On the angular distribution of the low-energy components of TGE recorded at mountain levels.

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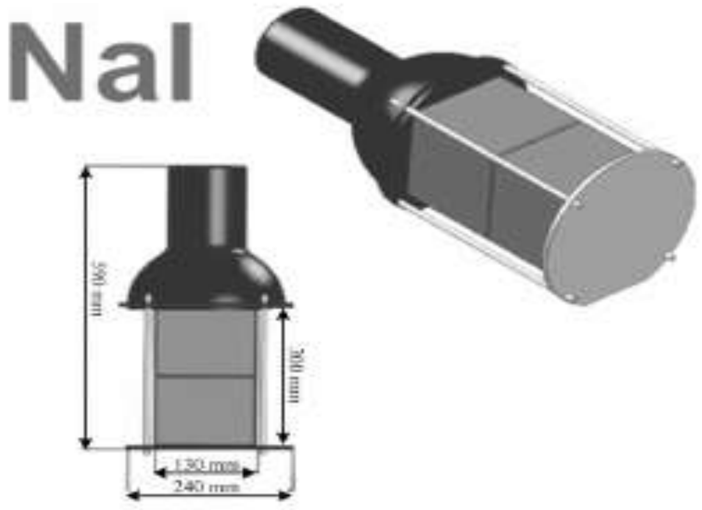
The study of the energy characteristics of the excess flux of secondary cosmic rays from thunderclouds (TGE) showed that there are two components: high-energy from 3-4 MeV and higher and low-energy - less than 3 MeV.

In the first case, the duration of the excess does not exceed tens of minutes, and in the second case, the process lasts for hours.

The low-energy part is associated with the penetration into the atmosphere (emanation) of natural radiation sources (daughter isotopes from Rn). The presence of an electric field greatly increases the process of radon emanation into the atmosphere. Based on general considerations of isotope emission processes (spontaneity and izotropy), the low-energy TGE component should have angular characteristics close to a uniform distribution.

This report is devoted to the experimental verification of the uniformity of the angular distribution of low-energy TGE using a network of NaI (Tl) detectors located at the high mountain station Aragats.



- The network of NaI (Tl) detectors consists of 8 detectors with a crystal size of 11.5x11.5x28 cm3 equipped with a FEU-49. The energy resolution of the detectors - FWHM, according to Cz^{137}(662 keV), is ~ 50-60%. The detectors threshold corresponds to ~ 300 keV. One of the detectors with a high threshold (> 3 MeV) is used for quick analysis of the presence of a high-energy component in a recorded event (TGE).
- To experimentally verify the uniformity of the TGE angular distribution, three detectors with numbers 1, 2, and 4 were selected.

The first detector was installed directly on the concrete floor. The second detector is mounted on a 6 cm thick rubber absorber and the fourth detector, located on a rubber absorber and shielded with a lead filter, 1.5 cm thick, on all sides.

