Spectroscopy of alpha and gamma particles using solid-state detectors

Presented by

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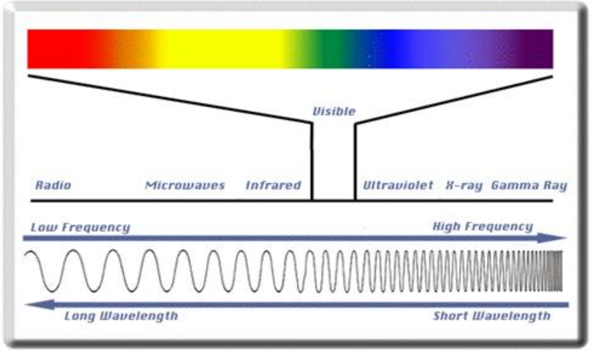
Alpha and Gamma Particles



- Gamma radiation or simply gamma ray, is electromagnetic radiation of very short wavelength, high energy frequency and no electric charge.
- Typical gamma ray frequencies, energies and wavelengths are around 10 exahertz Hz, 100 keV and10 pico-meters, respectively.
- Gamma rays frequently accompany alpha and beta radiation emissions
- Alpha particles have positive charge, two protons and two neutrons (helium -4 nucleus), commonly produced during alpha decay of radioactive isotopes
- Alpha particles are relatively heavy and slow moving, compared to γ-rays
- Scintillation and solid-state detectors are efficient in extraction of details required for energy measurements in γ-ray spectroscopy

Solid-state detectors: γ-rays

Detectors register energy spectra of radiation incident on their sensitive volume, where signal outputs are proportional to energy of the radiation

High purity Germanium (HPGe) detectors

- Best solution for precise γ- and X-ray spectroscopy
- More efficient than silicon detectors due to higher atomic number and lesser energy required to create an electron-hole pair (2.9 vs 3.6 eV)
- Highest resolution commonly available.
- Requires thermal cooling (N_2 @ -196°C) to prevent thermal excitation (generation of charge carriers) due to low band-gap energy (0.67 eV)

Solid-state detectors: α-particles

Si diode detectors

- Alpha spectroscopy is used to identify/qualify radionuclides based on α-particles emitted in the decay process.
- PIN-type Si diodes operating in reverse direction are used as counters
- Requires vacuum to prevent energy losses due to interaction with air molecules, resulting in degradation of *energy resolution* of the detector

Ge(Li) γ-rays detector

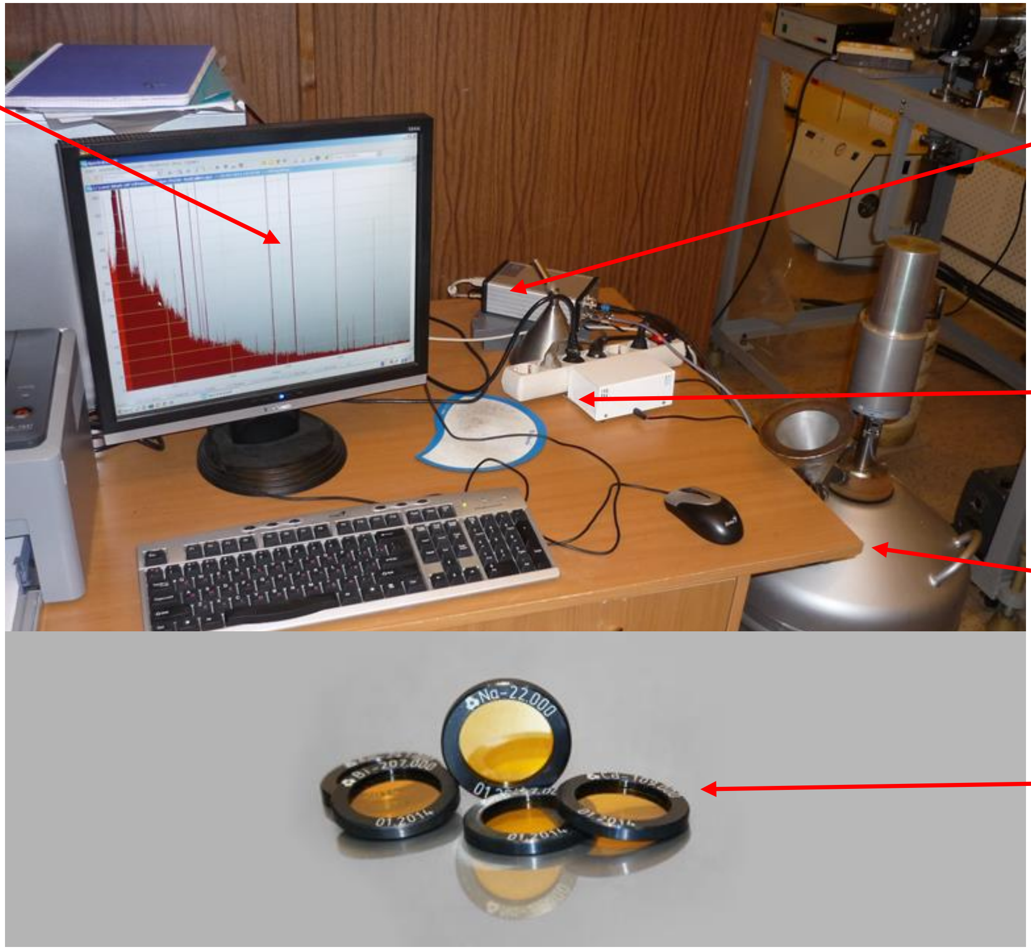
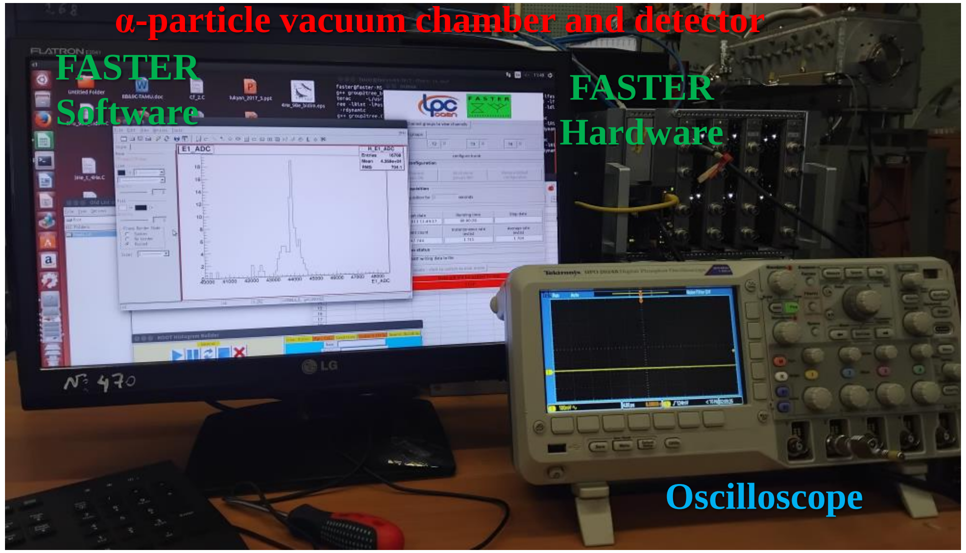


