Calibration and methods of working with NaI detectors of the Aragat complex installation.

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ANNOTATION

At the high-mountain station Aragats (3200 meters above sea level) the secondary component of cosmic rays is continuously monitored. The laboratory is equipped with modern equipment, which makes it possible to explore various components of cosmic rays.

Analysis of the obtained energy spectra and correlations between the flows of various particles, allows not only to study atmospheric phenomena, but also makes it possible to make conclusions about the theory of the passage of particles through the atmosphere in strong electric fields

Such fields are formed during thunderstorm phenomena and lead to an increase in the flux of relativistic electrons, gamma radiation and neutrons (TGEs). Similar events were multiple times observed by detectors located at the station.

The use of a network of 8 NaI (Tl) counters (activated by thallium and sodium iodide) on the Aragats station allowed to observe gamma-quanta flows and make conclusions about the processes of their acceleration and multiplication during thunderstorm phenomena/

Parameters and design of the NaI detector

Single crystal NaI (Tl) (activated by thallium) is a classic detector for detecting intermediate and low energy gamma radiation [1 Grupen C., 1996].

It has a high luminescence efficiency and can be performed in a wide range of sizes and shapes.

The crystal is hygroscopic, so it is placed in a sealed enclosure. Its parameters are as follows: - density - ρ- 3.67g / cm3, radiation length λ -2.4cm, light attenuation time, is about τ ≈ 0.23 μs

The wavelength at the maximum of the emission spectrum of photons is λmax = 410 nm.

The coefficient of temperature expansion is τ- 47.4 10-6 C-1, the temperature dependence of the light output is -0.3% C -1, the light output is 38 photons / KeVγ.

The crystal by size 12.5 x 12.5 x 30 cm, is placed in 1 mm thick sealed aluminum case with a transparent mica window on the front side.

A FEU-49 is attached to the transparent window, which has a large photocathode (15 cm in diameter) and provides full overlap of the crystal front side window.

The spectral range of sensitivity of the photocathode FEU-49 is 300-850 nm, and covers the entire emission spectrum of the NaI (Tl) crystal. Figure 1 shows the design elements of the detector.

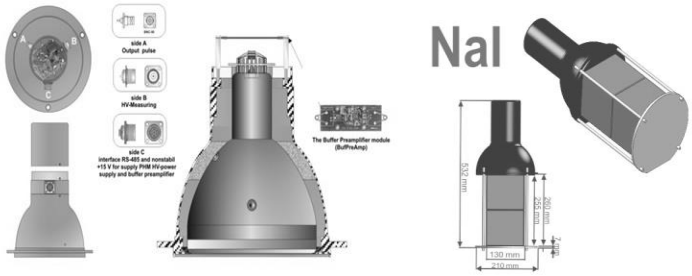


Fig.1 NaI (Tl) detector design

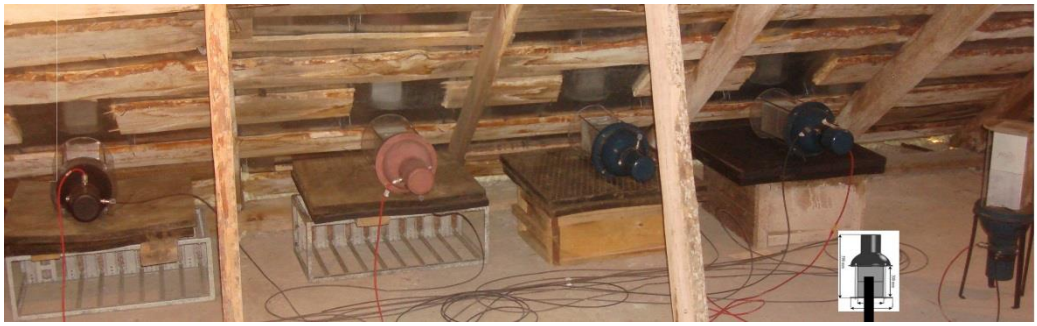


Fig. 2. NaI(Tl) detectors installed at Aragats station

To register the streams of secondary cosmic rays, the Data Acquisition System (SSD) is used, which consists of an 8-channel log-analog-to-digital converter (LADC) module, digital-to-analog converters (DC) for setting thresholds, a microcontroller and a serial interface -232, RS-485) for connection to a computer.

To power the PMT, adjustable high-voltage converters PHV 12-2.0 K 2500 P 0 ... +2000 VDC 2.5 mA are used. The PHV series is adjustable miniature high voltage power modules using SMD and hybrid technology

The use of high stability components guarantees minimal temperature drift and a very stable output voltage.

Primary power supply voltage of the module is in range from +10 to + 15V. The electronics of the PMT and the SSD-ADAS unit are powered from a low-voltage DC source of 12V and consumes about 100W, which allows the use of autonomous backup power systems (for example, batteries or solar batteries)

The specifics of the Log ADC is described in detail [2-4]. Their dynamic range is x200, and the amplitude is determined by the code that corresponds to the energy left by the particle during the passage of the crystal.

