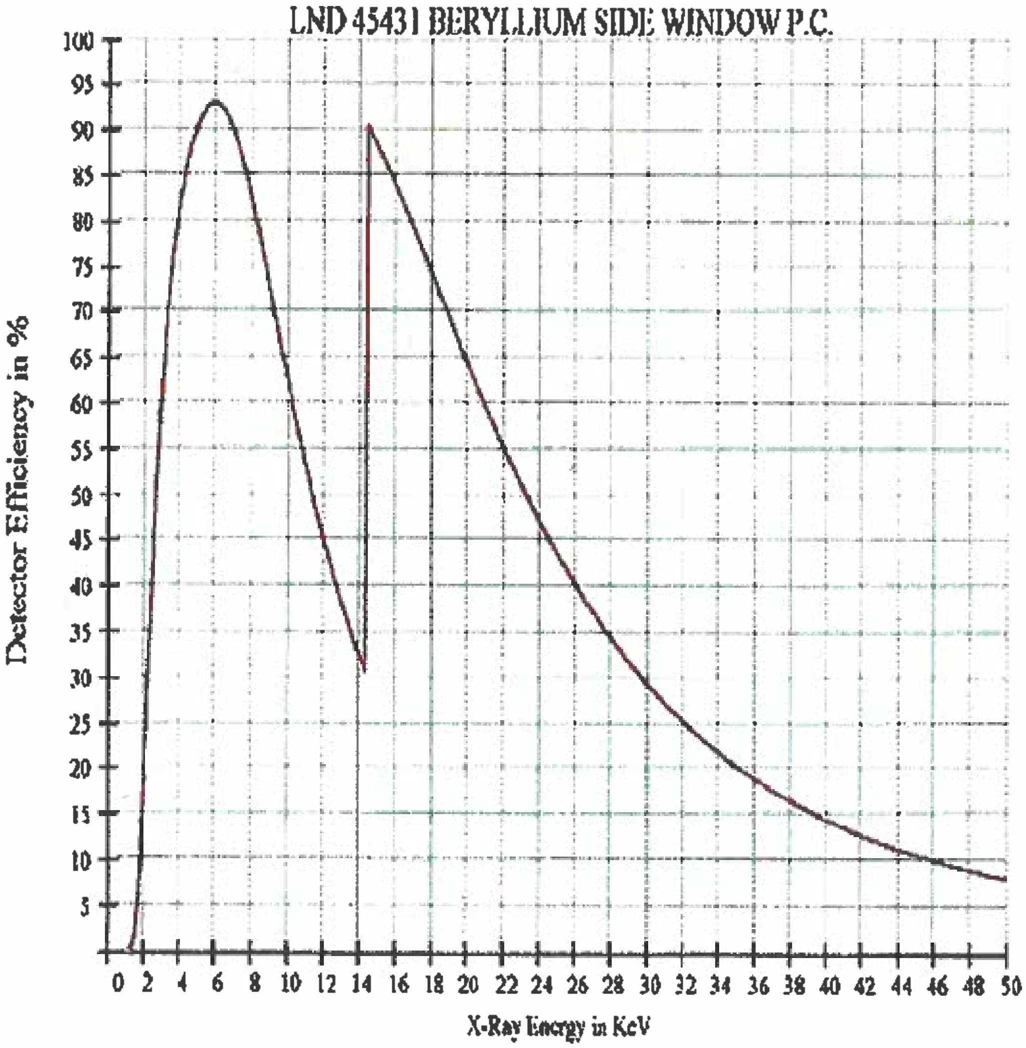
WINDOW SPECIFICATIONS

Material	Beryllium
Areal density (mg/cm²)	23
Thickness (inch/mm)	0.005/0.127
Diameter (inch/mm)	1.0/25.4

ELECTRICAL SPECIFICATIONS

Recommended operating voltage (volts)	1800
Operating voltage range (volts)	1700 - 1950
Typical resolution (fwhm Cd109)	10
Capacitance (pf)	3




LND 45431 BERYLLIUM SIDE WINDOW P.C.
Detector Efficiency in %
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
X-Ray Energy in KeV

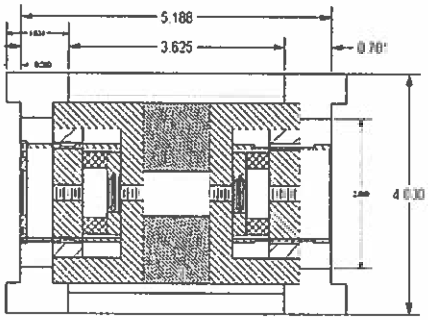
Science Engineering & Education Co

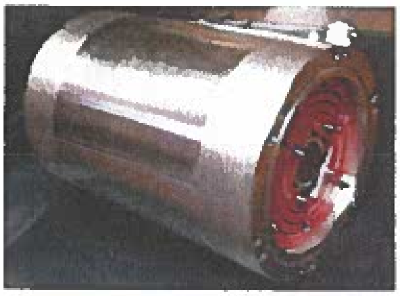
SEE Co

Helping you see the data

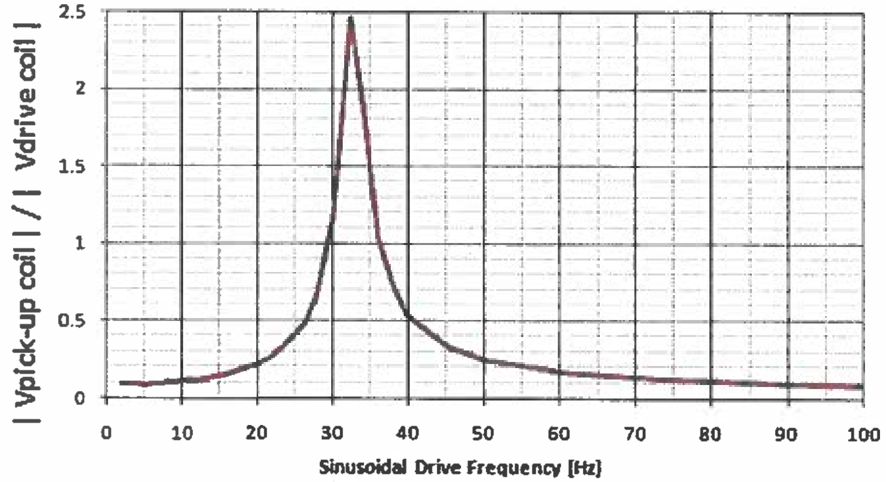
Model VT400 Linear Velocity Transducer

The Model VT400 is optimized for use with Mössbauer spectrometers. The VT400 s double voice coil design provides a highly linear velocity scan that is both stable and precise. The housing is equipped with O-ring seals for mounting on cryostats.





Specifications for VT400 s/n 905


VT400 Open Loop Frequency Response displayed as ratio of the amplitude of the Pick-up coil voltage to the amplitude of the sinusoidal drive coil voltage.

Geometry	Double voice-coil on single shaft
Mass	2,460 g
Diameter	10 cm
Length	14.4 cm
Resonance Frequency	32 Hz
Max. Velocity Range	+/- 100 mm/s
Pick-Up Coil Sensitivity	16 mV / mm/s
Pick-up Coil Resistance	445 ohms
Drive Coil Resistance	27 ohms
Magnets	Bonded NeFeB
Linearity	Integral non-linearity < 0.1% over range +/- 10 mm/s
Connections	Connector on transducer: Amphenol MS3112E8-4S four pin female. Pin A Pick-up coil + Pin B Pick-up coil - Pin C Drive coil + Pin D Drive coil - Supplied with 3 m cable that mates to transducer connector and has 9-pin male sub-D connector on other end. Cable male 9-pin sub-D Connector Pin 2 Pick-up coil + Pin 4 Pick-up coil Pin 7 Drive coil + Pin 8 Drive coil -

Experiment	
Oscilloscope Practice, Electronics	Osc
Photon Spectroscopy w. NaI Detectors	NaI
Spectroscopy w. Solid-State Detectors	GeSi
Radiation Measurements w. Gas Detectors	GPC
Coincidence/Imaging Experiments	PET
Interactions of Cosmic Radiation (τ_μ)	Mu
Mössbauer Spectroscopy	MB
Neutron Activation (β-Decay)	NA
Data Acquisition	DAQ
Data Analysis	IGOR
Template Laboratory Report	Rep
Auxiliary Documents	Aux

ANSEL Experiment Neutron Activation Analysis

Experimental Tasks

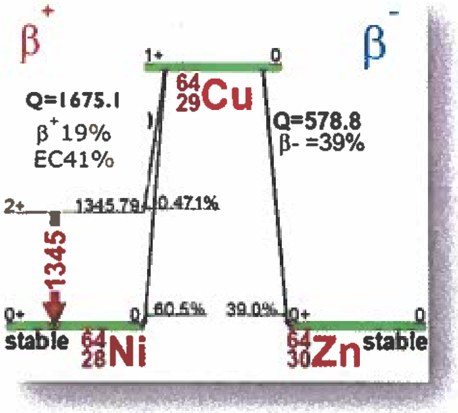
Activities: Activate *Cu* and "*unknown*" samples with generator or AmBe neutrons, measure activation γ spectra with NaI (*Tl*) and/or HPGe γ detectors, keep accurate time line.

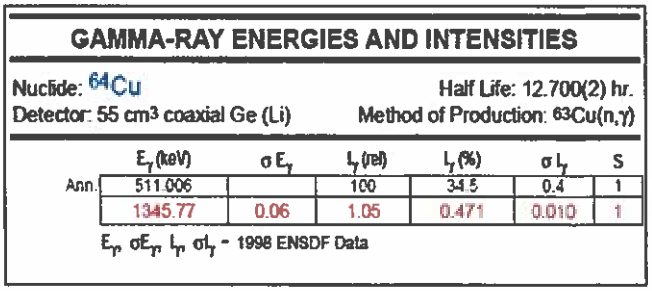
Note: Accurately record the complete time line of the experiment: start and stop times for neutron activation, transfer of sample and insertion into counting station (waiting time), start and stop of each measurement and prior waiting time.

1. Setup γ detector(s), if available in shielded low-level counting stations. Prepare time keeping, quick sample insertion and placement procedures.
2. Setup fast-slow electronic logics for energy measurements. If necessary, include pulse generator for normalization.
3. Set up Data Acquisition System.
4. Calibrate energy spectrum with γ sources (^{22}Na,^{137}Cs). Choose a ~1.9-MeV full energy scale.
5. Verify the intrinsic efficiency of the γ detector at 0.511 MeV and 1.27 MeV (compare to data provided by manufacturer).
6. Obtain a blank Cu sample and record its dimensions and weight. Measure background γ spectrum. Produce an IGOR histogram for later comparison.
7. Obtain a neutron activated ***Cu*** sample, which has been exposed to nGen and/or AmBe neutron source during a specific time.
8. Quickly transfer the activated ***Cu*** sample to the NaI γ counting station.
9. Perform several successive 1-hr measurements of the activation γ–ray spectrum.
10. Identify the main lines in the **activation** γ–ray spectrum that were absent or weak in the blank-sample spectrum and/or seem to disappear in time.
11. Repeat steps 7-9 if necessary, ideally with fresh ***Cu*** samples.

---.

Note: natural Cu has two isotopes, ^{63}Cu (69.2%)and ^{65}Cu (30.8%)





GAMMA-RAY ENERGIES AND INTENSITIES

Nuclide: ^{64}Cu
Half Life: 12.700(2) hr.
Detector: 55 cm^3 coaxial Ge (Li)
Method of Production: ^{63}Cu(n,γ)

	E_γ (keV)	σE_γ	I_γ (rel)	I_γ (%)	σI_γ	S
Ann.	511.006		100	34.5	0.4	1
	1345.77	0.06	1.05	0.471	0.010	1

E_γ, σE_γ, I_γ, σI_γ - 1998 ENSDF Data

12. Obtain a ***blank of an unknown sample***. Record its sample # and weight.
13. Measure the energy spectrum of the unknown blank for one hour.
14. Obtain a ***neutron-activated version of the unknown sample***. Record its sample # and weight. Quickly transfer activated sample to the γ counting station
15. Perform two 1-hr measurements of the energy spectrum of the activated sample. Save the data in individual files. Produce an IGOR histogram for comparison.
16. Identify the main lines in the **activation** γ–ray spectrum that were absent in the blank spectrum and/or disappear in time.
17. Start a long-term measurement of the activation γ–ray spectrum, to search for long-lived activities.

Abbreviated NA Procedure

1) NaI (Ge) calibration to > 1.9-MeV full scale.

2) Invert sequence of background/blank to activated target measurements, if required by time.

3) Obtain irradiated Cu, unknown samples from Hutchison 441/442. Note time of activation, start, stop and transfer.

