NUKLEONIKA 2001;46(4):165–169

Decreasing of the natural background counting – passive and active method

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Abstract The methods of passive and active shielding and the results of background gamma measurements, during the years 1996–2000 are presented. The spectrometer background was recorded in various shielding configurations. The ultra-low level gamma-spectrometer (called in the paper the spectrometer E), equipped with a veto-detector for cosmic muons (active shield) was under tests during 1999–2000.

Key words active shield • background reduction • environmental radioactivity

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Received: 4 June 2001, Accepted: 21 September 2001

Apparatus

We present three sets of spectrometers used in our laboratory for low gamma background measurements. A brief history of the shields is summed up below:

Spectrometer K

1987 – standard lead bricks of 50 mm in thickness, all sides around detector; 1988 – inner lining made of copper (2 mm) and cadmium (2 mm) added; 1991 – 100 mm thick standard lead bricks on the top of the shield; 1993 – LN_2 vapours flow in added; 1997 – change to 100 mm thick standard lead bricks all sides except the bottom, reduction of the diameter of cryostat pass by a hole in the bottom shield from 140 mm to 100 mm; 1999 – 18 mm thick inner electrolytic copper shield added.

Spectrometer S

1991 – 100 mm thick standard lead bricks, all sides around detector, inner lining made of copper (2 mm) and cadmium (2 mm); 1993 – LN_2 vapours flow in added; 1997 – 80 mm thick outside paraffin on the top added; 1998 – 20 mm thick inner electrolytic copper shield added.

Spectrometer E

1997 – 100 mm thick standard lead bricks all sides around detector, 50 mm thick 2500-year-old lead inner shield all sides (see Fig. 1), 2 mm thick cadmium lining between old and standard lead, LN_2 vapours flow in; 1998 – 10 mm thick inner electrolytic copper shield added, 120 mm and 80 mm thick outside paraffin on the top and all other sides, respectively; 1999 – a multiwire Charpak's chamber (Veto detector) added on the top (see Fig. 1 for details).
The basic data on the present spectrometers and shields are presented in Table 1.

Table 1. Basic data – spectrometers and shields (present status).

	Spectrometer K	Spectrometer S	Spectrometer E
Detector	Ge(Li)p-type Coaxial Detector	HPGe p-type Coaxial DET. GC105 VD	HPGe Coaxial Detector
Relative efficiency	15%	10%	25%
FWHM (for 661.6 keV)	3 keV	1.8 keV	1.9 keV
Preamplifier	POLON	SILENA	INP
Power supply / Amplifier	HV-Supply 7716 / Amplifier	7611/L (SILENA)	3106D/ 2022 (Canberra)
ADC / MCA ADC	8K 7411 / Memory Buffer 7329 16K 4096 (SILENA)		
Passive shielding (thickness)			
- standard lead bricks	50-100 mm	100 mm	100 mm
- 2500 years old lead	no	no	50 mm
- copper sheet	20 mm	22 mm	10 mm
- paraffin	no	no	80-120 mm
- cadmium sheet	2 mm	2 mm	2 mm
Active shielding			
Veto detector	no	no	multiwire chamber

A significant component of detector background arises from the secondary radiations produced by cosmic-ray interactions in the earth's atmosphere. A lot of this radiation reaches the earth's surface and can create background pulses in a detector [4]. The cosmic-ray component of detector background can be removed only using massive conventional shielding. An alternative method for highly penetrating cosmic radiation to be eliminated is the use of anticoincidence shield [6].

The ultra-low background gamma spectrometer E, with both passive and active shields is presented. Construction materials for detector have been examined for the content of traces of radioactive elements. Apart from this active shield, the spectrometer has a special passive shield (see Fig. 1), which consists of 80–120 mm of paraffin (external neutron moderator), 10 cm of standard lead, 2 mm of cadmium, 50 mm of 2500-year-old lead and 10 mm copper (from outside-to-inside, respectively). The inner shielded volume of the spectrometer is flushed with liquid nitrogen vapours, to reduce radon daughters contribution to the spectra.

