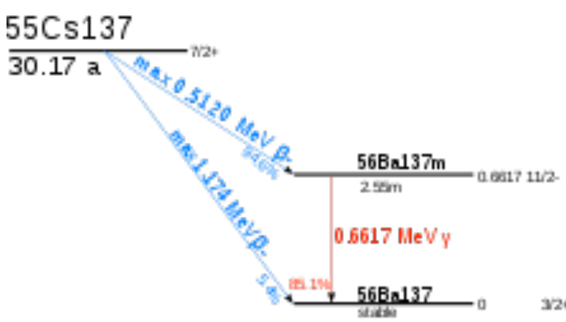
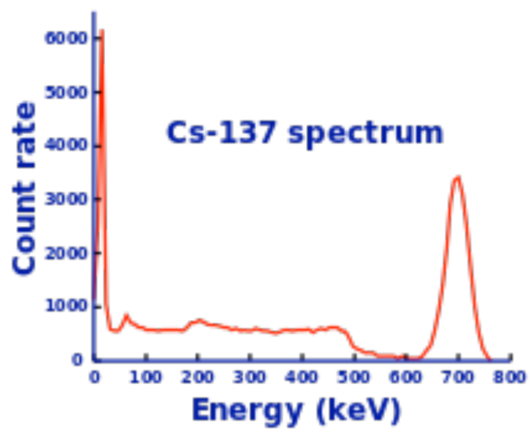
PHYS 575 – Radiation and Detectors – Wilkes
Lab 2. Energy Measurement Using Photomultiplier Tubes (PMT)

In this week's lab you will learn about pulse-height measurements and how to use pulse-height spectra to measure the energy of gamma rays emitted by different radioactive sources. You will study the relationship between high-voltage bias and the output of a photomultiplier tube, and compare the spectra made with plastic and sodium-iodide scintillator detectors.

2.1 Energy Response of a Scintillation Counter

To study energy response and energy resolution of NaI and plastic scintillator detectors, we will observe gamma rays from ^{137}Cs . (If time permits you can also try some of the following sources: ^{133}Ba, ^{60}Co, ^{22}Na.)





For these measurements we will use the 2-inch thick plastic detector and a NaI scintillator PMT combination.

Plastic scintillator and PMT

NaI crystal and its PMT

Figure 2. Plastic and NaI detectors used in this lab.

Note that the plastic and NaI detectors should be powered from **separate** high voltage power supplies. The high voltage for the NaI detectors is always +1000 volts. The voltage to apply to the plastic detector PMT is marked on the outside.

2.2.1 Comparison of Plastic and NaI

Connect the signal output of each detector to a channel on the oscilloscope and terminate the input to the scope with 50Ω. Place a ^{137}Cs source near the pair and adjust the gain on the scope so that you see pulses on both channels. It may be necessary to switch the trigger between the channels to observe clearly each channel. This is one situation where using the "VERT MODE" setting on the trigger source (= trigger on whichever channel is active) is appropriate.

Look at the output pulses from both the plastic scintillating material and the NaI crystal using one of the sources. ***Note any differences. Pay particular attention to the decay time of the pulses and the height of the pulses.*** The 50Ω termination cable results in a small PMT load. Consequently, the pulse shape seen should be dominated by the scintillator response, not the electronics.

Make a very approximate estimate of the decay time of the pulse (τ_s), which is the time for the pulse to fall to 1/e of its peak value, for each type of detector.

2.2.1.1 Pulse Height Spectra

Connect the output of the plastic detector to the Ortec 113 preamp and the output of the preamp to the 575A shaping amplifier. The preamp not only boosts the level of the signal, but also matches the rise and fall times of the pulses to the expected input to the 575A. A well-shaped single-polarity pulse should be seen on the oscilloscope screen. If the "pole-zero" adjustment on the 575A is properly set, the baseline offset will be minimized, which optimizes the resolution of the detector system.

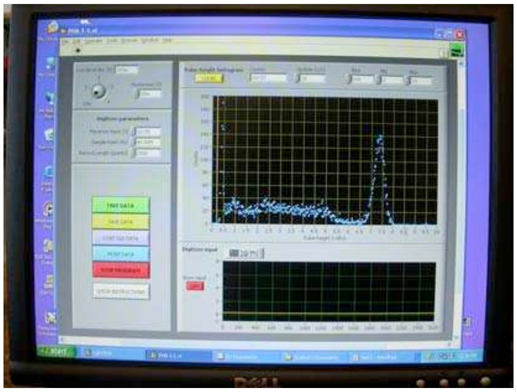


Figure 3: The PC screen when running the LabVIEW pulse height analyzer to take pulse height spectra. The spectrum shown is from a ^{137}Cs source.

While observing the output of the amplifier on the oscilloscope, adjust the gain of the amplifier so that the maximum pulse height from a ^{137}Cs source is about 5 volts. Make a sketch of the pulse from the amplifier, noting its rising edge and width.

Input the amplifier signal to the pulse height analyzer, while continuing to observe the output of the amplifier on the oscilloscope. (Hint: use a TEE.) See write-ups for LabView or Norland PHA as needed. Take pulse height spectra until you see clearly defined features (usually 10,000 to 30,000 total counts are sufficient). Save and print copies of the spectrum for each member of your group.

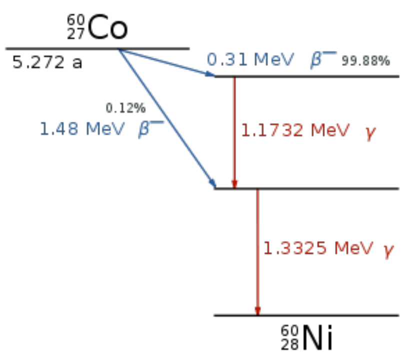
The plastic scintillator pulses are too short for the shaper to clean up well, so you may see bipolar shapes – the PHA should provide useful results anyway.

