# Study of the Alpha-energies of Ra-226 with MCA

**(Item No.: P2522315)**

## 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, energy loss of alpha-particles in matter, semiconductor barrier layer

## Overview

## Short description

### Principle

An $\alpha$-particle striking the barrier layer of a detector diode generates a number of charge carriers proportional to the energy deposited in the barrier layer by the $\alpha$-particle. The charge carriers are collected by the electrodes of the reversely biased diode and a current pulse results in the diode circuit. A preamplifier converts the current pulse to a voltage pulse, the multi channel analyser (MCA) processes the pulses by shaping their form such that the pulse height is proportional to amount of charge. The pulse is registered then by adding one count to a specific channel if its pulse height fits the pulse height interval of that channel or else rejecting it if the height does not fit any channel. The pulse height intervals of the channels strung together form a larger interval without overlap. The counts per channel plotted over channel number represent the pulse height spectrum which in turn corresponds to the energy spectrum of the $\alpha$-particles reaching the detector, if all the pulse forming processes are completely linear plus if all the $\alpha$-particle's energy is deposited in the barrier layer.

$\alpha$-particles coming from an open $^{241}\mathrm{Am}$-emitter in a vacuum are used for calibrating the set-up. It is assumed that they have no energy losses before reaching the detector. The remaining peak width is assigned to limited detector resolution and assumed to be only little asymmetric around the peak centre due to detector front covering.

Fig. 1: Experimental set-up.

## Eqiupment

| Position No. | Material | Order No. | Quantity |
|---|---|---|---|
| 1 | Multichannel analyser | 13727-99 | 1 |
| 2 | measure Software multi channel analyser | 14452-61 | 1 |
| 3 | Alpha and Photodetector | 09099-00 | 1 |
| 4 | Radioactive source Am-241, 3.7 kBq | 09090-03 | 1 |
| 5 | Radioactive source Ra-226, max. 4 kBq | 09041-00 | 1 |
| 6 | Container for nuclear physics exp. | 09103-00 | 1 |
| 7 | Pre-amplifier f.alpha detector | 09100-10 | 1 |
| 8 | Vacuum gauge DVR 2, 1 ... 1000 hPa | 34171-00 | 1 |
| 9 | Diaphragm pump, two stage, 220V | 08163-93 | 1 |
| 10 | Vacuum tube, NBR, 6/14mm, 1 m | 39289-00 | 2 |
| 11 | Tubing connector,Y-shape, ID 8-9mm | 47518-03 | 1 |
| 12 | Pinchcock, width 20 mm | 43631-20 | 1 |
| 13 | Screened cable, BNC, l = 750 mm | 07542-11 | 3 |

## Tasks

1. The spectrum of an uncovered $^{241}\mathrm{Am}$ emitter is recorded with the MCA. The energy of the principal peak, corresponding to a particle energy of $5.486\,\mathrm{MeV}$, is used for calibration.
2. Some air is used to slow down the a-particles of known energy resulting in a mean energy shift and a peak broadening. The mean energy loss to peak broadening relation is measured and assumed to be linear in a range above $2.8\,\mathrm{MeV}$.
3. The energy spectrum of the $\alpha$-particles emitted from the covered $^{226}\mathrm{Ra}$ source is recorded and evaluated.

# Set-up and procedure

## Set-up and evaluation

**Set-up**

Fig. 1 shows the experimental set-up.

The black shielding is mounted on the detector and the detector is attached to the flange cover. The uncovered $^{241}\mathrm{Am}$ source is put into the black detector shielding up to the bedstop so the source is as near to the detector as possible. The sliding rod is retracted and secured with the milled screw. The flange cover is mounted to the experimental container.

The upper two switches of the preamplifier have to be set to "$\alpha$" and "Inv.". The "Bias" switch has to be set to "Ext." and the polarity switch for the internal bias should be kept to "–" to avoid accidental wrong polarisation of the detector diode.