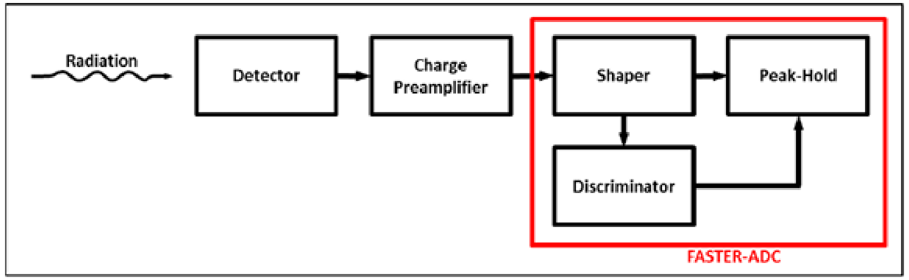
Figure 1: (a) Ge(Li) detector (a)workstation utilising GammaMCA software for real-time and offline viewing of γ-ray energy spectra and (b) γ radiation calibration sources

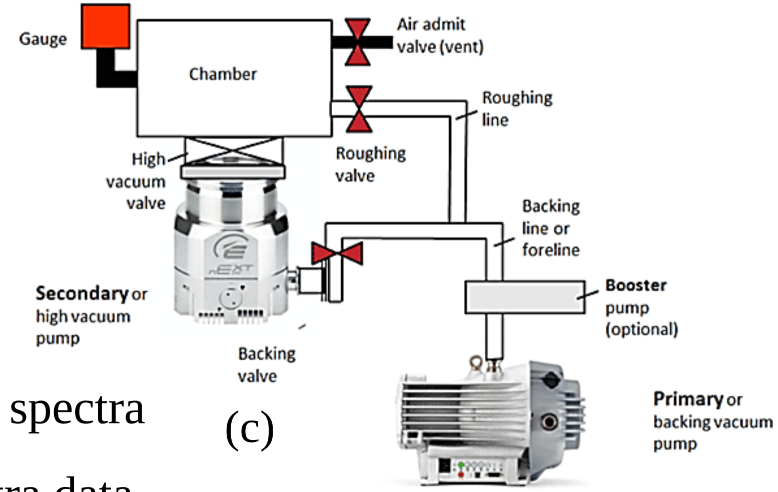
Si detector α-particle Spectrometry

(a)



(b)



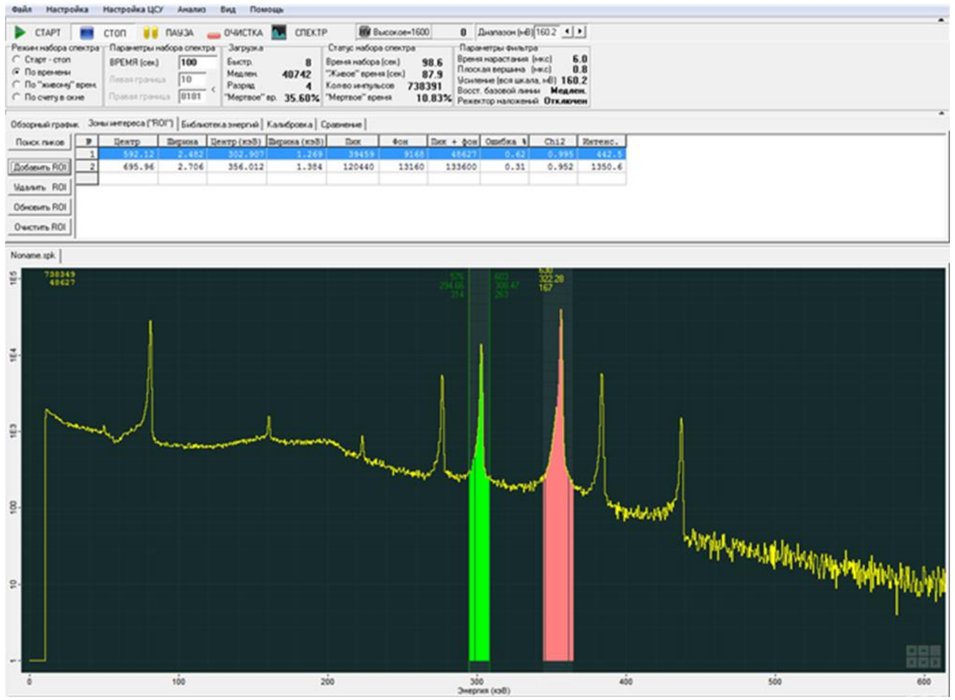


(c)

- FASTER-ADC module contains all modules shown in **Figure 2(b)**
- FASTER software for real-time/online viewing of α-particle energy spectra
- CERN Root is used for offline processing of α-particle energy spectra data

Figure 2: Si detector (a)workstation utilising FASTER hardware (ADC module) and software and oscilloscope, (b)essential hardware modules for electronic signal processing and (c)schematic of detector vacuum pump.

Calibration of the Ge(Li) γ-rays detector



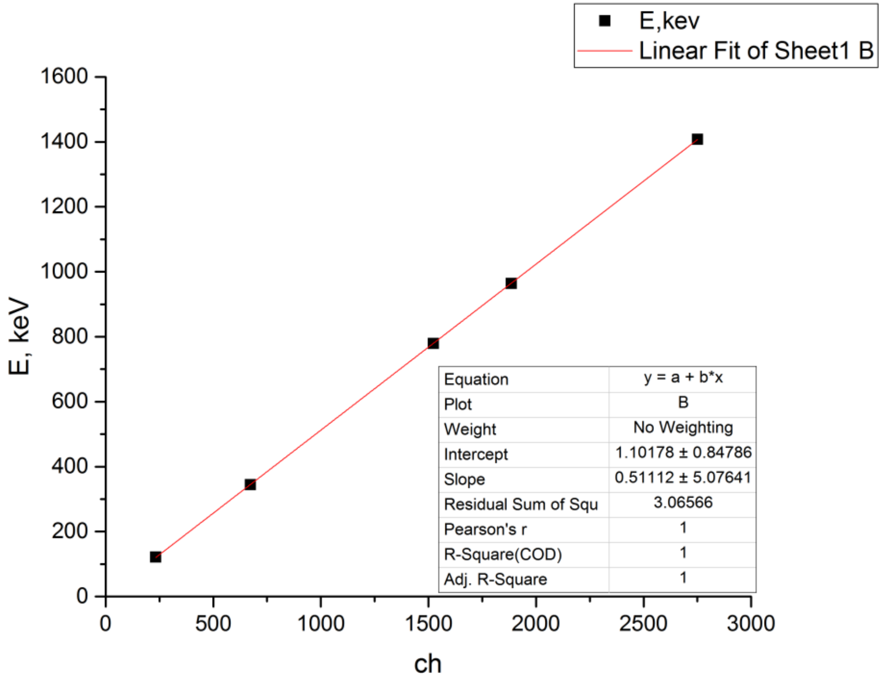
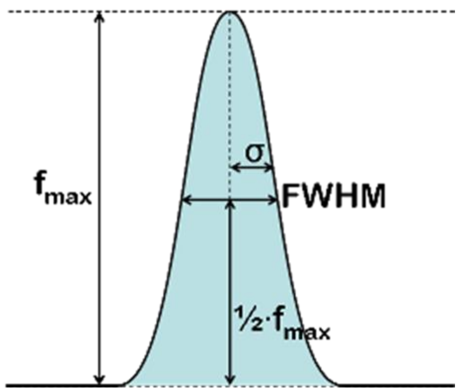


Figure 3: (a)GammaMCA program and (b)calibration line in Origin, where E is energy (keV), D is channels.

