# Alpha-energies of different sources with Multi Channel Analyzer (Item No.: P2522015)

## Curricular Relevance

| Area of Expertise: | Education Level: | Topic: | Subtopic: | Experiment: |
|---|---|---|---|---|
| ILIAS | Physik | Hochschule | Moderne Physik | Kernphysik - Radioaktivität |

| Difficulty | Preparation Time | Execution Time | Recommended Group Size |
|---|---|---|---|
| Difficult | 1 Hour | 2 Hours | 2 Students |

**Additional Requirements:**

- PC

**Experiment Variations:**

**Keywords:**

Decay series, radioactive equilibrium, isotopic properties, decay energy, particle energy, potential well model of the atomic nucleus, tunnel effect, Geiger-Nuttall law, semiconductor barrier layer

## Overview

## Short description

### Principle

An $\alpha$-spectrometer, consisting of a photodetector, a preamplifier and a multi channel analyser (MCA) is calibrated with the help of two $\alpha$-emission lines of a $^{226}\mathrm{Ra}$ source which is in radioactive equilibrium with its decay products. The a-emission energy of a $^{241}\mathrm{Am}$ source and other detectable lines of the $^{226}\mathrm{Ra}$ source are determined. The a-energies found in this way are assigned to the corresponding nuclides of the radium decay series.

The kinetic energy of $\alpha$-particles is measured the following way: $\alpha$-particles are stopped within the barrier layer of a reversely biased semiconductor detector. The generated charges are separated by the field in the barrier layer and produce a charge pulse at the detector output. The amount of charge produced is proportional to the $\alpha$-particle energy deposited in the barrier layer so the energy of each incoming $\alpha$-particle can be determined by the amount of charge in the pulse. A preamplifier converts the charge pulse into a voltage pulse. A multi-channel analyser (MCA) forms the voltage pulses in a way that they have a well defined height (no sharp peak) and their pulse height is proportional to the initial amount of charge.

A pulse-height spectrum of the pulses from the detector is then recorded by the MCA by assigning each pulse according to its height to one of the channels - each representing a specific pulse height interval. The range from some minimal to a maximal pulse height is divided into equal intervals each corresponding to a single channel. If an incoming pulse's height matches some channel's interval, the count of incidents belonging to that channel is increased by one. The diagram channel number vs. number of incidents in that channel depicts the pulse height spectrum.

The pulse height spectrum corresponds to the emission energy spectrum of the $\alpha$-particle emitter.