The short BNC cable is used to connect the experimental vessel to the "Detector" socket of the $\alpha$-preamplifier. One of the other BNC cables connects the "Bias" socket of the $\alpha$-preamplifier with the "Bias" socket of the MCA. The bias selector switch of the MCA is to be set to "-$33\ \mathrm{V}$". The other BNC cable connects the "Output" socket of the a-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 a-preamplifier.

Turn MCA and preamplifier on right at the beginning so they have time to thermalise before starting the measurement. But complete the electrical connections and the preamplifier settings prior to turning on the MCA.

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

**Procedure**

Close the venting screw of the flange cover and evacuate the experimental vessel. When the final pressure achievable with the pump is reached, close the pinch cock and then turn off the vacuum pump. Start the "measure" program, select "Gauge" > "Multi Channel Analyser". Select "Spectra recording" and use the "Continue" button (Fig. 2).

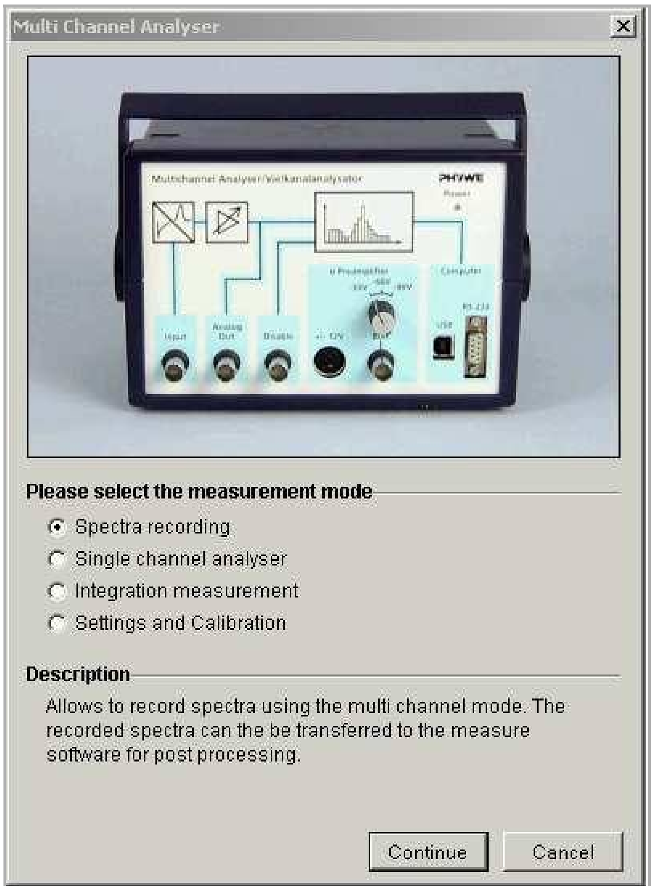


Fig. 2: Start window for the MCA

Set "Gain" to "Level 2" and "Offset [%]" to 5. The counting rate should be between 50 and 60 per second.

Select "Channel number" as "X-Data" and "1" as "Interval width [channels]".

Stop the measurement with the "Accept data" button, when the position of the main $^{241}\mathrm{Am}$-peak is clearly visible for evaluation. 5000 impulses should be sufficient for this purpose.

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.

Vent the vessel until the pressure is 500 hPa and record a spectrum at this pressure collecting about 10000 impulses. "Accept data" and save the resulting spectrum.

"Accept data" and save the resulting spectrum.

Fully vent the experimental vessel and record a spectrum at ambient pressure (about 1000 hPa) the source still right in front of the detector collecting again about 10000 incidents.

Exchange the $^{241}\mathrm{Am}$ source with the $^{226}\mathrm{Ra}$ source: Push the $^{226}\mathrm{Ra}$ source up to the bedstop into the black detector shielding. Evacuate the vessel again and record a spectrum of the radiation with the same settings as before. The counting rate should be between 200 and 250 per second. Record about a quarter of a million impulses. Finally use the "Accept data" button.