Assuming that the energy release in the detector is proportional to the pulse charge at the anode of the PMT, we can write:

$K = d * \ln (EK / EMIP) + KMIP$, (1)

where d is the shock circuit damping decrement, K is a digital code corresponding to the energy release EK in the detector, KMIP is the code of the minimum ionization loss of muons in the NaI (Tl) crystal: $dE / dX \approx 1.305$ MeV / (g / cm2).

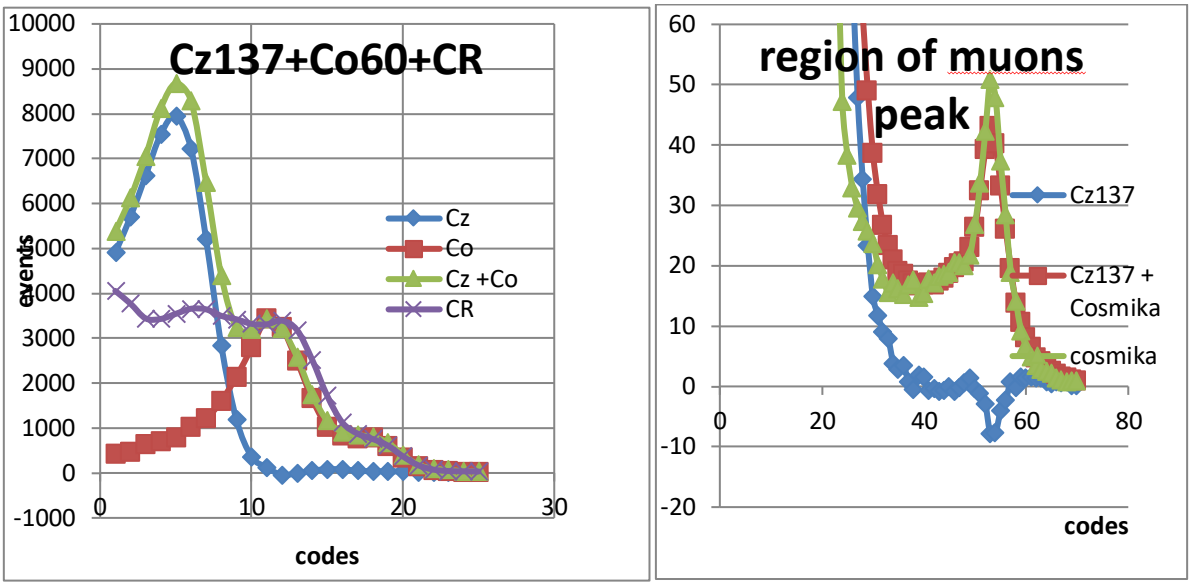
Simulations have shown that the most probable path length of particles in a crystal body is 12.5 cm, or ≈ 46 g / cm2 and EMIP ≈ 60 MeV

Those. the mode of distribution of energy release from muons corresponds to Emod = EMIP ≈ 60 MeV

The KMIP code value corresponding to the EMIP energy release is set by the high voltage of the photomultiplier on the basis of the required dynamic range, registration threshold, etc., required by the experiment.

To correctly restore the energy loss values of the particles under study, it is necessary to accurately determine the parameter d. To determine it, it is necessary to have at least two calibration points with known values of the Log ADC codes and the corresponding values of the energy release in the detector. Such values were obtained using 137Cz isotopes (662 keV), for which 60 the most

probable is the cascade emission of gamma quanta with energies of 1.1732 MeV and 1.3325 MeV and the values of the most probable energy losses of CR muons when they pass through NaI crystals (Tl) (60 MeV) (Fig. 2 and 3).



The results of the calibration measurements 137Cz and Co60 detector NaI (Tl).

The energy resolution of the detectors was determined using the 137Cz isotope, which are presented in Table 1. The values of d for each used AC channel are also given. These values are derived from the max code values from 137 Cz and the max code of the CR muons.

Table 1. Energy resolution of NaI (Tl) detectors at 662 keV and the ADC scale factor.

Det.	FWHM (MeV)	σ =FWHM/2.355	σ (%)	d
1	0.44	0.187	29	11.2

2	0.4	0.168	25	10.9
3	0.4	0.168	25	11.1
4	0.34	0.143	22	11.4
5	0.34	0.143	22	11.2

Having a high-frequency signal generator, you can perform a series of calibration measurements, and more accurately estimate the parameters used by LogADC:

1. Get more accurate decrement values for each channel

2. Find out the change in the operation of LogADC from increasing the intensity of the particle flow

3. To assess the effect of the threshold to be set on the magnitude of the recorded pulse.

4. Determine the change in the code value depending on the size of the input signal.

In order to correctly restore the Scale factor d, the code-amplitude dependencies were determined for 5 amplitudes separately for each channel.

50 mV- (A1), 200mV-(A2), 500mV (A3),

1V - (A4), 1.5V- (A5).

Below are the average Scale factor d values for each LogADC channel.