Energy resolution of solid-state detectors

- Energy resolution relates to ability of a detection system to distinguish between two adjacent energy peaks, specified in terms of full width at half maximum height (FWHM) of the energy spectrum.

(a)



(b)

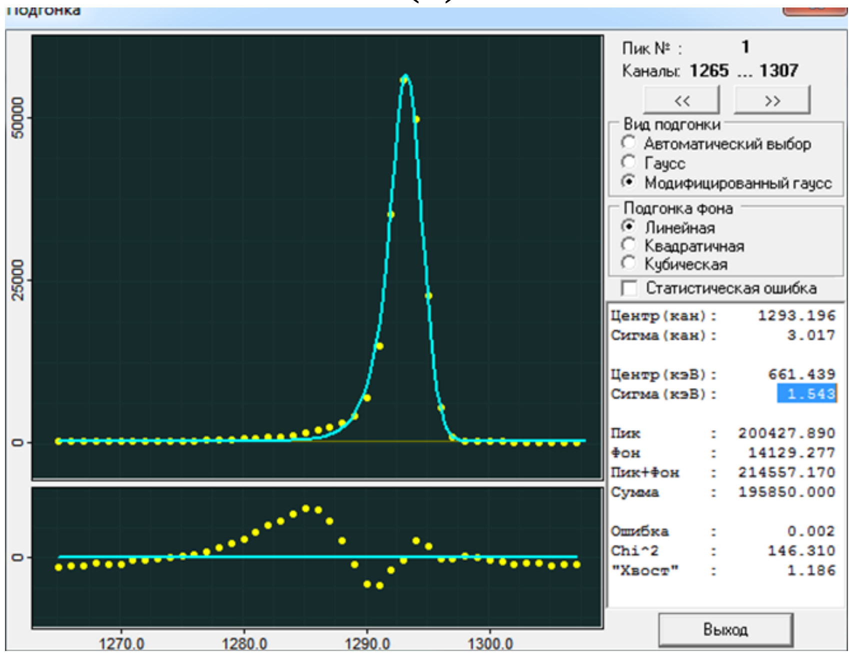


Figure 4: Energy resolution determination ((a), (b) graphical and analytical methods)

Energy efficiency of γ-rays detectors

- Efficiency of a γ-ray detector relates to its ability to accurately detect and measure gamma radiation. Efficiency is defined as the ratio of detected γ-rays to total γ-rays emitted by source and determined by:

$$\boldsymbol{\varepsilon(E_i) = \frac{N}{A_0^{tk} q t m K_C}}$$

q – Gamma-photon output per one act of beta decay

t - Time of measurement

m - Mass of the source

N - Number of counts in the spectrum over time t

Kc - Coefficient of radiation self-absorption

A_0^{tk} - Attestation value of specific activity of source at time of measurement

