

**Joint Institute for Nuclear Research  
Flerov Laboratory of Nuclear Reactions  
University Center**

***LABORATORY WORK***

**Ge(Li)-detector for energy measurements of gamma-activity**

**2014**

## §1 Introduction

Invention of semiconductor detectors of nuclear radiation in the 1960s became a milestone in the development of experimental nuclear physics. Currently, detectors take the leading position among other instruments detecting radiation. A semiconductor detector is a solid-state alternative to an ionization chamber. It has several great advantages over the other types of detectors, the most important of which is high resolution. Among the other advantages of semiconductor detectors one should note: linearity over a wide energy range, low pulse rise time, relative simplicity and small size, and insensitivity to magnetic fields. The first detectors were used for detection of heavy charged particles, their use immediately led to advances in the study of nuclear reactions. Mastering the process of lithium drifting in silicon and germanium has made it possible to produce large volume detectors. Such Ge(Li) detectors were used in the study of high-energy particle spectra and in electron spectroscopy. Application of lithium-drifting-in-germanium technique has led to the creation of large detectors suitable for detecting gamma-rays.

Further on, the technique of purification of silicon and germanium crystals from impurities was developed, which led to the emergence of high-pure crystals. These crystals were used in the so-called HP-detectors (HP - high pure). Such detectors do not contain lithium and can be stored at room temperature; however, when detecting gamma-photons and particles, they have to be cooled.

Nowadays, semiconductor detectors have virtually replaced scintillation crystals in the field of spectroscopy.

There are diffused, surface-barrier and drift detectors.

The thickness of the sensitive layer of diffused and surface-barrier detectors is limited by the specific resistance of the materials applied. In order to register gamma-photons and high-energy particles with low ionizing properties, both of the above-mentioned types of detectors are unsuitable. In order to obtain large carrier-depleted volumes, Pell in 1960 proposed a method for compensation of impurity carriers with lithium ions. The lithium donor ions relatively easily diffuse into Si and Ge and compensate the acceptors in the *p*-type material. The thickness of the depletion layer in such detectors depends on the drifting conditions (temperature, voltage applied to the sample, etc.). Currently, large Ge(Li) and HP Ge crystals with the sensitive layer volume of  $\sim 200 \text{ cm}^3$  and more have been obtained. The efficiency of such detectors for gamma-ray registration is comparable to the efficiency of scintillation crystals.

The main characteristics of the detectors are the detector response function, temporal characteristics, the energy resolution, and the detection efficiency.

## §2 Description of a Ge(Li) -gamma spectrometer

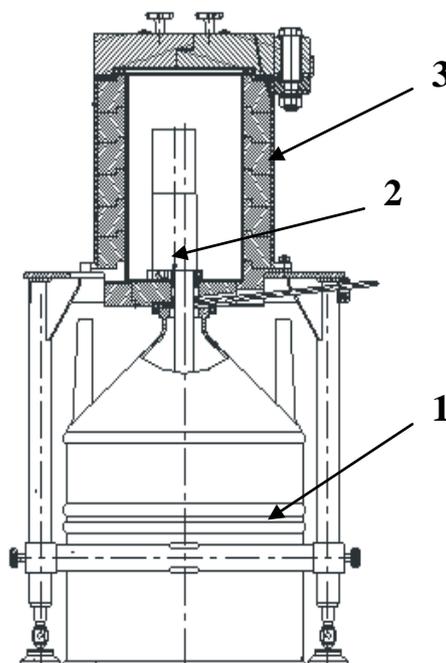
Germanium detectors are solid-state p-n junction-structure detectors, in which the built-in area is sensitive to ionizing radiation, especially to X-rays and gamma-rays.

Since germanium has a relatively low conduction band, these detectors have to be cooled to reduce heat generation of charge carriers in the acceptor layer. Otherwise, the interference created by the leakage current will lower the energy resolution of the detector. Liquid nitrogen, which has a temperature of  $77^0\text{K}$ , is a common cooling medium for such detectors. The detector is placed in a vacuum chamber, which is placed into the Dewar vessel. Thus, the sensitive surfaces of the detector are protected from moisture and condensible impurities.