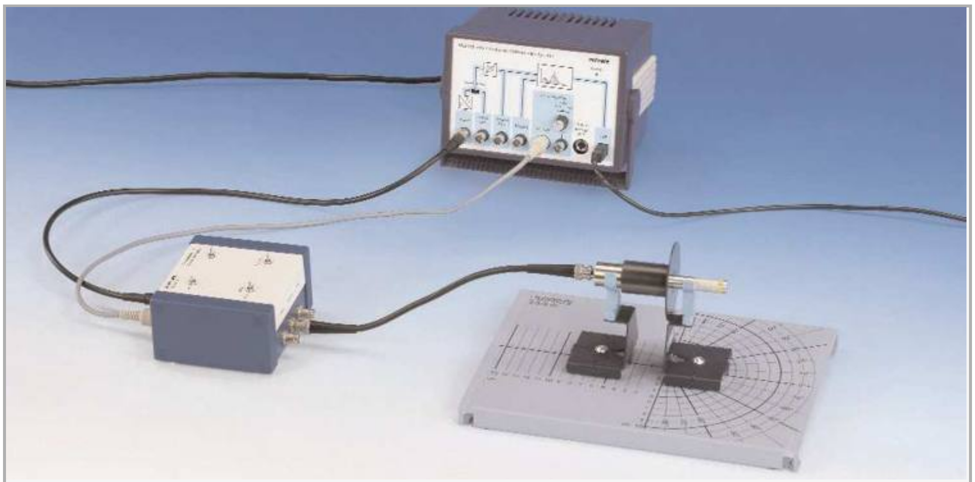

Fig. 1: Experimental set-up

## Equipment

| Position No. | Material | Order No. | Quantity |
|---|---|---|---|
| 1 | Radioactive source Am-241, 3.7 kBq | 09090-03 | 1 |
| 2 | Radioactive source Ra-226, max. 4 kBq | 09041-00 | 1 |
| 3 | Pre-amplifier f.alpha detector | 09100-10 | 1 |
| 4 | Screened cable, BNC, l = 750 mm | 07542-11 | 1 |
| 5 | Screened cable, BNC, l 250 mm | 07542-10 | 1 |
| 6 | Multichannel analyser | 13727-99 | 1 |
| 7 | measure Software multi channel analyser | 14452-61 | 1 |
| 8 | Alpha and Photodetector | 09099-00 | 1 |
| 9 | Base plate for radioactivity | 09200-00 | 1 |
| 10 | Source holder on fixing magnet | 09202-00 | 1 |
| 11 | Counter tube holder on fixating magnet | 09201-00 | 1 |

## Tasks

1. Perform a two-point calibration of the set-up with the $^{226}\mathrm{Ra}$ source.
2. Record the a-spectrum of $^{226}\mathrm{Ra}$ with the same settings as in the calibration.
3. Record the $\alpha$-spectrum of the $^{241}\mathrm{Am}$ source.
4. The $\alpha$-energies corresponding to the individual peaks of the $\alpha$-spectrum of the radium decay series and the main $^{241}\mathrm{Am}$ source $\alpha$-energy are determined and compared to literature values.

# Set-up and procedure

## Set-up and procedure

**Set-up**

Fig. 1 shows the experimental set-up.

The upper two preamplifier switches have to be set to "$\alpha$" and "Inv.". The "Bias" switch has to be set to "Int." and the polarity switch for the internal bias must be kept to "–". Wrong polarisation of the detector diode is to be avoided.

The short BNC cable is used to connect the detector to the "Detector" socket of the $\alpha$-preamplifier. The other BNC cable connects the "Output" socket of the $\alpha$-preamplifier with the "Input" socket of the MCA. The 5-pole cable connects the "+/-$12\,\mathrm{V}$" jack of the MCA with the corresponding socket of the $\alpha$-preamplifier.

Complete the electrical connections and preamplifier settings prior to turning on the MCA.

You may allow some minutes warm up time for the preamplifier before starting the measurement.

The MCA is connected by USB to a computer with "measure"- software installed on it. It may be necessary to remove a USB driver that "Windows" installs automatically and to install the correct USB driver for the MCA manually if the MCA is used with the computer for the first time.

The black shielding is mounted on the detector and the detector is attached to the counter tube holder on fixing magnet. The $^{226}\mathrm{Ra}$ source is put into the source holder and inserted into the black detector shielding up to the bedstop – so the source is as near to the detector as possible.

**Procedure**

Start the program "measure", select "Gauge" > "Multi Channel Analyser". Select "Settings and Calibration" and press the "Continue" button (Fig. 2).

The "Settings" window appears as in Fig. 3. Use the "Calibrate" button. Then the window of Fig. 4 appears.