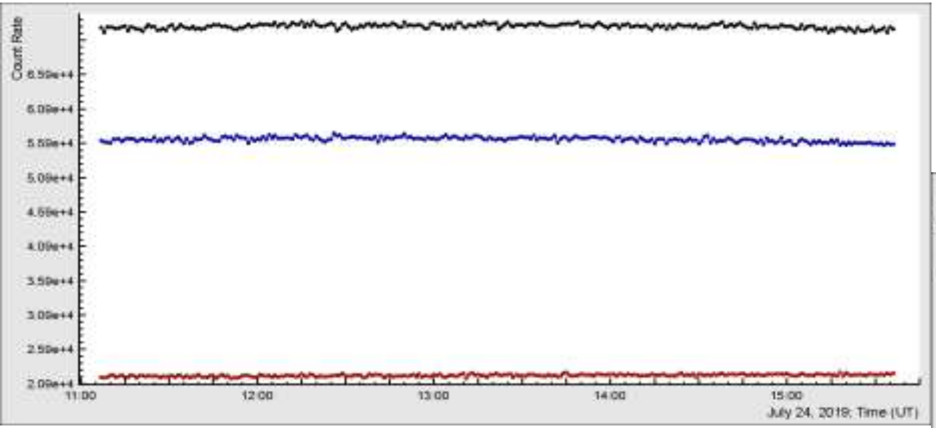
Det.#2 On 6 cm rubber

Det.#4 Open 115 cm^2 area

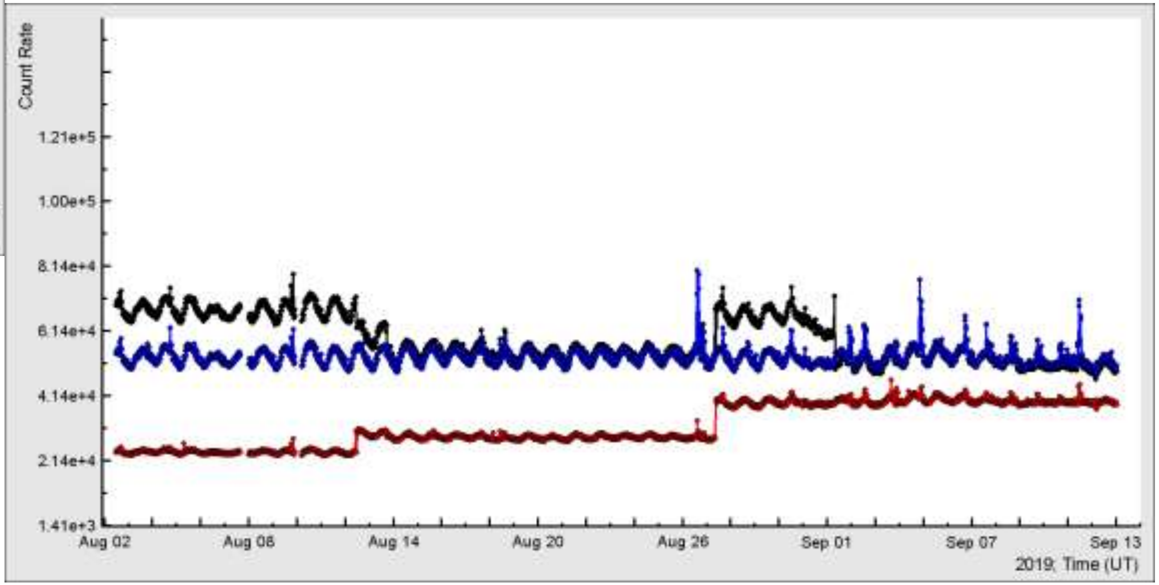
Det.#4 All shielded

Det.#4 Open top

The average count of detector 1 is 7.2 $*10^4$ min-1; for detector 2, the count is 5.6 $* 10^4$ min-1 and 2.1 $* 10^4$ min-1 for the 4th detector, respectively.



The c**ount rate of detectors 1 (black), 2 (blue) and 4 (red).**



The count rate of the NaI(Tl) detectors for August-September 2019 1 – black, 2 -blue and 4 -red.

An experimental check of the uniformity of the angular distribution of low-energy TGE was carried out by comparing the average fluxes of the measured TGE. The datas of all three detectors are analyzed separately. The number of events in TGE was calculated statistically:
- TGE = (TGE + CR_{bgr1}) -CR_{bgr2}.

The average flux <J> was determined by the expression <J> = TGE / (T_{TGE} * S), where T_{TGE} is the duration of the event in minutes, S is the effective surface of the detector registration. Effective surface for an uniform angular distribution of TGE is

$$S = \int_D (\overrightarrow{dS}\,\vec{n})\, d\Omega = \int_D dS \cos\theta \sin\theta \, d\theta \, d\phi \qquad (1)$$

The calculation of the effective surface is carried out according to the formula (1) for each of the recording surfaces separately :- top, sides and end.

For detectors 1 and 2, their sum is used, and for the 4th detector: - corresponding to the measurement configuration with this detector.

In July - September, events with different configurations of detector 4 were recorded:

23 luly 2019 – all det. 4 was closed.

29 luly 2019 – opened 10x11.5cm^2 area on top.