The gamma-spectrometer comprises the following elements:

1. Itself, semiconductor detector;
2. Pre amplifier unit;
3. Data taking and spectra analyzing system.

The schematic representation of the detector is shown in Fig. 1

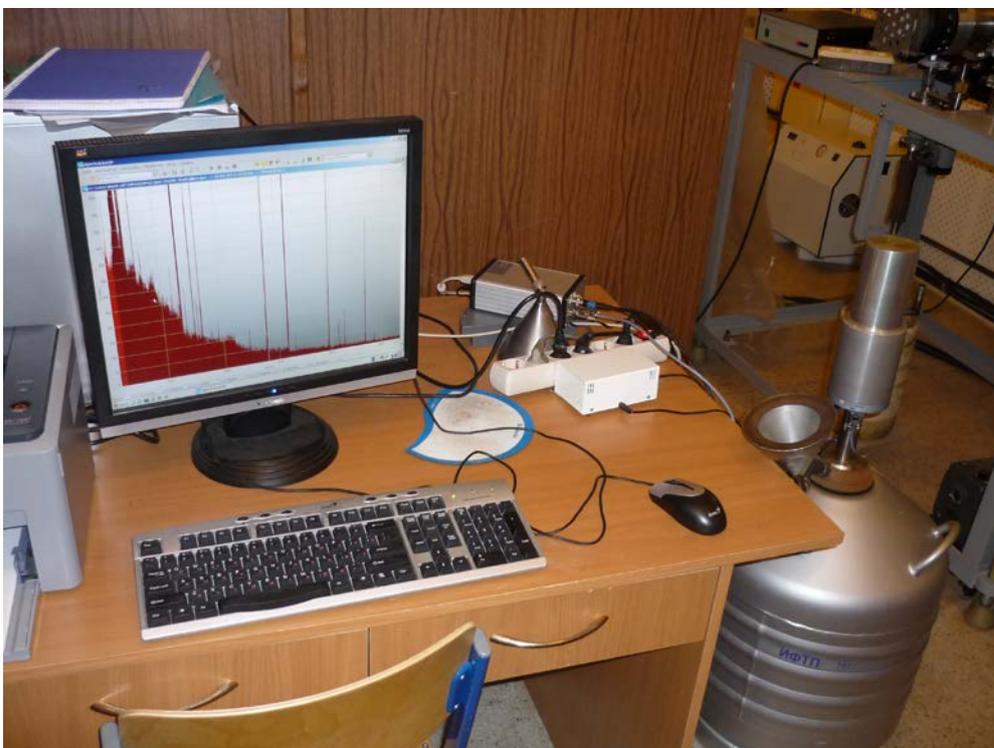


**Fig.1** Scheme of the spectrometer with a Ge(Li) detector

1) Dewar vessel, 2) Ge(Li) detector with a cryostat, 3) Lead shield.

Before starting the measurements, it is necessary to conduct the following:

1. Setting the parameters of the digital filter of the central control system (CCS).
2. Setting the supply voltages of the detector.
3. Saving and loading the CCS working modes.
4. Conditioning the end of data collection.
5. Start, stop and continuation of the spectrum data collection.
6. Saving and loading the spectrum from the disk.
7. Energy calibration.
8. Calculation of peak parameters in the predetermined regions.
9. Dead-time correction.



**Fig. 2** *General view of the Ge(Li) gamma spectrometer .*

### §3 Description of the Gamma MCA data collection (see APENDIX)

Gamma MCA allows following:

- View spectra with a possibility to choose linear or logarithmic scale; colour spectra; stretch and shrink spectra, both vertically and horizontally, and during data collection.
- Work with several (up to ten) spectra simultaneously.