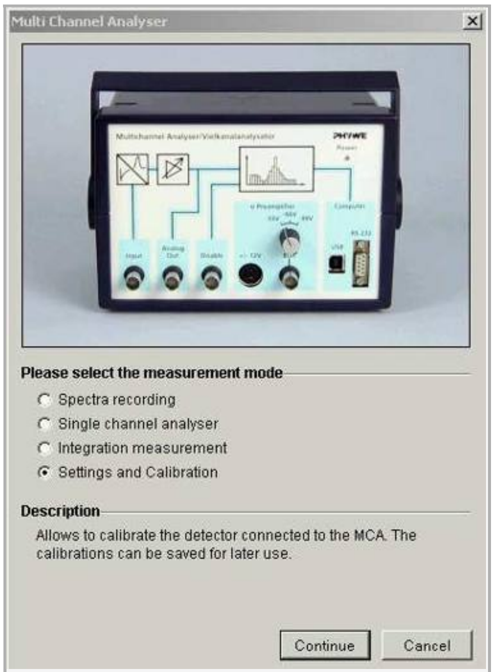


Fig. 2: Start window for the MCA

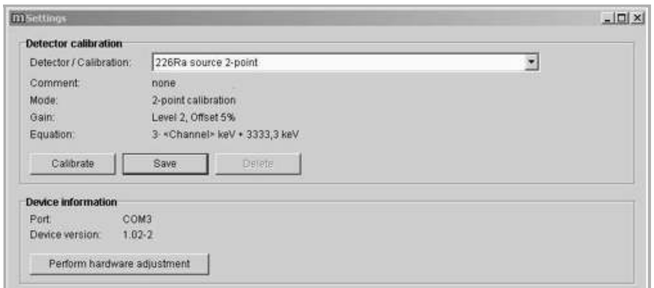


Fig. 3: Calibration settings window

Set the "Calibration mode" to "2-point calibration", "Unit" to "keV" and type "4784" and "7687" into the fields for the calibration energies.

Set "Gain" to "Level 2" and "Offset [%]" to 5.

Move the bars to the corresponding peaks as seen in Fig. 4. Use the "Apply" button, then click the "Save" button in the window of Fig. 3 that appears again.

Enter an appropriate name for the calibration and use the "Save" button of Fig. 5. Use the "Close" button in the window of Fig. 3. Select "Spectra recording" in the window seen in Fig. 2 and use the "Continue" button.

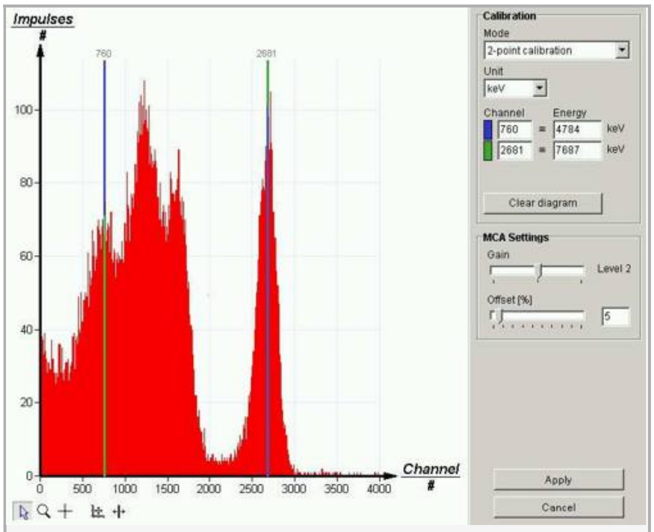


Fig. 4: Calibration window with Ra-226

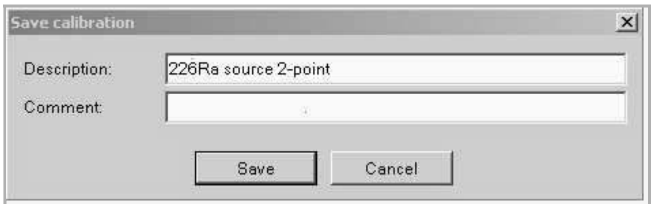


Fig. 5: Naming the calibration

The "MCA spectra recording" window opens. See Fig. 6. Set "Gain" to "Level 2" and "Offset [%]" to 5.