$$\boldsymbol{A_0^{tk} = A_0 e^{-0.693(t_0 - t_k)/t_{1/2}}}$$

A_0 - Specific activity at the time of certification

$(t_0 - t_k)$ - Time period from certification to the measurement

$t_{1/2}$ - Half life

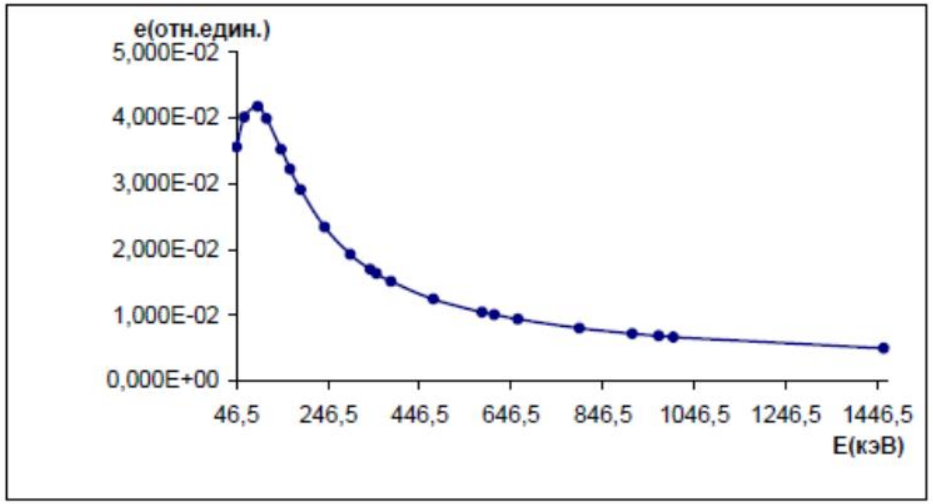


Figure 4: Variation of efficiency with energy

Energy spectrum of Eu-152 as registered by a Ge(Li) detector

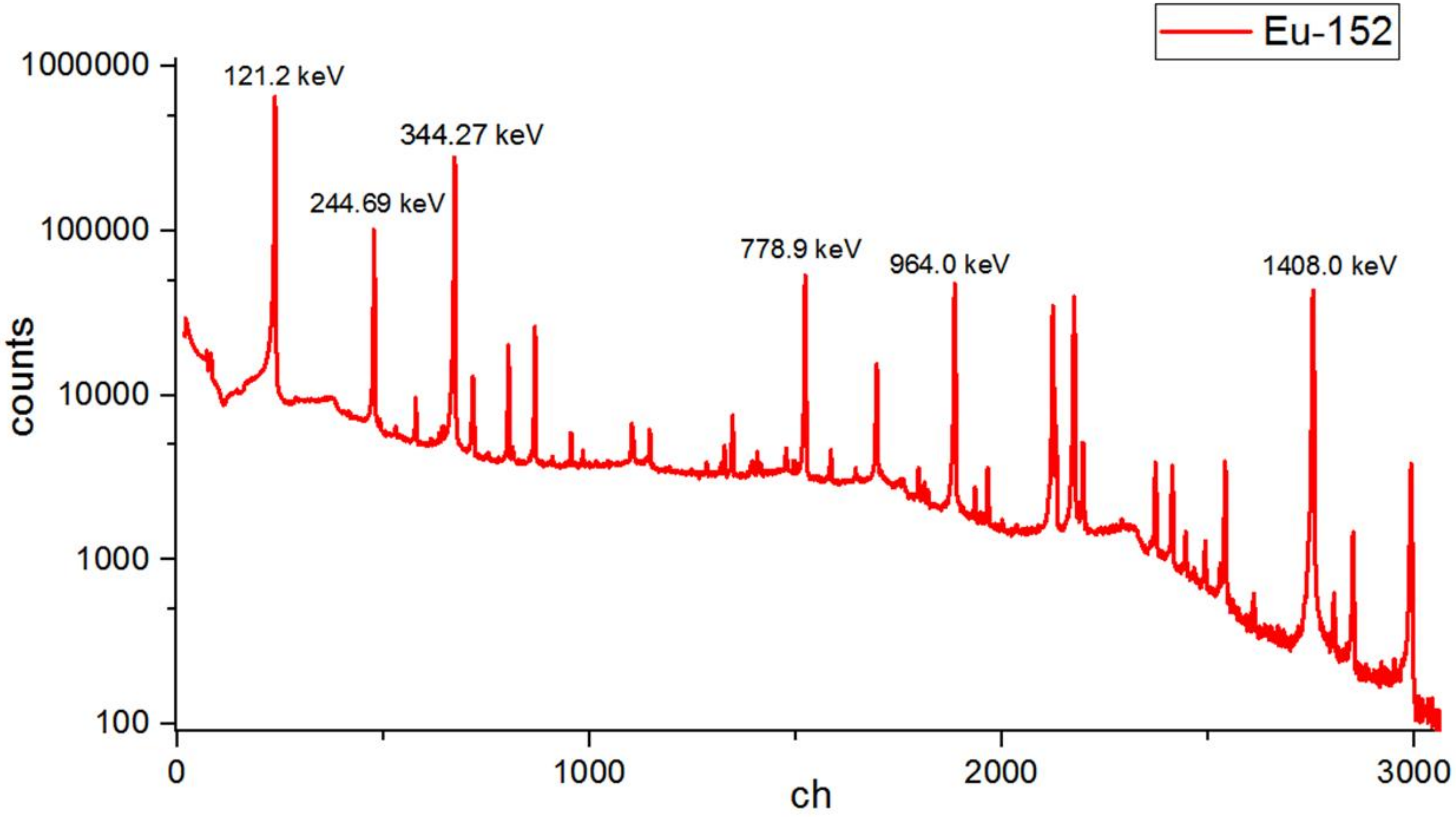


Figure 5: 152-Eu energy spectrum registered by a Ge(Li) detector showing energy in keV

Other solid-state γ-rays detectors

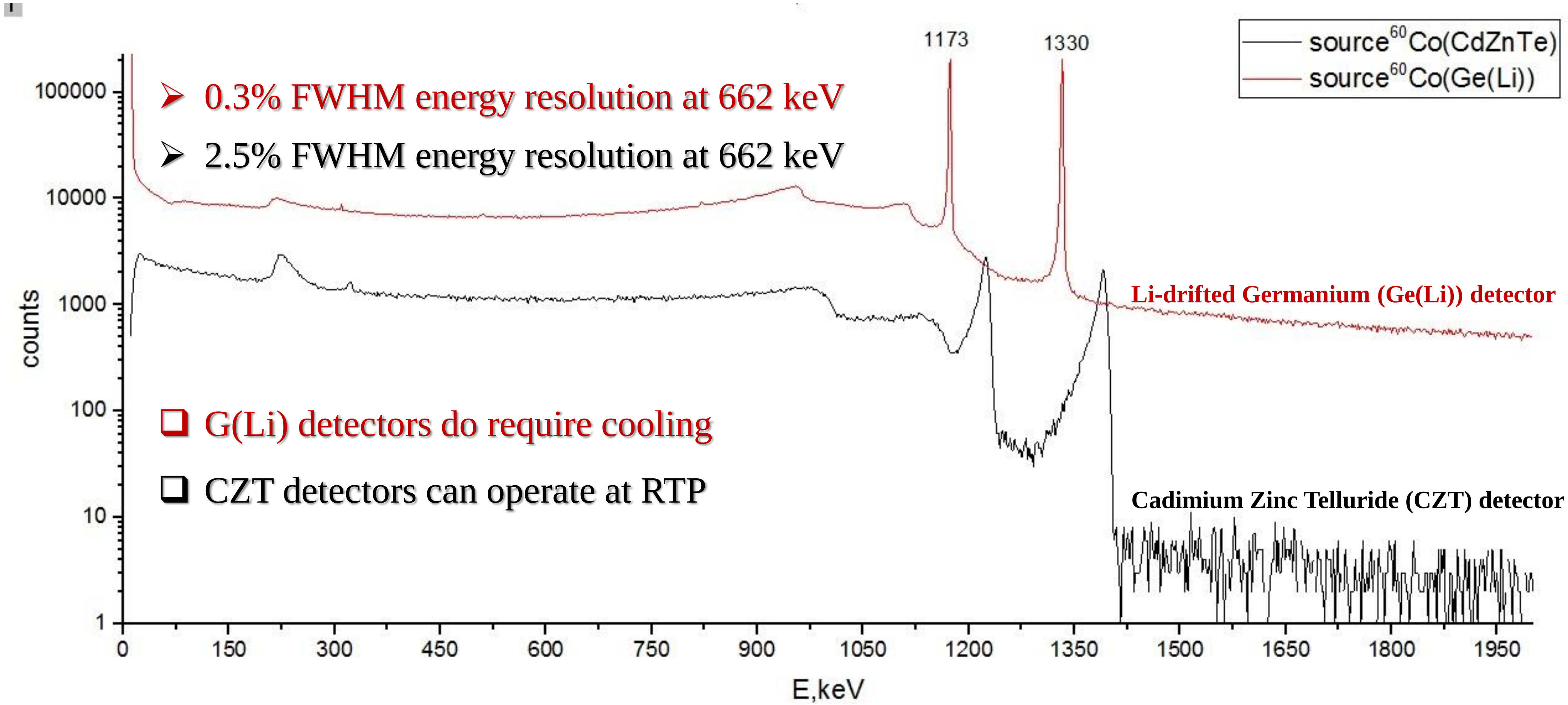
Cadmium Zinc Telluride (CdZnTe or CZT) detector

- Used in X-ray and γ-ray detection systems, laser optical modulation, high-performance solar cells
- CZT detectors have inferior energy resolution and efficiency, compared to Ge(Li) γ-ray detectors

(a) (b)

Figure 5: Zinc Cadimium Telluride (CTZ) (a)wafer, (b)compact detector for γ-rays detection

Energy resolution of different solid-state detectors



- ➢ 0.3% FWHM energy resolution at 662 keV
- ➢ 2.5% FWHM energy resolution at 662 keV

- ❑ G(Li) detectors do require cooling
- ❑ CZT detectors can operate at RTP

Figure 6: Comparison of energy resolution of a Ge(Li) detector to that of a CZT detector using Co-60 source