4) Place sample on detector face, or between 2 detectors close together.

5) Start gamma measurement with activated sample (note start and stop times). Observe data coming in. Search for activation γ-ray lines. Stop after one hour (note time), save and inspect data.

6) Start additional measurements with increasingly longer acquisition periods (note times for start and stop), until interesting γ lines have disappeared.

7) Accumulate data for a longer time. If needed, perform overnight measurement.

Analysis and Report:

1) Perform energy calibrations for the detector(s) used in the NA experiment.
2) Determine the intensities measured for the most characteristic (specific) NA γ lines for ***Cu*** and ***unknown*** samples #1 or #2, for various runs with their specific acquisition time periods.
3) Fit the measured time-dependent, accumulated γ-ray intensities ***with appropriate expressions*** based on the exponential decay law.
4) Derive estimates of mean life times for neutron-activated samples.
5) Estimate experimental uncertainties.

6) Discuss briefly the process of neutron activation.
7) Based on characteristic energies of activation γ lines and associated half-lives, identify the final activated sample elements and isotopes.
8) Produce decay schemes for both, Cu and unknown, samples. For each sample, include the decaying parent state, the states of the final daughter isotope and state expected relative probabilities.
9) On the schemes, indicate identified the γ-ray transitions observed.
10) Are all expected lines actually observed, and if not, why not?,

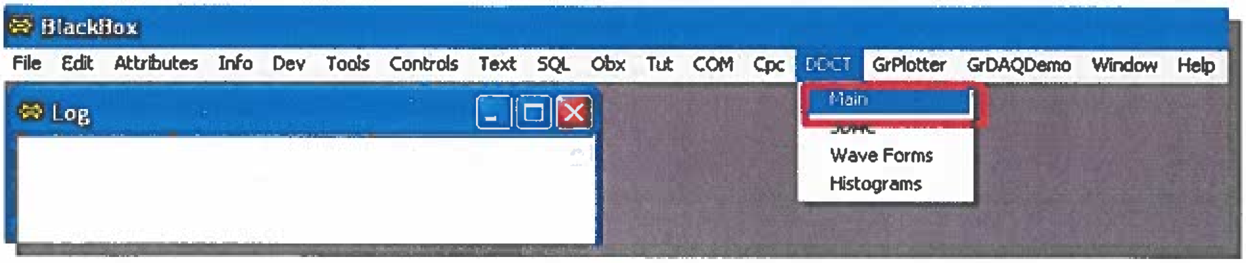
11) Show spectra of neutron activation (NA + Background) γ-rays and the background spectra. Identify the most prominent line structures in all spectra, explain their origin.
12) Compare accumulated activities for ^{64}Cu and unknown NA γ lines to your estimates based on known lifetimes.
13) Determine and discuss the decay and disappearance rates of the NA parent isotopes. For branching decays, determine the partial decay rate of the process leading to the observed isotope.

Experiment	
Oscilloscope Practice, Electronics	Osc
Photon Spectroscopy w. NaI Detectors	NaI
Spectroscopy w. Solid-State Detectors	GeSi
Radiation Measurements w. Gas Detectors	GPC
Coincidence/Imaging Experiments	PET
Interactions of Cosmic Radiation (τ_μ)	Mu
Mössbauer Spectroscopy	MB
Neutron Activation (β-Decay)	NA
Data Acquisition	DAQ
Data Analysis	IGOR
Template Laboratory Report	Rep
Auxiliary Documents	Aux

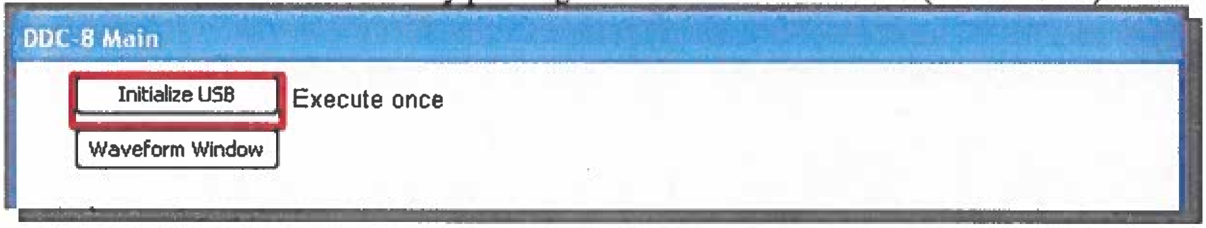
1. Make sure the DDC-8DSP module is connected to the host computer via a USB cable.
2. Power up the module using the rectangular switch on the right side of the module

3. Start up the "BlackBox ANSEL" environment

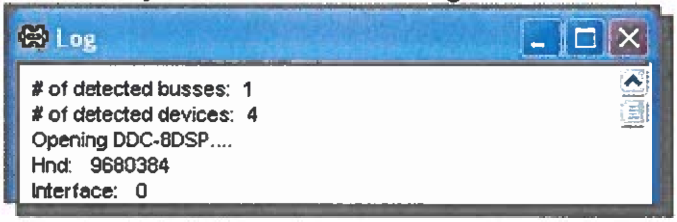
4. Go to " DDCT → Main"



5. Initialize the USB connection by pressing the "Initialize USB" button (execute once)



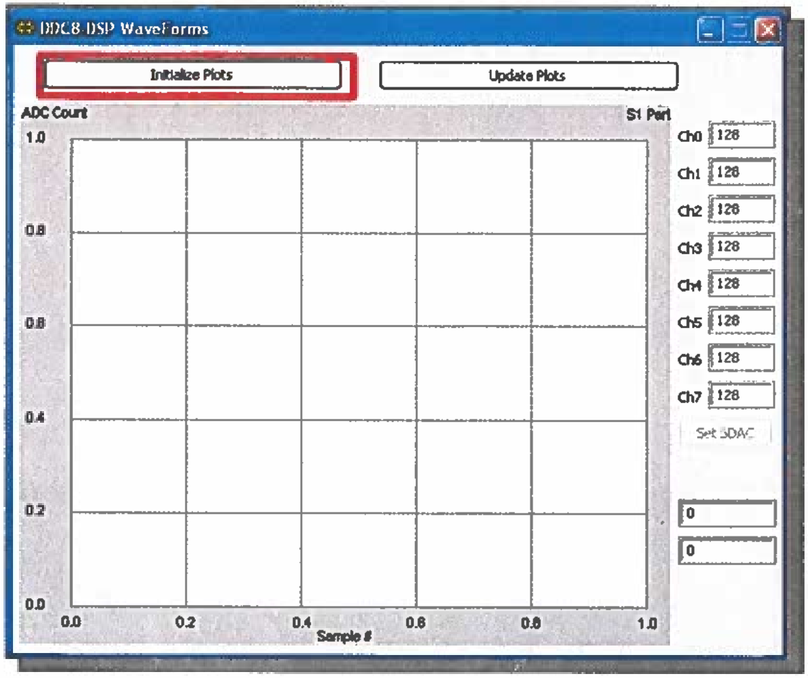
Upon successful connection you should see something like this:



```
# of detected busses:  1
# of detected devices:  4
Opening DDC-8DSP....
Hnd:   9680384
Interface:   0
```

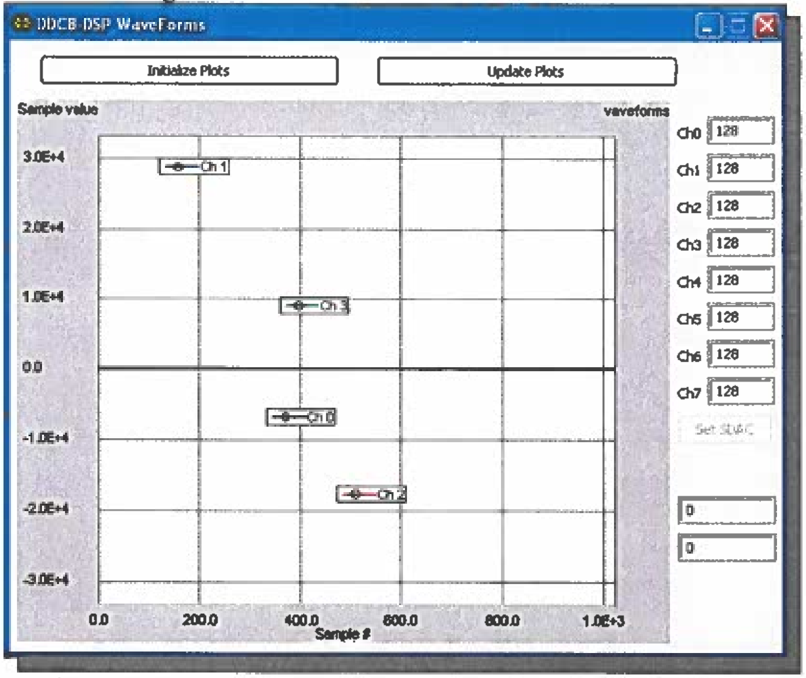
The interface number should be 0 ("zero").

6. Open the “Waveform Window” and “Initialize Plots”



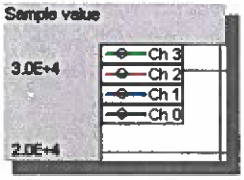
Ch0 128
Ch1 128
Ch2 128
Ch3 128
Ch4 128
Ch5 128
Ch6 128
Ch7 128
0
0

You should see something like this:

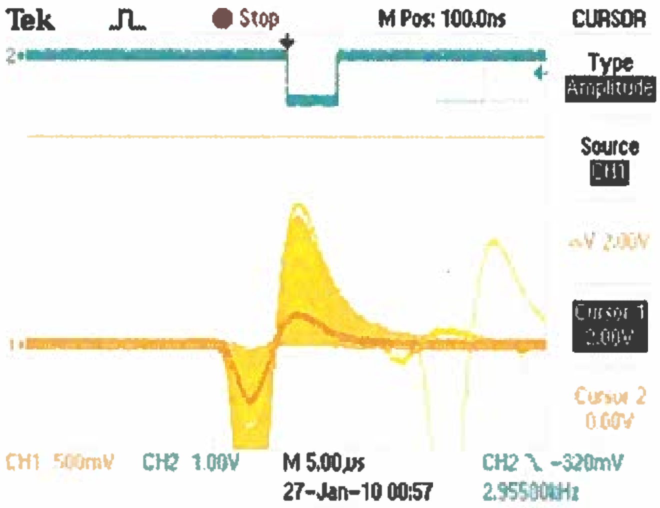


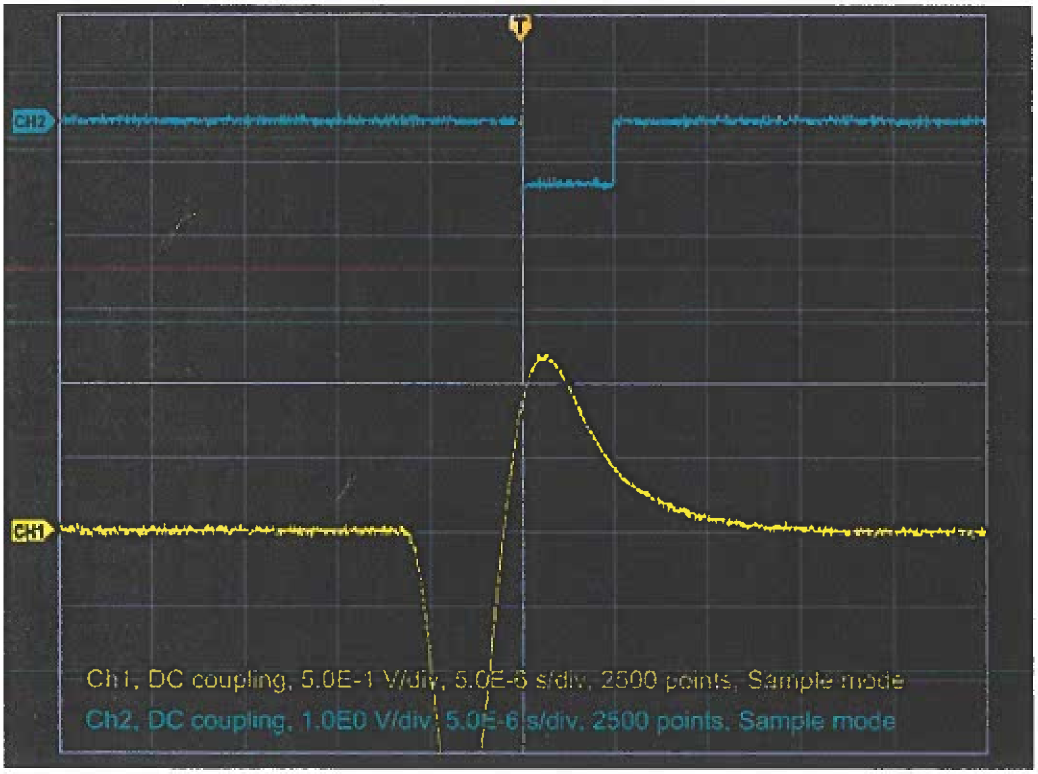
Ch0 128
Ch1 128
Ch2 128
Ch3 128
Ch4 128
Ch5 128
Ch6 128
Ch7 128
0
0