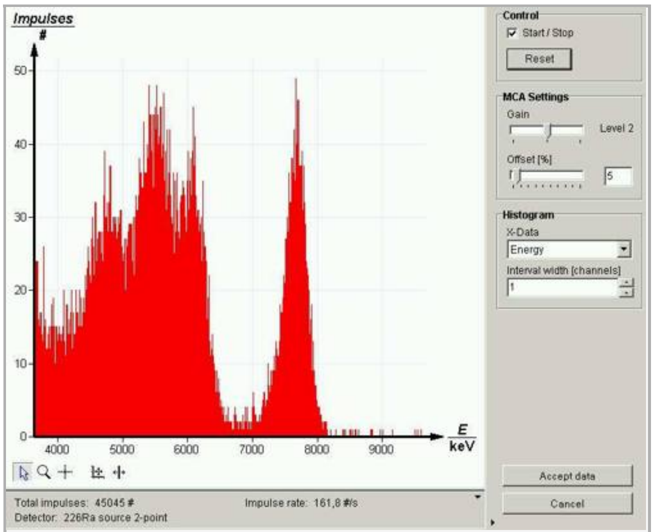


Fig. 6: Spectra recording window with Ra-226

Select "Energy" as "X-Data" and "1" as "Interval width [channels]". Counting rate is now around 160 per second. Record data until the peak positions are well visible, approx. 15 minutes.

Stop the measurement with the "Accept data" button.

The recorded data appear now in a window in the "measure" main program. Denote the measurement parameters using the "Display options" dialog and save the measurement data.

Replace the $^{226}\mathrm{Ra}$ source with the $^{241}\mathrm{Am}$ source, again the source as close to the detector as possible. Start a measurement with all other settings unchanged. The counting rate should be around 450 per second. See Fig. 7.

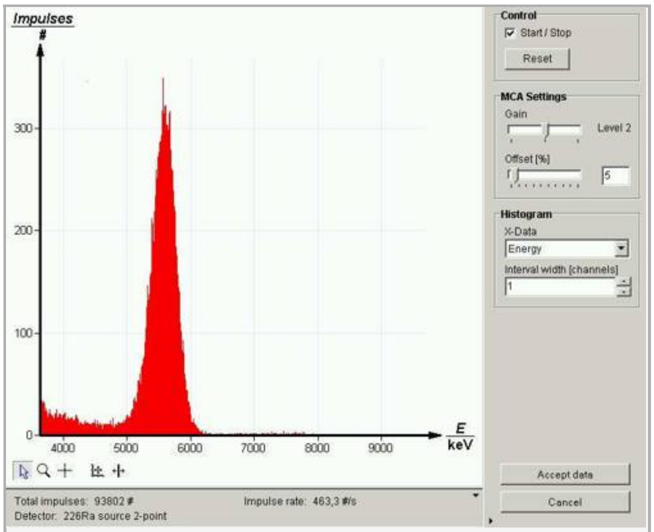


Fig. 7: Spectra recording window with Am-241

Record 120.000 impulses or 5 minutes.

Use the "Accept data" button to end measurement and save the data after denoting the measurement parameters.

# Theory and evaluation

### Theory

The $\alpha$-decay is a special form of nuclear fission, where a nucleus splits into an $\alpha$-particle, which is the helium nucleus ${}^{4}_{2}\mathrm{He}^{2+}_{2}$, and a nucleus with mass number 4 less, atomic number 2 less and neutron number 2 less than the initial nucleus. An example is the reaction

$$ {}^{226}_{88}\mathrm{Ra}_{138} \rightarrow {}^{222}_{86}\mathrm{Ra}^{2-}_{136} + {}^{4}_{2}\mathrm{He}^{2+}_{2} + \Delta E $$

alternatively written as

$$ {}^{226}_{88}\mathrm{Ra}_{138} \rightarrow {}^{222}_{86}\mathrm{Ra}_{136} + \alpha + \Delta E. $$

According to the liquid drop model of the atomic nucleus, an $\alpha$-decay sets energy free for all nuclei heavier than 165 atomic mass units while proton emission does not yield net energy. The $\alpha$-particle has to overcome the short-range attracting force of strong nuclear interaction to be set free and to gain energy from the relatively long-ranged repelling force of Coulomb interaction.

So an $\alpha$-particle inside a heavy nucleus is in a metastable state and has to cross a potential barrier to be emitted which can only happen by tunnel effect. The tunnel effect favoures the emission of smaller particles over heavier ones so the rate of other spontaneous fission incidents is always lower than the rate of $\alpha$-decay incidents.

