Práctica de laboratorio número 1:

High resolution Gamma Ray Spectroscopy using HPGe detector

1) Scope

In this experiment the HPGe detector will be used to study gamma-rays and their interactions in the detector. It will be seen that the superior resolution of these detectors allows the measurement of gamma lines from nuclear levels that cannot be observed with NaI(Tl) detectors. In the experiment, an energy calibration curve will be constructed with known gamma lines from standard radioactive sources. The resolution of the detector for the 1.33 MeV gamma ray from ^{60}Co will be measured and compared to the specified value for the detector. The efficiency of the detector will be measured for different energies. From the calibration curves, the gamma energies and the activity of an unknown emitter will be determined.

2) Materials

1. High purity germanium detector (HPGe) with RC preamplifier.
2. High voltage bias supply
3. Digital signal processor (DSP) (replaces the traditional shaping amplifier + ADC)
4. PC with Genies MCA software for spectra data acquisition
5. Analog ratemeter
6. Set of radioactive sources

Source	$T_{1/2}$	Principal emissions (keV)	Intensity (%)
^{137}Cs	30.2 yr	661.660	84.7
^{60}Co	5.3 yr	1173.238	99.89
		1332.502	99.983
^{133}Ba	10.5 yr	79.614	2.62
		80.997	10.67
		276.398	7.16
		302.853	18.33
		356.017	62.05
		383.851	8.94

Table 1. Characteristics of the isotopes used for detector calibration

3) Experimental procedure

The instructor will provide information in regard to the proper bias voltage and other data for the HPGe detector. The student should understand how the different electronic modules are interconnected, <u>making a plot of the electronic set-up</u>. The MCA should have an elevated number of channels in order to take advantage of the inherent resolution capabilities of the detector. For this experiment the MCA will be set at 8192 channels.

1) Place a ^{60}Co source 1 cm from the detector and <u>adjust the gain of the DSP to set the full gamma ray energy range approximately up to 2 MeV</u>. The input count rate (ICR) should range between 500-1000 Hz.

2) <u>Calibration in energy and resolution</u>: Measure the spectra for the different isotopes of Table 1, placing the sources at about 1 cm from the detector surface. Set the DSP* rise time to 5.6 μs and the flat top to 0.8 μs. Adjust the Pole/Zero using the automatic P/Z matching. From the data collected, use a linear least squares fit to obtain the energy calibration curve and determine the FWHM in keV of each of the peaks in the Table. Compare with the specified detector resolution (FWHM =1.8 keV @ 1.33 MeV).
   **The DSP replaces the traditional shaping Amplifier/ADC combination in analog based spectroscopy systems. The DSP performs pre-conditioning and amplification of the signal presented by the preamplifier, then digitalizes the signal directly at a very high sampling rate. This reduces noise effects while making possible the use of more efficient filtering algorithms that can be achieved in the analog domain. The net result is a reduced processing time for better throughput with improved resolution. The weighting function applied to the DSP filter algorithm produces a symmetrical Triangular/Trapezoidal filter function. The rise time selection is equivalent to the conventional Gaussian shaping time, while the duration of the flat top can be adjusted to eliminate detector ballistic deficit and charge collection effects.*

3) <u>Discussion of a simple gamma-ray spectrum:</u> Once the MCA is calibrated in energy, identify and explain the main features of the ^{137}Cs spectrum (photopeak, continuous Compton, backscatter peak).

4) <u>Study of the detector resolution as a function of the ICR</u>. Place the ^{137}Cs source at different distances from the detector (1-20 cm) to obtain ICR in the range 10 – 1 kHz and measure the detector resolution for the 662 keV peak.

5) <u>Efficiency of the HPGe detector</u>: Knowing that in 1st December 1998 the activity was 1 μCi for the ^{133}Ba and ^{60}Co sources, respectively, and 5 μCi for the ^{137}Cs source, calculate their present activity in Bq. Register a background spectrum. Place the ^{137}Cs source at 12 cm from the face of the detector and count for a period of time long enough to obtain 5000 counts in the photopeak. Repeat the same procedure for the ^{60}Co and ^{133}Ba sources. Calculate the *absolute* and *intrinsic** efficiency of the detector as a function of the gamma ray energy.
   **Note: Suppose that the solid angle can be estimated as* $\Omega = A/4\pi d^2$*, where A is the area of the detector face and d is the distance source-detector. Detector diameter: 60 mm. Distance crystal from window: 6 mm.*

6) Identification of an unknown sample: Place the *problem source* at 1 cm from the detector and register the spectrum. From the energy calibration curve determine the energy of the photopeaks and identify the isotope (for that, you can use reference [2]). Place the *problem source* at 12 cm from the detector. Using the efficiency curve of the detector, calculate the activity of the unknown source.

4) Report

Each student will elaborate a report which will includes a short theoretical background, the explanation of the different spectra and the required calculations (with errors). The following questions need to be addressed as well**:**

Question 1: Number of channels required: In any pulse height distribution measurement, for a faithful representation of the continuous spectrum, the true distribution should not change drastically over the width of one channel. If peaks are present in the spectrum, this requirement translates into specifying that at least 5 channels should be provided over a range of pulse height corresponding to the FWHM of the peak [1]. Calculate the minimum number of channels required for a detector whose energy resolution for a 1 MeV peak is 0.2% if the full range of pulse amplitude is 2 MeV.

Question 2: Theoretical FWHM of the full-energy peak obtainable from a HPGe detector: The overall energy resolution obtained in a germanium system is determined by a combination of three factors: the inherent statistical spread in the number of charge carriers, variations in the charge collection efficiency and electronic noise. Neglecting the two last terms and knowing that the energy necessary to create one electron-hole pair in Ge is ⍰ =2.96 eV, calculate the FWHM for a 1.333 MeV gamma-ray. How does this compare with your measured (optimum) value? Explain any difference.

Question 3. Does the resolution depend on energy? Why?

Question 4: What produces the counts between the full energy peak and the Compton edge of a spectrum as seen on the MCA?

Question 5: Describe the origin of the “backscatter peak”. Can the backscatter peak appear at a higher energy that the Compton edge? Why?

5) References

[1] G.F. Knoll, Radiation Detection and Measurement, (John Wiley & Sons, Inc.). Fourth Edition (2010)

[2] http://nucleardata.nuclear.lu.se/toi/