02 August 2019 – opened only top of the detector 4

04 August 2019

18 August 2019 – opened only one side of the detector 4

26 August 2019

27 August 2019 – opened all sides with top covered with lead on an area of 20x28 cm

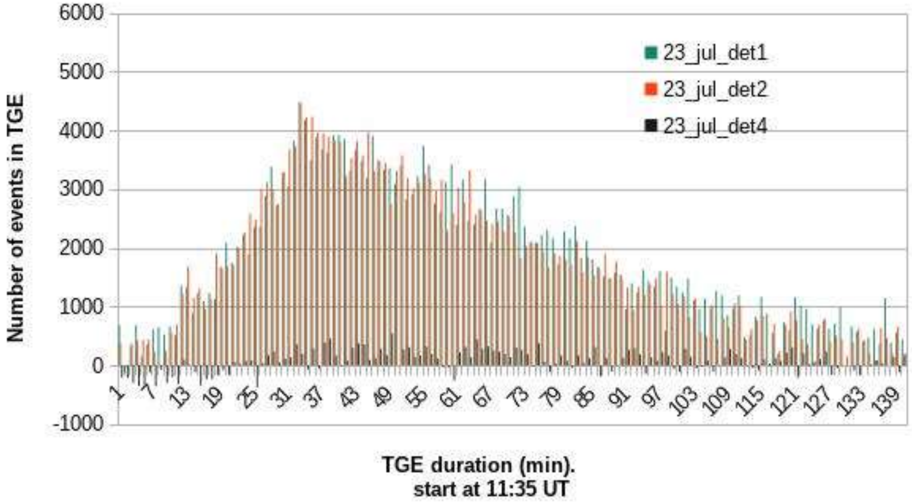
30 August 2019

01 September 2019

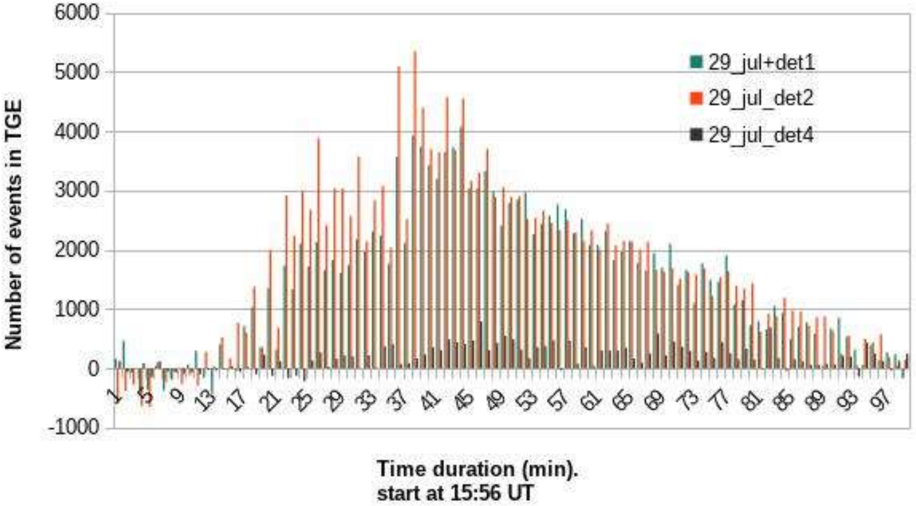
02 September 2019

11 September 2019

28 September 2019

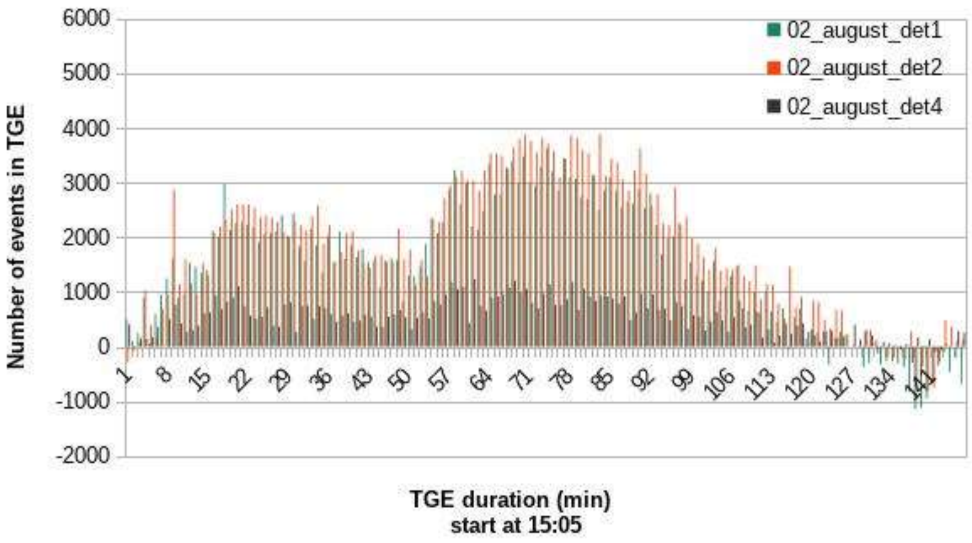


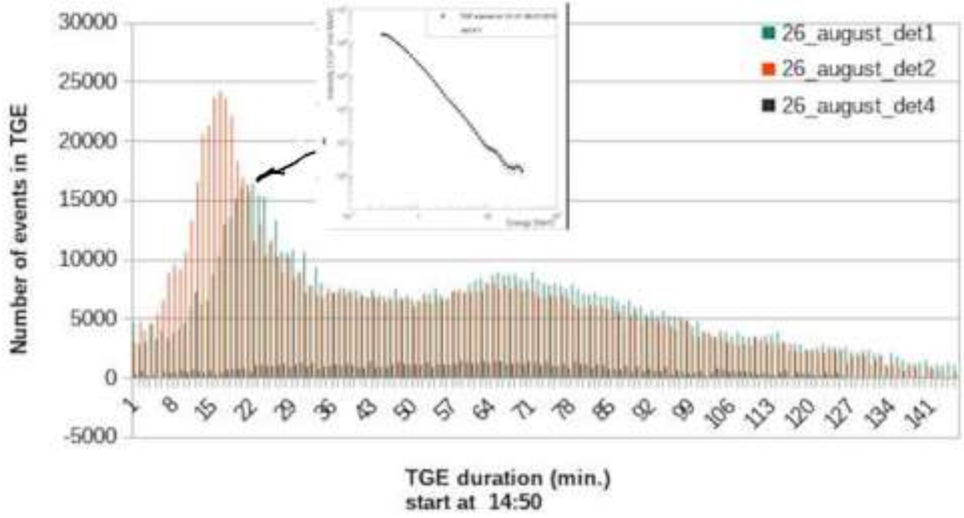
The average count rate per unit area per min. observed by TGE for detectors 1 and 2 is almost the same: 0.57 $(cm^2 min\ sr)^{-1}$ and 0.55 $(cm^2 min\ sr)^{-1}$, respectively. The readout of the shielded detector is 0.02 $(cm^2 min\ sr)^{-1}$. This indicates effective shielding of the detector, and no more than 3-4% of the registered TGE passes through the absorber.



With an open area of $S = 115 cm^2 sr$ at the top of the detector, an event of June 29, 2019 was recorded. The beginning of TGE was at 15:56 duration, respectively T = 100 min.

The average count rate per unit area per min. observed by TGE for detectors 1 and 2 is almost the same: 0.46 $(cm^2 min\ sr)^{-1}$ and 0.53 $(cm^2 min\ sr)^{-1}$, respectively. The readout of the shielded detector is 0.5 $(cm^2 min\ sr)^{-1}$.

