Nuclear Physics: Lab II
Single Channel Analyzer (SCA)

Purpose: To investigate the operation of a single channel analyzer and use it to determine the pulse height spectrum from a $^{137}$Cs source (0.662 MeV $\gamma$-ray).

Part I: Understanding the signal processing system using a pulsar input

Setting up the electronics: Our system consists of a pulser to generate signals, an amplifier, the SCA and a scaler. To set up the system, make the following connections. The output of the Ortec pulser goes into the Harshaw amplifier. Use the ATTENUATED output on the pulser. The amplifier output goes to the Harshaw SCA (analyzer), and from there to the Ortec scaler (timer/counter). Note that there is an input and an output connector on both the front and back panels of the amplifier and the SCA. There is an input connector on the front panel and back panel of the scaler. The cable from the SCA can go either to the POSITIVE input connector (under the COUNTER INPUT label) on the front panel or the POSITIVE connector on the back. The back panel connectors on the amplifier and SCA can be used for connecting one unit to another while the front connectors can be used for connecting the oscilloscope. The oscilloscope is used to look at pulses at any point in the system. You should have sketches of the pulses at each point in the system.

Set the middle and right slide switches on the pulse generator to the up position. Sliding the left switch up will produce pulses at the rate of 60 per sec. (The down position of that switch is not used.) Be sure to turn the pulser off when it is not being used. The pulses from the pulse generator should be less than 50 millivolts when the PULSE HEIGHT dial is set at 10. (Setting the 2X, 2X, and 5X switches up and the two 10X switches down works well. It will give an output of about 40 mV when the PULSE HEIGHT dial is set at 10 and the pulser is not connected to the amplifier. You may need to adjust the NORMALIZE dial to get this voltage. The pulse output drops to about 35 mV when connection to the amplifier is made.) Use the oscilloscope to look at the pulses from the pulse generator output. You should find that the pulses are positive-going with a very fast rise time and a fall off of about one millisecond.

Set the pulse generator PULSE HEIGHT dial at 10. For the amplifier, set the coarse gain at 320, the fine gain about mid range, the upper switch to up (NON INV) and the lower switch to down (positive and negative going output pulses). With the oscilloscope, look at the pulses from the output of the amplifier (these pulses are very narrow and aligned with the left edge of the pulser pulse). Adjust the pulse generator NORMALIZE dial so that the amplifier output pulses are 10 volts. (Ignore the undershoot following the positive-going pulse.) Once this adjustment has been made, the amplitude of the pulses to the SCA can be varied from 0 to 10 volts with the PULSE HEIGHT dial on the pulse generator.

Measurements and observations: The window level of the SCA is adjusted with the E dial and the window width is set with the $\Delta E$ dial when the SCA is in differential mode. (Integral mode means that all pulses above the E dial level setting will generate output pulses.) Use the oscilloscope to observe the output pulses from the SCA. How do they change as the voltage of your input signal varies? With the E dial set somewhere in the mid range, the $\Delta E$ dial set at 1.0 and the oscilloscope connected to the output of the SCA, run the pulse height up and down.
Describe and explain what you see. Press the COUNT button on the EG&G Ortec scaler. Run the pulse height up and down and note the response from the scaler. How does it work?

Explore the significance of the window width for various settings of the window-width dial (while the window level, or E dial, remains constant). To do this, leaving E constant, determine the minimum and maximum settings on the pulse height dial which allow you to get a signal for various settings of $\Delta E$. Plot on one graph these pulse height settings corresponding to both lower and upper window levels (y-axis) vs. the window width dial settings (x-axis).

Next, explore the significance of the position of the window for various window level settings (while the window width remains constant). Take data as above and make the same type of plot.

**Part II: Taking and analyzing a $\gamma$-ray spectrum**

**Theoretical background: GAMMA RAY DETECTION**

The detector assembly consists of a large, thallium activated sodium iodide crystal optically coupled to a photomultiplier tube. The crystal is protected against atmospheric moisture by a thin-walled aluminum can and the entire assembly is contained in a light-proof, magnetic shield.