Unknown radioactive source identification by γ-ray spectrum

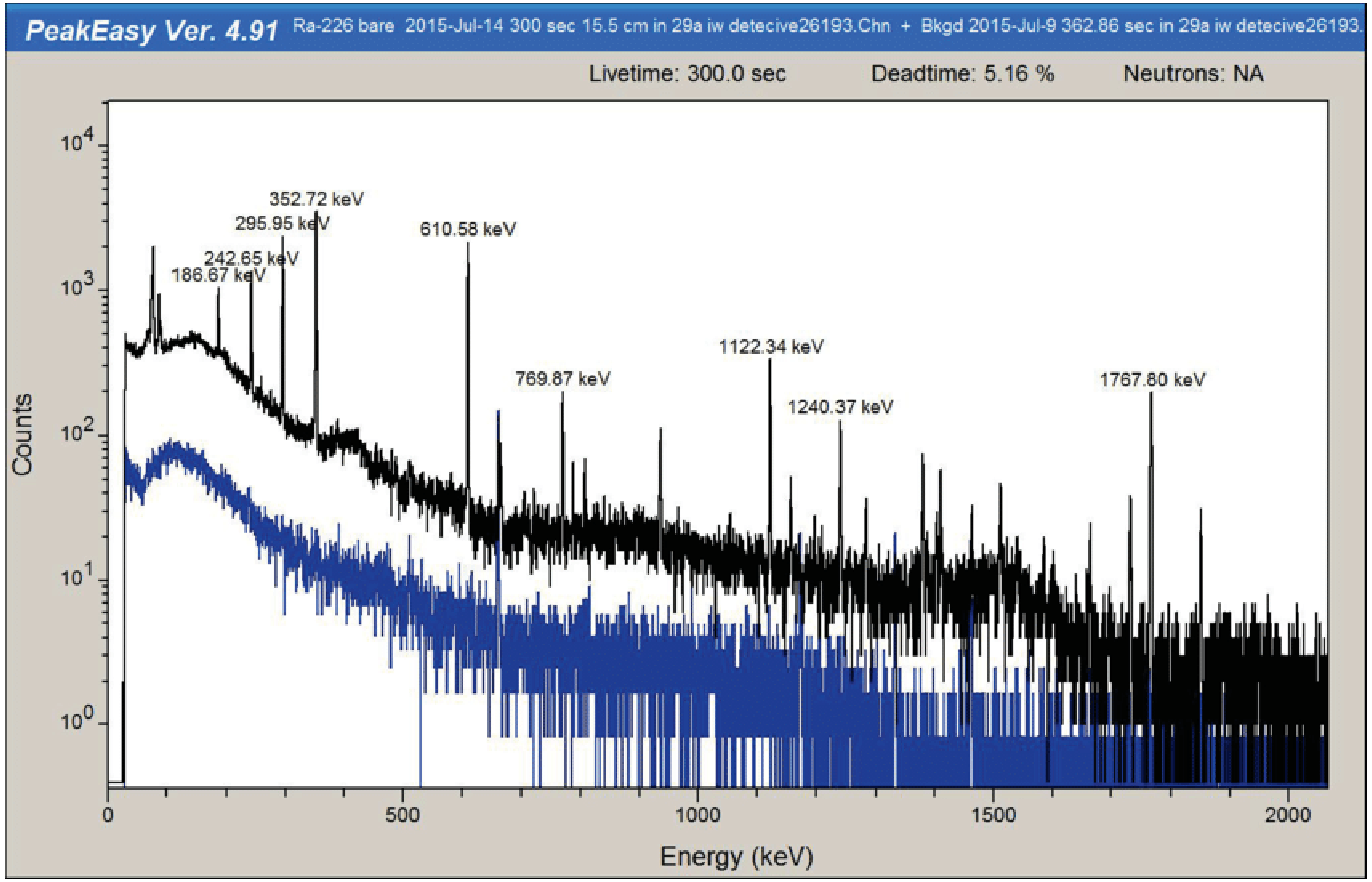
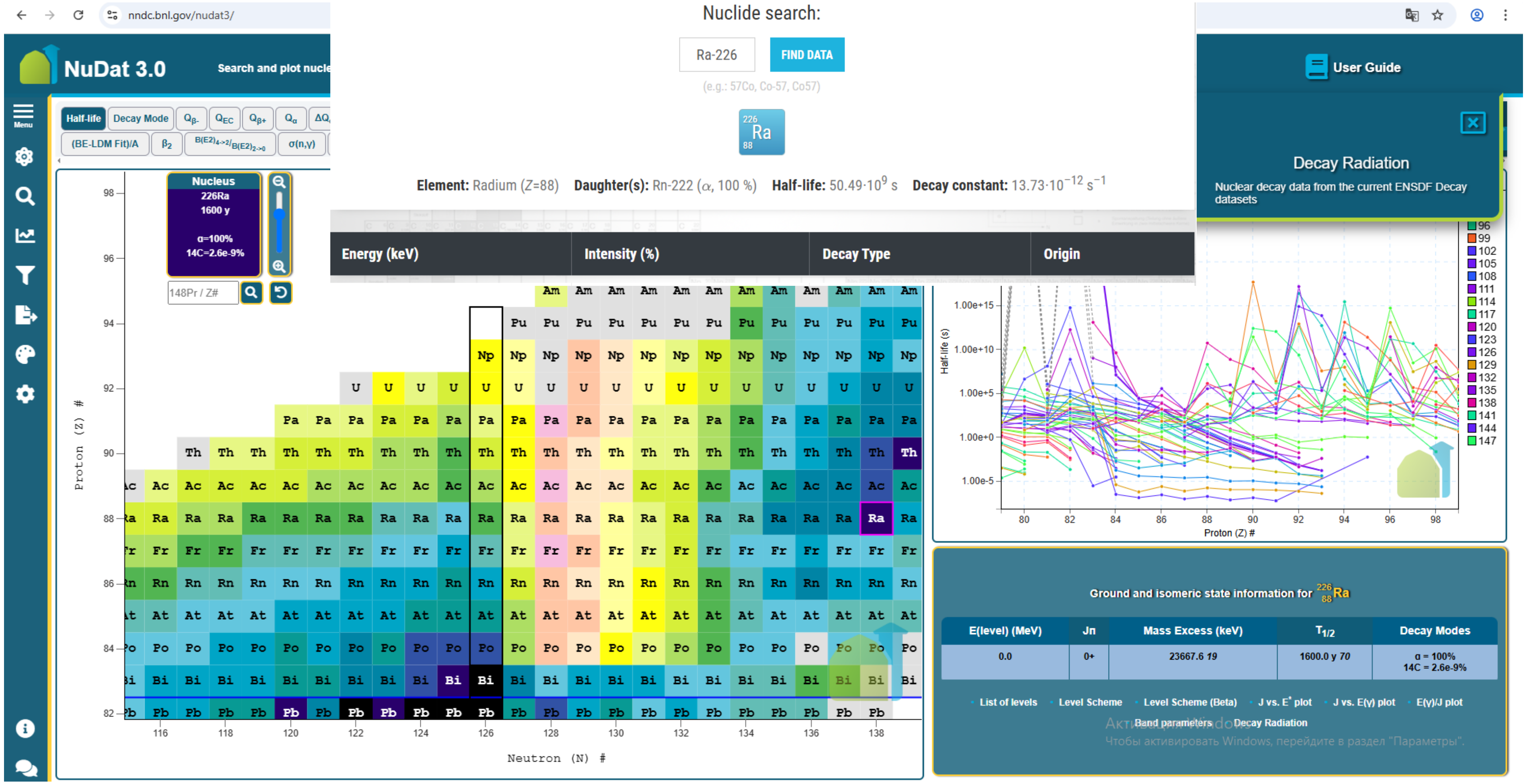


Figure 7: Spectrum of an unknown isotope and γ-ray radiation source.

Solid-state γ-ray detectors - Data Tables



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iThemba LABS Laboratory for Accelerator Based Sciences