As you can see the channel legends are all over the place. To make it cleaner you can double click with the mouse in the plotting area (white) and you should see the legends align in the left top corner:



7. Make sure using the standalone scope that your trigger signal is aligned with the output of the shaping amplifier. The falling edge of the trigger should arrive before the peak of the pulse coming out of the amplifier. Make sure the amplitude of the signal coming out of the amplifier is not more then 2V. (some pulses will be above 2V but most of them by eye should be bellow)

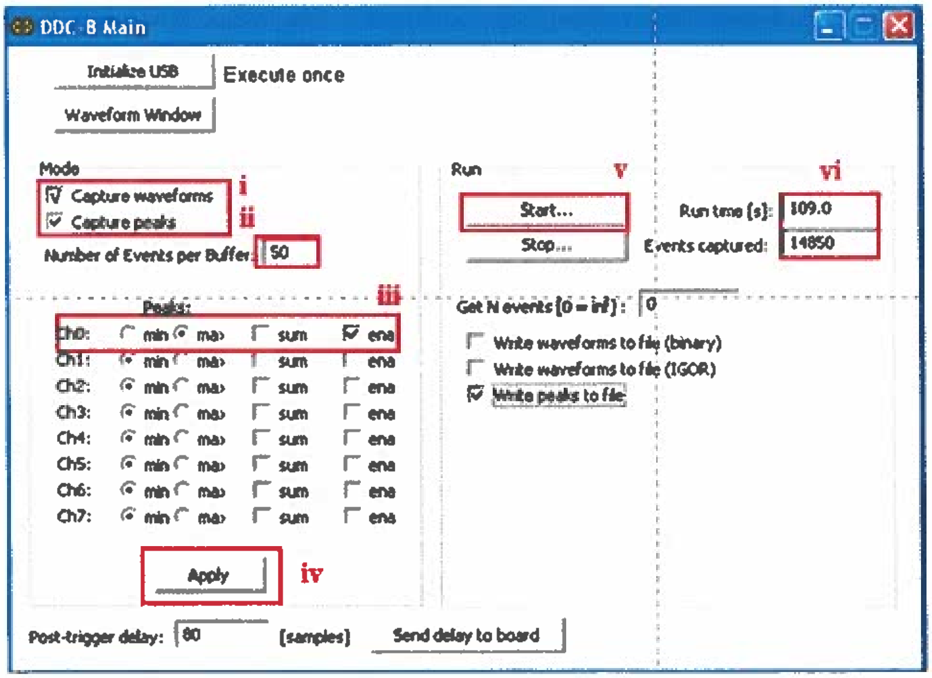




Ch1, DC coupling, 5.0E-1 V/div, 5.0E-6 s/div, 2500 points, Sample mode
Ch2, DC coupling, 1.0E0 V/div, 5.0E-6 s/div, 2500 points, Sample mode

8. Plug the amplifier output to Ch0 of the DDC-8DSP module and the trigger signal into NIM_IN0

9. Now we want to see the waveforms that the board captures and see if it looks ok. Go back to "DDCT → Main" window.
   i. Select "Capture waveforms"
   ii. Select "Capture peaks"
   iii. Set peak detection for Ch0 to "max" - since we will be detecting maximums
   iv. Apply the settings
   v. Start capturing data
   vi. You should see "Run time[s]" and "Events captured" increasing



Mode
☑ Capture waveforms
☑ Capture peaks
Number of Events per Buffer: 50

Run
Run time [s]: 109.0
Events captured: 14850

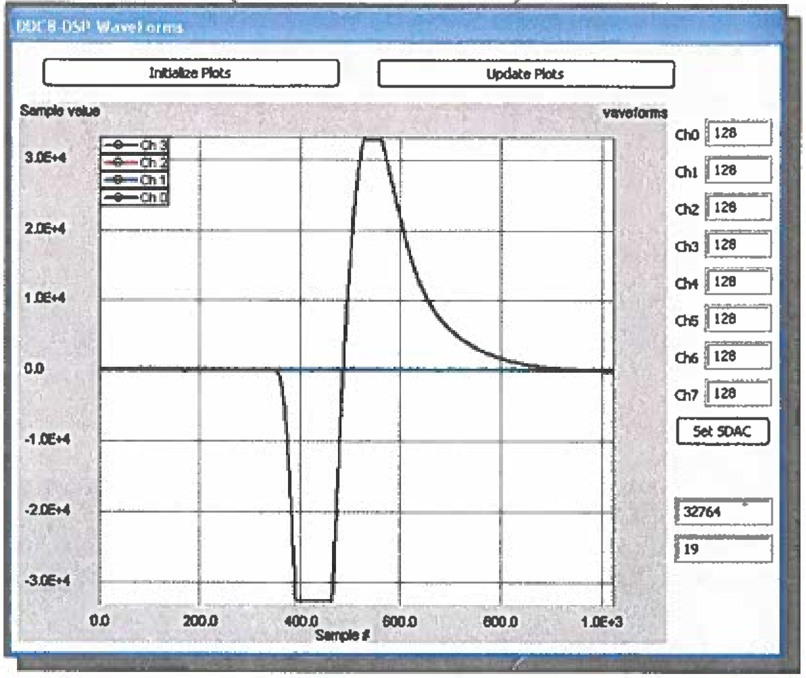
Get N events [0 = inf]: 0
☐ Write waveforms to file (binary)
☐ Write waveforms to file (IGOR)
☑ Write peaks to file

Peaks:

Ch0:	○ min	● max	☐ sum	☑ ena
Ch1:	● min	○ max	☐ sum	☐ ena
Ch2:	● min	○ max	☐ sum	☐ ena
Ch3:	● min	○ max	☐ sum	☐ ena
Ch4:	● min	○ max	☐ sum	☐ ena
Ch5:	● min	○ max	☐ sum	☐ ena
Ch6:	● min	○ max	☐ sum	☐ ena
Ch7:	● min	○ max	☐ sum	☐ ena

Post-trigger delay: 80 [samples]

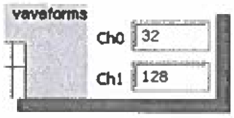
10. Go to the Waveform Window (DDCT → Wave forms). You should see something like this:



Ch0 128
Ch1 128
Ch2 128
Ch3 128
Ch4 128
Ch5 128
Ch6 128
Ch7 128
32764
19

11. The range of the input is +/- 1V and as you can see the signal is clipped. Since we are interested only in the positive part of the pulse we can move the baseline close to the -1V.
    i. Go to DDCT → Main and stop the acquisition

    ii. Go to DDCT → Wave form and set Ch0 offset to 32

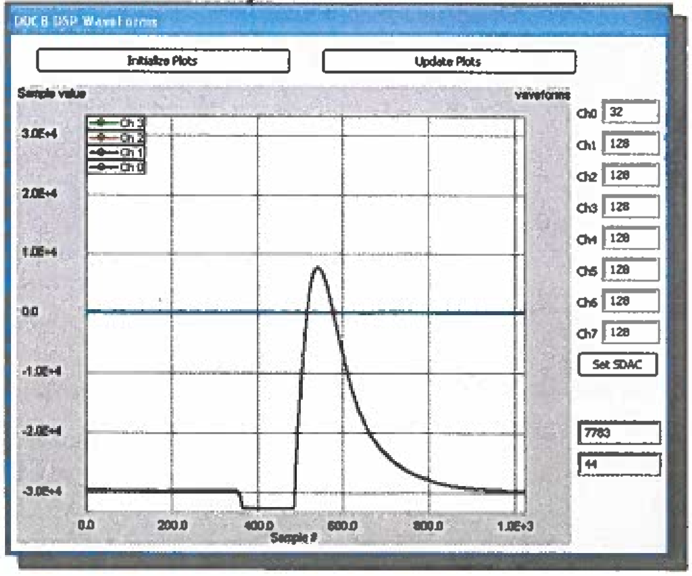


Ch0 32
Ch1 128

    iii. Apply the offset setting

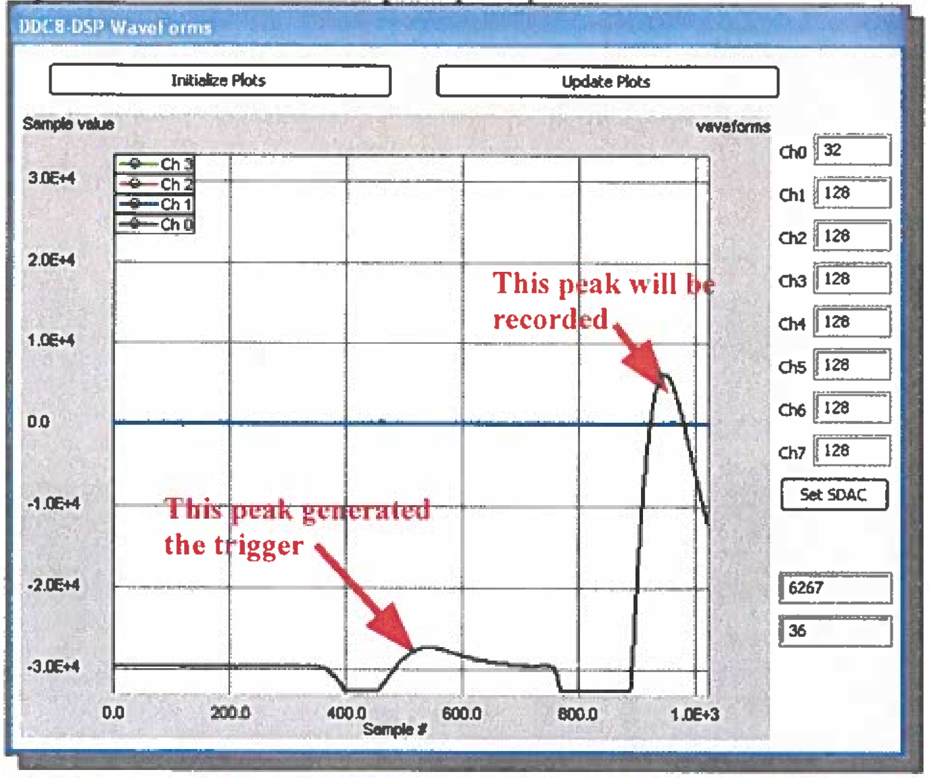
    iv. Go to DDCT → Main and resume (start) the acquisition

    v. Go to DDCT → Wave form and you should see that the waveform in Ch0 is lower:



Ch0 32
Ch1 128
Ch2 128
Ch3 128
Ch4 128
Ch5 128
Ch6 128
Ch7 128
7783
44

12. The next problem is that there can be pulse pile-up:



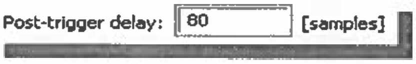
Ch0 32
Ch1 128
Ch2 128
Ch3 128
Ch4 128
Ch5 128
Ch6 128
Ch7 128
6267
36

This peak will be recorded

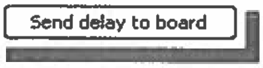
This peak generated the trigger

i. Go to DDCT → Main and stop the acquisition

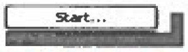
ii. Set the Post-trigger delay to 80.
The Post-trigger delay defines how many samples are scanned/captured past the falling edge of the trigger.