# Theory and evaluation

### Theory

For a short sketch of $\alpha$-decay theory refer to LEP 5.2.20-15. $\alpha$-particles interact strongly with matter because of their electric charge and are stopped by some cm of air or some tens of $\mu\mathrm{m}$ of condensed matter. At the beginning of their path the energy loss in matter is nearly proportional to the path length or the electron density. This holds in case the $\alpha$-energy is still higher than $2.8\,\mathrm{MeV}$.

Here in the experiment the $^{226}\mathrm{Ra}$ source in use is covered so all $\alpha$-particles originating from it have to pass some material when leaving the source before they reach the detector. The source covering leads to a specific peak broadening and since the energy loss is proportional to layer thickness and all $\alpha$-particles have to cross the same covering, the mean energy loss in the cover may be assumed to be equal for all of them.

Another effect can broaden the peak and shift the mean energy: The emitting nuclides may not sit in an indefinitely thin layer underneath the source cover but may be dispersed in some metal of some layer thickness so $\alpha$-particles coming from different depth undergo different energy losses and peak broadenings.

The effects of peak energy shift and energy distribution broadening due to source cover and depth distribution of the nuclides can be discerned by comparing actual peak form to peak form caused by a layer of matter resulting in a specific energy loss.

The $^{226}\mathrm{Ra}$ source can be considered to be in radioactive equilibrium with it's decay products up to $^{210}Pb$, 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:

$4784\,\mathrm{keV}$ $^{226}\mathrm{Ra}$
$5304\,\mathrm{keV}$ $^{210}\mathrm{Po}$
$5489\,\mathrm{keV}$ $^{222}\mathrm{Rn}$
$6002\,\mathrm{keV}$ $^{218}\mathrm{Po}$
$7687\,\mathrm{keV}$ $^{214}\mathrm{Po}$

| 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 | $^{222}Rn$ |
| $^{222}Rn$ | $\alpha$ | 3.8235d | 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

| 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

$^{241}\mathrm{Am}$ 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.

Fig. 4 shows a decay scheme and Table 1 lists decay data for $^{241}\mathrm{Am}$. The $5.486\,\mathrm{MeV}$ line is used here for calibrating the setup.