1 -10,27 ; 2 -10,69 ; 3 - 10,46 ; 4 - 10,43 ;

5 - 10,45 ; 6 - 10,16 ; 7 - 10,45 ; 8 - 10,62.

The accuracy of determining the parameter d for each channel was not worse than 5%. The average value for all channels can be taken all

Dcp = 10,44 σ= 0, 1593 ;

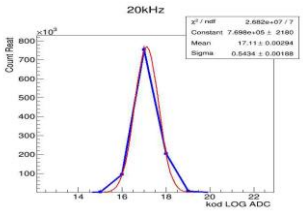
Determining the effect of increased signal flow on the LogADC registration code offset.

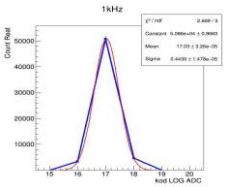
Another important parameter used by LogADC is the stability of the registration of a stream of particles, regardless of their intensity. For this purpose, the generator gave pulses simulating the signals of the detector. Studies were carried out both when loading one channel, and when simultaneously sending signals to all channels. Checking the stability of the LogADC operation with an increase in the intensity of the flow was carried out by pulses with amplitude A = 70 mV and duration 500 ns. When d = 10.5, this corresponds to an energy of about 2 meV.

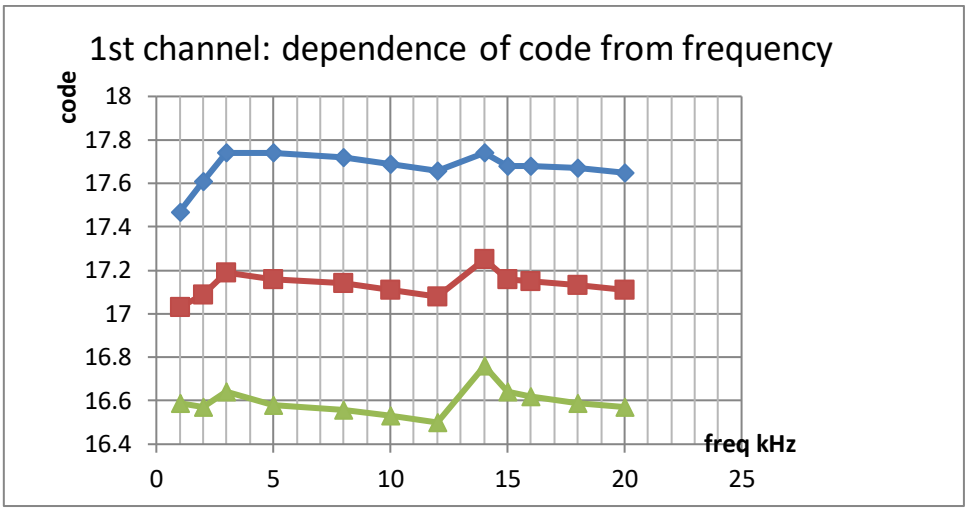
cod	freq kHz
17.03 +/-0,44	1
17,09 +/- 0,52	2
17,19 +/- 0,55	3
17,16 +/- 0,58	5
17,14 +/- 0,58	8
17,11 +/- 0,58	10
17,08 +/- 0,58	12
17,25 +/- 0,49	14

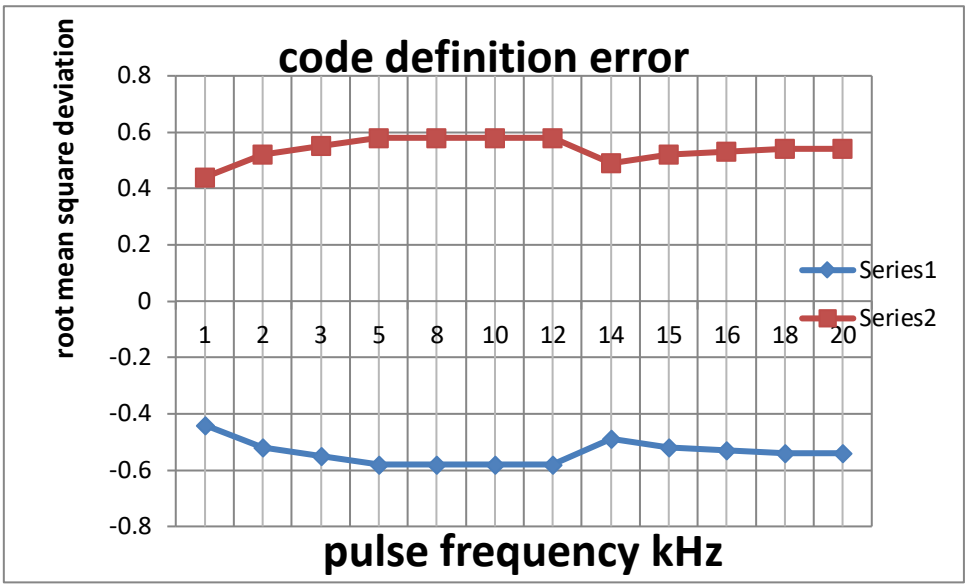
17,16 +/- 0,52	15
17,15 +/- 0,53	16
17,13 +/- 0,54	18
17,11+/- 0,54	20