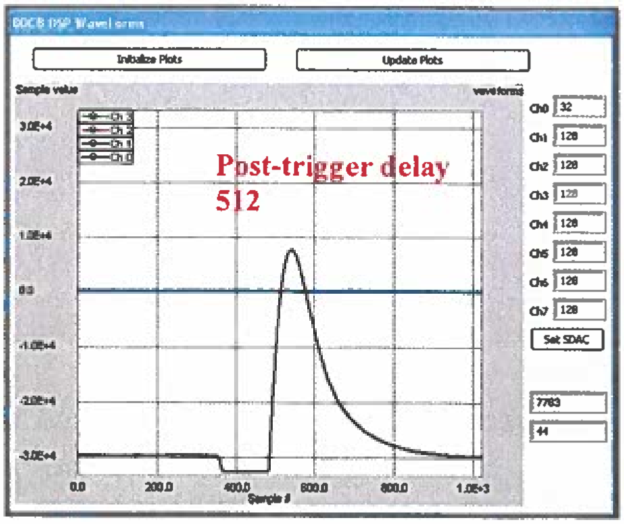

Post-trigger delay: 80 [samples]

iii. Apply the Post-trigger value by pressing



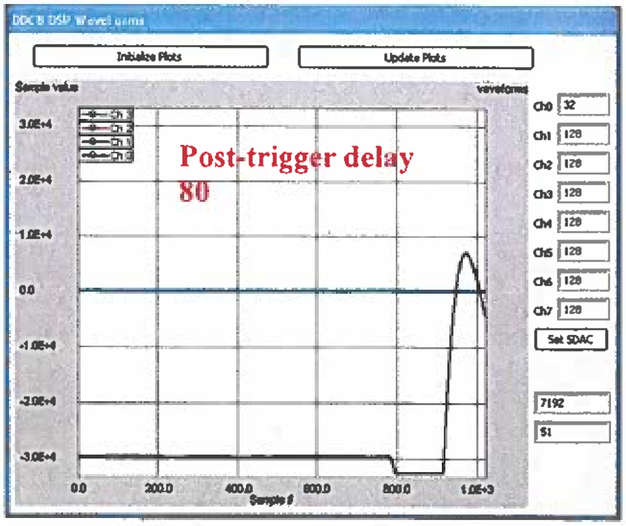
iv. Resume (start) data acquisition





Post-trigger delay 512

Ch0 32
Ch1 128
Ch2 128
Ch3 128
Ch4 128
Ch5 128
Ch6 128
Ch7 128
7783
44

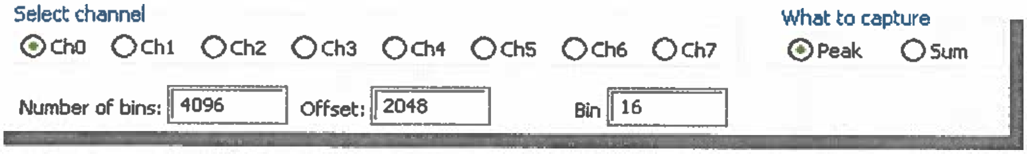


Post-trigger delay 80

Ch0 32
Ch1 128
Ch2 128
Ch3 128
Ch4 128
Ch5 128
Ch6 128
Ch7 128
7192
51

14. Now its time to generate a histogram
    i. Go to DDCT → Main and stop acquisition

    ii. Go to DDCT → Histograms
    iii. Set "Select channel" to Ch0
    iv. Set Number of bins to: 4096
    v. Set Offset to: 2048
    vi. Set Bin to: 16
    vii. Set "What to capture" to "Peak"



Select channel

● Ch0 ○ Ch1 ○ Ch2 ○ Ch3 ○ Ch4 ○ Ch5 ○ Ch6 ○ Ch7

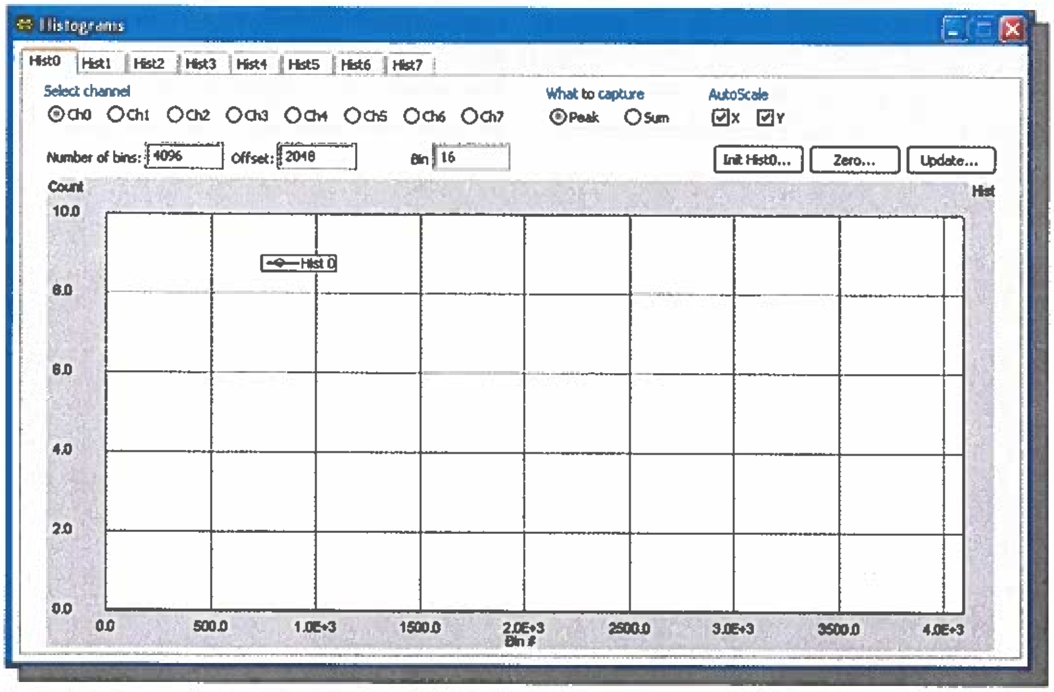
What to capture

● Peak ○ Sum

Number of bins: 4096 Offset: 2048 Bin 16

    viii. Initialize the histogram

    ix. You should see something like:



Select channel

● Ch0 ○ Ch1 ○ Ch2 ○ Ch3 ○ Ch4 ○ Ch5 ○ Ch6 ○ Ch7

What to capture

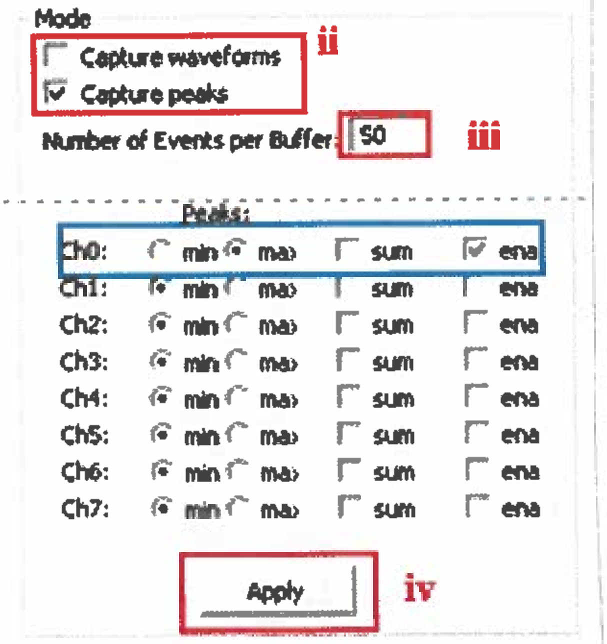
● Peak ○ Sum

AutoScale

☑ X ☑ Y

Number of bins: 4096 Offset: 2048 Bin 16

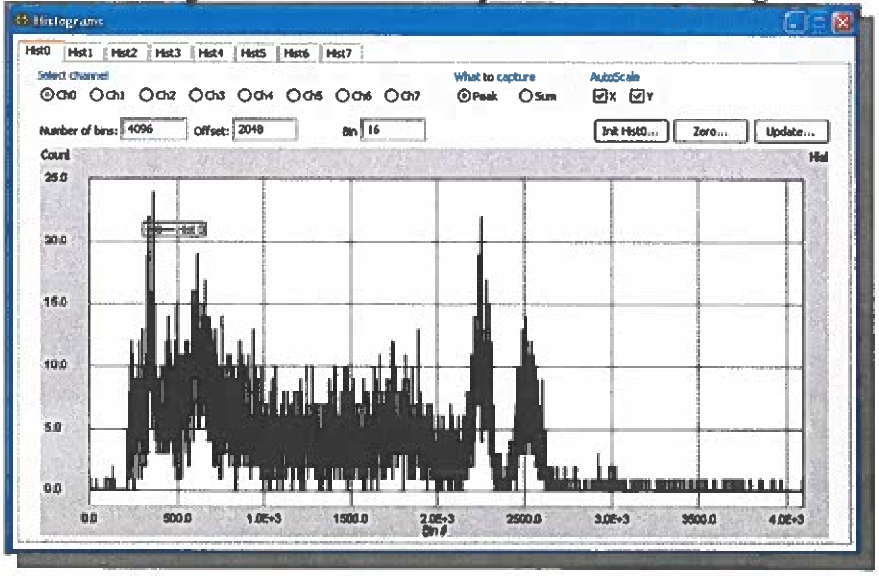
15. To start capturing the peak values at a higher rate with out the waveforms
    i. Go to DDCT → Main
    ii. Un-check the "Capture waveforms"
    iii. Set "Number of Events per Buffer" to 50
    For high rate experiments this value speeds up the acquisition, because in this case the board will be accumulating 50 events and then sending them at once for processing.
    iv. Apply the settings


Mode
☐ Capture waveforms ii
☑ Capture peaks
Number of Events per Buffer: 50 iii

Peaks:
Ch0: ○ min ● max ☐ sum ☑ ena
Ch1: ● min ○ max ☐ sum ☐ ena
Ch2: ● min ○ max ☐ sum ☐ ena
Ch3: ● min ○ max ☐ sum ☐ ena
Ch4: ● min ○ max ☐ sum ☐ ena
Ch5: ● min ○ max ☐ sum ☐ ena
Ch6: ● min ○ max ☐ sum ☐ ena
Ch7: ● min ○ max ☐ sum ☐ ena

iv

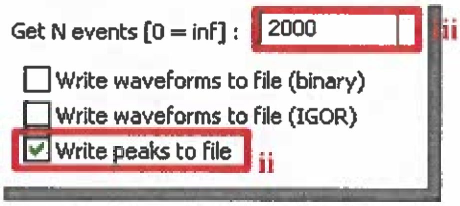
16. To begin collecting peak data and see the histogram being updated
    i. Being in DDCT → Main, start the acquisition
    You should see the "Run Time" increasing and the "Events captured" increasing by number of events per buffer that was set earlier (50).
    ii. Go to DDCT → Histograms and after a while you should see a histogram:



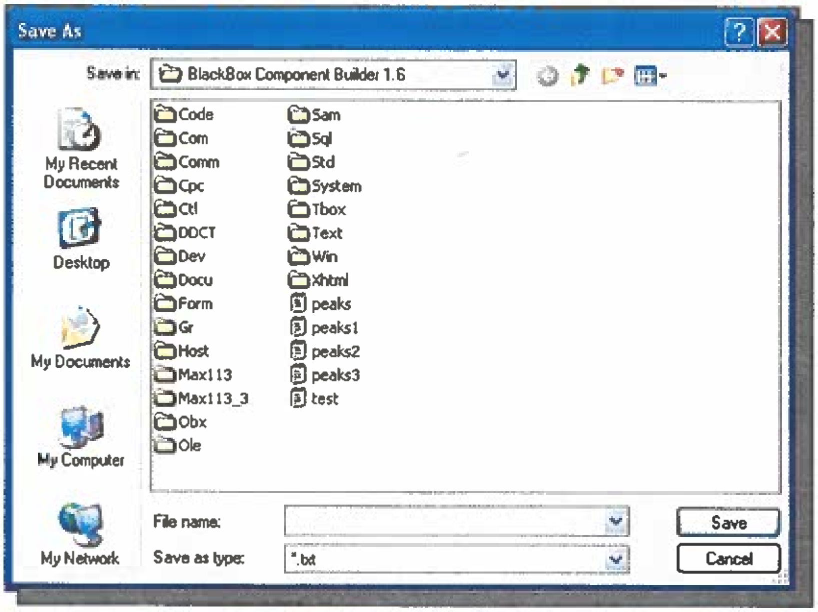
Select channel: ● Ch0 ○ Ch1 ○ Ch2 ○ Ch3 ○ Ch4 ○ Ch5 ○ Ch6 ○ Ch7
What to capture: ● Peak ○ Sum
AutoScale: ☑ X ☑ Y
Number of bins: 4096 Offset: 2048 Bin 16

Co60

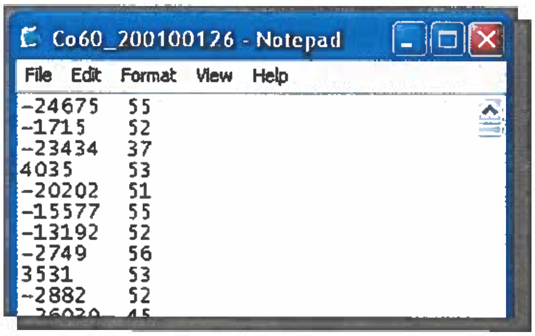
17. Once the histogram you see seems to make sense you want to capture a data set of the peak values for off-line analysis (for example in Igor)
    i. Go to DDCT → Main and stop the acquisition
    ii. Check the "Write peaks to file"
    iii. Set "Get N events" to a desired number of events (probably more like 60000 for a nicer histogram). Should be a multiple of the "Number of Events per Buffer" set earlier.