In case of higher energy gain by $\alpha$-decay the potential barrier is thinner and the decay more likely, that is the half-life is shorter. On the other hand potential wall curvature is less for heavy nuclei so a-particles from high $Z$ nuclei may have higher energy, which is both stated by the Geiger-Nuttall law.

Because the emission of $\alpha$-particles is favoured over emission of bigger nuclear fragments, heavy nuclei may have to undergo several decays until they get sufficiently small to be stable.

The neutron fraction of nucleons needed for stability has to be larger in heavy nuclides than in light nuclei. An $\alpha$-particle carries away the same numbers of neutrons and protons. It lowers thus the neutron excess. So $\beta$-decays transforming protons to neutrons need to occur in the resulting decay series (or-chain), too. Table 1 lists such a decay series.

| nuclide | decay mode | half-life | $E$ / MeV | product of decay |
|---|---|---|---|---|
| $^{238}$U | $\alpha$ | $4.468 \cdot 10^{9}$ a | 4.270 | $^{234}$Th |
| $^{234}$Th | $\beta$- | 24.10 d | 0.273 | $^{234}$Pa |
| $^{234}$Pa | $\beta$- | 6.70 h | 2.197 | $^{234}$U |
| $^{234}$U | $\alpha$ | 245500 a | 4.859 | $^{230}$Th |
| $^{230}$Th | $\alpha$ | 75380 a | 4.770 | $^{226}$Ra |
| $^{226}$Ra | $\alpha$ | 1602 a | 4.871 | $^{222}$Rn |
| $^{222}$Rn | $\alpha$ | 3.8235 d | 5.590 | $^{218}$Po |
| $^{218}$Po | $\alpha$ 99.98 %<br>$\beta$- 0.02 % | 3.10 min | 6.115<br>0.265 | $^{214}$Pb<br>$^{218}$At |
| $^{218}$At | $\alpha$ 99.90 %<br>$\beta$- 0.10 % | 1.5 s | 6.874<br>2.883 | $^{214}$Bi<br>$^{218}$Rn |
| $^{218}$Rn | $\alpha$ | 35 ms | 7.263 | $^{214}$Po |
| $^{214}$Pb | $\beta$- | 26.8 min | 1.024 | $^{214}$Bi |
| $^{214}$Bi | $\beta$- 99.98 %<br>$\alpha$ 0.02 % | 19.9 min | 3.272<br>5.617 | $^{214}$Po<br>$^{210}$Tl |
| $^{214}$Po | $\alpha$ | 0.1643 ms | 7.833 | $^{210}$Pb |
| $^{210}$Tl | $\beta$- | 1.30 min | 5.484 | $^{210}$Pb |
| $^{210}$Pb | $\beta$- | 22.3 a | 0.064 | $^{210}$Bi |
| $^{210}$Bi | $\beta$- 99.99987 %<br>$\alpha$ 0.00013 % | 5.013 d | 1.426<br>5.982 | $^{210}$Po<br>$^{206}$Tl |
| $^{210}$Po | $\alpha$ | 138.376 d | 5.408 | $^{206}$Pb |
| $^{206}$Tl | $\beta$- | 4.199 min | 1.533 | $^{206}$Pb |
| $^{206}$Pb | | stable | | |

Table 1: Radium decay series

Typical $\alpha$-decay energies are around $5\,\mathrm{MeV}$, so the a-particles gain a speed of $15{,}000\,\mathrm{km/s}$ or $5\,\%$ of the speed of light. Decay momentum is split evenly between both reaction partners but the lighter $\alpha$-particle gains the main fraction of the reaction energy. Still the recoil energy of the decaying heavy nucleus is in the range of $100\,\mathrm{keV}$, thus much higher than binding energy of the outer electrons or chemical or lattice binding, and may not be neglected.