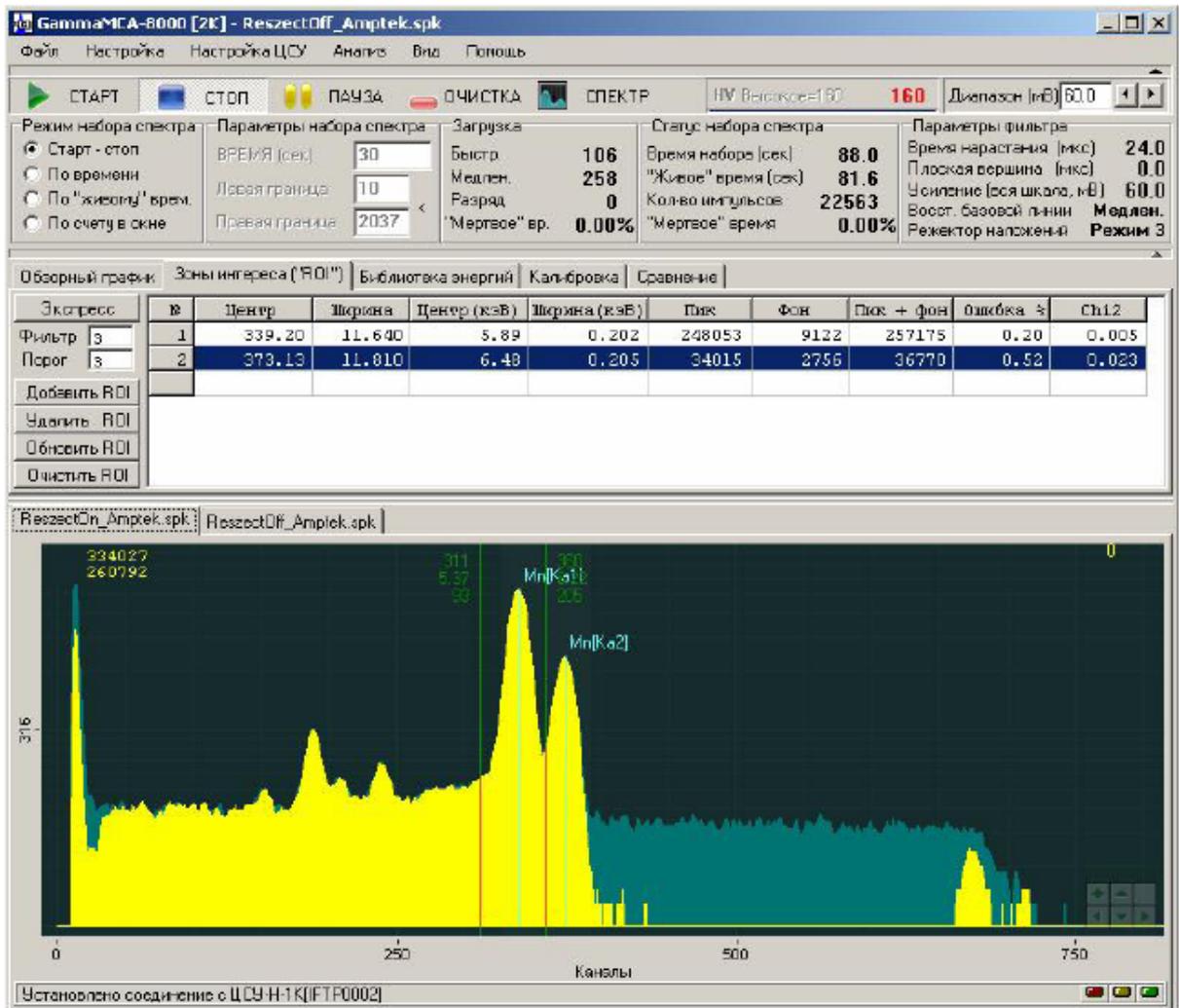
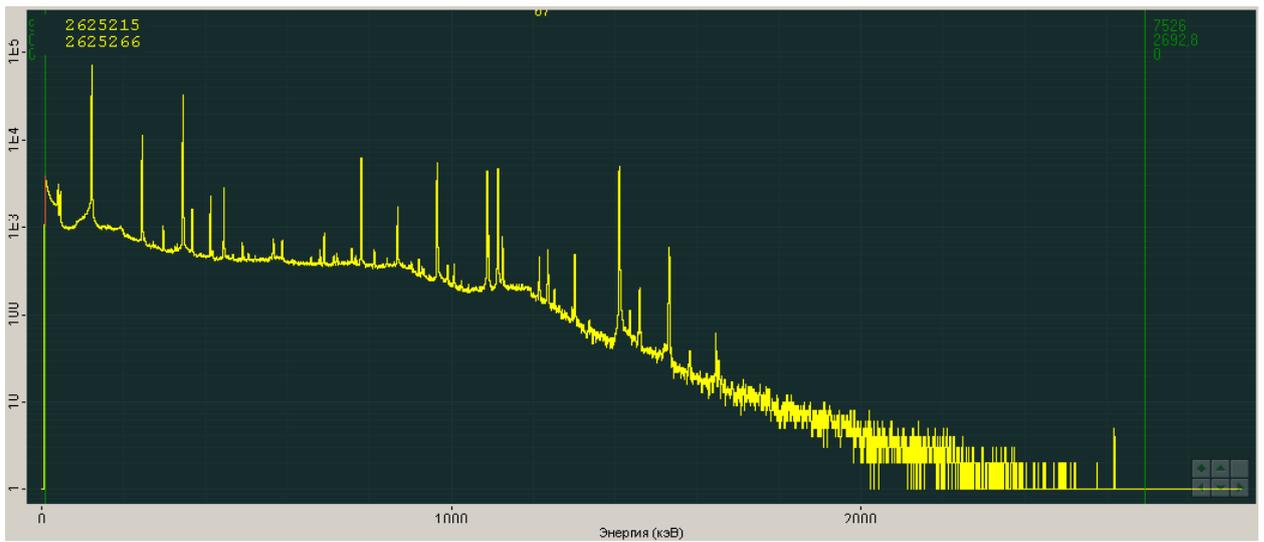