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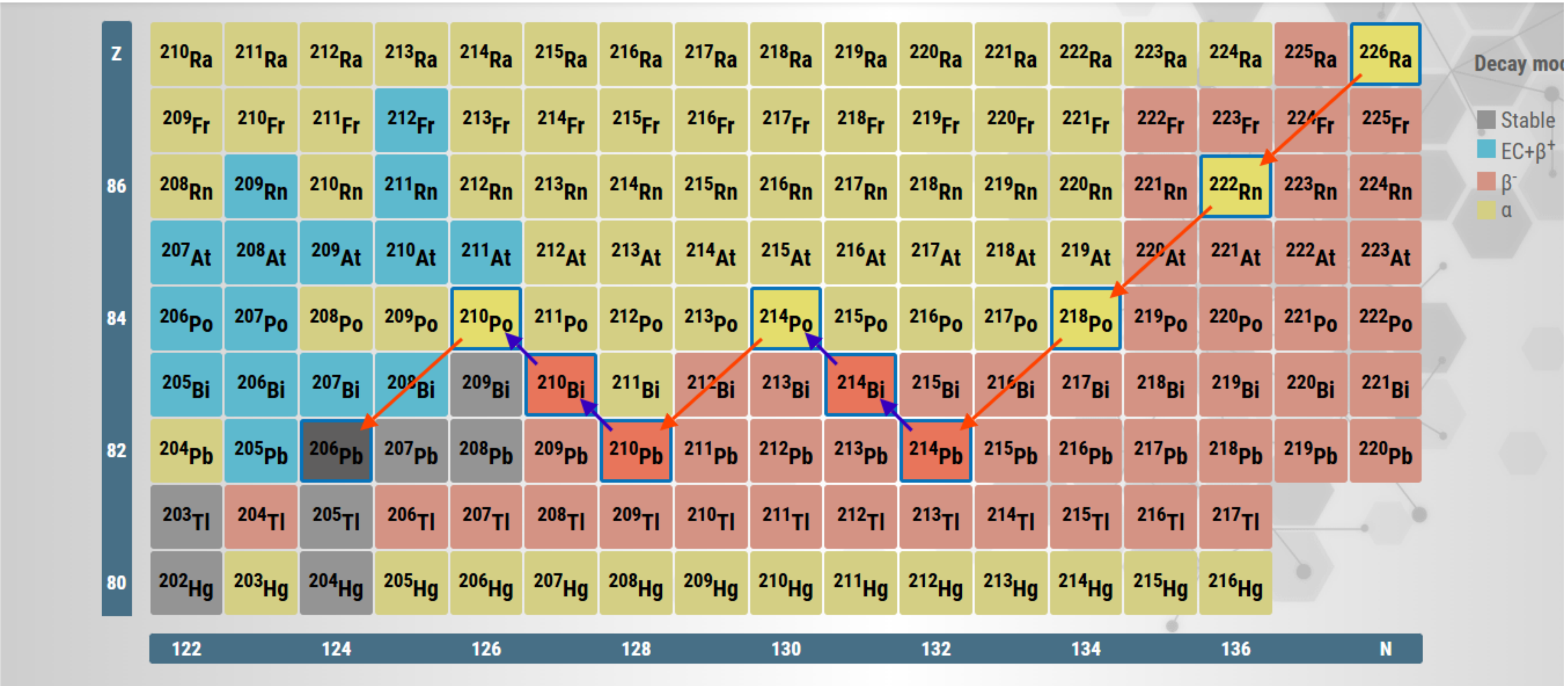
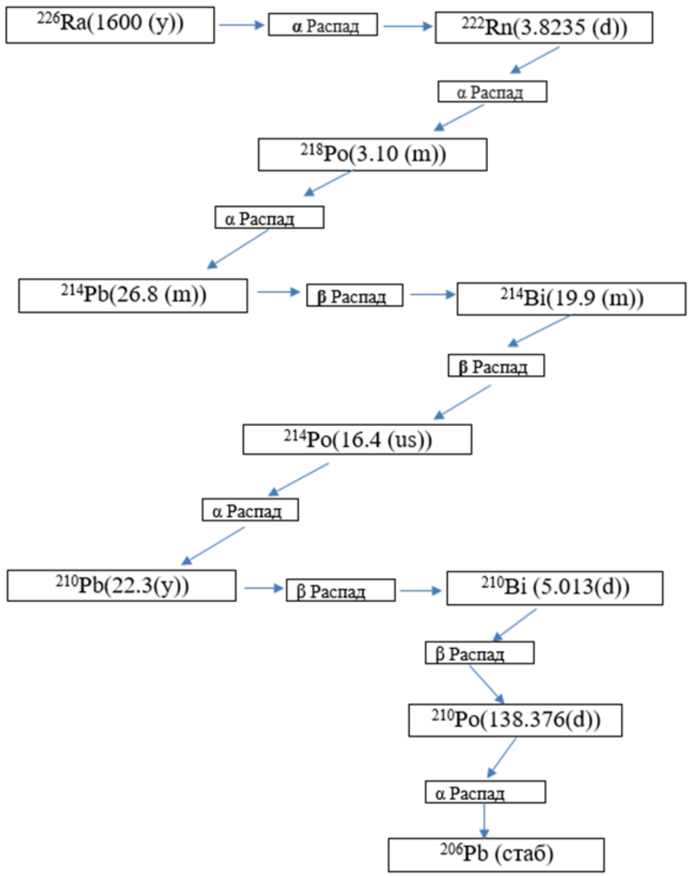


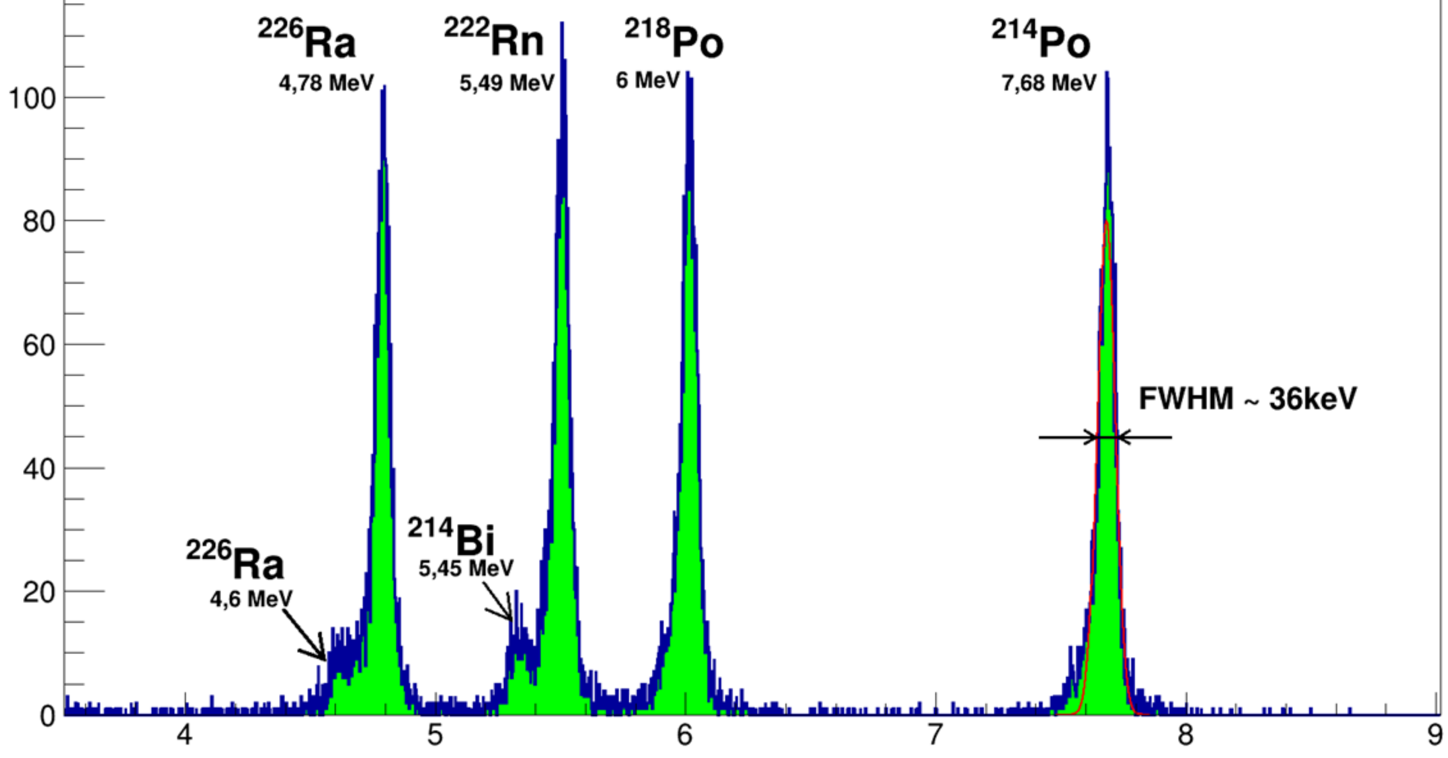


- Ra-226, Pb-214 and Bi-214 isotopes were identified (from chart of nuclides search).
- Using data from NuDat 3 website, decay chain of the unknown source was restored and the initial isotope defined as **Ra-226**

