Scintillating spectrometer for long-term study of the sea level gamma-ray background variations caused by changes of concentration of radioactive isotopes and particle acceleration during thunderstorms

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In this talk we present an experiment for the long-term measurements of flux and spectral variations of the sea level gamma-ray background radiation. The instrument has moderately large (80x80 mm) scintillating detector with energy resolution ~7% at 662 keV. The data are recorded in event-by-event mode with ~15 µs time resolution thus permitting detection of the terrestrial gamma-ray bursts at the moment of lightning during thunderstorms. Regular testing of 40K background line position (E=1.46 MeV) is used for calibration of the spectrometer during the whole measurements session. This set-up helps to exclude temperature variations of the signal in a long-term experiment. The instrument design, as well as results of its long-term employment are discussed in this paper.
**Scientific goal:**
- Study of spectral characteristics of TGEs in 20-10000 keV range
- Measure of the direction of TGE gamma-radiation
- Search for fast gamma-ray flashes from lightning

**Principles of instrument design:**
- Detectors are scintillator spectrometers with NaI(Tl) or CsI(Tl)
- Electronics allows to analyze pulse shape in order to use phoswich detectors and/or to remove imitations of gamma-events by thunderstorm electric discharges
- Recording all data in “event” mode with fine time resolution
- All data are recorded to SD card for further analysis
- Exact timing with GPS receiver
- Measurements with collimated detector placed on rotating platform are provided
Design of instrument electronics
Analog part of instrument electronics

HV supplier
TracoPower THV series
Low Voltage supplier
TracoPower TEN5

Amplifiers
AD8055, AD8014

Comparator
AD8561

SPDT switch
ADG736BRM

Simple logics
74AC00, 74AC02

ADC
AD7492 or external
ADC of MCU
Digital electronics and data format

- Producing time data with accuracy 15 mcs. Stability of internal timer is ~1s/day and synchronyization via GPS every second
- Forming data frames each second.
- Producing ~15mcs timer data starting at the beginning of the frame
- Interrupt on the request from analog card and digitize pulses of fast and slow components
- At the beginning of a frame digitize signal on the additional analog input

Board STM32F4 DISCOVERY with Cortex M4 microcontroller

7b - Frame start marker - E4 57 B4 C0 3F 66 99
4b – Frame number
6b - Time – YY MM DD hh mm ss
2b – Number of events in the frame
4b – Number of counts of 15mcs timer during the frame
2b – ADC data for external analog input
N*(3b+3b) – Data records: ADC data + timer value
4b – Frame end marker – CC 11 00 00
Gamma-ray spectrometers used in this work:

Detector: NaI(Tl) 40x40 mm
PMT: ФЭУ-176
Range: 20 кэВ-1 МэВ
Resolution 12% at 662 keV

Detector: CsI(Tl) 80x80 mm
PMT: Hammamatsu R1307
Range: 20 кэВ-3 МэВ
Resolution 7.2% at 662 keV
Placed on rotating platform
Calibration and data processing

Gamma to gamma data were processed and three kinds of secondary files were produced:

1) Monitoring time sequences in several energy channels with 1s resolution
2) Detailed energy spectra for requested periods
3) Event data sequences (useful for short burst search)

Autocallibration algorithm was used for large detector data: every 300s of the data the program determined the actual position of well visible 1.46 MeV background gamma-line of K-40, then the energy of gammas in keVs was calculated. It allowed to minimize the effects of false variations connected with temperature drift of the detector characteristics.
Results of observations 50 km North from Moscow
Conditions: thunderstorms (peaks), rain, next - clear weather
Energy spectrum of TGE 28.07.2015
05 of September 2015.
Conditions: small rain without thunderstorms
27 of September 2015.
Conditions: clear weather, then thunderstorm with powerful rain, then the rain stopped and the sun appeared
Energy spectrum of TGE 27.09.2015
Search for short bursts

The data of thunderstorm 27.09.2015 were processed. The moments of short burst candidates when >7 gammas occur in 1 ms were determined (yellow triangles)
The graph of expected number of imitations vs threshold value shows that probably all candidates pointed on the left figure are random and the criterion must be some harder with threshold of 9 gammas per 1 ms. Such events were not observed.
1) There are no gamma-ray flashes at the moments of lightnings
2) The moment of gamma-ray flux increase exactly coincide with the rain start.
3) When the rain stops the TGE decays exponentially with time index $\sim 1h$
Test for directivity

Angular characteristics for 662 keV for \( \theta = 0 \) deg, 30 deg and 70 deg

Monitoring data plotted separately for 8 directions (graphs are shifted with 20 unit step)
Measurements in extended energy range
Calibration energy spectrum obtained with 10 cm CsI(Tl) detector on 2016, may (in energy range up to 15 MeV)
One can see no change of gamma-ray flux in energy range $E>3200$ keV.

The increase of the instrument readings in low energy range can be explained by Rn-222 daughters.
Measurements with 40 mm NaI(Tl) detector in Nor-Amberd (Armenia) during thunderstorm 22.09.2014
Energy spectrum of gamma-ray enhancement (TGE) 22.09.2014
Gamma-ray flux monitoring on Aragatz mountain (3200 m)
Energy spectrum obtained on Aragatz station (3200 m) 04.10.2015

Monitoring in several channels
Measurements on Aragatz during TGE 2016-03-04

From A.Chilingaryan group
From SINP MSU gamma-detector
One can not conclude whether the 609 keV line is present in additional radiation spectrum or not.

The detector on Aragatz will be improved soon to have better sensitivity for gamma-lines detection.
Thank You!