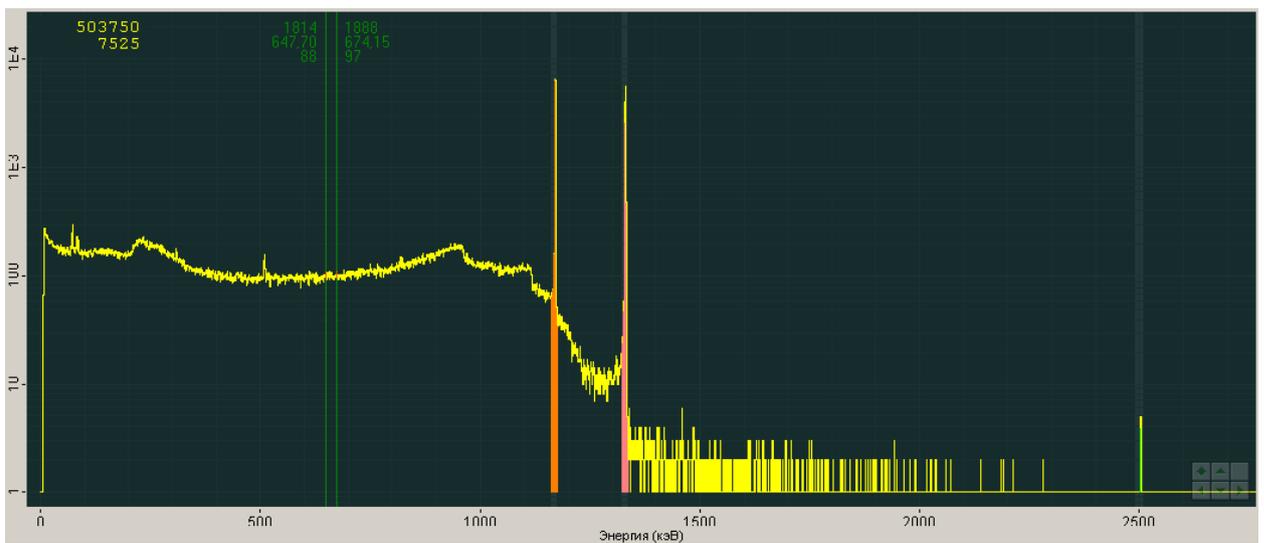


