

High Resolution Gamma-ray Spectroscopy

Practical 2

Aims and Objectives;

To measure the main characteristics of a Germanium detector and to identify unknown radionuclides.

After this practical you should be able to;

- Measure/check the relative efficiency of a Germanium detector
- Measure/check the peak-to-Compton ratio
- Do an energy calibration
- Appreciate the difference in resolution at low energy
- Measure and plot an absolute efficiency calibration
- Know that the annihilation peak is a special case, and why
- Know the best strategy for identifying unknown gamma-emitting radionuclides

Detector characteristics and spectrum analysis

A new germanium detector from a supplier will be provided with data on its particular characteristic properties. It is advisable to check these numbers experimentally, not least because much money has been spent on buying these characteristics. They are 1) resolution [which we measured in Practical 1] and 2) a particular sort of efficiency and 3) a peak-to-Compton ratio.

3.1 Relative Efficiency

Manufacturers classify the size of a Germanium detector by means of relative efficiency. This is defined as the efficiency of the detector relative to that of a 76mm x 76mm Sodium Iodide (NaI) detector. A standardised ⁶⁰Co source is placed 25cm from the detector and the count rate in the net area of the 1332.5keV gamma peak is determined.

- a) Place a ⁶⁰Co source of known activity 25cm from the endcap of the detector axis. Set the digital amplifier time constant to 8.8µs rise-time and 1.2µs flat top. Collect a spectrum for a time sufficient to get good statistics in the full-energy peak.
- b) Complete data collection and calculation as follows.

Net area of 1332keV peak:		counts	
Live time:		s	
Count rate:		counts/s	(a)
⁶⁰ Co activity given:		Bq	
At a date of:			
Today's date:			

Calculation of decay correction :

[⁶⁰Co half-life is 5.27 years], the sheet called 'A checklist of Formulae' may help.

Corrected ⁶⁰Co activity: Bq (b)

Efficiency of detector
 = $\frac{\text{count rate (a)}}{\text{Activity (b)}}$: (c)

Efficiency of NaI detector in these conditions is 1.2×10^{-3} . (d)

Relative efficiency of Ge detector = (c)/(d) :
 Previously known relative efficiency :

Is this an acceptable agreement?

3.2 Peak-to-Compton Ratio

This measures the size of the full-energy peak relative to the Compton background. It is defined using a ⁶⁰Co spectrum, as the number of counts in the maximum channel of the 1332.5keV peak divided by the average count per channel in the background between 1040 and 1096keV.

- a) Collect a well-setup ⁶⁰Co spectrum. Set up a region of interest between 1040 and 1096keV. Collect data and calculate as follows.

Number of counts in the biggest channel in the 1332keV peak: (a)

Number of counts in the 1040-1096 region:

Number of channels in this region:

Therefore, average number of counts per channel: (b)

Peak to Compton ration (a)/(b):

3.3 Summary of the Detector Specifications

Summarise the measured detector specification for the 1332.5keV peak.

Resolution (FWHM) :

(FWTM) :

Relative efficiency :

Peak-to-Compton ratio :

3.4 Energy calibration (optional if needed)

The energy calibration is now determined more properly to cover a wider range. ¹⁵²Eu has many gamma emissions. Put a ¹⁵²Eu source of about 10⁵Bq [or about 10μCi] 10cm from the detector. Collect a spectrum.

- a) Locate the 121.8keV and 1408.0keV peaks. Use these in the system software to do an energy calibration. Seek advice from a demonstrator if required.
- b) Now find three intermediate peaks in the spectrum; note these in terms of energy, and check with generally accepted standard energies in a published source.

Energy found (keV)	Energy in published data (keV)

Does the linearity (agreement) look acceptable?

Source of the published data:

3.5 Detector Resolution at Low Energy

Use the ¹⁵²Eu spectrum to measure the resolution, FWHM, for the 121.8keV gamma ray.

Resolution (FWHM) at 121.8keV:

keV

The following section can be omitted if you are short of time.

3.6 Absolute Efficiency Calibration

- a) The absolute full energy efficiency at a particular energy, distance, and source geometry is the intensity (net counts per second) of a peak at that energy divided by the number of gamma rays emitted. The latter is the disintegration rate (activity or number of Becquerels) of the nuclide multiplied by the emission probability of the gamma ray at that particular energy.