Ra-226 decay chain:

$$^{226}_{88}Ra \xrightarrow{\alpha} {}^{222}_{86}Rn \xrightarrow{\alpha} {}^{218}_{84}Po \xrightarrow{\alpha} {}^{214}_{82}Pb \xrightarrow{\beta^-} {}^{214}_{83}Bi \xrightarrow{\beta^-} {}^{214}_{84}Po \xrightarrow{\alpha} {}^{210}_{82}Pb \xrightarrow{\beta^-} {}^{210}_{83}Bi \xrightarrow{\beta^-} {}^{210}_{84}Po \xrightarrow{\alpha} {}^{206}_{82}Pb$$

Utilising α-spectroscopy to ascertain results obtained from γ-ray spectroscopy



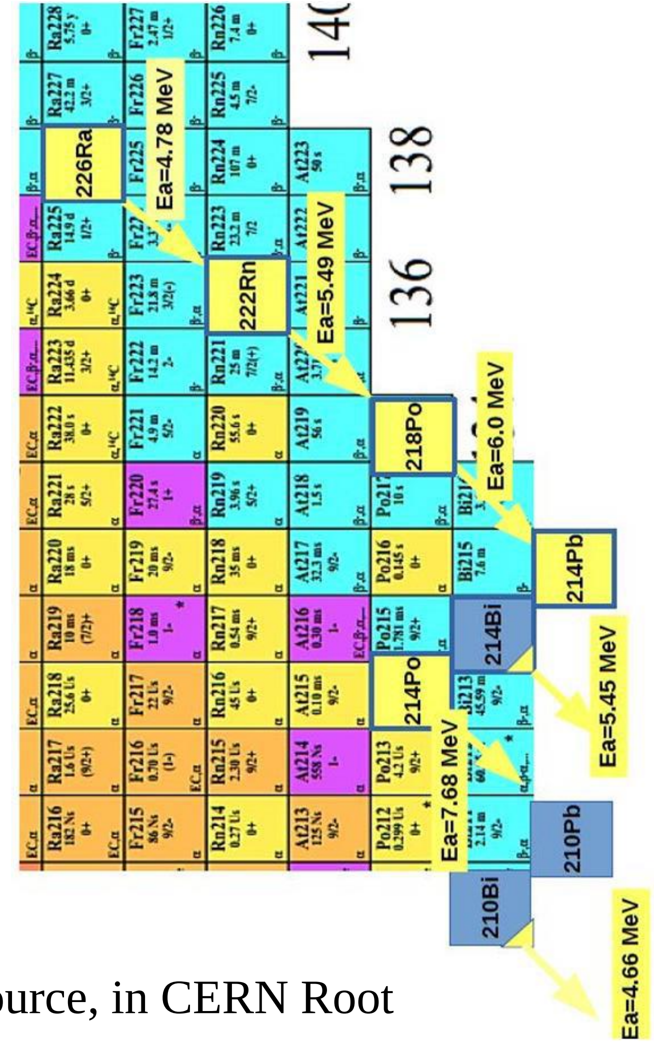


Figure 8: Energy spectrum of emitted α-particles from the unknown source, in CERN Root

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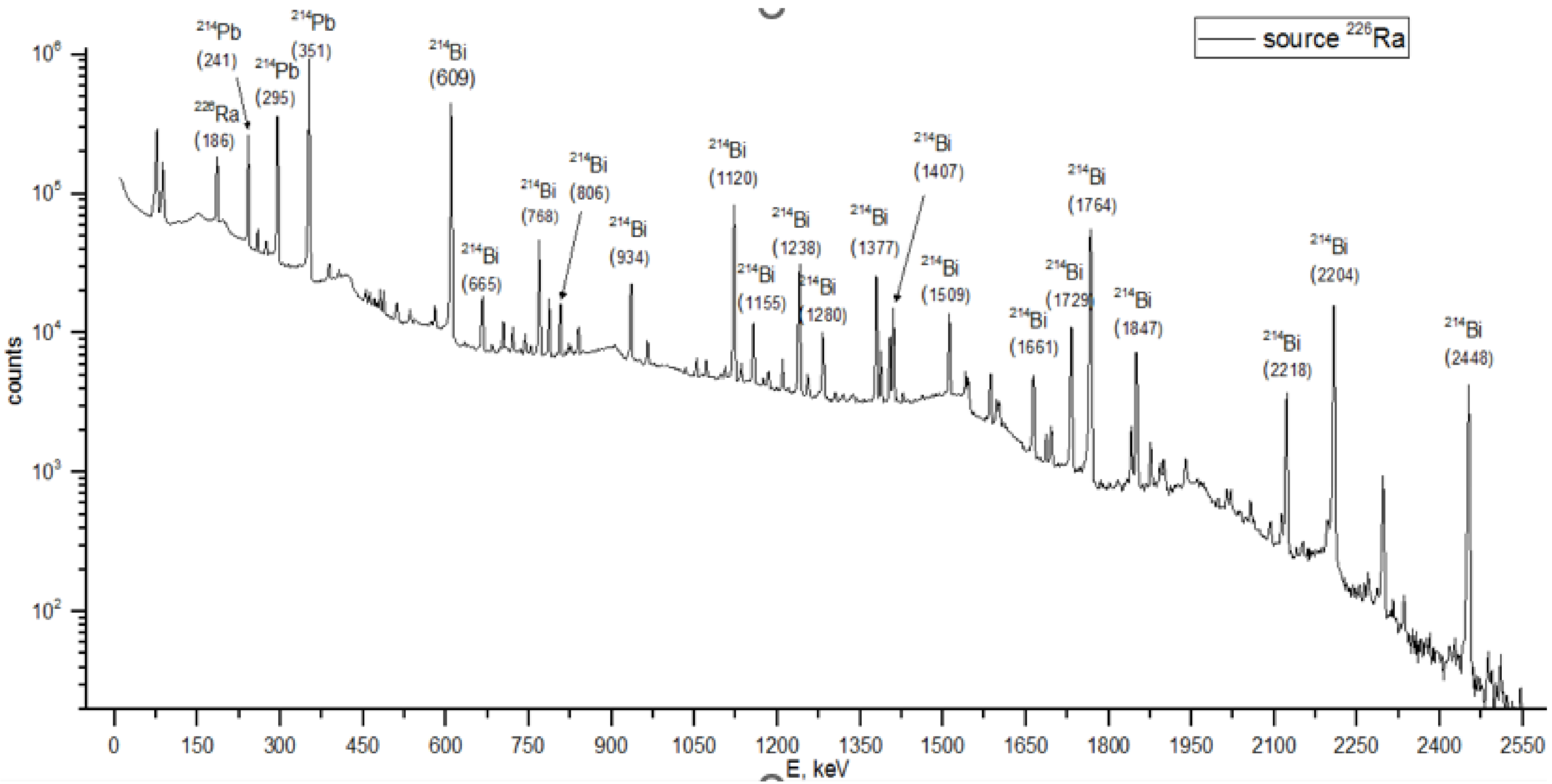