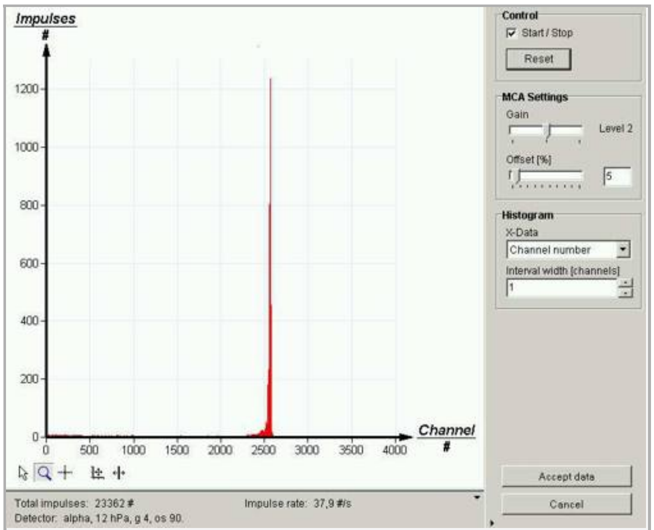


Fig. 3: Spectra recording window

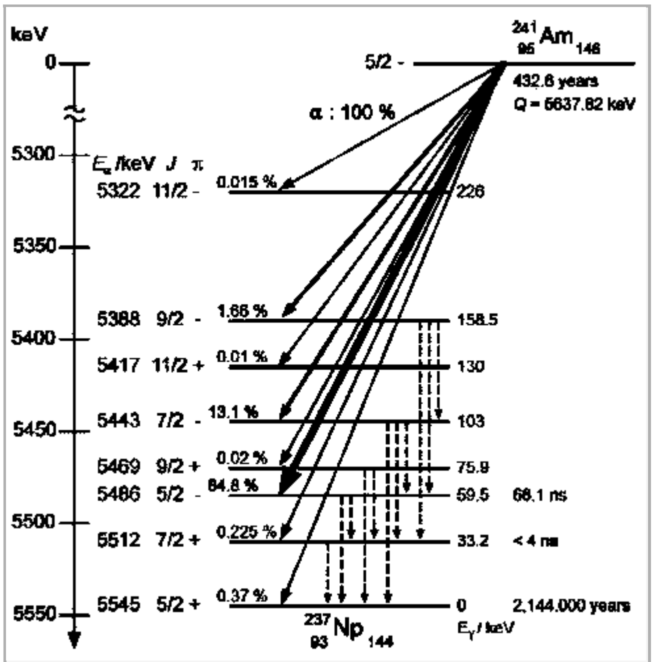


Fig. 4: Am-241 decay scheme

| Reaction: ${}^{241}_{95}\mathrm{Am}_{146} \rightarrow {}^{237}_{93}\mathrm{Np}_{144} + {}^{4}_{2}\mathrm{He}_{2} + \Delta E$ | | | |
|---|---|---|---|
| $\alpha$-Energy/keV | Fraction/% | ${}^{237}$Np state/$J\pi$ | $\gamma$-Energy/keV |
| 5544.5 | 0.37 | 5/2 + | - |
| 5511.5 | 0.225 | 7/2 + | 33.2 |
| 5485.6 | 84.8 | 5/2 - | 59.5, 26.3 |
| 5469 | 0.02 | 9/2 + | 75.8, 42.7 |
| 5442.8 | 13.1 | 7/2 - | 103, 69.8, 43.4 |
| 5416.5 | 0.01 | 11/2 + | |
| 5388 | 1.66 | 9/2 - | 125.3, 99, 55.6 |
| 5322 | 0.015 | 11/2 - | |

Table 3: ${}^{241}\mathrm{Am}$ decay radiation

**Evaluation**

Results for the ${}^{421}\mathrm{Am}-$radiation may look like Fig. 5.

You may use "Measurement" > "Adopt cannel..." to display several measurement results in a single plot.

In the "measure" main program zoom in on the interesting region of your measurement curve either using the -tool (magnifying glass) or using the mouse - clicking and holding while moving the mouse on the x- or y-scale will move the graph if left mouse button is used or will alter the magnification if the right mouse button is used.

Use the "Survey" function ( -button) to determine the positions of the peaks to be evaluated: Determine the full width at half maximum (FWHM) of the main peak. Assume the peak centre to beat the mean value of the positions of both peak sides at half maximum. Alter the scaling if necessary.

| hPa, air | peak/ height/ counts | FWHM | $x_1$/ch. # | $x_2$/ch. # | $(x_1+x_2)/2$/ch. |
|---|---|---|---|---|---|
| 11 | 260 | 11 | 2335 | 2346 | 2340.5 |
| 500 | 266 | 25 | 2144 | 2169 | 2156.5 |
| 1000 | 366 | 39 | 1937 | 1976 | 1956.5 |

Table 4: "Survey" read-outs for $^{241}\mathrm{Am}$ with $x_1$ position of left side of peak at half maximum and $x_2$ position of right side of peak at half maximum