The active shield is a multiwire proportional counter, situated on the upper side of the shield, between the neutron moderator and commercial lead. This is a Cosmic-Rays Muon Veto Detector, which works in anti-coincidence mode with a germanium detector. The muon detector, constructed in the Department of Leptonic Interactions (INP) [5], is a multiwire Charpak's chamber. It has two active layers, with a volume of 0.0098 m^3 (0.07×0.07×0.02 m) each. The fast NIM signal is collected from 160 anode wires, which are grouped in 4 sections in each layer. Several logical configurations of sections were tested to optimise the effectiveness of the shielding. As a result, the logical sum of signals from all sections was chosen. This signal is transformed to a long TTL pulse, which is used as a veto for spectrometer's ADC. Timing and duration of TTL pulse were also optimised to achieve highest possible effectiveness.

An HPGe detector, constructed in the Department of Nuclear Spectroscopy (INP), has on aluminium-free cryostat top. The aluminium is not recommended for construction of the low-background detectors due to the presence of traces of uranium in most aluminium alloys.

Results and conclusions

A comparison of the background gamma spectra obtained with the ultra low-level gamma spectrometer E with the Veto detector in both on and off modes is presented in Fig. 2. The spectrum ON was measured for 683 820 s with the operational Veto detector, and the spectrum OFF was measured for 1 159 380 s without the Veto detector. Count rates (cps) for several energies from both spectra (ON, OFF) are presented in Table 2. The absence of 186

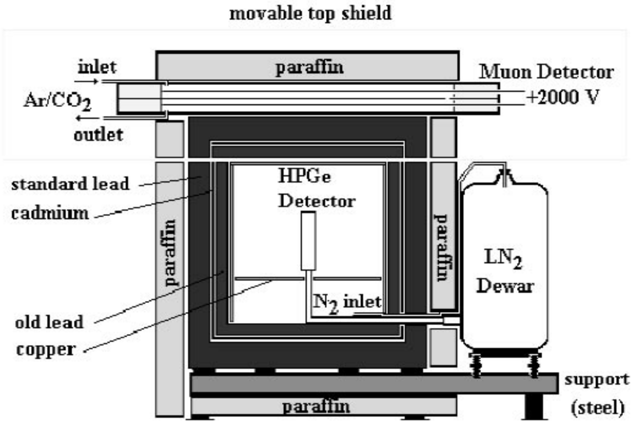


Fig. 1. A scheme of construction of ultra low-level gamma spectrometer shield.

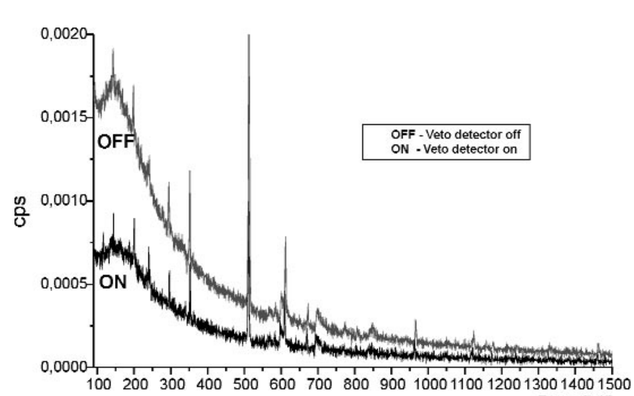


Fig. 2. Comparison of background gamma spectra obtained with ultra low-level gamma spectrometer (spectrometer E) with Veto detector ON or OFF.

Table 2. Cps for several energies from both spectra obtained with spectrometer E.

Energy [keV]	Spectrum OFF [cps]	Spectrum ON [cps]
186	Not present	0.000295
511	0.00962	0.00419
662	Not present!	Not present!
911	0.000106	0.000484
1461	0.000214	0.000283

keV line in the spectrum obtained with the Veto detector OFF is a result of higher continuous background. The line visible in Fig. 2 at about 200 keV is not the 186 keV line but it is the result of (n, γ) reaction occurring in the germanium crystal at 198 keV [2, 3].

The active shield itself reduces the spectrometer continuous background (from 80 keV to 3 MeV) by a factor of about 2 (from 0.88 cps to 0.46 cps), increasing dead time by less than 0.5%. The influence of each part of the shield of spectrometer E on the background was studied. Results will be published after some additional tests.

Only the background measurements lasting longer than 100000 seconds were considered. Shorter background measurements were performed routinely to control the possible contamination after counting of highly active samples. In this presentation those measurements are excluded. The background changes for different spectrometers and energies due to shield modifications are presented in Figs. 3 and 4 on the basis of 50 and 25 measurements with spectrometers K and S, respectively.