Get N events [0 = inf] : 2000
☐ Write waveforms to file (binary)
☐ Write waveforms to file (IGOR)
☑ Write peaks to file

    iv. Start the acquisition and you will be asked where to store the file. Input a desired file name and location. Press the "Save" button and the acquisition should star.


Save in: BlackBox Component Builder 1.6
File name:
Save as type: *.txt

    v. After the desired amount of events is captured or when the user stops the acquisition, a file will be generated with the acquired data. The file should contain the peak values found for Ch0 (first column) and Ch1 (second column) which you can use in other program for analysis.



```
-24675  55
-1715   52
-23434  37
4035    53
-20202  51
-15577  55
-13192  52
-2749   56
3531    53
-2882   52
```

DDC-8/BlackBox Quickstart User's Guide

1) Turn on the DDC-8. Wait to hear **3 dings** come from the computer speakers
2) Open up BlackBox and choose **DDCT>Main** from the top menu
3) Begin the initalization procedure
    a. click on Initialize USB (only once!). You should see "**Interface: 0**" in the log window
        i. If you see something else (possibly -5 or -22), close Blackbox, push the button labeled "Reset USB" on the front panel of the DDC-8 (or power-cycle the device)
    b. Open the waveform preview window, click "**Initialize Plots**"
        i. Several flat lines should appear, as well as a legend
        ii. Double click on the plot to auto-arrange the legend
    c. Choose the offsets for each channel with the boxes on the right hand side.
        i. For most cases you will want to input "**32**". This will make the offset approx -0.8V, enabling full scale digitization of ~1.8V pulses.
        ii. Other offsets can be used here (namely if negative [use "**225**"] or Bipolar [use "**128**"] pulses are to be expected.) For now, stick to an offset of "**32**".
4) Inspect the waveform and ensure the DDC-8 is reading the proper signal.
    a. Attach the signal to be measured to **Ch_0** and the trigger signal to **NIM_IN_0** BNC panels
        i. Remember to inspect them in the scope first to ensure they are <2V!
    b. Check the box for "**capture waveforms**"
    c. Choose a value for **# of events/buffer**.
        i. This adjust how often the GUI will update information from the FPGA. **25-50** is sufficient for high count rates. If the events you are recording are sparse, you can bring this down to single digits. Feel free to experiment here!
    d. Set each of the desired Ch#s to **max** and **ena**
    e. Press Apply to save all of the settings adjusted so far.
    f. Adjust the post trigger delay
        i. This lets the DDC-8 know after how many samples (40ns ea.) after the trigger it should stop capturing the waveform. **80** is a good value to start with, but try several values to explore the effect of changing it!
    g. Click "send delay to board".
    h. Click run to see the waveform of the signal. (don't bother saving it)
5) After observing that the waveform is correctly displaying, you want to see a histogram of pulse heights
    a. From the top menu, select **DDCT>Histograms** to display the histogram window
    b. Configure the histogram parameters, then initialize the histogram
        i. Good settings to use are **4096** Bins, **2048** Offset & **16** Bin. These should be the default
    c. This is just for the initial preview, you will be able to re-bin your data in Igor at home
    d. Back in the main menu, Uncheck "**capture waveforms**" and check "**capture peaks**"
        i. ensure that you have set the "**max**" and the "**ena**" of the proper channels, if you indeed want to collect the peak height.
        ii. The device is not fast enough to capture both waveforms and peak heights simultaneously. Keep this in mind
    e. Click "**Apply**", then "**Send Delay to board**" to collect data and **view the histogram**.
6) After ensuring the waveform & histogram are properly displayed, it is time to collect data by checking the "**Write Peaks to File**" box.
    a. You may set a specific # of events to collect for a simple energy spectrum (**60,000 - 120,000** should be sufficient depending on the activity of your source and detector used)
    b. Or you can put "**0**" to stop collection manually.

B.Hmiel 1/17/12, WUS 2020
ANSEL 2012/20

Tips/Troubleshooting:

1) After changing any setting, you need to press "**Apply**", then "**Send delay to board**" before starting data collection. This finalizes the changes in the software, then sends them to the FPGA.

2) Be sure to write down in your logbook the Runtime & # of events collected after each run.
    a. Don't worry if you forget, however, as this information is accessible from the output file.

3) Be sure to save all of your data on the EXPERIMENTAL_DATA partitions on the hard drives. Most of the C: drives will fill up quickly.
    a. This was a common problem in previous years for students. If you data is not saving correctly, be sure to check and make sure the HDD isn't full.

4) Keep an eye on the Log Window. If the machine starts to display "**-5**"'s, there is likely a problem with the connection and its better to power cycle the instrument and reinitialize.

5) Sometimes, you will hear the "ding" of the USB disconnect. This happens occasionally via static discharge or jostling of cables. Power cycle the box & reinitialize to continue

6) If you want to quickly export the histogram from Blackbox, double click on the legend entry for "**Hist_0**" and a window will appear with the bin values in a list. This makes for easy importation into IGOR, but you will want to get used to doing the histograms manually on your own.

7) If you want to adjust the scaling on the histogram to zoom to a particular region, double click on either axis to bring up the menu.
    a. Be sure to uncheck the "**autoscale**" box in order to change the scale of a particular axis.

Experiment	
Oscilloscope Practice, Electronics	**Osc**
Photon Spectroscopy w. NaI Detectors	**NaI**
Spectroscopy w. Solid-State Detectors	**GeSi**
Radiation Measurements w. Gas Detectors	**GPC**
Coincidence/Imaging Experiments	**PET**
Interactions of Cosmic Radiation (τ_μ)	**Mu**
Mössbauer Spectroscopy	**MB**
Neutron Activation (β-Decay)	**NA**
Data Acquisition	**DAQ**
Data Analysis	**IGOR**
Template Laboratory Report	**Rep**
Auxiliary Documents	**Aux**

Introduction to Data Analysis
IGOR Pro

WaveMetrics Igor Pro 6.1
Based on slides by Adi Robinson

Introduction to Igor Pro

Igor Pro is an integrated program for visualizing, analyzing, transforming and presenting experimental data.

Igor Pro's features include:
- Publication-quality graphics
- High-speed data display
- Ability to handle large event-by-event data sets
- Curve-fitting, Fourier transforms, smoothing, statistics, and other data analysis algorithms
- Waveform arithmetic
- Image display and processing
- Combination graphical and command-line user interface
- Automation and data processing via a built-in programming environment
- Extensibility through modules written in the C and C++ languages

Igor Pro - Waves

We use the term “wave” to describe an Igor object that contains an array of numbers. “Wave” is short for “waveform”, a term used in digital signal processing (DSP). The *wave* is the most important Igor concept.

In the context of ANSEL experiments, a typical wave consists of a sequence of numbers describing a series of “events,” for example, the stream of signal amplitudes generated by an operating radiation detector during some period of time.

Igor was originally designed to deal with waveform data. A waveform typically consists of hundreds to thousands of values measured at evenly spaced intervals of time. Such data are usually acquired from a digital oscilloscope, a scientific instrument or an analog-to-digital converter.

Igor Pro – Loading Waves

Most Igor users create “waves” by loading data from a file created by another program. In ANSEL, these original files are produced by the DDC8-Data Acquisition routines.

The process of *loading a file* reserves an array of computer cells and then stores data from the file in these cells.
The waves can contain numeric or text data.

Optionally, one can create a new wave or overwrite an already existing wave.

Igor provides routines for loading files with a number of different data types.

(There is no single universal file format for numeric or text data that all programs can read and write.)

IGOR Pro Manual

Guided Tour of Igor Prc

Chapter I-2 — Guided Tour of Igor Pro

Guided Tour 1 - General Tour

In this exercise, we will generate data in three ways (typing, loading, and synthesizing) and we will generate graph, table, and page layout windows. We will jazz up a graph and a page layout with a little drawing and some text annotation. At the end we will explore some of the more advanced features of Igor Pro.

Launching Igor Pro

The Igor Pro application is typically installed in:

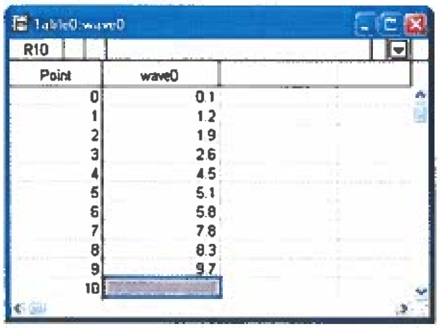
```
/Applications/Igor Pro Folder (Macintosh)

C:\Program Files\WaveMetrics\Igor Pro Folder (Windows 32-bit)

C:\Program Files (x86)\WaveMetrics\Igor Pro Folder (Windows 64-bit)
```

1. **Double-click the Igor Pro application file on your hard disk.**
   On Windows you can also start Igor using the Start menu.
   If Igor was already running, choose the File→New Experiment menu item.
2. **Use the Misc menu to turn preferences off.**
   Turning preferences off ensures that the tour works the same for everyone.

Entering Data

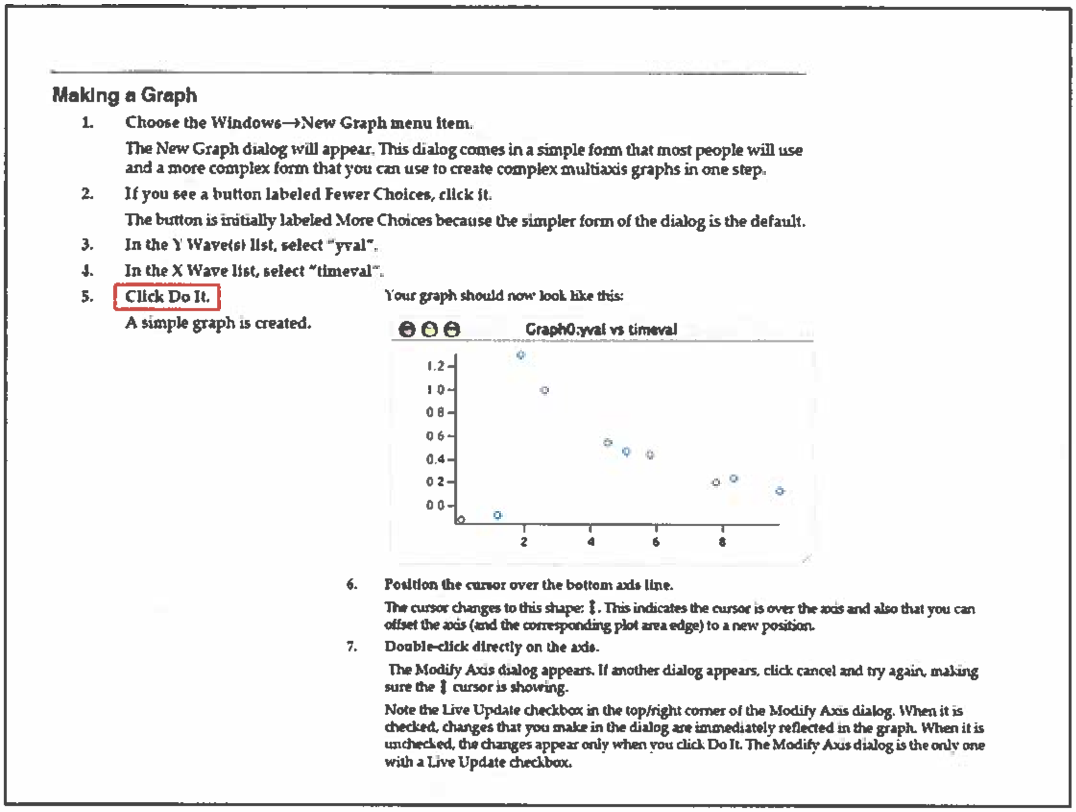
1. **If a table window is showing, click in it to bring it to the front.**
   When Igor starts up, it creates a new blank table unless this feature is turned off in the Miscellaneous Settings dialog. If the table is not showing, perform the following two steps:
   1a. **Choose the Windows→New Table menu item.**
   The New Table dialog appears.
   1b. **Click the Do It button.**
   A new blank table is created.
2. **Type "0.1" and then press Return or Enter on your keyboard.**
   This creates a wave named "wave0" with 0.1 for the first point. Entering a value in the first row (point 0) of the first blank column automatically creates a new wave.
3. **Type the following numbers, pressing Return or Enter after each one:**
   1.2
   1.9
   2.6
   4.5
   5.1
   5.8
   7.8
   8.3
   9.7

Your table should look like this:



Point	wave0
0	0.1
1	1.2
2	1.9
3	2.6
4	4.5
5	5.1
6	5.8
7	7.8
8	8.3
9	9.7
10	

4. **Click in the first cell of the first blank column.**
5. **Enter the following numbers in the same way:**
   -0.12
   -0.08
   1.3
   1
   0.54
   0.47
   0.44
   0.2
   0.24
   0.13
6. **Choose Data→Rename.**
7. **Click "wave0" in the list and then click the arrow icon.**
8. **Replace "wave0" with "time".**
   Notice that you can't use the name "time" because it is the name of a apologize for usurping such a common name.
9. **Change the name to "timeval".**
10. **Select "wave1" from the list, click the arrow icon, and type "yval".**
11. **Click Do It.**



Making a Graph

1. **Choose the Windows→New Graph menu item.**

   The New Graph dialog will appear. This dialog comes in a simple form that most people will use and a more complex form that you can use to create complex multiaxis graphs in one step.