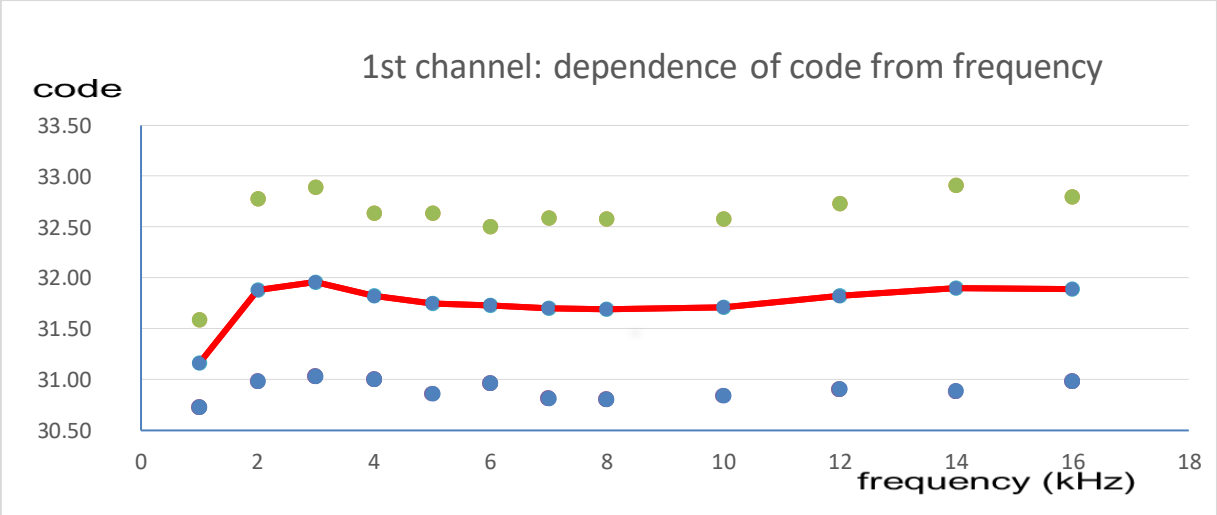
As you can see, up to the frequency of 20 kHz, the code offset is practically not observed. For each signal repetition frequency, it was believed that the result obtained was subject to the Gaussian distribution and the code value was determined from the mean and variance values.







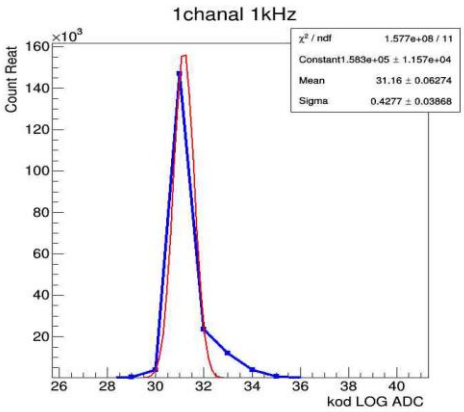


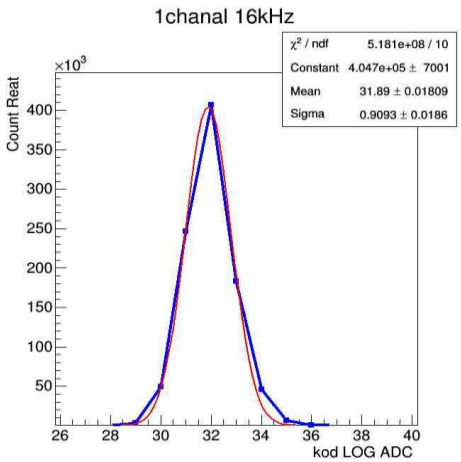


The value of the code depending on the intensity of the following signals

As we see from the obtained graphs, with an increase in the frequency of signals following the signal, the registration code of this signal changes by less than 5%. Those. Up to a frequency of 20 kHz, the code offset is practically not observed.

Accuracy of code determination was fitted with gauss:





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Next, we checked the operation of LogADC while simultaneously loading all eight channels at different frequencies.

F kHz	ch1	ch2	ch3	ch5	ch6	ch7	ch8
3	31,8	31,1	29,6	28	29,9	30,6	31,7
6	31,3	31	29	28	29,6	30,1	31,4
8	31,6	31	29,1	28	29,7	30,2	31,5
10	31,4	31	29,1	28	29,8	30,3	31,6
сред	31,5	31,05	29,2	28	29,7	30,3	31,5
σ	0,125	0,005	0,18		0,045	0,125	0,045

The results showed that up to a frequency of 10 kHz, while simultaneously sending signals to all 8 channels, LogADC works stably and the supplied signals fall into almost the same code.

Background measurements of the NaI (Tl) detector registered during operation

Natural sources of radiation background are divided into natural radioactive substances and cosmic rays. The source of natural radioactive substances entering the environment are rocks.