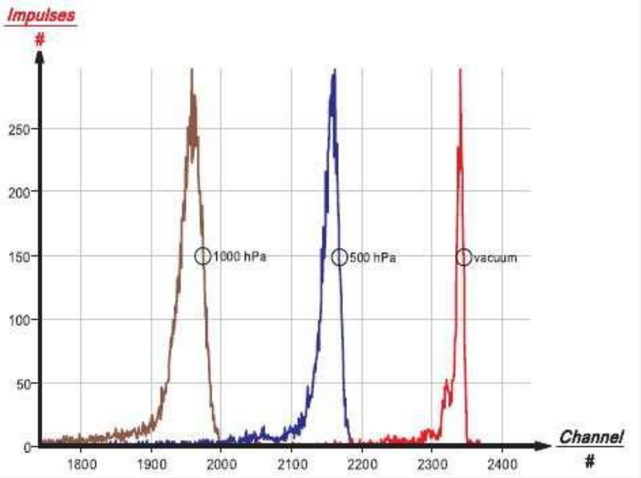


Fig. 5: Am-241 results

The MCA cuts an interval from $0\,\mathrm{V}$ to $4\,\mathrm{V}$ into 4000 equal intervals each assigned to a single channel, so each channel represents an interval of one $\mathrm{mV}$. The offset function shifts the whole $4$-$\mathrm{V}$-interval about the specified percentage of $4\,\mathrm{V}$. For example the offset $5\,\%$ means that the measuring interval begins at $0.050 \cdot 4.000\,\mathrm{V} = 0.200\,\mathrm{V}$. Then the zero channel counts pulses between $0.1995\,\mathrm{V}$ and $0.2005\,\mathrm{V}$ and the 3999th channel counts pulses between $4.1935\,\mathrm{V} \ldots 4.2005\,\mathrm{V}$.

Here the offset setting was 5% and the main peak is at channel # $n = 2340.5$, then the original pulse height $P$ was:

$$P = 0.05 \cdot 4\,\mathrm{V} + 2340.5 \cdot 0.001\,\mathrm{V} = 2.5405\,\mathrm{V}$$

or

$$P = (n + 200) \cdot 1\,\mathrm{mV},$$

the number $200$ is $5\,\%$ of $4000$ channels.

With the $\alpha$-energy of $5486\,\mathrm{keV}$ given this yields a sensitivity $s$ of the detector set-up of

$$s = \frac{2.5405\,\mathrm{mV}}{5486\,\mathrm{keV}} = 0.4631\,\frac{\mathrm{mV}}{\mathrm{keV}}$$

as calibration factor. The energy $E$ corresponding to a channel number $n$ is then

$$E = \frac{(n+2)}{s}$$

The dependence of the peak width $\sigma$ on mean energy loss $\Delta E$ shows Table 5 and Fig. 7 is a graphic plot of these data.

| peak ch. # | $\Delta$ ch. | $\Delta E$ /keV | $\sigma$ /ch. | $\sigma$ /keV |
|---|---|---|---|---|
| 2340.5 | 0 | 0 | 11 | 23.8 |
| 2156.5 | -184 | 397.3 | 25 | 54.0 |
| 1956.5 | -384 | 829.2 | 39 | 84.2 |

Table 5: Peak width in dependence on energy loss

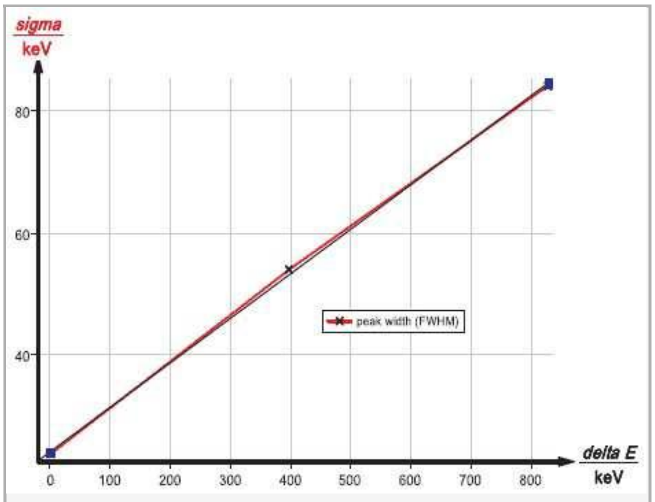


Fig. 6: Peak width in dependence on energy loss

The line of best fit is

$$\sigma = 0.073 \cdot \Delta E + 24.2\,\mathrm{keV}$$

where the $24.2\,\mathrm{keV}$ are due to the limiting resolution of the detector.