2. **If you see a button labeled Fewer Choices, click it.**

   The button is initially labeled More Choices because the simpler form of the dialog is the default.

3. **In the Y Wave(s) list, select "yval".**
4. **In the X Wave list, select "timeval".**
5. **Click Do It.**

   A simple graph is created.

   Your graph should now look like this:

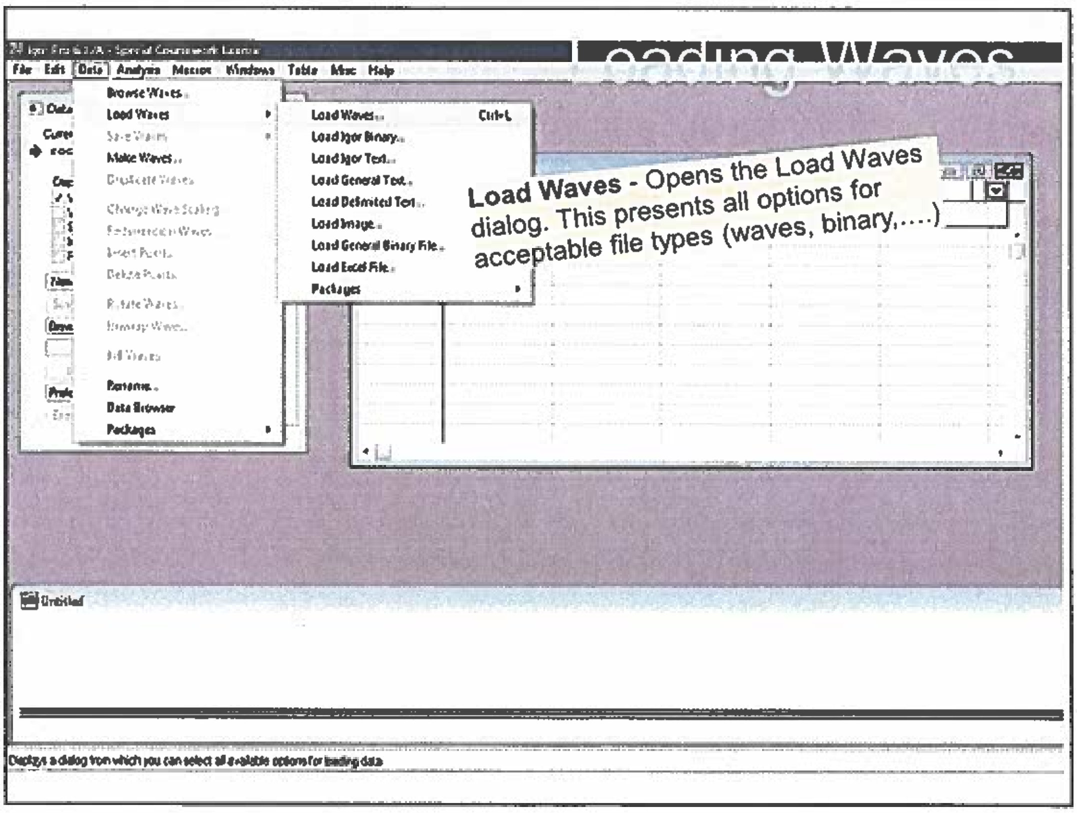
6. **Position the cursor over the bottom axis line.**

   The cursor changes to this shape: ⇕. This indicates the cursor is over the axis and also that you can offset the axis (and the corresponding plot area edge) to a new position.

7. **Double-click directly on the axis.**

   The Modify Axis dialog appears. If another dialog appears, click cancel and try again, making sure the ⇕ cursor is showing.

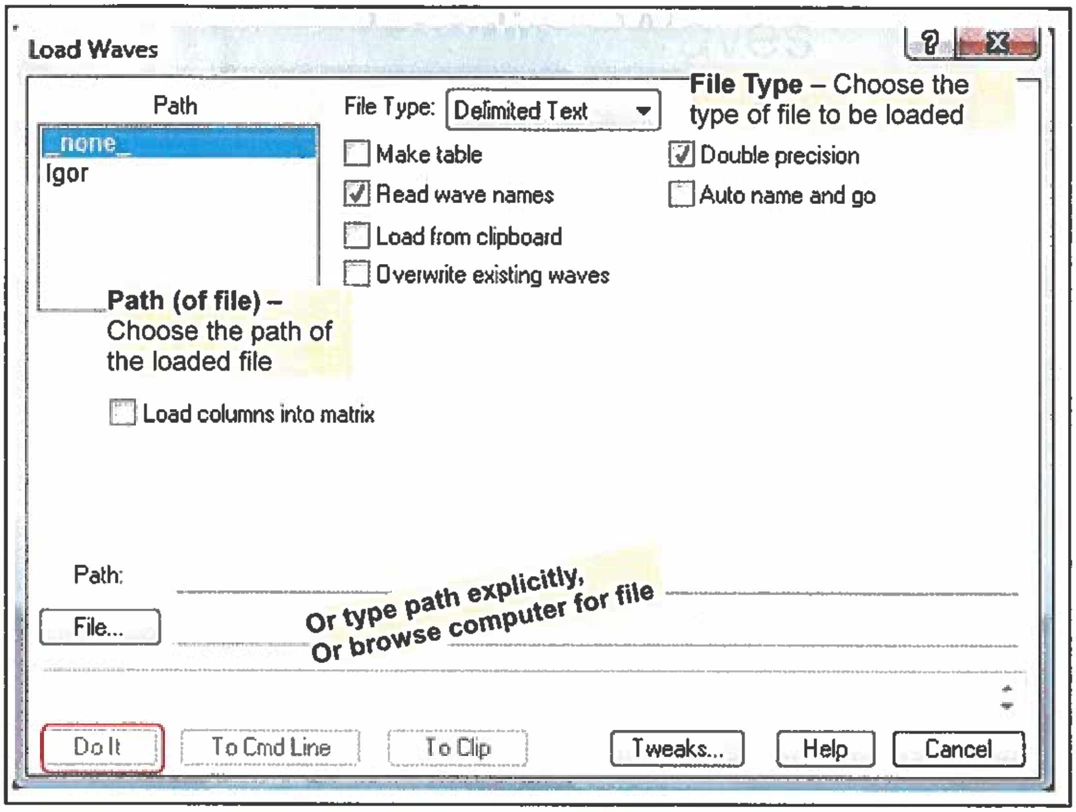
   Note the Live Update checkbox in the top/right corner of the Modify Axis dialog. When it is checked, changes that you make in the dialog are immediately reflected in the graph. When it is unchecked, the changes appear only when you click Do It. The Modify Axis dialog is the only one with a Live Update checkbox.



oading Waves

Load Waves - Opens the Load Waves dialog. This presents all options for acceptable file types (waves, binary,....)

Displays a dialog from which you can select all available options for loading data



none
Igor

File Type: Delimited Text

☐ Make table
☑ Read wave names
☐ Load from clipboard
☐ Overwrite existing waves
☑ Double precision
☐ Auto name and go
☐ Load columns into matrix

File Type – Choose the type of file to be loaded

Path (of file) – Choose the path of the loaded file

Or type path explicitly,
Or browse computer for file

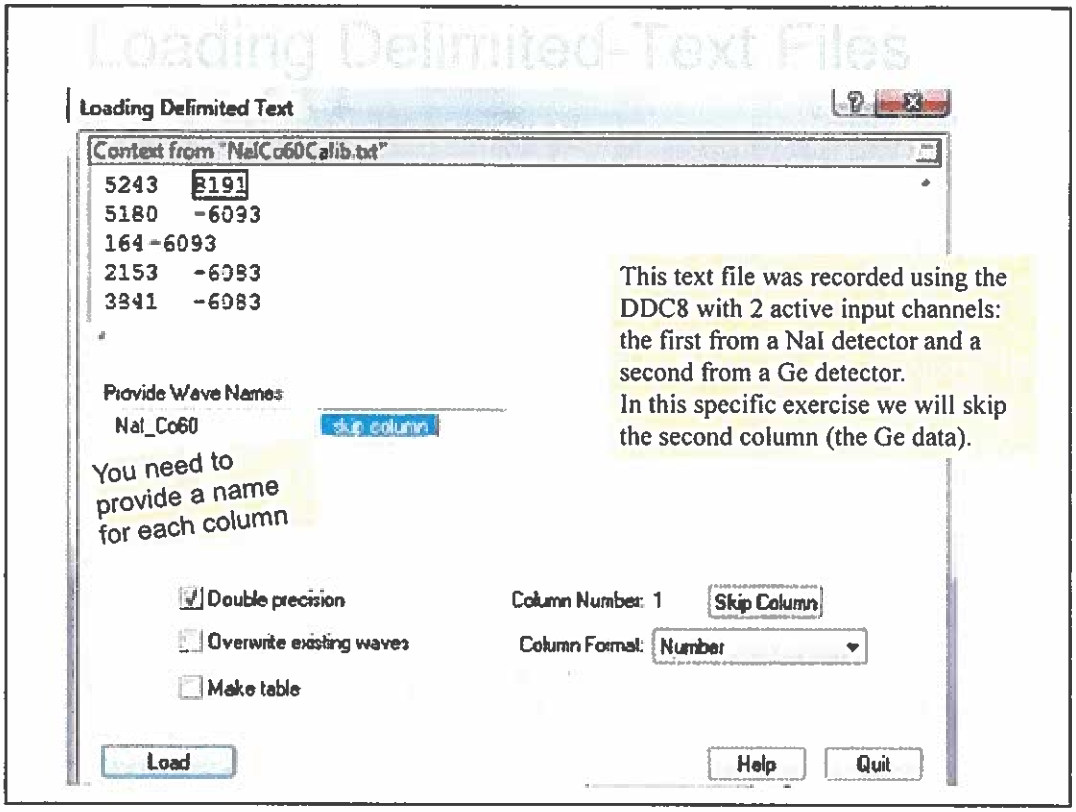
Loading Data

Summary: The basic sequence of actions to load 1D data, encoded as a delimited-text file, into IGOR

1. Bring up the ***Load Waves*** dialog.
2. Choose ***Delimited Text*** from the File Type pop-up menu.
3. Click the ***File*** button to select the file containing the data.
4. Click ***Do It***.

When you click *Do It*, the *Load Wave* operation runs. It executes the *Load Delimited Text* routine.

