Variations of gamma radiation spectra during precipitations

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Abstract. In the present paper results of prolonging studies of variations of a natural gamma (X-ray) radiation during precipitations registered at cosmic ray station in Apatity are presented. To the present time in the complex installation realizing monitoring of the near ground radiation, the detector is added on the basis of a scintillation crystal by size Ø150×100 mm. The special procedure of working out of the differential energy spectra obtained on the basis of this detector is designed. Due to this it is found, that increases are produced by an additional flux of radiation with the non-regular descending energy spectrum superimposed on a background radiation, having a power law energy spectrum. The clear upper energy limit of the additional radiation, accompanying with precipitations, is observed. It is 1.8-2.0 MeV. Any spectral lines, which could be produced by radio nuclides, are not revealed in all researched gamut. It is concluded that these fluxes are produced by energetic charged particles during their passage through the atmosphere, i.e. Bremsstrahlung generation process. Based on the energy balance, the minimum field strength, which can cause a secondary increase, was performed.

1. Introduction
In Polar geophysical institute of the Russian Academy of Science (PGI) in Apatity for several years the monitoring of the X-rays and gamma-ray background are carried out. Complex installation is used, which consists of radiation detectors based on scintillation crystals of NaI(Tl) (Ø62×20 mm), the detector of the charged particles based on Geiger-Muller counters and the precipitation gauge. Since the first days of observations the increases of X-ray background reaching 50 % were detected. These increases are observed all the year round and are usually accompanied by precipitations. Increases are not connected wit the release of radon from the soil, with fallout any radionuclides together with precipitations and occur only in an electromagnetic component [1, 2]. The same results are obtained at PGI station on Spitsbergen where analogous instruments are disposed.

Example of such increase is shown in figure 1. The lack of increase in the channel Geiger-Mueller indicates the lack of charged components in the secondary radiation, which causes an increase. The differential energy spectrum of radiation both in clear weather, and during of increases has no any characteristic lines that specifies the bremsstrahlung process of generation. Spectra of radiation were measured with the help of the 4096-channel pulse-height analyser.

Recently in addition to available detector based on crystal of NaI(Tl) of sizes Ø62×20 mm a detector with sizes of crystal Ø150×100 mm has been added. It is allowed to expand the energy range of measurements from 300 keV to 4 MeV and more. Besides the large detector has been connected simultaneously to the two systems: to the discriminators with the fixed thresholds >200 keV, >1000 keV and to the pulse-height analyser. As the amplitude of the electrical impulse that comes from the detector is proportional to the energy left by quantum in the crystal, the amplitude spectrum of pulses is clearly related with the energy spectrum of X-rays [3].

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2. Energy spectra of the background and increases

As it was mentioned above, with the help of the large detector measurements in two various ways are proceeding: the continuous measuring of a flux of gamma-ray quanta with energy > 200 keV and > 1000 keV and measuring of a differential energy distribution of a gamma-ray background with 30 minutes discretization. Differential spectra are convenient because a spectrum of purely increase (i.e. additional radiation, which causes increase in radiation flux above the background) is simple enough to subtract spectra. During increases the measured spectrum of gamma radiation $S_e$ is the sum of spectra of background $S_f$ and the radiation flux that was added to background $S_a$ (it would be called the spectrum of the actual increase in contrast to the total spectrum increase $S_e$). Thus,

$$S_a = S_e - S_f$$

Spectra were collected for 30 minutes, have a lack of statistical accuracy. However, as shown in figure 1, in an event it is possible to allocate a time interval of approximately constant intensity near the maximum of increase with duration of 2-3 hours or more, and get the average spectrum for this time, which has better accuracy. It can be processed to calculate the average background spectrum too. Summery we shall obtain (2):

$$\overline{S}_a = \overline{S}_e - \overline{S}_f$$

where a line above a numeral means a time averaging.

Examples of energy spectra are shown in figure 2. The background energy spectrum (it is shown as black line) is well approximated (except for a small wide bulge on 0.7-1.6 MeV) by a power law with an index $\gamma = -1.8$ (a red line). During the spectrum measurements (more than 6 months), significant changes in the shape of background spectrum were not observed. Variations of $\gamma$ value are not more than 2-3%. The spectrum during an increase is shown in figure 2 as green. It is clearly seen that the
spectr of increase and background are merging at energies more than \( \sim 1.8-2 \) MeV. Thus, by direct comparison of differential spectra it is shown that the spectrum of the actual increase does not extend above 2 MeV. It confirms the estimates of upper energy limit of increase made earlier on the basis of other methods [2]. In figure 2b the spectrum of the actual 20% increase, obtained by formula (2) and then integrated is shown. The difference between two spectra obtained by the formula (2), is little and fluctuates. To improve accuracy, the resulting spectrum turned into the integral one. Its form not described by an analytical dependence and is intermediate between the power and exponential forms.