Fig.3 Screenshot of GammaMCA program

Fig. 4, 5 illustrate calibration spectra using various gamma sources ( $^{152}\text{Eu}$  or  $^{60}\text{Co}$ )



**Fig.4.** *Spectrum of the  $^{152}\text{Eu}$ -source*



**Fig.5.** *Spectrum of the  $^{60}\text{Co}$ -source*

## **§4 Instructions on how to do the laboratory work**

### Laboratory work

#### Part 1

#### *Energy Calibration and chose energy scale of the semiconductor gamma-spectrometer*

Purpose of work: to calibrate the energy and chose the scale of the Ge(Li) spectrometer

#### Equipment and tools:

1. spectrometric Ge(Li)- see Section 3)
2. a set of calibration sources based on  $^{152}\text{Eu}$ ,  $^{133}\text{Ba}$ ,  $^{241}\text{Am}$ ,  $^{137}\text{Cs}$ ,  $^{40}\text{K}$  (provided by a laboratory assistant) placed in a Marinelli geometry of 1 l, Marinelli of 0.35 l, Denta 0.1 l, Denta 0.04 l, Dent 0.02 l, Denta 0.015 l
3. a PC with the software package for processing gamma spectra
4. a log for registering information on gamma spectra, which should include:
  - information on the calibration source being used (number, composition, specific activity, density, date of certification, geometry of a count sample)
  - information on the measured calibration gamma-spectra (spectrum code, measurement date, start time, time of spectrum taking, total measurement time (min), detector number, geometry of a count sample, names of executives, notes)

#### Working procedure:

1. In the presence of a supervisor switch the power of the spectrometer on. Warm the device up during 10 minutes. Be sure the detector is rather well cooled: there no temperature prohibition signal.
2. Place the calibration source (provided by the supervisor) on the detector.
3. Switch the control computer on. Start the analyzer control programme.
4. Enter the name of the source, its characteristics, measurement date, names of executives in the register log.
5. Collect data on the spectrum.
6. For each source, it is necessary to measure the spectrum not less than 3 times.
7. Calculate the average peak position by three (or five) measurements of the spectrum (in the channels) for each gamma-line.
8. Using the Origin-Graph utility, plot the dependence  $n(E)$ , where  $n$  - the average peak

- position by three (five) measurements, channel. E – energy of the gamma-line, keV.
9. Using the package of approximation curves of the Origin programme, approximate the resulting dependence  $n(E)$ , calculate the approximation coefficients and the rms deviation of the theoretical curve from the experimentally obtained one.
  10. Write a progress report indicating the purpose of work and the sources used; attach the spectra and the graphs.
  11. Make conclusions.

#### Test questions

1. What is the point in the energy scale calibration of the spectrometer setup?
2. What are the main characteristics of the Ge(Li)-detector-based setup?

#### Part 2

##### *Measurement of the efficiency of the semiconductor spectrometer*

Purpose of work: to determine the efficiency of the semiconductor spectrometer.

#### Contents of work

The efficiency of the spectrometer is determined by the absolute-calibration sources. In this case, measures are taken to reduce the possibility of errors due to measurement techniques: the error of geometric reproducibility of measurement conditions is brought to a value of 0.1%.

The efficiency of detection of gamma-rays with energy  $E_i$  in predetermined conditions (geometry, sample) is defined by the formula:

$$\varepsilon(E_i) = \frac{N}{A_0^{tk} qtmK_c}$$

where  $A_0^{tk}$  - attestation value of the specific activity of the source at the time of measurement;

q – gamma-photon output per one act of beta decay (see the decay scheme of the calibration source)

t - time of measurement;

m - mass of the source;

N - number of counts in the spectrum over time t;

$K_c$  - the coefficient of radiation self-absorption.