Figure 9: Identity and energy spectrum of the unknown isotope and radiation source

Example of α-spectroscopy application

- Measurement of target film thickness using the ionisation energy loss (Eloss) and material properties

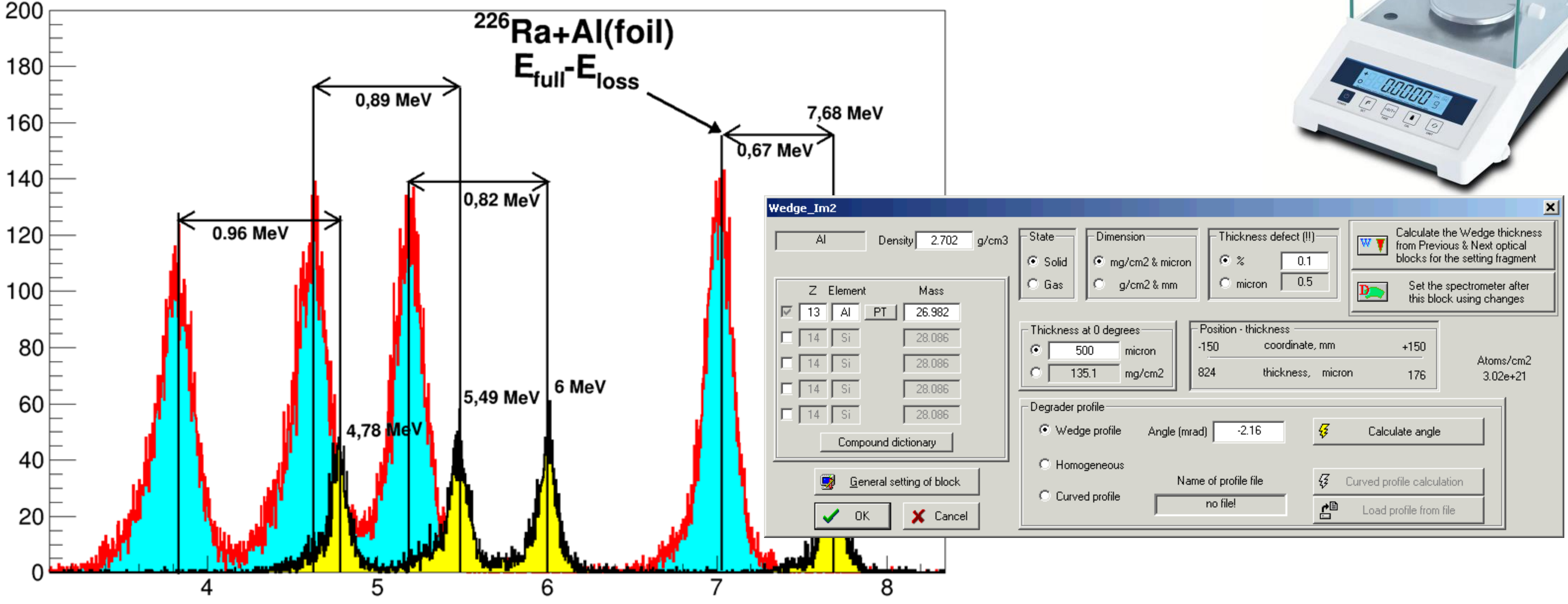
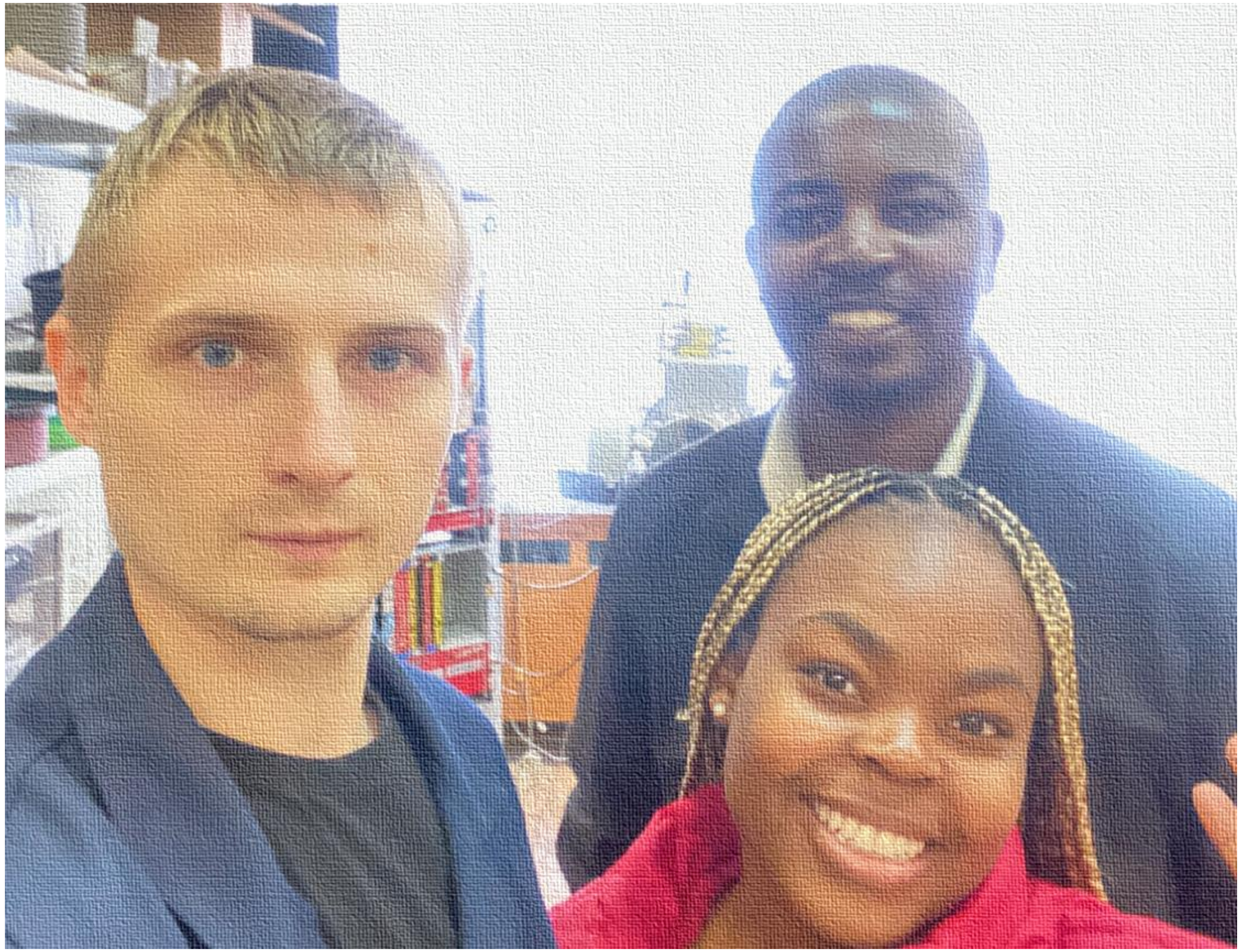


Figure 10: Energy loss calculation/foil thickness using Lise++ software

THANK YOU



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