Repeat the above procedure for the NaI detector. Connect the output to the preamp and shaping amplifier and look at the output; set the gain to give 5 volt pulses and sketch the amplifier pulse for use in your lab notes.

For your notes: Compare the spectrum of the ^{137}Cs source taken with the two different scintillator detectors. Comment on the different features you see, and how they might correlate between each spectrum. What is the purpose of the "shaping" property of the amplifier?

Features of the pulse height spectrum

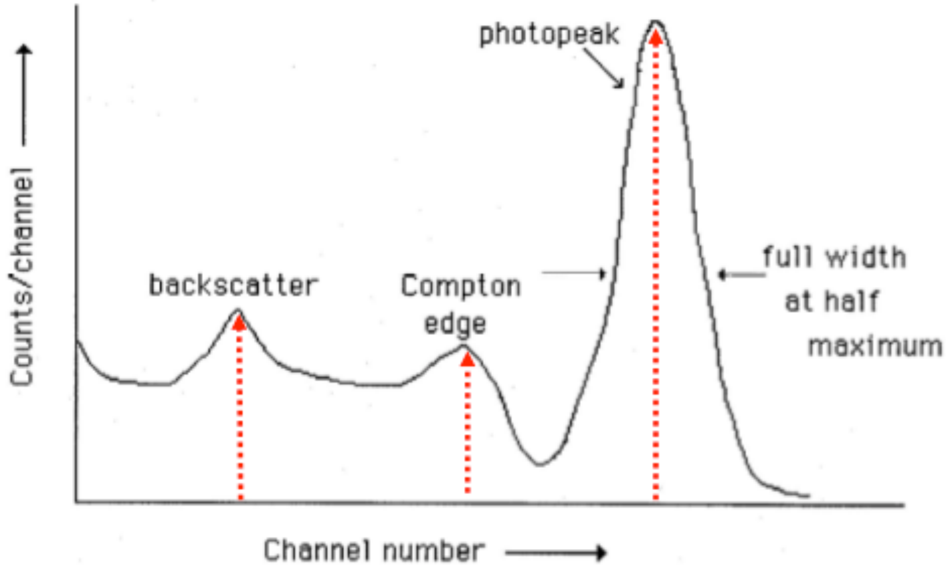
Obtain a ^{60}Co source and set the gain of the 575A so that the top bright line is a little less than 9 volts. ***Important: Use this amplifier gain setting to measure the spectrum of each source for the NAI detector.*** ^{60}Co produces very sharp gamma ray lines at 1.3 MeV, so pulses it produces can be used to calibrate energy estimates.



Record spectra with the NaI detector again, with the new amp setting. (If time permits you can also try ^{22}Na and ^{60}Co). Record data long enough to get clear peak features that may be fitted with a peak-fitting program.

Important: Only the source you are currently studying should be at your lab station (immediately return each source to the storage box after you have taken your data). There are two reasons for this: first, you want to minimize your overall exposure to the radiation, and second, if you have another source nearby your detector, you will contaminate your spectra.

Identify the various features of the pulse height spectra recorded by the NaI detector: the photopeak, the Compton edge, the Compton continuum, the Compton backscatter peak, and, if visible, x-ray peaks. Estimate the energy of features seen, knowing you set the 1.3 MeV ^{60}Co calibration lines at 9V.



Schematic view of Cs spectrum in NaI counter. (from www.physics.fsu.edu)

You can send data collected on the PHA to the pulse shape-fitting program on the PC, see its writeup. If you used the Norland PHA, push RUN, then select I/O to upload the data to the PC. The fitter will allow you to find the central peak location and width of the photopeak that best fit the data set. Why does a Gaussian (normal distribution) shape fit well?

Optional (probably wont have time but read):
Energy scale and resolution of a spectrometer

The NaI detector, preamp, pulse-shaping amp, and pulse height analyzer together form a type of gamma-ray spectrometer. You could, in principle, use this instrument to measure the gamma-ray spectrum of other sources and identify them. To do so requires a *calibration curve*: something that relates the pulse height in terms of volts or channel number to the energy of the gamma rays in units of MeV.

The table "Commonly used radioactive sources" (by E. Browne, Lawrence Berkeley National Laboratory) lists the most common emission type and energy of a number of sources. Look up the energies for the sources you used, and note which peaks on your spectra correspond to which energy.

Load each spectrum data file into the relevant LabVIEW program. If you used the Norland MCA, use the "Norland Interface" program; if you used the "Pulse Height Analyzer" program, use that again. You can look at previous data sets via the LOAD OLD DATA button.

Click on ANALYZE DATA to open up the peak fitting window. Click on the ANALYZE DATA button for instructions. Fit each important photopeak to obtain the peak position and width with a Gaussian lineshape. (Note: you can only fit one peak at a time, so make sure that you only see one peak when you run the fitting routine.) There is no need to print out a copy of every peak you fit, but recording the fit results is a must!

For your notes. For each of the Gaussian peaks you identified, plot the peak positions (in channel or voltage units) along the x-axis and the corresponding known energies along the y-axis. Fit the results to a straight line ($y = A + Bx$). Excel or KaleidaGraph can be used to make the fit. If you have one point that seems to be an outlier, make sure you have it correctly identified. This is a calibration curve. Your line fit parameters should also show their uncertainty, as determined by the line fit.

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Rev for 575, 10/15 JW