Experiment # 12: High Resolution Gamma Ray Spectroscopy and Neutron Activation Analysis

References:

Lecture Notes
Evans, The Atomic Nucleus
Knoll, Radiation Detection and Measurement
Tsoulfanidis, Measurement and Detection of Radiation

Objective:

The objective of this experiment is to study the use of high purity germanium (HPGe) detectors for high resolution gamma spectroscopy, as well as to illustrate the process of sample preparation and neutron activation analysis.

Introduction:

High purity germanium (HPGe) detectors, which first became available to most researchers in the mid to late 1980's, have allowed significant improvements in several areas of nuclear science. With excellent resolution and energy stability, the added convenience HPGe detectors provide by not requiring cooling when not in use has made these detectors the first choice of the modern spectroscopist.

When purchasing an HPGe detector, operating characteristics such as resolution, absolute efficiency and the peak to Compton ratio are commonly used to compare different systems and to judge performance. In this lab, you will learn the differences between these parameters and their significance.

One field of research that has particularly taken to HPGe detectors is spectroscopy. Either measuring natural occurring radioactivity or inducing radioactivity in materials to determine elemental makeup, HPGe detectors have proven themselves to be reliable and convenient while providing good energy resolution and detection efficiencies for the needs of most investigators. Using well characterized irradiation facilities and standard reference materials with known elemental concentrations for reference, activation analysis techniques can be used to determine the concentrations of numerous elements in materials to levels on the order of parts per billion (nanograms per gram.)

Equipment:

The equipment used for this experiment includes a high resolution HPGe detector, accompanying cryogenic and electrical support equipment, a computer based data acquisition and analysis system, the MIT reactor, and various sample preparation and handling equipment. Some of the equipment is complex and expensive; for this reason, the experiment will be guided by an experienced operator of the equipment.

Procedure: This experiment will be done in two parts. First, you will carry out four basic steps necessary to calibrate the detector before measuring a gamma-ray spectrum: energy calibration, energy resolution determination, absolute efficiency calibration, and measurement of the peak to Compton ratio. After the detector has been fully characterized, you will use the detector to carry out a neutron activation analysis experiment on some samples of interest (e.g., toe nails, finger nails, hair, lichen, water, ...)

1. *Energy Calibration* You will obtain a calibration curve for a specific detector so that energies of unknown gamma ray sources can be identified. A straight line fit will be used to create an energy calibration equation for the MCA (multi-channel analyzer) using data from two standard gamma ray sources.

^{60}Co: 1332.5 keV

^{133}Ba: 356.0 keV

- The electronics for this experiment will be set up by the lab coordinator, be sure to make a sketch of the arrangement.
- Place the ^{60}Co and ^{133}Ba sources in front of the detector.
- Adjust the coarse and fine gain controls of the linear amplifier so that the 1332-keV photopeak from ^{60}Co falls near the middle bin.
- Take a measurement with the two sources in place, counting long enough so that more than 1000 counts are in each photopeak. Determine the photopeak channel numbers.
- Use the built in calibration function of the analysis software to establish an energy calibration for the MCA.

2. *Energy Resolution* The overall energy resolution achieved in a germanium system is normally determined by a combination of three factors: the inherent statistical spread in the number of charge carriers, variations in the charge collection efficiency and contributions of electronic noise. The most common method of expressing energy resolution is to use the ratio of the FWHM of a particular photopeak to the energy of photons producing that photopeak.

- Calculate the resolution of the system from your ^{60}Co spectrum using the FWHM of the 1332 keV ^{60}Co peak.

3. *Absolute Efficiency Calibration* Absolute efficiency relates the number of detector pulses to the number of gamma rays emitted by the source. A set of calibrated sources is required to make an absolute efficiency measurement as a function of energy. The calibrated sources are specified by the activity on a certain date (the correction for decay since that date must be accounted for). In this experiment, we will use a radioactive standard from the National Institute of Standards and Technology (NIST),

standard reference material (SRM) SRM4275. The gamma ray energies, half-lives and activities of the SRM4275 source will be handed out in class.

- Place the NIST SRM4275 radioactivity standard source on the detector and take a measurement.
- Calculate the number of counts in each peak by reading out the region around each peak and subtracting background counts from total counts.
- Calculate the activity of the source on the experimental day.
- Divide the corrected counts per second from your spectra by the activity of the sources to obtain the absolute detector efficiency.
- Plot a graph of efficiency on log-log paper. This graph is the absolute full-energy peak efficiency from different gamma ray sources to the detector for a source in the geometry examined. You should observe a linear response above 300 keV, which is characteristic of Ge detectors.

4 *Peak to Compton Ratio* The peak to Compton (P/C) ratio is an important detector performance index for all gamma rays with energies between 150 keV and ~2000 keV where the Compton interaction is the dominant ~~interaction process. The~~ ratio is higher when the total absorption of gamma rays is maximized; either via single photoelectric, multiple Compton scattering or pair production processes. The P/C value is inversely proportional to the resolution, or FWHM.

The ratio is dependent upon the size and geometry of the detector, the detector efficiency and the materials surrounding the sample and detector including the detector housing, sample matrix and the cryostat.

- Collect channel counts in the MCA long enough to determine the height the 1332 keV cobalt peak and the maximum height of the single Compton scattering distribution (Compton Plateau) to a fair degree of accuracy.
- Calculate the peak to Compton ratio, which is the height of the photopeak divided by the maximum height of the Compton plateau.

5. *Sample Preparation, Neutron Activation and Spectrum Analysis* This section of the experiment will depend on the measurements in process in the laboratory at the time of this experiment. The instructor will provide information necessary for this section.

Write-Up: You should write up this experiment to present the work you have done and your conclusions regarding the operating performance of the HPGe detector(s) analyzed in the lab. Be sure to include graphical and tabular presentations of your results (all results should have an uncertainty associated with them, i.e., ± or error bars). Also, carry out proper statistical analysis on your data to ensure that the detector is functioning properly.

Discuss the sample preparation process and data collected for your unknown experimental samples. Can you draw any conclusions regarding this data?

Include a section describing any discrepancies you have with data you find elsewhere and discuss possible causes for these discrepancies.

Include a section describing changes that could improve the educational quality of this experiment or make it easier to perform.