Z36 – Model of a Positron Emission Tomograph (PET)

Physics Laboratory II
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The goal of the exercise is demonstration of the operating principle of a Positron Emission Tomograph (PET). Using a model of a tomograph, based upon two scintillation detectors with adjustable position and a coincidence unit, a student determines the position of a radioactive source emitting β^+ radiation and, subsequently, of a system of two such radioactive sources. Prior to that, a student sets up the electronics necessary to process signals from detectors, comprising single-channel analyzers, coincidence units and scalers.

Preparatory questions

1. Radioactive β^+ decay, decay scheme of the ^{22}Na isotope [1, 2, 3, 4]
2. Annihilation of positrons [1, 2, 4]
3. Tumour marking using radio-pharmaceuticals [1, 2, 4]
4. Operating principle of a positron emission tomograph [1, 2, 4]
5. What is meant by the line of response (LOR)? [1, 2, 4]
6. Operating principle of a scintillation detector [3, 4]
7. Functions of electronic modules: linear amplifier, single channel analyzer, coincidence unit, scaler (based on previously performed exercise Z29)

Computational assignments

1. What is the current activity of a radioactive ^{22}Na source if the source was characterized in August 2013 and at that time its activity was equal to 430.8 kBq?
2. Estimate the effective dose received by a student during the exercise, assuming a 10-hour exposure to radiation of a ^{22}Na source placed at a distance of 2 m. Assume the source activity as calculated in the first problem. Which other assumptions are necessary in your calculation? Compare obtained result with average yearly dose received from natural sources.

Apparatus and materials

Experimental setup is presented in figure 1. It consists of:

- two scintillation detectors NaI(Tl) equipped with photomultipliers and high voltage (HV) supplies,
- a box for positioning of radioactive sources in various positions with respect to the set of detectors,
- digital oscilloscope,
- electronic modules: amplifiers, single-channel analyzers, delays, coincidence units, scalers and a multi-channel analyzer with a PC interface.

Experiment

A typical scenario (to be consulted with a tutor):

1. Switch on power supply of the crate and detectors. For the latter, set voltage as specified on detector housings, paying attention to the voltage polarity.
2. Observe the spectrum from each detector on the computer screen, adjust settings of the single-channel analyzers such that they respond only to signals from registration of gamma quanta of energies corresponding to the annihilation line.
3. Prepare the setup as in figure 2, adjust delays of signals to minimize the coincidence time of the coincidence unit.
4. Take a full and detailed record of the setup geometry: distances of detectors from the rotation axis, position of the box with respect to the rotation axis and the coordinate system of the table.
5. Place a radioactive source in central location between the detectors. Perform a scan of angular correlation, i.e. fix the position of the first detector and record the coincidence rate as a function of the position of the second detector. Repeat the procedure for several (at least three) positions of the first detector.
6. Repeat previous point for two peripheral (but different) source positions.
7. Repeat the procedure for a certain configuration of two radioactive sources. Note, that here measurements for a larger number of fixed detector positions will be needed.

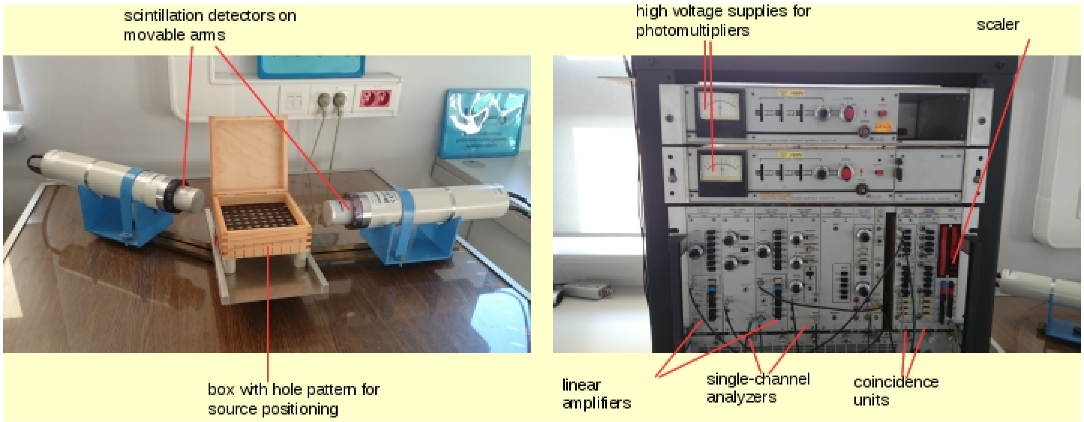

Figure 1: Experimental setup with necessary electronics.

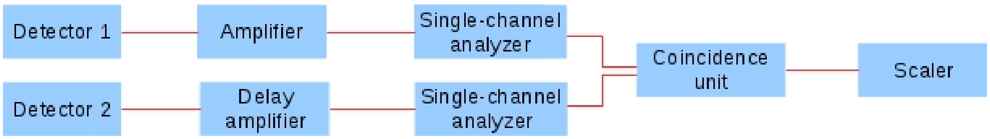

Figure 2: Scheme of electronic setup for registration of coincidences

Data analysis

For each of the scans obtained in points 4-6 find the position of the second detector corresponding to a maximum in coincidence rate (via a Gaussian fit to experimental data). Subsequently, for each scan construct a line of response LOR. For all scans performed at the same source location draw obtained LORs in a coordinate system, superimpose the pattern of positioning holes in the box. Determine source location by averaging the coordinates of LORs intersection points from a selected area. Estimate uncertainty of such position determination. Compare obtained coordinates with the real position of the source in the measurement, measured with a ruler, discuss possible origins of discrepancies.

Safety rules

Avoid unnecessary exposure to radiation, i.e. do not store radioactive sources in the vicinity of your body, after setting up the experiment build a wall of lead bricks between your work place and the radioactive source. Do not consume any food or beverages in the 2. Students Laboratory.

References

[1] Z36 instruction.

[2] E. Czaicka, *Liniowy model pozytonowego tomografu emisyjnego* – Diploma Thesis, Jagiellonian University 2008

[3] Kenneth S. Krane, *Introductory Nuclear Physics*, John Wiley & Sons, pdf widely available online, please google

[4] Shankar Vallabhajosula, *Molecular Imaging*, Springer Berlin Heidelberg, 2009, available online here.

Items 1, 2 are available in Polish on the Laboratory web pages upon sign in. They are helpful but not necessary.