Fig. 7 shows a spectrum of the $\alpha$-emissions of the ^^{226}\textrm{Ra} source combined with the $^{241}\mathrm{Am}$ results. Use the "measure" function "Analysis" > "Smooth..." to obtain a curve where you can evaluate the peak positions and peak width more ease. Four lines can be evaluated. The whole line profile is visible as one line. Table 6 summarises the results.

| $n$/ Ch. # | $E$/keV | Literature value/keV | energy loss $\Delta E$ /keV | peak dis-placement/ channels |
|---|---|---|---|---|
| 2897 | 6688 | 7687 | 999 | 463 |
| 2027 | 4809 | 6002 | 1193 | 552 |
| 1744 | 41988 | 5489 | 1291 | 598 |
| 1407 | 3470 | 4784 | 1314 | 608 |

Table 6: Example of measurement results

The peak width FWHM of the peak with the highest energy was 211 channels or $456\,\mathrm{keV}$. On the other side if the mean energy loss of $999\,\mathrm{keV}$ was equal for all $\alpha$-particles, this would result in a peak width according to (*) of $97\,\mathrm{keV}$ or 45 channels.

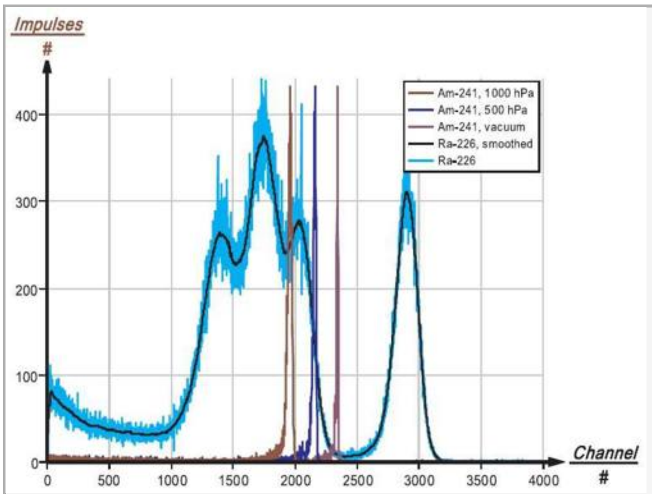


Fig. 7: Ra-226 spectrum example with Am-241 peak positions as reference

A peak width of about 166 channels or $358\,\mathrm{keV}$ is due to layer thickness of the layer containing the nuclides. So if same density of material is assumed for nuclide containing metal and cover, the layer containing the nuclides has about $36\,\%$ the thickness of the cover.

As the values for the energy loss show, the assumption of linearity of energy loss with layer thickness or the energy independence of energy loss rate is only very roughly fulfilled. A deviation of $30\,\%$ is observed over the energy range of the measurement. A displacement of the daughter nuclides by recoil inside the source can be excluded because the $\alpha$-particles from the daughter nuclides show less loss.

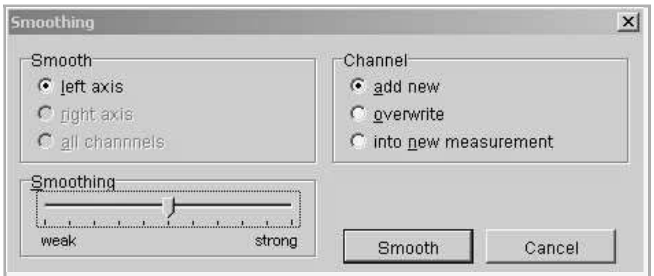


Fig. 8: "Smooth" dialog box