The changes in intensities of the line 186 keV (which most likely come from both ^{226}Ra and ^{235}U) are not correlated with moments of shield modernizations. Low values from

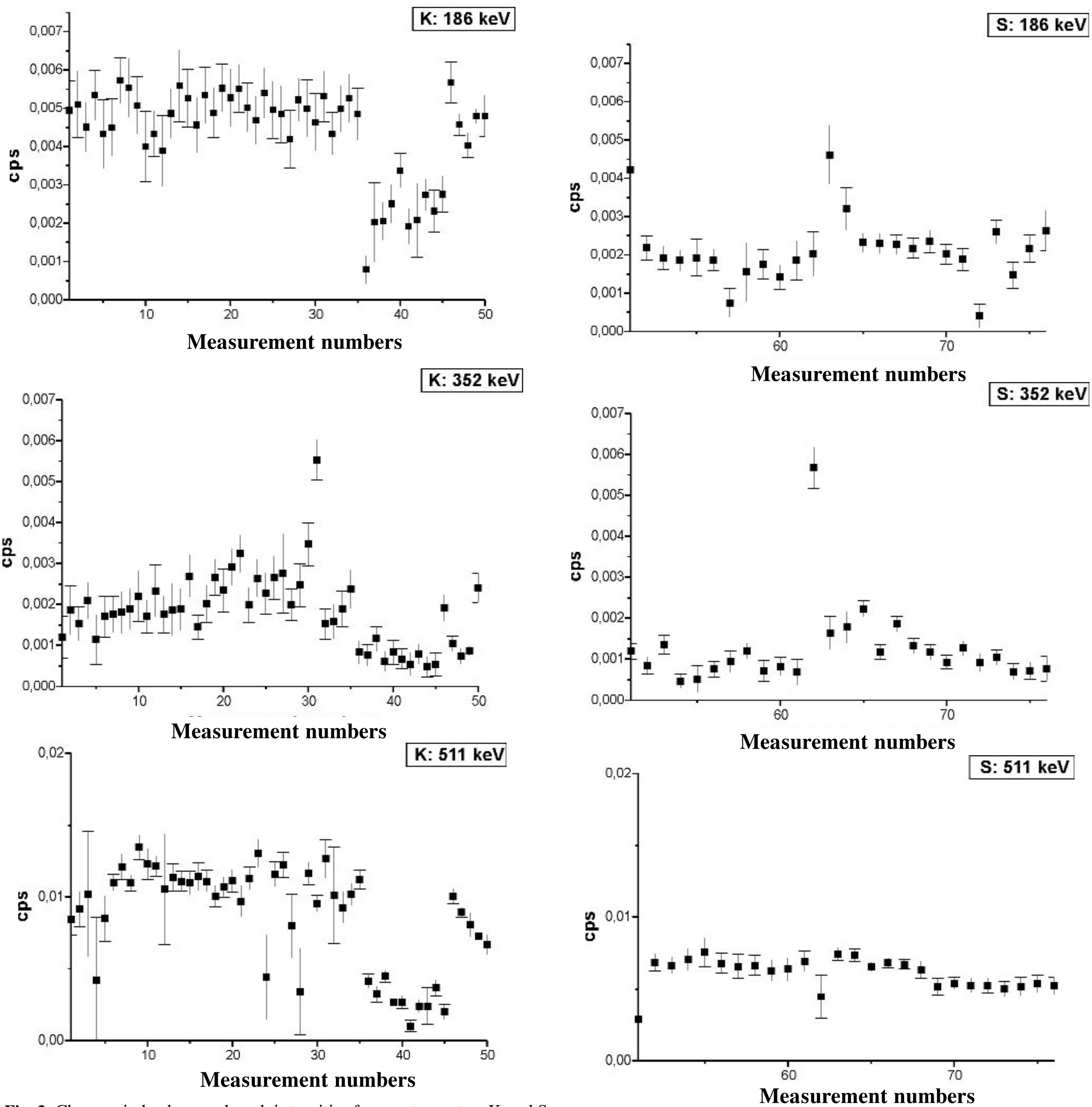


Fig. 3. Changes in background peak intensities for spectrometers K and S.