The radiation background on granite rocks is due to the fact that granite contains impurities, uranium and thorium. With the decay of uranium nuclei, including radioactive gas radon. The main source of radon in the enclosed space is the ground. Penetrating through the foundation and the floor of the soil or released from the materials used in the construction of the house, radon accumulates in closed unventilated areas. Among the isotopes of radon are known: 222Rn (most dangerous) with a half-life of 3.8 days, 220Rn with a half-life of 54.5 s, 219Rn with a half-life of 3.9 s.

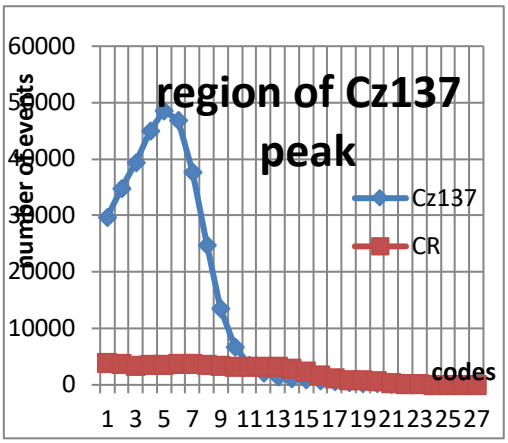
Another radioisotope that is widespread in terms of the generated activity is the potassium isotope 40K.

Despite the fact that the nuclei of potassium-40 decay extremely rarely, the large number of these nuclei around us makes the presence of the isotope quite noticeable.

Considering that the physical processes studied by us are based on monitoring the fluxes of particles of cosmic rays, it is of great interest to determine the components that make up the constant background recorded by the detector. For this purpose, we used one of the working detectors NaI and a small gamma spectrometer, the resolution of which is 7%.

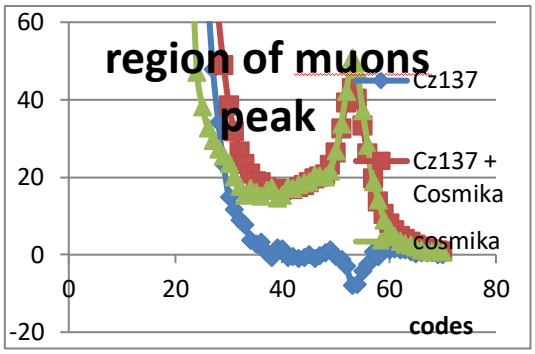
Measurements were carried out in the working room, in the open field and in the basement of the building. The operation of the NaI (Tl) detector was controlled by the Cz137 source. The voltage at the photomultiplier was 1700v., While the peak from the Cz137 source was in code 5, and the peak from one of the partial muon spectrum was 52-53. When the source was installed on the detector, the flux intensity increased almost 4 times, however, the shift of the muon peak was not observed. The result shown in the graph corresponds to the counting rate from the cosmic and the background - 930 h / s, and together with the Cz137 source, the count became 3600 h / s. In this case, the decrement of LogADC is d = 10.5

Cz+ CR	33590,09	38474,77	42916,92	48489,41	52160,97	50629,1	41425,33	28356,74
CR	3849,952	3649,952	3423,524	3467,286	3605,333	3758,429	3684,81	3495
Cz137	29740,14	34824,82	39493,4	45022,12	48555,64	46870,67	37740,52	24861,74
codes	1	2	3	4	5	6	7	8
energy	452,2853	497,478	547,1863	601,8616	662	728,1475	800,9045	880,9315



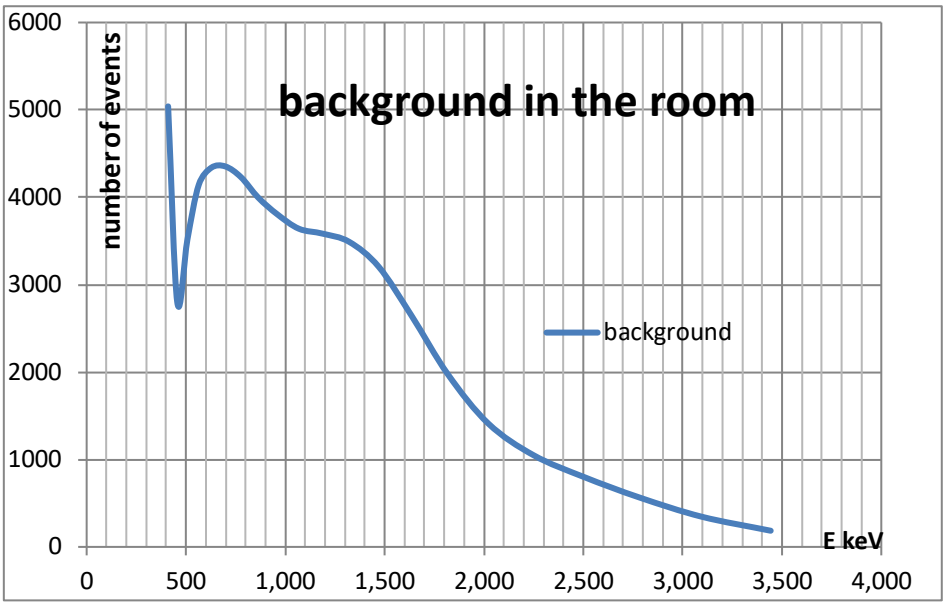
Calibration measurements of the background (area Cz137)