A photon entering the crystal will interact with an electron giving it energy. The electron will then lose its energy by exciting electrons of the iodine atoms to the conduction band. The number of electrons being excited is proportional to the energy lost by the electron. The de-excitation of these excited electrons will result in a scintillation or flash of light, the intensity of which is proportional to the energy absorbed from the electron that was given energy by the photon. The flash of light liberates electrons (called photoelectrons) from the photocathode of the photomultiplier tube. The number of photoelectrons is increased as they are attracted sequentially to the dynodes in the tube. (See diagram below.) Finally, the electrons go through an electronic circuit that converts them to an electrical pulse of a few millivolts. The amplitude of this pulse is proportional to the light intensity and hence to the energy deposited in the crystal by the electron that was given energy by the photon.
A small percentage of thallium is included in the NaI crystal to shift the wavelength of the scintillation to about 410 nm which optimizes the response of the photocathode. The thallium also produces a rapid decay of the scintillation with the result that the detector recovers promptly and is ready for the next event.

The output pulses from the photomultiplier tube are coupled through a pre-amplifier to a linear amplifier. The linear amplifier is capable of accepting the millivolt pulses from the preamp and producing positive pulses of up to 10 V in amplitude with full preservation of linearity. If, for example, a $^{137}$Cs gamma of 0.662 MeV is completely absorbed in the crystal by giving all its energy to an electron, the gain or amplification of the amplifier can be adjusted so that the output pulse is 6.6 volts in amplitude. Thus, each volt of pulse height has been made to represent 100 KeV of absorbed energy.

**Setting up the detector:** Set up the scintillation detector to obtain a spectrum of pulses within the range of the SCA. To do this, first connect the cable from the POWER connector on the PRE-AMP to the nine-pin connector on the back of the amplifier. Then connect a BNC cable from the OUTPUT of the PRE-AMP to the INPUT of the amplifier (be sure to disconnect the pulser). Connect the detector tube to the DET connection on the preamp. Finally, connect the high voltage cable from the PRE-AMP to the EG&G Ortec Bias Supply and set the supply to 700 volts. Turn on the Bias Supply. Use the oscilloscope to observe the pulses coming from the amplifier. Use a time base of 1 ms to compare the scope output with and without the $^{137}$Cs source in place. With the $^{137}$Cs source close to the scintillation crystal (e.g., resting against or taped to the end of the detector) adjust the oscilloscope time-base such that you are looking at single pulses. Adjust the amplifier gain so that the maximum pulse height (corresponding to the photoelectric peak) is at 8 volts relative to the baseline of the pulses.

Note that the increment by which the window level is changed needs to be the width at which you set the window (be sure you understand why this is the case). Choose a width that will do a good job at showing the details of the pulse rate variation with pulse height but which will not take an inordinate amount of time.

Use the scaler (i.e., the Timer/Counter) to take data in one-minute time intervals. For this, set up the scaler as follows: TIMER AND COUNTER set to "COUNTER" mode. TIME BASE set to MIN with M=1 and N=0 (so count time is $1 \times 10^4$ minutes). Turn the knob labeled DWELL to the OFF position (full counterclockwise). Now press sequentially the buttons labeled STOP, RESET, COUNT. When pulses are coming from the SCA, you should see counts being recorded on the display. The scaler will turn off after 1 min. Pressing the RESET button will both reset the counts and start the next 1 min count. Pressing STOP and then RESET will reset the counts but not start the next interval. Pressing COUNT will start the next interval.

**Data acquisition and analysis:** Use the scintillation detector and SCA to obtain a graph of pulse rate as a function of pulse height for $^{137}$Cs. Clearly show in your lab notebook what window width you are using and the window level for each data point. Make a plot of the spectrum, with # counts/min on the y-axis and Volts or energy on the x-axis. Identify the major features of this spectrum.