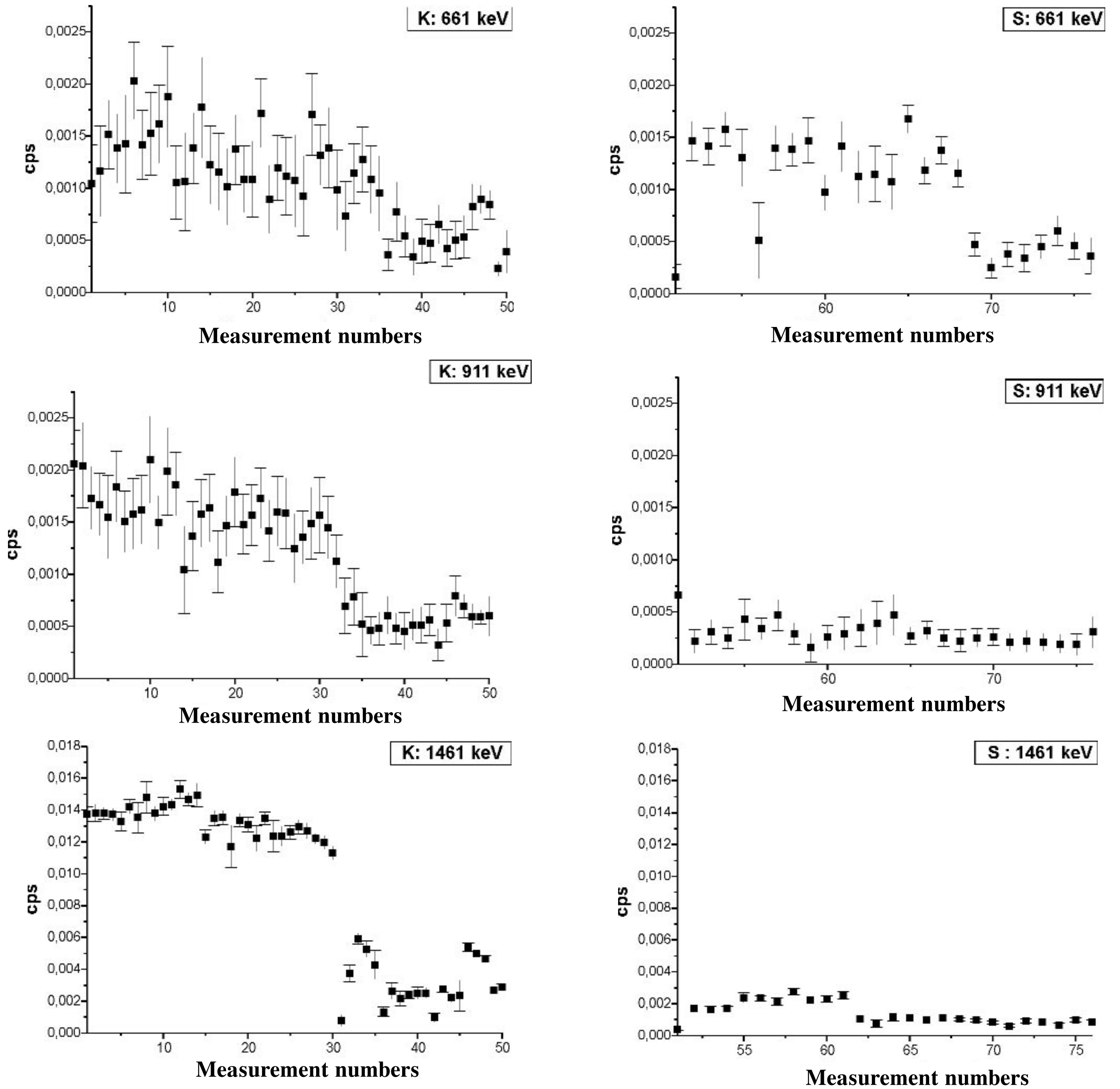


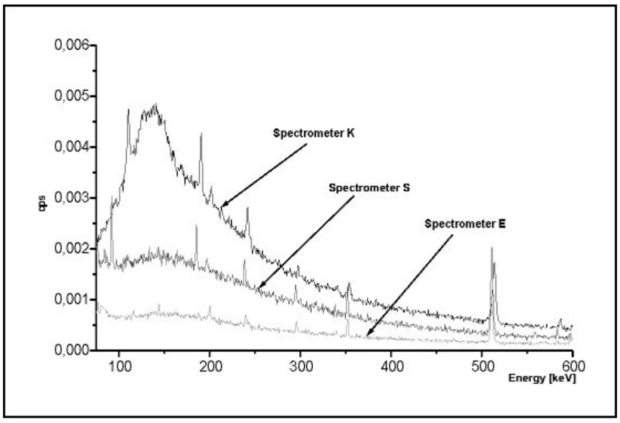
Fig. 4. Changes in background peak intensities for spectrometers K and S.