Loading Delimited-Text Files



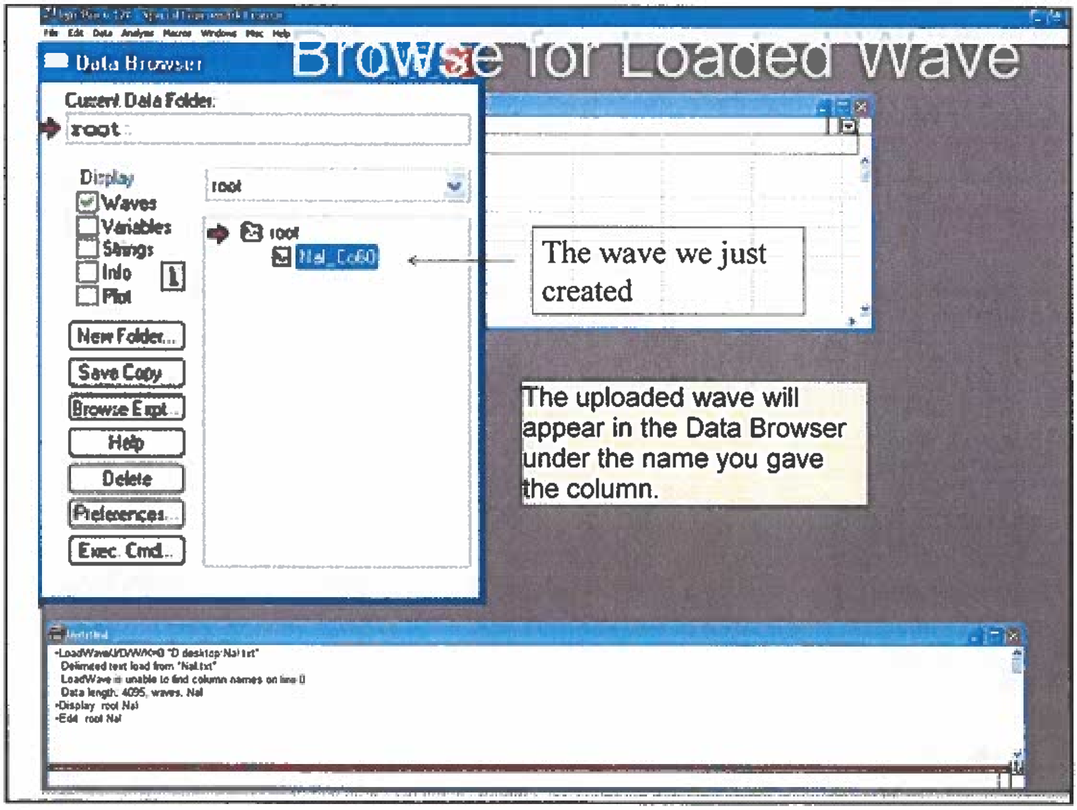
```
5243   8191
5180   -6093
164 -6093
2153   -6083
3841   -6083
```

Nal_Co60

You need to provide a name for each column

This text file was recorded using the DDC8 with 2 active input channels: the first from a NaI detector and a second from a Ge detector.
In this specific exercise we will skip the second column (the Ge data).

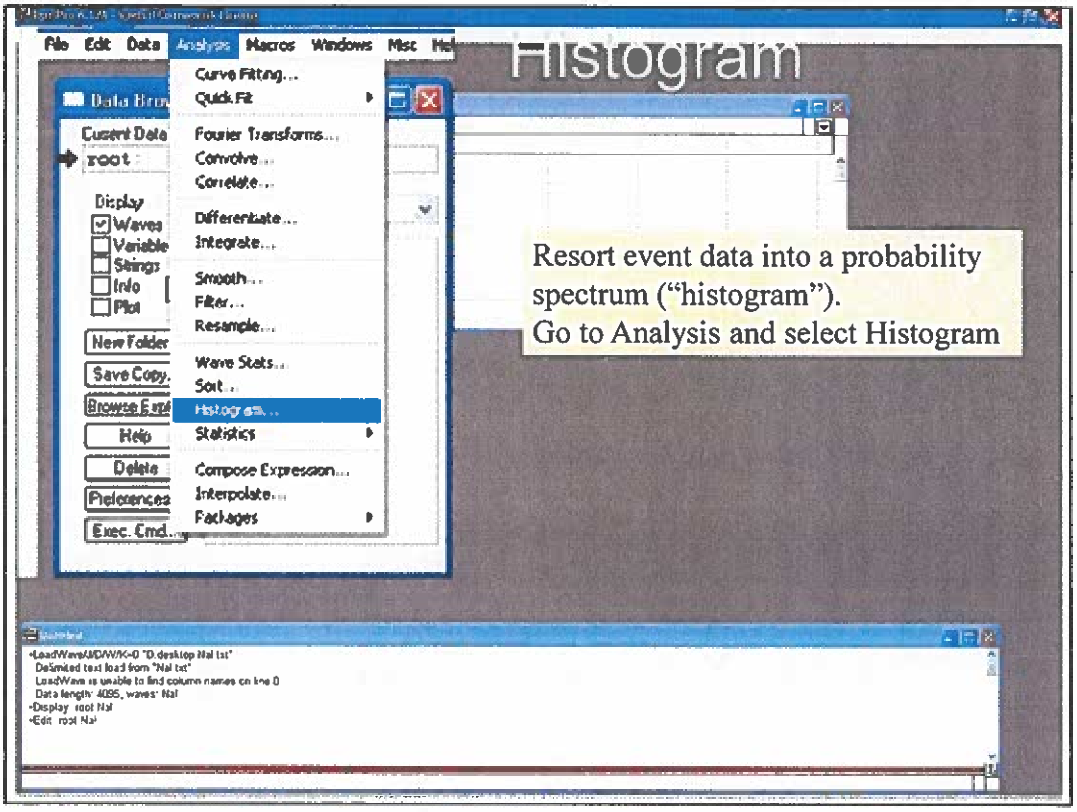
Browse for Loaded Wave



The wave we just created

The uploaded wave will appear in the Data Browser under the name you gave the column.

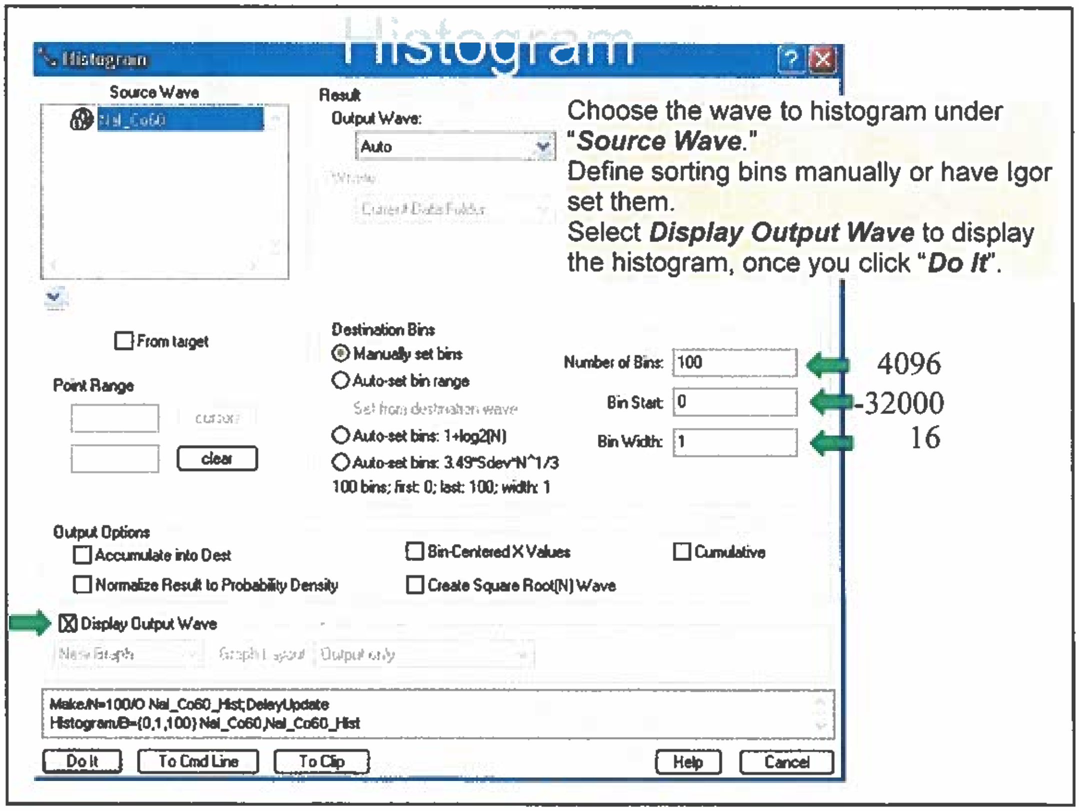
```
•LoadWave/J/D/W/K=0 "D:desktop:NaI.txt"
  Delimited text load from "NaI.txt"
  LoadWave is unable to find column names on line 0
  Data length: 4095, waves: NaI
•Display  root:NaI
•Edit  root:NaI
```



Histogram

Resort event data into a probability spectrum (“histogram”).
Go to Analysis and select Histogram

```
•LoadWave/J/D/W/K=0 "D:desktop:NaI.txt"
  Delimited text load from "NaI.txt"
  LoadWave is unable to find column names on line 0
  Data length: 4096, waves: NaI
•Display  root:NaI
•Edit  root:NaI
```



Histogram

Choose the wave to histogram under "***Source Wave***."
Define sorting bins manually or have Igor set them.
Select ***Display Output Wave*** to display the histogram, once you click "***Do It***".

● Manually set bins
○ Auto-set bin range
○ Auto-set bins: 1+log2(N)
○ Auto-set bins: 3.49*Sdev*N^1/3
100 bins; first: 0; last: 100; width: 1

Number of Bins: 100 ← 4096
Bin Start: 0 ← -32000
Bin Width: 1 ← 16

☐ Accumulate into Dest
☐ Normalize Result to Probability Density
☐ Bin-Centered X Values
☐ Create Square Root(N) Wave
☐ Cumulative
☒ Display Output Wave

```
Make/N=100/O NaI_Co60_Hist;DelayUpdate
Histogram/B={0,1,100} NaI_Co60,NaI_Co60_Hist
```

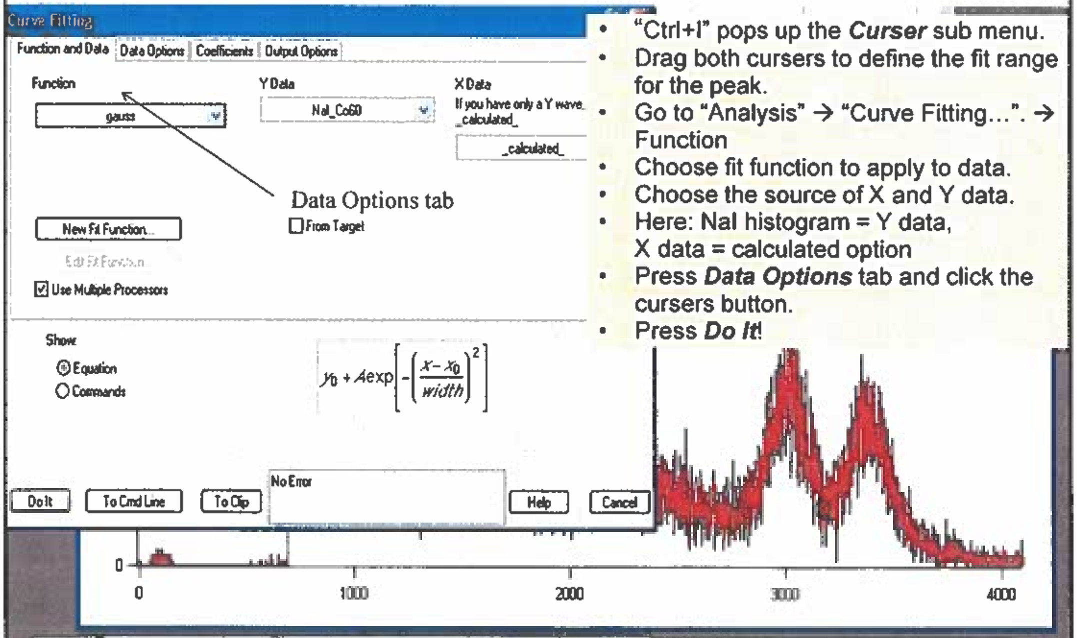
Displaying and Editing Histograms

- If you chose not to display the histogram from the histogram menu, you can right click the histogram name and click display.

- Once a histogram is displayed you can edit the figure.
- Double clicking on one of the axes pops up the "Modify Axis" menu.
- You can set the range of each axis, label them and do other fancy things.

- Right clicking the middle of the figure pops a menu that lets you append traces to the graph, add an annotation and edit other features of the figure.

Analysis – Fitting a Curve to Data



- "Ctrl+I" pops up the ***Curser*** sub menu.
- Drag both cursers to define the fit range for the peak.
- Go to "Analysis" → "Curve Fitting…". → Function
- Choose fit function to apply to data.
- Choose the source of X and Y data.
- Here: NaI histogram = Y data, X data = calculated option
- Press ***Data Options*** tab and click the cursers button.
- Press ***Do It***!

A fit trace should appear in the range between the cursers. The command box below shows values of each parameter and its error.

User Defined Functions

A user-defined procedure is a routine written in Igor's built-in programming language by entering text in a procedure window. It can call upon built-in or external functions and operations as well as other user defined procedures to manipulate Igor objects. Sets of procedures are stored in procedure files.