39,21053	42,99248	40,13033
42,19048	50,90476	47,80952
-2,97995	-7,91228	-7,6792
52	53	54
58189,26	64003,57	70398,85

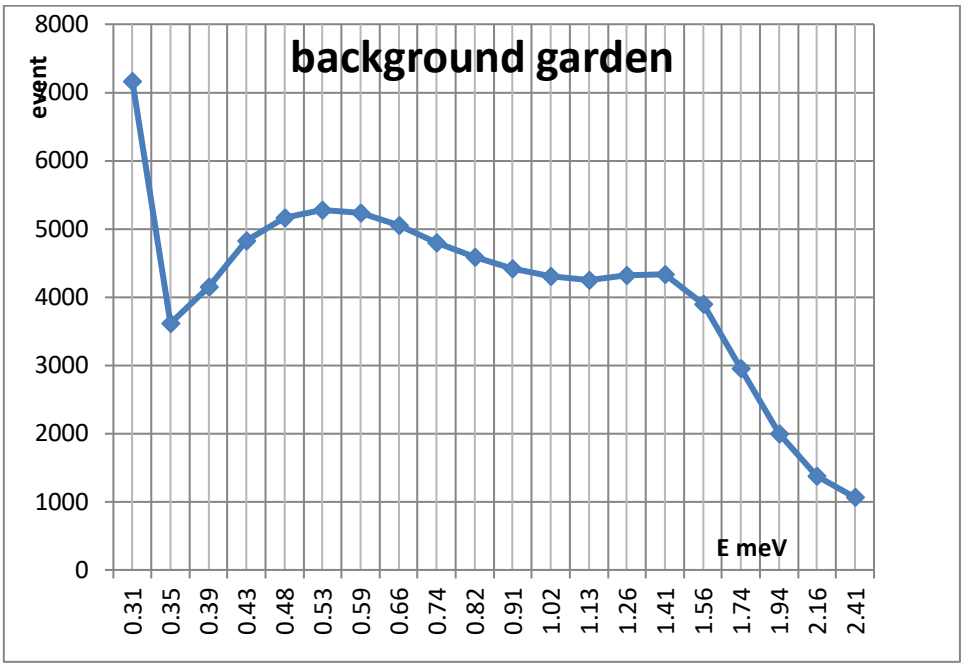


Gauge background measurements (μ-peak area)

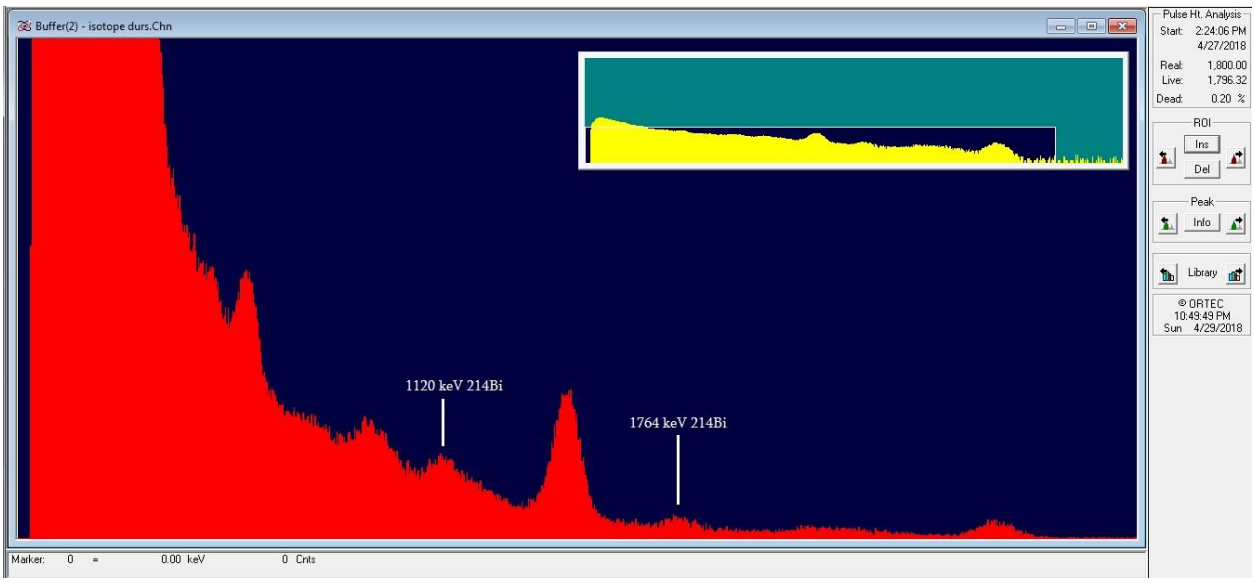
The results of measuring the background of both our detector and gamma spectrometer are shown in the graphs.



