# Gamma-Ray Spectrometry Using NaI(Tl) and HPGe Detectors

Objectives: This experiment will familiarize you with the instrumentation used in gamma-ray spectrometry and with the quantitative aspects of gamma counting. You will also compare the performance of a NaI(Tl) scintillation detector with that of a germanium semiconductor detector by measuring gamma detection efficiency and resolution parameters.

References: Ehmann & Vance: pp. 205-206, 220-242.

As you have previously noted, gas-filled ionization detectors offer very poor counting efficiencies for gamma radiation because the likelihood of a gamma-ray interaction with the counter gas is quite small. Furthermore, no photon energy discrimination is possible with such gas-filled counters because seldom is the total energy of the gamma ray ever deposited within the detector. To overcome both of these problems, solid detectors of the scintillation or semiconductor type are used for monitoring gamma radiation. Such detectors not only offer improved gamma detection efficiency, but, when used with multichannel analyzers (MCA), permit high resolution of the incident photon energies - the key to the analytical application of gamma-ray counting.

## PROCEDURE

### A. Basic Instrumentation and General Operation of a Gamma-Ray Spectrometry System.

Your instructor will explain the nature and operation of each component in the counting systems used in this experiment. You should take careful note of all instrument settings and should not alter these unless instructed to do so. Several gamma standards will be counted with both a 3-inch x 3-inch NaI(Tl) "well" detector and a high-purity germanium semiconductor detector, and the important features of the recorded gamma-ray spectra will be discussed.

### B. Energy Calibration of the Spectrometers

In order to be able to identify the energy associated with each photopeak in the gamma-ray spectra of your samples, a calibration of the counting system must be made for the particular high voltage, amplier and ADC gain settings used. This calibration involves counting sealed gamma standards (counting geometry is not important) and locating the analyzer channels corresponding to the centers of the photopeaks of known gamma energies.

For the $^{137}$Cs, $^{60}$Co and $^{54}$Mn gamma sources place each source by the NaI(Tl) detector and count until sufficient counts are collected to enable a definite determination of the photopeak center location (counting time involved is not important). All counting should be performed so the ADC percent losses (dead time) are less than 2%. Adjust the location of the source to ensure this. After counting, run the Peak Analysis sequence to locate photopeak centers. Repeat this procedure for the HPGe detector, using a $^{133}$Ba source in addition to the ones listed above. Note that you may count all of the sources together for the HPGe detector calibration, provided that they are placed on an upper shelf to minimize the dead time. After counting, run the CSUN Peak Analysis 2 sequence to locate photopeak centers. Print out the report for this calibration standards spectrum.

Construct an energy calibration curve for each detector system by plotting gamma-ray energy versus channel number of the corresponding photopeak center. This is conveniently done by using the Energy Only Calibration program under the Calibration menu. Print out the resulting calibration plot for each detector.

C. Detector Resolution

For a NaI(Tl) detector, the figure of merit for detector resolution is usually expressed as the percent resolution (%R) for the 661.6-keV photopeak of $^{137}Cs$,

$$\%R = \frac{FWHM}{E_\gamma} \cdot 100 \tag{V.1}$$

where FWHM is the full width of the photopeak at half maximum (in keV) and $E_\gamma$ is the photopeak energy in keV. Detector resolution for a germanium semiconductor detector is usually expressed as the FWHM (in keV) for the 1332.5-keV photopeak of $^{60}Co$.

To determine the resolution of the NaI(Tl) detector count a $^{137}Cs$ source until a well-defined 662-keV photopeak is recorded, print out the necessary photopeak data and plot the counts observed versus channel number for the photopeak to obtain the FWHM. Calculate %R according to eq V.1. Repeat the procedure for the 1332-keV photopeak of $^{60}Co$ and compare your %R values.

For the Ge detector, count a $^{60}Co$ source until a well-defined 1332-keV photopeak is recorded, print out the analyzer data and again plot counts versus channel number for the 1332-keV peak to determine the FWHM. Repeat this procedure for the 662-keV photopeak of $^{137}Cs$ and compare FWHM values. Convert these semiconductor detector FWHM values to %R values and compare to those obtained for the NaI(Tl) detector.

D. Photopeak Counting Efficiency

The absolute photopeak counting efficiency ($\varepsilon_{pp}$) is given by:

$$\varepsilon_{pp} = \frac{R}{I \cdot A_t} \tag{V.2}$$

where R is the count rate associated with the photopeak of interest and is calculated by dividing the net photopeak counts by the counting time; $A_t$ is the disintegration rate of the gamma source at the time of counting; and I is the frequency at which the photopeak gamma ray is emitted per decay.

The net photopeak counts (NPPC) are determined by summing up all of the counts in the channels assigned to the photopeak (to give the gross photopeak counts, GPPC) and subtracting the Compton background (BD) under the photopeak. Thus,

$$NPPC = GPPC - BD \tag{V.3}$$

The background to be subtracted is usually calculated by assuming a linear background under the photopeak. Thus, the background can be obtained by finding the average background counts per channel on each side of the photopeak, averaging these values and multiplying by the number of channels assigned to the photopeak. Mathematically then,

$$BD = \frac{n}{2}\left[\frac{BD_L}{Ch_L} + \frac{BD_R}{Ch_R}\right] \tag{V.4}$$

where n is the number of channels in the photopeak, and $BD_L$ and $BD_R$ represent the total number of counts in the channels $Ch_L$ and $Ch_R$ to the left and right of the photopeak, respectively. Typically one chooses five or so channels on each side of the photopeak to establish the average background counts per channel, although one is limited by how free these photopeak-neighboring channels are of interferences (e.g., other photopeaks).

Count each of the available gamma standards in a well-defined counting geometry with the HPGe system. Again ensure that the analyzer percent losses are less than 5% for each count. (Position the standards as close to the detector as possible while still minimizing percent losses.) Count each source until several thousand counts are recorded for each photopeak. Print out the analyzer data and determine the NPPC for each photopeak. Calculate the absolute photopeak counting efficiency for each photopeak according to eq. V.2. Plot log $\varepsilon_{pp}$ versus log $E_\gamma$.

Using a similar counting geometry as with the Ge detector, count the $^{137}Cs$ source with the NaI(Tl) detector and determine $\varepsilon_{pp}$ for this counting system. Compare this value to that obtained with the semiconductor detector.

## E. Identification of an Unknown Gamma Emitter

You will be given a radioactive unknown and asked to identify as many radionuclides present as you can based on the gamma-ray spectrum generated by your sample.

Count your unknown with the germanium system for about 1000 sec. Position your sample as close to the detector as possible (percent losses should be <5%). Print out analyzer data so that you can determine the location of all major photopeaks. Using your energy calibration curve determine the energies of all observed photopeaks. Consult the gamma-ray tables in Appendices B and C, and assign all photopeaks to specific radionuclides. Report those radionuclides present in your unknown.