Igor uses a combination of the familiar graphical user interface and a command-line interface. This approach gives Igor both ease-of-use and programmability. The job of the user interface is to allow you to apply Igor's operations and functions to objects that you create. You can do this in three ways:

- Via menus and dialogs
- By typing Igor commands directly into the command line
- By writing Igor procedures

User Defined Functions - Example

Type in the procedure window the following:

```
FUNCTION FitGauss (wav, from,to)
VARIABLE from,to
WAVE wav
   CurveFit/Q gauss wav(from,to) /D
   VARIABLE PeakPos, sig, FWHM, PeakArea
   WAVE W_Coef = W_Coef
   PeakPos = W_Coef[2]
   FWHM = W_Coef[3]*2*sqrt(ln(2))
   sig  = W_Coef[3] / sqrt(2)
   PRINT "  pos, sigma, fwhm =", PeakPos, sig, FWHM, "
   DC pedestal=", W_Woef[0]
END
```

User Defined Gaussian Fit

- After compiling the user defined function, you can again place the cursers in the peak range you want to fit.
- Type "FitGauss (name of the fitted wave, xcsr(A), xcsr(B))" in the command bar in the command window.
- After you press enter the command window will process the fit and give you the position of the peak (pos), the width of the peak (sigma) and the full width at half maximum (FWHM).
- The user and create all sorts of function to assist him or hers analysis such as multiple gaussian fits, linear fits and more.

Experiment	
Oscilloscope Practice, Electronics	Osc
Photon Spectroscopy w. NaI Detectors	NaI
Spectroscopy w. Solid-State Detectors	GeSi
Radiation Measurements w. Gas Detectors	GPC
Coincidence/Imaging Experiments	PET
Interactions of Cosmic Radiation (τ_μ)	Mu
Mössbauer Spectroscopy	MB
Neutron Activation (β-Decay)	NA
Data Acquisition	DAQ
Data Analysis	IGOR
Template Laboratory Report	Rep
Auxiliary Documents	Aux

ANSEL Report: Tests with analog and digital nuclear electronics

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(Experiment performed 01/25/2018 – 2/5/2018, Report submitted 2/28/2018)

Abstract

The first ANSEL experiment entailed hands-on tests of the functionalities of a digital oscilloscope and of various NIM electronic modules to be used in subsequent experiments. The response of a radiation detector was simulated with precision pulse generators and processed with main amplifiers. Discriminators were used to produce digital signals employed to set up trigger logics for the data acquisition system. The linearity of the analog circuitry, tested with a pulse generator, was found to be better than 1%.

1. Introduction (Motivation/Purpose)

The tasks given for the first ANSEL experiments are designed to practice basic operations of digital oscilloscopes, as well as analog and digital electronics. The object was to practice spectroscopic applications for the subsequent experiments with gamma and charged-particle radiation detectors. Digital electronics is needed to define acceptance criteria and to produce signals to trigger the data acquisition system. The system was to be tested with a pulser calibration.

2. Experimental setup and procedures

For the first task with analog electronic modules, a low-amplitude pulser signal was generated using an ORTEC 419 precision pulse generator. Figure 1 illustrates the typical shape of the direct pulser output signal observed on the oscilloscope. Its amplitude is ...V, and it has a decay time constant of 2μs. This pulse was obtained with the pulser settings ....

Next, the pulser signal was inserted into an ORTEC 572 (?) Spectroscopy Amplifier. The amplifier to lowest coarse (x..) and fine gains (x...). Input polarity was set to.... As shown by the screen shot in Fig.2, the amplifier output signal shape was less than ideal ....It also showed a DC base line offset of 45 mV, which was cor-rected to less than 2 mV by activating the base line re-storer (Automatic BLR).

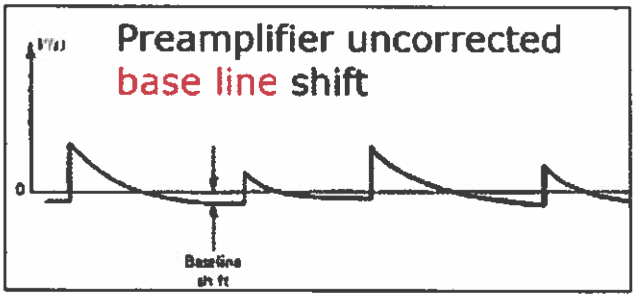

Figure 1: Output pulse shape of an ORTEC 419 precision pulse generator (Scope screen shot). The scales are ..V/division and ...μs/division, resp.

....base line restorer toggle switch (BLR) to automatic .... The ORTEC 419 pulse generator allows one to adjust the output signal shape by adjusting various front panel controls, including rise and fall time, in addition to pulse amplitude and frequency. Table 1 lists the corresponding parameters read off the scope display and compares them to the control settings. Rise times were varied between .... and ...., fall times from .... to......

Following tests of the behavior of analog electronic modules, the experiment was set up to generate a logical circuitry. First, a digital NIM signal was produced by inserting the .....output signal into a fast leading-edge discriminator. The term "leading edge" implies that ...... The discriminator used (Type ...) has two modes of operation, an integral, lower level threshold, and a differential window (single-channel) mode. Figure 3, taken from Ref 2 illustrates the two functions....... In the integral mode,...In the differential mode,......

Table 1: ORTEC 419 Pulse Shape Parameters

The discriminator output signals were duplicated with a Fan-In/Fan-Out module. One of the latter signals were used to produce a wider "gate" signal, the other was fed into a Delay Generator (Type) producing a copy of the input signal but delayed by an adjustable time delay. The gate signal had a width of ....., the delayed signal had a width of only ...ns. Undelayed gate and delayed NIM signals were put into a Universal Coincidence Module (Type) to test coincidence and anticoincidence modes. The setup is represented by the schematic electronics block diagram shown in Fig. 4, which also includes the analog part of the electronics.

In the tests, the delayed signal....... The resulting coincidence resolution time turned out, as expected, to be equal to ...., i.e., equal to .. A similar test was done using the Veto input of the .....

3. Data Analysis

Describe the results of the various phases of the experiments, as far as a data reduction was done. Include a discussion of statistical and systematic uncertainties.

....

The approximate pulser signal shape U(t) was observed to have an analytical form given by

$$U(t) = U_0 \cdot t^a \cdot \exp\{-\beta \cdot t\} \qquad (1)$$

Approximate fit parameters are listed in Table 1, together with their estimated uncertainties.

The results of the "pulser fence" measurement described in the previous section are displayed in Fig. 5 where the counts/bin or channel are plotted vs. bin or channel number. The corresponding correlation between input signal amplitude (S) in V and channel number (Ch) is displayed in Fig. 6 as solid dots. The straight line drawn through the data points represents a calibration of the abscissa in volts,

$$S(Ch) = S_0 + DS \cdot Ch \qquad (2)$$

4. Summary of Results and Conclusions

Overall, the first experiments with analog and digital electronics worked out well. All modules used were in working order and functioned as described in the manual. Understanding and using the data acquisition system efficiently will probably require some more practice but the quick start sheet was sufficiently detailed to allow a simple setup and running. ……..

The main lessons taken away from these experiments can be summarized as follows:

1)

2)

…

References

1. Glenn F. Knoll, *Radiation Detection and Measurement,* Wiley & Son, 2000, Ch. 16.
2. W. U. Schroeder, ANSEL Lecture Notes, Lect 3, 2018
3. ……
4. ……

Experiment	
Oscilloscope Practice, Electronics	**Osc**
Photon Spectroscopy w. NaI Detectors	**NaI**
Spectroscopy w. Solid-State Detectors	**GeSi**
Radiation Measurements w. Gas Detectors	**GPC**
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Neutron Activation (β-Decay)	**NA**
Data Acquisition	**DAQ**
Data Analysis	**IGOR**
Template Laboratory Report	**Rep**
Auxiliary Documents	**Aux**

Gamma Energy (KeV)	Nuclide	Half-Life	Percent Yield per decay
8	Er-169	9.4 days	0.3
22	Sm-151	87 years	4
24	Sn-199m	250 days	16
30	Ba-140	12.8 days	11
31	Mg-28	21 hours	96
35	I-125	60 days	7
35	Te-125m	58 days	7
37	Br-80m	4.38 hours	36
40	Rh-103m	57 minutes	0.4
40	I-129	1.7x10^7 years	9
47	Pb-210	21 years	4
51	Rh-104m	4.41 minutes	47
53	Te-132	78 hours	17
58	Gd-159	18.0 hours	3
58	Dy-159	144 days	4
59	Te-127m	109 days	0.19
60	Am-241	458 years	36
63	Yb-169	32 days	45
63	Th-234	24.1 days	3.5
68	Ta-182	115 days	42
68	Ti-44	48 hours	90
70	Sm-153	47 hours	5.4
77	Pt-197	18 hours	20
77	Hg-197	65 hours	18
78	Ti-44	48 hours	98
80	Ba-133	10.51 years	36
81	Ho-166	26.9 hours	5.4
81	Xe-133	5.27 days	37
84	Tm-170	130 days	3.3
84	Th-228	1.90 years	1.6
87	Eu-155	1.81 years	32
88	Pd-109 / Ag-109m	13.47 hours / 40 seconds	5
88	Cd-109 / Ag-109m	453 days / 40 seconds	5
88	Lu-176m	3.7 hours	10
91	Nd-147	11.1 days	28
93	Th-234	24.1 days	4
95	Dy-165	139.2 minutes	4
99	Gd-153	242 days	55
99	Au-195	183 days	10
100	Pa-234	6.75 hours	50
103	Sm-153	47 hours	28
104	Sm-155	23 minutes	73
105	Eu-155	1.81 years	20
113	Lu-177	6.7 days	2.8
122	Co-57	270 days	87
122	Eu-152	12 years	37
123	Eu-154	16 years	38
124	Ba-131	12 days	28
128	Cs-134m	2.9 hours	14
129	Os-191	15 days	25
133	Hf-181	42.5 days	48
134	Ce-144	284 days	11
136	Hg-197m	24 hours	42

344	Eu-152	12 years	27
351	Bi-211	2.15 minutes	14
352	Pb-214	26.8 minutes	36
356	Ba-133	10.51 years	69
360	Se-83	25 minutes	69
362	Pd-103	17 days	0.06
363	Gd-159	18.0 hours	9
364	I-131	8.05 days	82
368	Ni-65	2.56 hours	4.5
388	Sr-87m	2.83 hours	80
393	Sn-113	115 days	64
393	In-133m	100 minutes	64
403	Kr-87	76 minutes	84
405	Pb-211	36.1 minutes	3.4
412	Au-198	2.698 days	95
427	Sb-125	2.7 years	31
439	Zn-69m	13.8 hours	95
Gamma Energy (KeV)	**Nuclide**	**Half-Life**	**Percent Yield per decay**
441	I-128	25.0 minutes	14
444	Hf-180m	5.5 hours	80
468	Ir-192	74.2 days	49
477	Be-7	53 days	10.3
479	W-187	23.9 hours	23
482	Hf-181	42.5 hours	81
487	La-140	40.22 hours	40
490	Cd-115	53.5 hours	10
496	Ba-131	12 days	48
497	Ru-103	39.6 days	88
511	Cu-64	12.8 hours	38
511	Ga-68	68.3 minutes	176
511	As-74	17.9 days	59
511.0034	Na-22	2.60 years	180
512	Ru-106 / Rh-106	367 days / 30 seconds	21
514	Sr-85	64 days	100
514	Kr-85	10.76 years	0.41
520	Se083	25 minutes	59
527	Xe-135m	15.6 minutes	80
530	I-133	21 hours	90
530	Cd-115	53.5 hours	26
533	Nd-147	11.1 days	13
537	Ba-140	12.8 days	34
538	I-130	12.4 hours	99
554	Br-82	35.34 hours	66
559	As-76	26.5 hours	43
564	Sb-122	67 hours	66
570	Bi-207	30 years	98
583	Tl-208	3.10 minutes	86
Gamma Energy (KeV)	**Nuclide**	**Half-Life**	**Percent Yield per decay**
596	As-74	17.9 days	61
599	Sb-125	2.7 years	24
603	Sb-125	60 days	97
605	Cs-134	2.05 years	98
609	Bi-214	19.7 minutes	47
619	Br-82	35.34 hours	41
622	Ru-106 / Rh-106	367 days / 30 seconds	11

1293	Ar-41	1.83 hours	99
1308	Ca-47	4.53 days	74
1332.5	Co-60	5.26 years	100
1350	Mg-28	21 hours	70
1369	Na-24	15.0 hours	100
1380	Ho-166	26.9 minutes	0.9
1408	Eu-152	12 years	22
1426	Cs-138	32.2 minutes	73
1434	V-52	3.76 minutes	100
1460	K-40	1.29×10^9 years	11
1481	Ni-65	2.56 hours	25
1524	K-42	12.4 hours	18
1570	Pr-142	19.2 hours	3.7
1596	La-140	40.22 hours	96
1600	Cl-38	37.3 minutes	38
1692	Sb-124	60 days	50
1764	Bi-214	19.7 minutes	17
1780	Al-28	2.31 minutes	100
1811	Mn-56	2.58 hours	29
2614	Tl-208	3.10 minutes	100
2754	Na-24	15.0 hours	100
6130	N-16	7.2 seconds	69
7110	N-16	7.2 seconds	5