Figure 2. a) Differential spectra of the background (black), increase (green) and the approximation function (red). b) Differential actual spectrum of increase (black) and its approximation (red).

The actual spectra are obtained during the observations of more than two dozen increases. They are about the same shape and differ only in intensity, which is explained the increase amplitudes in events. The nature of the bulge in the spectrum is not yet clear exactly. It is present in all spectra as well as during increase and background both. Furthermore, it can be also observed in the spectra of the actual increase (see figure 2b). This indicates not only the presence of this phenomenon in a calm clear weather and during precipitation, but also for its contribution to the actual increase.

3. The origin of increases
Numerous experiments [1, 2] have been additionally carried out to clarify the nature of the radiation calling increases X-ray. It is authentically clarified, that increases are observed only in an electromagnetic component and completely miss in the charged component of radiation in a ground stratum (see figure 1a). Increases are not linked to a radioactive contamination of precipitations any anthropogenous radionuclide or a radium emanation from ground. More details are in [2].

Argument against radionuclides is next. It is apparent that on increase profile, that reduction to background level is \( \tau_0 \sim 100 \) minutes. Which have caused increment, it is not clearly. Where did long-lived radionuclides disappear after 2-3 hours? If one supposes, that it is precipitation with short-lived radionuclides (around a \( \tau_0 \) life time), there is a reasonable problem: where is a source of them? A distance between our detectors and the source must not be more than

\[
L_c = \tau_0 \cdot V_c
\]

where \( V_c \) is an average cloud velocity, \( \sim 15-20 \) m/s. Expression (3) restricts an area size less than 100 km, from which short-lived radionuclides could placed in the atmosphere and transport to the detectors. At length, X-ray increases are observed in Barentsburg (Spitsbergen) where any industry is absent around thousands km and anthropogenous factor is minimum. Outgoing from the gathered data and results we suggest that X-ray background and its increases both are caused Bremsstrahlung processes. Possible mechanism of increase can be additional acceleration of energetic particles in electric fields into clouds.

Muon acceleration in thunderstorm clouds is studied in many papers, for example [4]. However, this mechanism can’t be steeply converted to our problem of electron additional acceleration in rain clouds. Electric fields in rain clouds are present, but they did not exceed 5-10 kV/m [5, 6]. Some
restricts are set at Bremsstrahlung processes too [7] (for example, a characteristic transport length). In short we can’t now suggest full and detailed way of electron acceleration into rain clouds. However, it is possible to make estimations on the basis of total energy balance. Let’s use function $I(>E)$ in figure 2b, approximating an integral spectrum actual increase. The function is given in an analytic form, it is easy to obtain a differential spectrum $J(E) = I(E)/E$, which mean an energy flow brought on the detector via quanta with energy $E$. Expression

$$\Psi = \int_{E_{\text{min}}}^{E_{\text{max}}} \Phi(E) dE$$

(4),

where $E_{\text{max}}$ and $E_{\text{min}}$ are the upper and lower energy limits in our spectrum, is the complete energy flux brought all registered quanta. The specific flux $\psi$ is in expression

$$\psi = \frac{\Psi}{S \cdot T \cdot \sigma}$$

(5),

where $S$ is a detector cross-square, cm$^2$; $T$ is time of gathering of a spectrum, s; $\sigma$ is a field of detector view in parts of the upper hemisphere, $\sigma \approx 0.3$. A unit of $\psi$ is keV/(s·cm$^2$). Having substituted numerical values of all quantities in (5), we obtain $\psi = 35 \text{ keV/(s·cm}^2\text{)}$. We can say, that electrons (because only they can produce Bremsstrahlung quantum) during increase get somewhere such additional energy. Outgoing from our suggestion it can estimate a field gradient necessary for accumulation by energetic electrons such energy. It is known [8], that near surface electron flux, originating from muons decay, is $\sim 0.3 \text{ per (s·cm}^2\text{)}$. Taking into account that electron of any energy in the atmosphere passes approximately one radiation length $l_0$ on which it transmits all energy to radiation [8], electron may accumulate energy on the same distance $l_0$ only. Force of electric field is

$$\chi = \frac{\psi}{n \cdot l_0}$$

(6),

where $\chi$ is an electric field strength in a cloud, (B/cm); $n$ is electron flux, (s cm$^{-3}$); $l_0$ is a radiation length, cm. Having substituted values, we obtain $\chi = 4 \text{ V/cm or 400 V/m}$. Of cause, not all accumulated energy transferred to Bremsstrahlung quantum, but the value points to that 20 % increase of X-ray flux is easily produced by additional acceleration into electric field of clouds.

4. Conclusions

Upper limit of energy 2 MeV was found in actual spectrum of increase. It is obtained at differential energetic spectra of X-ray measured during precipitation. According to energy balance electric field strength into cloud was estimated. It is enough less that 1 kV/m to produce 20 % increase.

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