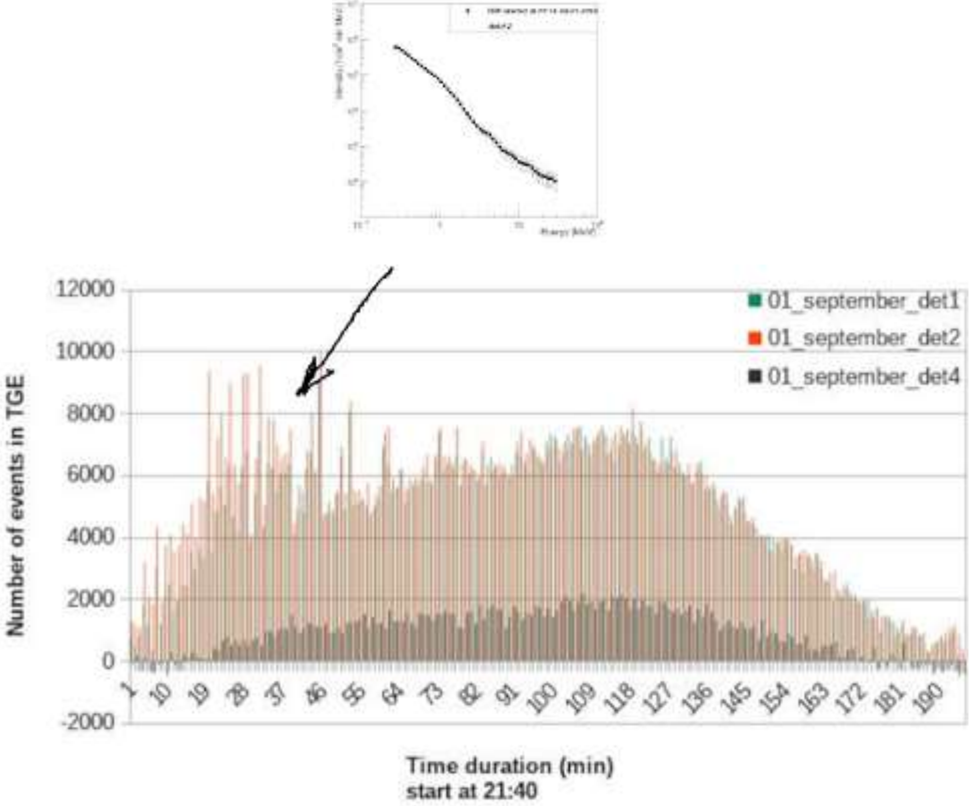




With an open area of S = 322cm^{2}sr at the top of the detector, an event of August 2, 2019 was recorded. The beginning of TGE was at 15:05 duration, respectively T = 145 min.

The average count rate per unit area per min. observed by TGE for detectors 1 and 2 is almost the same: 0.46 (cm^{2}min sr)$^{-1}$ and 0.56 (cm^{2}min sr) $^{-1}$, respectively. The readout of the shielded detector is 0.53 (cm^{2}min sr)$^{-1}$.

More interesting event was August 26th! The event started at 14:50 and the first 20-30 minutes a high-energy component was observed. The maximum energy in the spectrum corresponded to 30 MeV! The duration of the entire TGE is 145 minutes. The average count rate per unit area per min. for all duration observed by TGE for detectors 1 and 2 is almost the same: 2.1 (cm^{2}min sr)$^{-1}$ and 2.2 (cm^{2}min sr) $^{-1}$, respectively. *But the fluxe of the shielded detector is 0.996 (cm^{2}min sr)$^{-1}$. And if we are take the high energy region, up to 35 min of TGE, then for detectors 1 and 2 the count rate is* ***2.6*** *(cm^{2}min sr)$^{-1}$ and* ***4.0*** *(cm^{2}min sr) $^{-1}$, respectively. The readout of the shielded detector is* ***0.58*** *(cm^{2}min sr)$^{-1}$.*



Next interesting event was September 01 The event started at 21:40 and the first 20-30 minutes a high-energy component was observed. The maximum energy in the spectrum corresponded to 30 MeV! The duration of the entire TGE is 195 minutes. The average count rate per unit area per min. for all duration observed by TGE for detectors 1 and 2 is almost the same: 1.45 $(cm^2 min\ sr)^{-1}$ and 1.57 $(cm^2 min\ sr)^{-1}$, respectively. *But the shielded detector again two times less - 0.81* $(cm^2 min\ sr)^{-1}$*. And for the high energy region, up to 35 min of TGE, then for detectors 1 and 2 the count rate is* ***1.3*** $(cm^2 min\ sr)^{-1}$ *and* ***1.7*** $(cm^2 min\ sr)^{-1}$*, respectively. The readout of the shielded detector is* ***0.5*** $(cm^2 min\ sr)^{-1}$*.*

Table 1. The fluxes registered by detectors 1 and 2 and detector 4 with different configuration.

Date/expos. Time	S_{eff} (cm^2 sr)	D1	D2	D4	1-D4/<D1+D2>	E_{max} in TGE
23 July 2019/140min	3242	0.569	0.545	0.020		MeV
29 July 2019/100min	361	0.457	0.531	0.497	0.005	9.4
02 August2019/145min	1011	0.461	0.556	0.529	0.040	2
04 August 2019/97min	1011	0.289	0.473	0.310	0.186	12
18 August2019/160min	785	1.087	0.890	0.826	0.164	4.4
26 August2019/145min	785	2.096	2.202	0.996	0.536	35
high energy	785	2.634	4.065	0.583	0.826	
27 August2019/100min	1350	0.787	1.034	0.976	0.072	11.3
30 August2019/74min	1350	0.775	0.845	0.727	0.103	3
01 Sept.2019/195min	1350	1.453	1.572	0.889	0.412	32
high energy	1350	1.298	1.711	0.477	0.683	
02 Sept. 2019/214min	1350	1.692	1.486	1.400	0.119	10
11 Sept.2019/235min	1350	2.618	2.564	2.073	0.200	18
28 Sept. 2019/245min	1350	0.793	0.735	0.643	0.159	5

Conclusions.

1. Shielding provides 96-97% absorption of TGE, and the systematic error of the shielded detector fluxes does not exceed 4%

2. The fluxes of low-energy TGE on the all surface and on the selected areas of the detectors are the same with 10-20% accuracy , and therefore the low-energy component of TGE has a uniform distribution by the angles .

4. The high-energy component has a predominantly vertical direction.