$\alpha$-particles interact strongly with matter because of their electric charge. They are stopped by some cm of air or some tens of µm of condensed matter. At the beginning of their path the energy loss in matter is nearly proportional to the path length. Here in this experiment the sources in use are covered so all $\alpha$-particles have to pass some material before leaving the source and some millimetres of air before they reach the detector. The effect of the source covering prevails over the effect of the air and leads to a peak broadening. This limits the energy resolution to greater extent than the limited resolution of the detector.

The energy loss in the source cover and air is unknown but can be assumed to be roughly constant for all $\alpha$-particles so in case of assumed detector linearity (at least) two calibration lines are necessary to calibrate the set-up.

The $^{226}\mathrm{Ra}$ source can be considered to be in radioactive equilibrium with it's decay products up to $^{210}\mathrm{Pb}$, which has $22.3$ years of half-life. All branches of the decay series cross this nuclide and your source may not be old enough to be in equilibrium with the products following this nuclide. So the fraction of $^{210}\mathrm{Po}$ may be significantly lower depending on the production date of your source and the related peak may not be present. Actually you can calculate the source's age by comparing the $^{210}\mathrm{Po}$ peak height with neighbouring peaks. So the peaks to be expected in an intensity that can be registered in this experiment are:

| | |
|---|---|
| 4784 keV | $^{226}$Ra |
| 5304 keV | $^{210}$Po |
| 5489 keV | $^{222}$Rn |
| 6002 keV | $^{218}$Po |
| 7687 keV | $^{214}$Po |

$^{241}\mathrm{Am}$ decays to $100\,\%$ to stable $^{237}\mathrm{Np}$ and in $85\,\%$ of the decays an $\alpha$-particle of $5486\,\mathrm{keV}$ is emitted which contributes to the main peak.

| nuclide | fraction produced per atom $^{226}$Ra | $E$/keV | main $\alpha$-emission line / keV | fraction of $\alpha$-particles |
|---|---|---|---|---|
| $^{226}$Ra | 100 % | 4871 | 4784.34 | 94.45 % |
| $^{222}$Rn | 100 % | 5590 | 5489.48 | 99.920 % |
| $^{218}$Po | 100 % | 6115 | 6002.35 | 99.9789 % |
| $^{218}$At | 0.02 % | 6874 | 6693 | 89.91 % |
| $^{214}$Bi | 99.9 % | 5617 | 5452 | 0.0113 % |
| $^{218}$Rn | 0.10 % | 7263 | 7129.2 | 99.870 % |
| $^{214}$Po | 99.98 % | 7833 | 7686.82 | 99.9895 % |
| $^{210}$Po | 99.99987 % | 5408 | 5304.33 | 99.9988 % |

Table 2: Expected $\alpha$-radiation from the $^{226}\mathrm{Ra}$ source

**Evaluation**

For better visibility of the maximum of the peaks and reduced noise apply the "Smooth" function of "measure" using the -button. See Fig. 8. You may alter the appearance of the curve with the "Display options" function (-button) for example by choosing on the "Channels" chart of the "Display options" dialogue "Straight lines" for "Interpolation:".

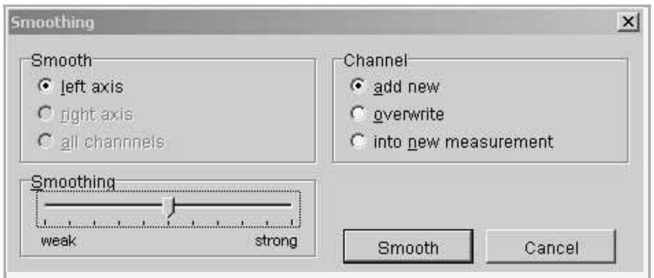


Fig. 8: "Smooth" dialog box

Then use the "Survey" function (-button) to determine the position of the $\alpha$-peaks to be evaluated and read out the energies in $\mathrm{keV}$. See Figs. 9 and 10. Also read out with help of the "Survey" function a full width at half maximum (FWHM) energy value to asses the measurement accuracy.

| measured energy / keV | literature value / keV | deviation |
|---|---|---|
| 5498 | 5489 | 0.16 % |
| 6065 | 6002 | 1.05 % |
| 5582 | 5486 | 1.75 % |

Table 3: Measurement results

FWHM of the $^{241}\mathrm{Am}$-peak is $424\,\mathrm{keV}$ at $5486\,\mathrm{keV}$ centre or $7.7\,\%$. So the literature values could be reproduced well though the presence of source cover and air broadened the energy distribution of the a-particles reaching the detector.