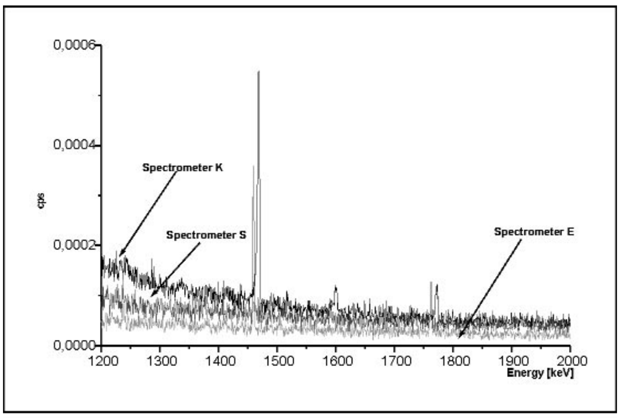
the spectrum number 36 to number 45 (Fig. 3) were obtained using a Canberra amplifier, which replaced the original Silena one during its repair. This suggests that the background reduction effect is an artefact made by electronics or software. Traces of the same artificial effect could be found in the lines 352, 511 and 661 keV (Figs. 3, 4). The first-order background reduction of external radiation comes from a lead castle. Introduction of the second-order background reduction system (a flow of evaporated nitrogen (LN_2) from the cryogenic dewar to minimize the influence of radon decay nuclei in measurements) reduces the counting rate in radon daughters and continuous background [5]. This is illustrated by the intensities of line 352 keV (see Fig. 3). The outlier (no. 62, spectrometer S) is a measurement with removed LN_2 flow. The intensities of line 511 keV for any spectrometer depend on the flux of secondary cosmic radiation [1]. However, the introduction of inner shield made of copper can be noticed (no. 48, 69 – Fig. 3). The intensities of line 661 keV depend mostly on the contamination of the inner part of the castle or detector. Despite of several cleanings of the inner part of the castle inside, the reduction was obtained only after adding an additional copper shield (no. 48, 69 – Fig. 3). However, cleaning effects are visible, for example, for the line 1461 keV (no. 63 – Fig. 4). An increase of the lead wall

Table 3. Reduction factors for different spectrometers due to shield modification.

Energy [keV]	Spectrometer/Spectrometer [cps]	Reduction factor
911	K_{2000}/S_{2000}*	7
	K_{1996}/K_{2000}	3
	S_{1996}/S_{2000}	2
1461	K_{2000}/S_{2000}	3
	K_{1996}/K_{2000}	6
	S_{1996}/S_{2000}	3

*Indexes denote years.





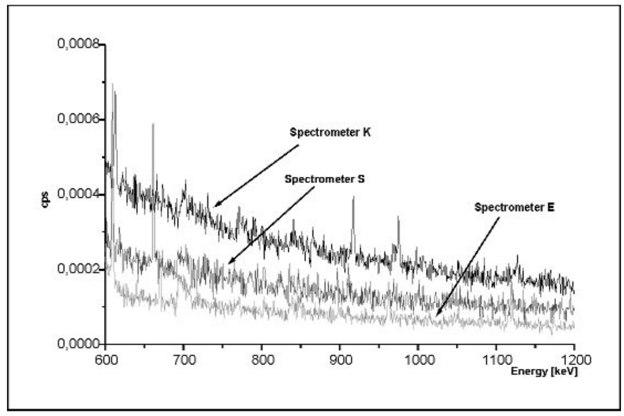


Fig. 5. Comparison of background gamma spectra for spectrometers: K, S, E (energy range from 80 to 600 keV, from 600 to 1200 keV and from 1200 to 2000 keV.

thickness for the shield of spectrometer K is clearly visible for the line 1461 keV (no. 31 – Fig. 4). For high energies, the advantages of thicker shield is clearly visible, but it is not seen for low energies. The modifications in shielding system of spectrometers resulted in a decrease of count rates (cps) in the spectra for natural radionuclides: lines – 911 keV and 1461 keV. The results for the present shields of spectrometers are shown in Table 3.

Fig. 5 shows the background spectra for different energy ranges: from 75 to 600 keV, from 600 to 1200 keV and from 1200 to 2000 keV. Displayed spectra were normalized for the unit of time (cps), but were not normalized for the spectrometer efficiency. This would result in even lower count rate for the spectrometer E.

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