Measurement of the background in the room

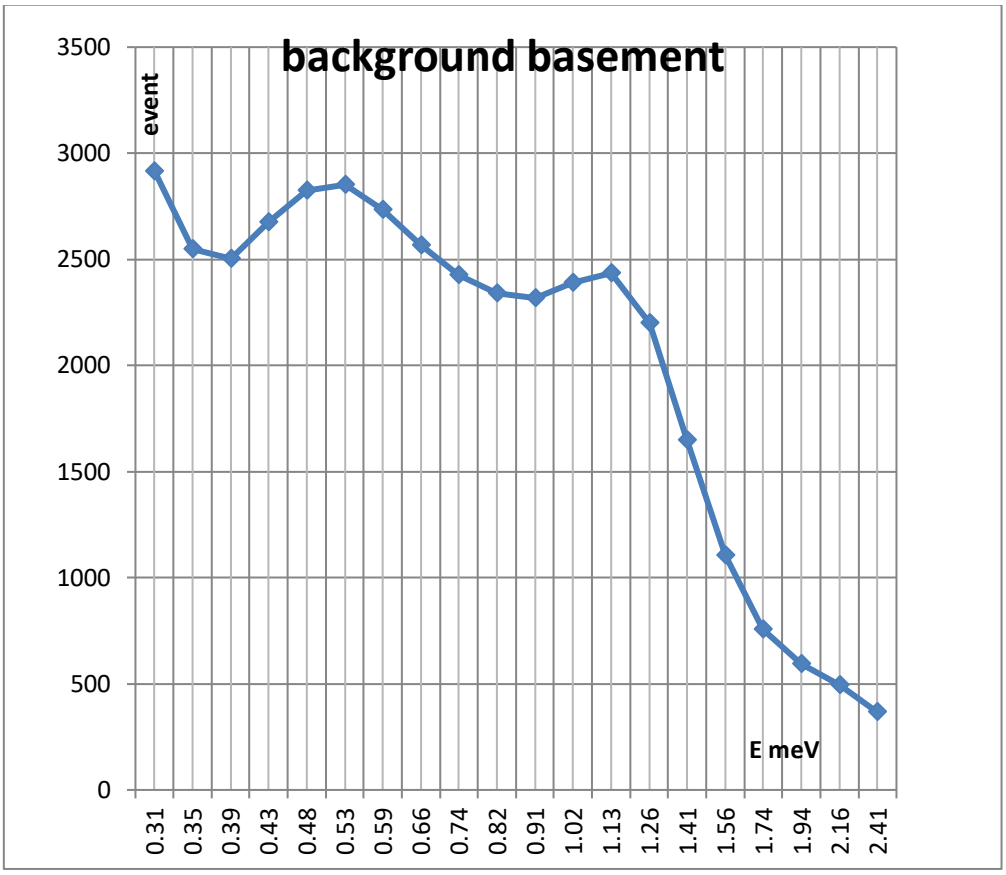


Garden background measurements

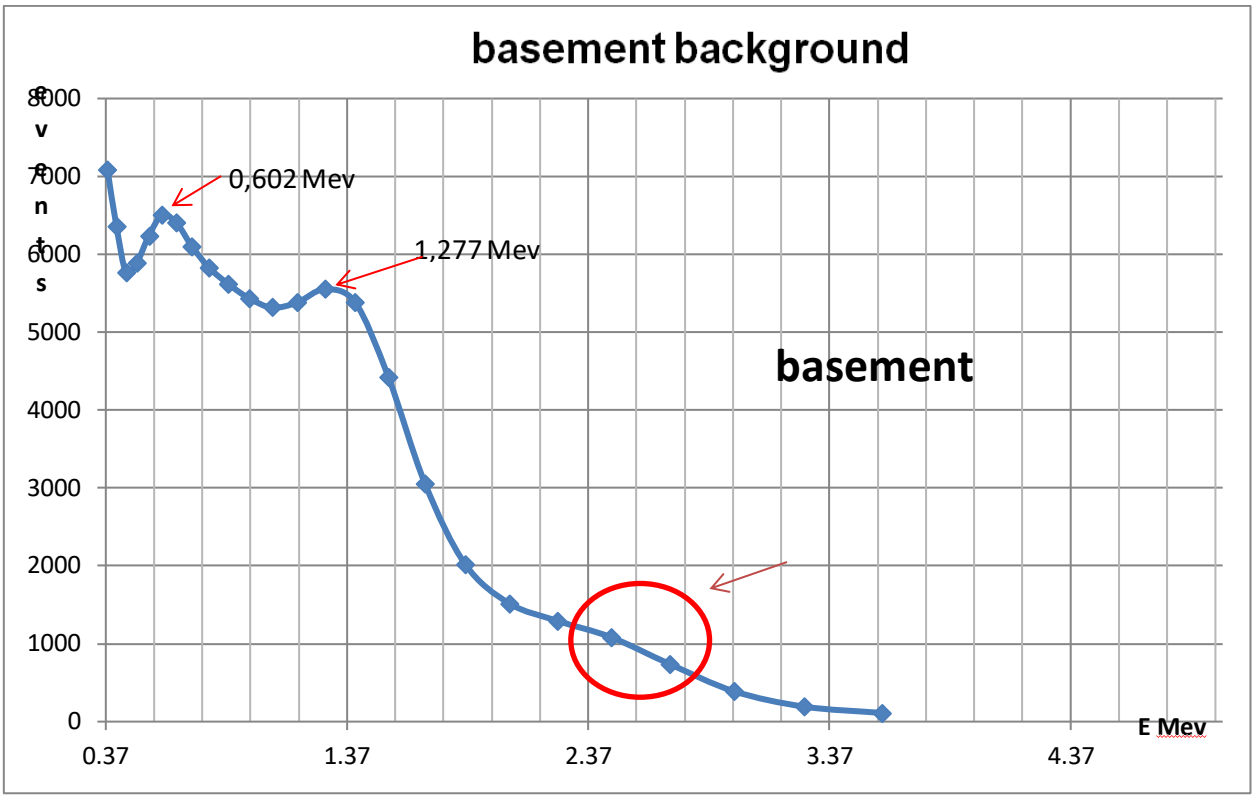


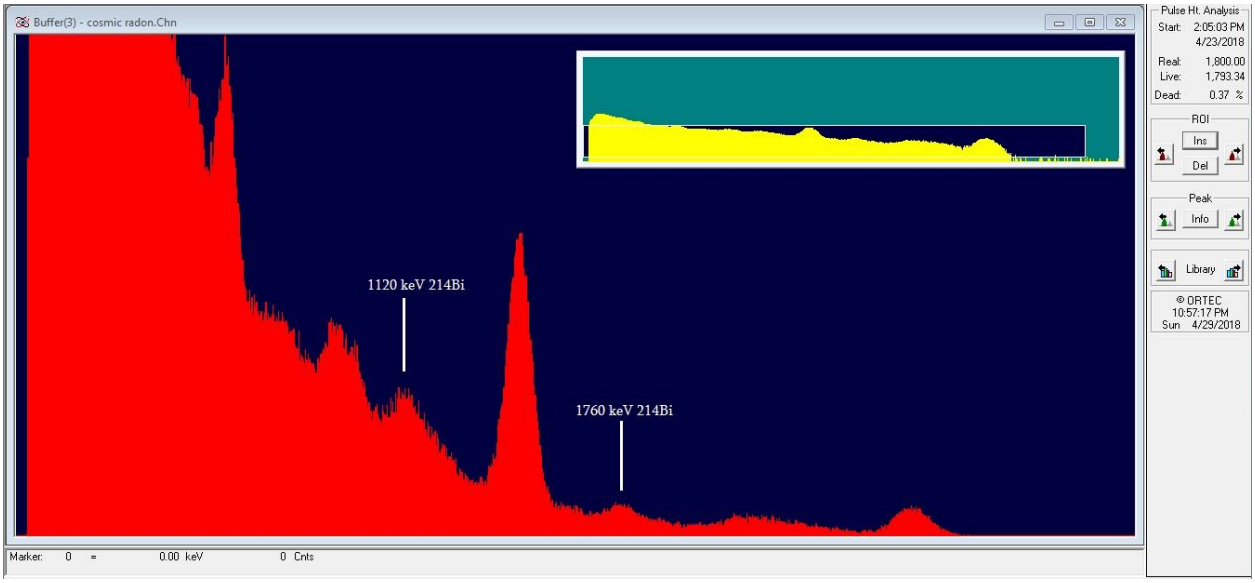
Measuring the background in a garden with a gamma spectrometer

The upper graph shows the results of measuring the background in the field with our detector with a resolution of 25-27%. Below are the results obtained with a 7% gamma spectrometer.



Measurement of the background in the basement.





Background measurement in the basement gamma spectrometer

Work results

The network of NaI (Tl) detectors operating on the Aragats w / s, besides the continuous monitoring of CRs, makes it possible to determine the distribution of the energy losses of particles in a crystal from the readings of codes. To correctly recover the energy spectra from the code values, it is necessary to reliably know the parameters of the detectors used, as well as to have information about the background processes around the working detectors. To do this, we calibrated the detector with 137Cz and Co60 crystals.

Using the generator, the parameter d of the used LogADC is calculated for all 8 channels of the device. The following values were obtained: Dav = 10.44 σ = 0, 1593

The resolution of the used detectors was determined, which, depending on the detector used, fluctuated around 22-29%

The effects of increasing signal flow intensity on the LogADC registration code offset were investigated. With the increase in loading of 1 channel up to 20 kHz, the change of the registration code did not exceed 5%. And when loading all 8 channels up to 10 kHz did not exceed 8%. LogADC is stable and the received signals fall into almost the same code.

Measurement of the background while operating the NaI (Tl) detector at 3 levels showed that the background in

the room is uncertain, while in the garden and in the basement there are peaks that are well viewed by a good resolution gamma spectrometer.

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