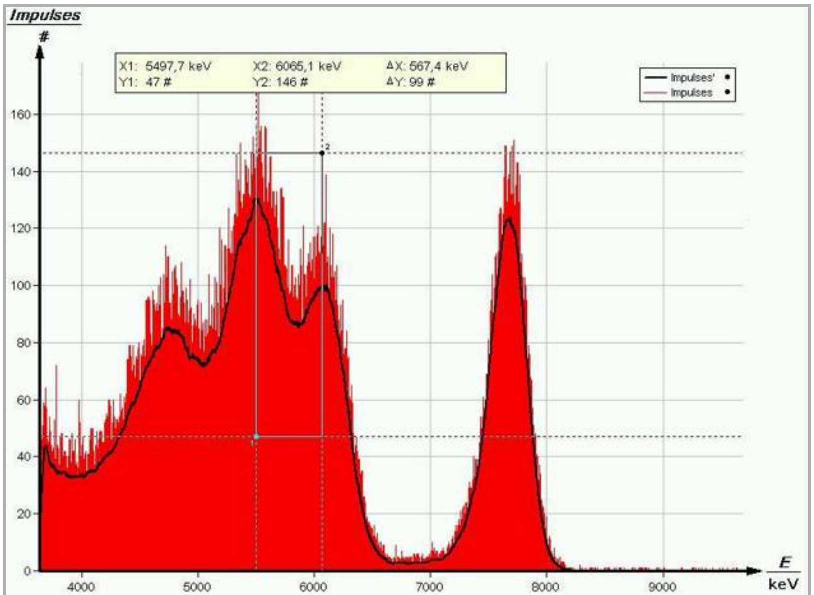


Fig. 9: Ra-226 measurement data

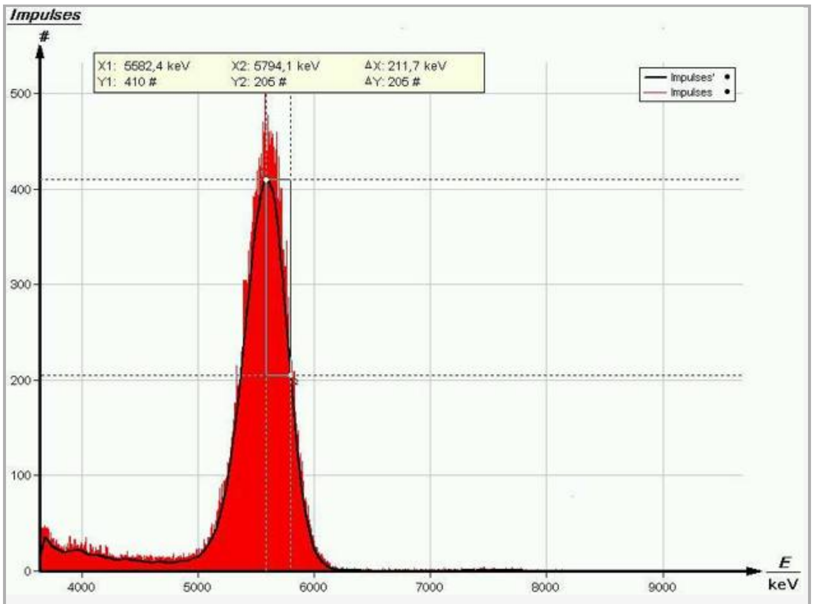


Fig. 10: Am-241 measurement data