Exp. N-3  Gamma Ray Spectrometry

References:
Melissinos, “Experiments in Modern Physics”, 2nd ed., Sec. 8.4 & 9.2.1
Manual, UCS-20 spectrometer software & operation

Objective:
To study the spectra of various gamma-ray emitters with a NaI scintillation counter. To calibrate the energy response of the counter over a range from ~100 keV to 1.3 MeV with a set of known gamma sources and use the counter to identify the radioactive elements contained in an unknown gamma emitter.

Apparatus:

Experimental procedures

CAUTION:
- Be sure that the high voltage for the PMT never exceeds 900 V (0.9 kV).
- Before turning on the HV for the first time, please have your lab instructor double-check your cabling.

1. Check the functions of the different NIM electronics modules with a fast digital oscilloscope. The amplifier should be set at such a gain that the max. output signal is just below 10 volts. Record the pulse shapes observed on the scope for all steps in the above detection chain (at pre-amp output, amplifier output, SCA output). Note that you can save scope screen shots by plugging a USB flash drive into some of our digital scopes. Measure durations and amplitudes of pulses as well as their rise and fall times.

2. Obtain energy spectra for the $^{60}$Co and $^{137}$Cs $\gamma$-sources with the single-channel analyzer (SCA). Note that the shaping time for the output signal of the spectroscopy amplifier should now be set to $\leq 2 \mu$s. The reason is that the SCA is not able to handle signals with very long rise and fall times correctly. Set the SCA to "diff"(erential) mode to enable the $\Delta E$ window function. The $\Delta E$ on the SCA should be set at ~0.1 on the dial. Record count rates as a function of the SCA "E" setting and produce an energy spectrum by varying E. Identify Compton edges in the spectrum if possible and check quantitatively that they are located in the spectrum where expected.
3. Replace the SCA & scaler with the UCS-20 Multi-Channel Analyzer (MCA) and learn how to record spectra with the UCS-20 software on the PC. Determine for which of the three MCA inputs (pre-amp, amp, direct) you get the best energy resolution. Document your measurements for the three choices with a sample spectrum. Continue with the best configuration.

4. Adjust the overall gain to make optimal use of the full ADC range of the MCA, but without saturating your amplifier output. Keep monitoring the pulse shapes on the scope while taking MCA data to check for saturation effects.

Make sure you are making use of the full channel range of the MCA in your measurements, i.e. adjust the overall gain so that the peaks corresponding to the highest-energy gammas that you will be recording show up near the highest channels numbers of the MCA (2048). Here it is helpful to first check which of the seven known sources emits the highest-energy gammas. Make sure that a full peak is recorded for all gammas including the gamma with the highest energy.

5. Calibrate the energy response of the gamma spectrometer online so you can determine approximate $\gamma$ energies as you are taking data. There are different ways to perform this calibration (one-point, two-point, …). Familiarize yourselves with those calibration methods and then implement the one you think works best.

6. Record spectra for all seven known sources from the gamma-ray source kit. Make sure to collect enough statistics for each source so that you obtain a clean spectrum with all features clearly visible.

7. Take a spectrum for the unknown emitter.

8. Also take a background spectrum without any source on the detector. Note that this will take some time as the rate is low.

9. Note, the UCS software can be downloaded from the manufacturer and installed on your PC if you want to analyze data offline that way as well.

10. Identify the unknown source based on its characteristic gamma emission energies. The unknown gamma source might contain one or more elements different from the known sources in the kit.

11. Note that the $^{109}$Cd source is somewhat contaminated with another isotope. Identify the contaminating isotope and figure out how large the contamination is.

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Data analysis

1. Pulse data:
   a. List measured rise times, fall times, and pulse durations for pre-amp output, amp output, and SCA output in a table.

2. SCA data:
   a. Fit Gaussians to all three photo peaks in the two spectra. Use the two peaks with the highest and lowest energies to calibrate the arbitrary “E” scale of the SCA in terms of keV or MeV in a two-point calibration. Measure the energy of the third photo peak of medium energy incl. its uncertainty and compare it against the expected value for this γ emission line.
   b. Determine the energies of the Compton edges and backscatter peaks in the two spectra and compare against expectations from the Compton scattering formula.
   c. Measure the NaI/PMT/amp/SCA energy resolution ΔE/E as a function of E, where ΔE is the width of a photo peak.

3. MCA data:
   a. Import the raw data into a data analysis program. If you know root, corresponding scripts for import and analysis are available on the Senior Lab web site.
   b. Subtract the background spectrum from all source spectra. Note that the spectra have to be scaled to the same measuring time.
   c. Either use the peak-finder feature of the UCS software using ADC channels or offline Gaussian fits to the peaks in the background-subtracted spectra to determine all photo peak positions incl. errors in terms of ADC channel numbers. Do not use the online calibration for this analysis.
   d. Re-calibrate the γ-spectrometer offline in terms of ADC channels vs. gamma energy in keV (or MeV) by plotting ADC channels for all photo peaks incl. errors over an appropriate energy range against known γ energies and by then fitting the curve with an appropriate calibration function.
   e. Using the channel calibration fit, determine the energies for all Compton edges and for at least one clear backscatter peak in the spectra and compare their energies against accepted values based on the Compton scattering formula.
   f. Measure the NaI/PMT/amp/MCA energy resolution ΔE/E as a function of E, where ΔE is the width of a photo peak.
   g. Identify the unknown source.
   h. Identify and quantify the contamination in the ¹⁰⁹Cd source.

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