Usually,  $\varepsilon(E_i)$  and  $K_c(E_i)$  are experimentally determined simultaneously

$$\varepsilon(E_i)K_c(E_i) = \frac{N_i}{A_0^{tk} qtm}$$

Value  $A_0^{tk}$  for a particular measurement is equal to:

$$A_0^{t_k} = A_0 e^{-0,693 (t_0 - t_k) / T_{1/2}}$$

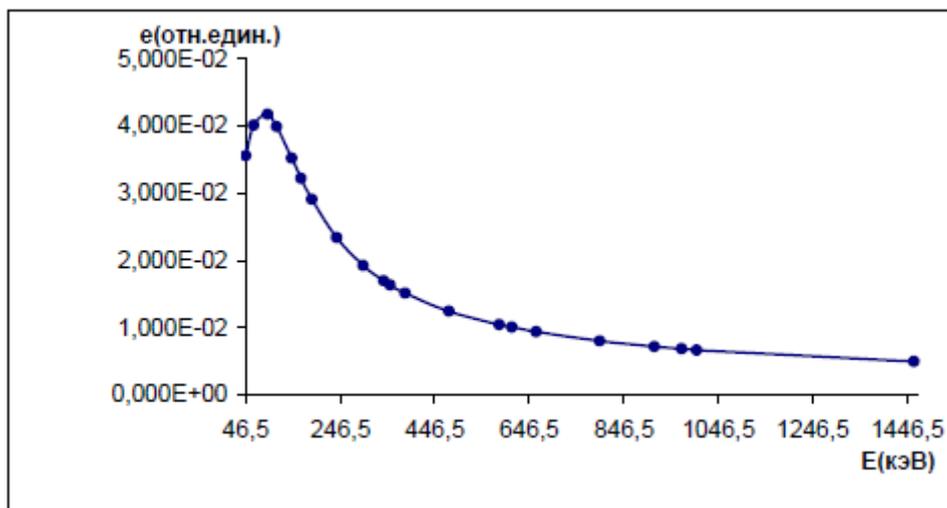
where  $A_0$  - specific activity at the time of certification;

$(t_0 - t_k)$  – time period from certification to the measurement;  $T_{1/2}$  – half life.

Next, the procedure of plotting an efficiency curve will be considered. The procedure of plotting the curve of efficiency dependence on energy  $E_i$  is performed in several stages. A set of standard (reference) sources of gamma-radiation, radionuclide fiducial markers, with a set of gamma-lines of different energies  $E_i$  (such as  $^{152}\text{Eu}$ ,  $^{133}\text{Ba}$ ,  $^{137}\text{Cs}$  and  $^{241}\text{Am}$ ) is used, for which the initial specific activity  $A_0$  is pre-determined (this specific activity is determined at the time of manufacturing). As a rule, the standard sources are in bulk or liquid state and are supplied on a centrally-controlled basis (All-Russian Scientific Research Institute for Physical-Technical and Radio-Technical Measurements, Mendelejevo village, Moscow region). They are put into the desired geometry, for which it is necessary to determine the efficiency of the count geometry depending on energy  $\varepsilon(E)$ . Next, it is necessary to measure the gamma-spectra of the standard sources, with the number of pulses (peak area) in each total absorption peak (TAP) being not less than 10000, which is required to minimize the statistical measurement error to  $\leq 1\%$ . The spectrum of each source is measured at least 5 times. The average efficiency for a given  $E_i$   $\varepsilon_i(E_i)$  is determined by averaging:

$$\overline{\varepsilon_i(E_i)} = \sum_{j=1}^5 \frac{\varepsilon_i(E_i)}{5}$$

After determining  $\varepsilon_i(E_i)$  for each peak of a particular spectrum, the curve of detector efficiency dependence on energy  $\varepsilon_i(E_i)$  is plotted graphically, and the obtained points are approximated by the analytic curve using the rms method.