[The emission probability, P_γ , is given here as a fraction; take care elsewhere as it is sometimes shown as a percentage.]

Thus,
$$\text{Efficiency} = \frac{\text{net area}}{\text{LT(s)} \times \text{Bq} \times P_\gamma}$$

- b) Collect a ^{152}Eu spectrum from a source that is about 10cm from the detector.
- c) Go through the spectrum setting up regions of interest (ROIs) about those peaks that are shown in the table on the next page. Arrange where possible for each ROI to contain at least three channels of background continuum on either side of the peak proper. It is best to do this on a log display.
- d) Measure the net peak areas, noting them in the appropriate column of the table.

Users of MAESTRO should set up ROIs in the spectrum while it is held in the MCB; these can then be used in latter counts.

- e) Calculate the efficiency for each energy.
- f) Use a spreadsheet to produce a log-log plot of the efficiency on the Y-axis vs. energy on the x-axis.

Absolute efficiency curve from ^{152}Eu .

Source name (NPRL);		
Source activity when delivered:		Bq
Number of days to today (see note below):		d
Source activity now [$T_{1/2} = 4933$ d]:		Bq
Count time [LT]:		s
Distance of source from the detector cap:		mm

E_{γ}^* (keV)	Emission probability P_{γ}^*	Net area of peak (counts)	Efficiency At mm
39.91	0.59100		
46.00	0.14900		
121.78	0.28370		
244.70	0.07530		
344.28	0.26570		
443.96	0.03125		
778.90	0.12970		
964.05	0.14630		
1112.09	0.13540		
1408.02	0.20850		

* ¹⁵²Eu data in this table is from the IAEA TECDOC 619 (1991) ; it is recommended.

<p>Δt, in days from 01/10/90;</p> <p>01/12/02 4443d; 01/12/03 4807d; 01/12/04 5174d; 01/12/05 5539d; 01/12/06 5904d; 01/12/07 6269d; 01/12/08 6635d; 01/12/09 7000d; 01/12/10 7365d; 01/12/11 7730d</p>
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3.7 Variation of FWHM with Energy

We will assume that the variation of the resolution with energy is linear.

3.7.1 Normal Parameters

- a) Take a ¹⁵²Eu spectrum. We will use the relatively large peaks near the extremes of the spectrum at 121.8 and 1408.0keV. As before, check that the ROIs extend at least three channels on each side beyond the point at which the peak begins to rise.
- b) Measure the FWHM of each peak:

E_{γ} [x] (keV)	FWHM [y] (keV)
121.78	
1408.02	

- c) If the relationship is $y = mx + c$
that is $(FWHM) = (\text{slope}) \times (\text{energy}) + (\text{intercept on y-axis})$
then derive the values from the slope of gradient and the intercept.

Value for slope (m) : keV/keV
(gradient of FWHM vs. E_γ)

General deduction:
As energy increases, peak width

3.7.2 The Special Case of the Annihilation Peak

- a) Collect a spectrum from the ^{22}Na source. Measure the FWHM of the 511keV peak.
- b) Compare this with what you would expect it to be from the equation derived above.

Measured FWHM of 511keV peak: keV

Expected FWHM of 511keV peak: keV

Ratio of found / expected :

- c) How is this explained?

3.8 Identification of an unknown

- a) Place the unknown material, which may be in a labelled paper package, close to the detector.

Reference name of unknown:

- b) Collect a spectrum for about 10 minutes. Note the energies of the major peaks from the screen into the table below.

Gamma Energy from Spectrum (keV)	Possible nuclide and its known energy

- c) Scan the Identification List which is provided and contains known energies in order of decreasing energy. Preferably start with significant peaks at higher energies.

When a nuclide is tentatively identified, check for the ‘key gamma’ and associated gammas’.

- d) If possible, check in a user-friendly book of nuclear data, such as Browne and Firestone, for all the significant gammas for that radionuclide.
- e) If possible, look at the location of the nuclide on the Chart of Nuclides for its likely origin as, say, a fission product or an activation product. Also the half-life can be very helpful, but be aware that the nuclide could be part of a decay chain and may be the supported short-lived daughter of a long-lived parent.

Likely identify, name and origin of the unknown:

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