6. Experiments with NaI crystal

6.1. Detector efficiency calibration and activity determination

Detection counting efficiency, absolute/photopeak efficiency or full energy peak efficiency of a detector is based on the shape and active area of the crystal, detector-source geometry and the photon interactions with materials close to the detector. Therefore detection efficiency is defined for a whole detector system including the effects of detector and other components. As written in different books, detector efficiency is expressed as 1)Absolute or photopeak efficiency, 2) Relative efficiency, 3) Total efficiency and 4)Intrinsic efficiency. These expressions are related to each other but their importance differs in terms of their used area. For example, the measurement of photopeak efficiency is more crucial for determination of the activity of a radionuclide in a sample. This quantity is measured is at a given photon energy at a distance between the source and the detector used.

In this experiment, point sources will be used for simplicity and practical situations. In order to determine radionuclide activity with any detector, the detector efficiency, i.e absolute counting efficiency will be measured in a source-detector geometry and this efficiency will be related to the intrinsic efficiency of a chosen detector. Then the activity for the radionuclide of interest will be calculated easily. As known from the text books on radiation detection and measurement, the detector efficiency is a key parameter which is used for quantitative analysis in a sample and even it represents the performance indicator of a detector for the minimum detectable activity.

In any given photon energy, E, and specific source-detector distance, x, the counting efficiency, ε_{int} (E,x) is related by:

$$\varepsilon_{int}(E,x) = \frac{N_k}{N_g}$$

Where N_k: pulse count obtained in a specific time period (t) and N_g: the total number of incident photons impinging upon the crystal which can be calculated as below:

$$N_g = \frac{1}{4\pi} \cdot \frac{A \cdot t_c \cdot S}{d^2}$$

Where, A: the activity of the radioactive source during measurements (Bq), t_c: time of the experiment (s), S: detector area (mm^2) and d: source-detector distance (mm). As can be seen, intrinsic efficiency depends on radiation energy, the detector material and the detector thickness in the direction of incident radiation but it does not depend on the solid angle. That is, $\varepsilon_{int} = \left(1 - \exp\left(-\mu_{crys}(E) \cdot t_{crys}\right)\right) \times \exp\left(-\mu_w(E) \cdot t_w\right)$ where μ_{crys} is linear attenuation coefficient for detector crystal and μ_w is detector window material. The thickness, t, is for crystal and window material, respectively.

On the other hand, absolute efficiency is defined as:

$$\varepsilon_{abs} = \frac{counted\ pulses\ on\ detector}{number\ of\ photons\ released\ from\ the\ source}$$

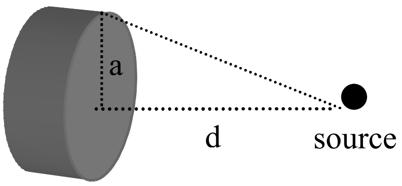
The relationship between intrinsic efficiency can be established in terms of solid angle:

$$\varepsilon_{\text{int}} = \frac{4\pi}{\Omega}\varepsilon_{abs}$$

For the most basic case, a right cylindrical detector can be subtended by a point source, and the solid angle can be expressed as:

$$\Omega = 2\pi\left[1 - \frac{d}{\sqrt{d^2 + a^2}}\right]$$

Where d is source-detector distance, a is radius of the detector.



In this case, detector efficiency can be calculated with the use of a point source having a known activity as below:

$$C = A \cdot f_\gamma \cdot \left(\frac{\Omega}{4\pi}\right) \cdot \varepsilon_{\text{int}}$$

Or

$$\varepsilon_{\text{int.}} = \frac{C}{A \cdot f_\gamma \cdot \left(\frac{\Omega}{4\pi}\right)}$$

Where C (cps) is the count rate obtained from the photopeak at energy E , A is the activity of the source (Bq), $\Omega/4\pi$ solid angle, f_γ is gamma ray emission probability and ε_{int} intrinsic detector efficiency.

METHOD

1. Perform the energy calibration as shown in earlier experiments.
2. Preset count time to 200 s.
3. Place ^{137}Cs source in front of the detector. Measure source-detector distance and calculate solid angle using this value.
4. Start the acquisition.
5. When the measurement is done place right and left cursor to the sides of photopeak. From the **ROIs (Region of Interest)** submenu in the **Display** menu, click on **Add ROI**. This action will change the colour of the spectrum between the cursors. When

wanted the ROIs can also be deleted by clicking on **Delete ROI** in the same menu. ROI can also be chosen with the + and – buttons on the left of the screen menu. The information of the area of a peak of interest in the spectrum can be seen on the screen.

6. Write down the Area value. This net value is the required count for the photopeak by subtracting the Compton continuum from the integral area of photopeak. In fact, it only represents the photoelectric effect.
7. Calculate the count rate by dividing net count value by live time elapsed for the acquisition.
8. Calculate the intrinsic efficiency by using this count rate value as above mentioned.
9. Place another ^{137}Cs source in front of the detector and count for 600 seconds.
10. Use the efficiency calculated in step 7 and calculate the activity of ^{137}Cs source. Consider that solid angle is changed because of the change in the source geometry.
11. Calculate the detector efficiency also for ^{60}Co, ^{57}Co isotopes by repeating the steps 3 to 7.

EVALUATION

1. Plot the detector efficiency values versus energy and interpret the change of the efficiency with increasing energy.
2. Compare the true activity of the source with the calculated activity. Interpret the results for possible discrepancy between them.
3. Did you make a decay correction for the used isotopes in the efficiency calculation procedure. If not, correct for decaying isotopes and interpret the corrected results.