**Fig.8.** Efficiency dependence on the energy.

#### Equipment and tools:

1. spectrometric Ge(Li)-detector based setup (for the description of the setup and the main characteristics, see above)
2. a set of calibration sources based on  $^{152}\text{Eu}$ ,  $^{133}\text{Ba}$ ,  $^{241}\text{Am}$ ,  $^{137}\text{Cs}$ ,  $^{40}\text{K}$  (provided by a laboratory a supervisor)
3. a log for registering information on gamma spectra, which should include:
  - information on the calibration source being used (number, composition, specific activity, density, date of certification, geometry of a count sample)
  - information on the measured calibration gamma-spectra (spectrum code, measurement date, start time, time of spectrum taking, total measurement time (min), detector number, geometry of a count sample, names of executives, notes)

#### Working procedure:

1. In the presence of a supervisor switch the power of the spectrometer on. Warm the device up during 10 minutes.
2. Place the calibration source (provided by the supervisor) on the detector.
3. Switch the control computer on. Start the analyzer control programme.
4. Enter the name of the source, its characteristics, measurement date, names of executives in the register log.
5. Collect data on the spectrum.
6. For each source, it is necessary to measure the spectrum not less than 3 times.
7. Calculate the average peak position by three (or five) measurements of the spectrum,

- peak energy, peak area, peak position error (in the channels) for each gamma-line.
8. Calculate the average efficiency by five spectrum measurements for each gamma line and the rms measurement error for each gamma-line.
  9. Using the Origin-Graph utility, plot the experimental dependence  $\varepsilon(E)$ , where  $\varepsilon$  – detector efficiency to radiation (relative unit),  $E$  – energy of gamma-photons, MeV.
  10. Using the package of approximation curves of the Origin-Graph utility, approximate the resulting curve by:

$$\varepsilon(E) = C_1 \cdot \exp[C_2 \cdot \ln(E) + C_3 \cdot \ln(E) \cdot \ln(E) + C_4 \cdot \exp\{-C_5 \cdot E\}]$$

11. Calculate the approximation coefficients  $C_i$ .
12. Write a progress report indicating the purpose of work, the setup used, geometry of the count sample, calibration sources, etc. Attach the “Approximation protocol”, gamma-spectra and the graphs to the report.
13. Make conclusions.

#### Test questions

1. What is the detector efficiency to radiation?
2. How are spectrometric setups calibrated by efficiency in the laboratory conditions?
3. What does the detector efficiency depend on?

## APPENDIX

### Purpose of the GammaMCA programme panels

#### *Library of energies.*

Panel "Library of Energies" provides access to a user database of spectral energy lines of the elements.

The database is created and edited by the user. The elements for which there is at least one record in the database are highlighted in black in the periodic table. The database is automatically saved in the file «Nuclide.dat» in the programme directory.

#### *Calibration.*

Panel "Calibration" is intended for the energy calibration by peaks defined in ROI.

When determining the areas of interest (see point 2.3 "Areas of interest (ROI)"), the parameters of the determined peaks (centre position) automatically get on the list of peaks for calibration, which is shown in the table on the "Calibration" panel. For any peak one can set the value of the corresponding energy.

**Peak energy editing** can be done in two ways: *by entering* a value directly into the corresponding table space or *by choosing the energy* from the list that is based on the energy database. Access to the list of energies for calibration is performed by right-clicking on the corresponding table space.

Proper calibration is performed by pressing the "Calibrate" button after setting the energies for all peaks that should be calibrated. It is not necessary to fill in all the spaces of the table, the calibration will be performed using only the filled-in spaces.

Due to the high linearity of the CCS this programme release can provide only linear energy calibration, in which the peak energy is calculated by the formula:

$$\text{Energy (keV)} = C0 + C1 * \text{peak\_centre (channels)}$$

where C0 and C1 - calibration coefficients

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