ЯДЕРНА ФІЗИКА ТА ЕНЕРГЕТИКА / NUCL. PHYS. AT. ENERGY 25 (2024) 316-321 ISSN 1818-331X

УДК 524+53.03+539.1 https://doi.org/10.15407/jnpae2024.04.316

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POSSIBLE COSMIC RAYS ORIGIN OF PERIODIC COMPONENTS IN GAMMA-BACKGROUND SIGNALS

Analysis of a long-term regular series of measurements of signals from the automated system of radiation control (ASRC) in the Chornobyl exclusion zone revealed many features, which are reproduced for different observation posts and which we will try to consider from the general position of the influence of cosmic factors. It is implied that these features are clearly linked to certain astronomical phenomena. It is possible to propose a model that describes all these phenomena, namely the possibility of manifestations of the influence of cosmic rays. Such a mechanism as a cause of changes in radioactive background signals in general and in ASRC signals, in particular, has not been considered previously. Probably because its contribution was considered small.

Keywords: gamma-background, Chornobyl exclusion zone, count rate variability, cosmic rays.

1. Introduction

In the 30-km zone around the emergency Chornobyl NPP (Ukraine), an automated system of radiation control (ASRC), consisting of several dozen gamma-background detectors, operates. Detectors are located on masts at a height of 3 - 4 m above ground level. Signals from this system (total signal for every 15 min or hourly) are stored and form a regular series of data. The analysis revealed certain regularities in these series. One would expect it to be a Poisson random series, skewed by weather conditions since the measurements are taken outdoors. However, careful studies [1 - 3] showed that obvious natural causes of the appearance of regular periodicities (heating of equipment, exhalation of radon, etc.) should be rejected, that is, the detected features are a property of the signals themselves [4].

These are not the only observations of variability in radioactive decay signals, and the idea that this is the observation of the effect of unknown external factors on the half-life is widely discussed (see [5] and the literature cited there). In this work, the possibility that the detected variability of ASRC signals may be due to the reception of cosmic rays is considered.

The possibility that the detected pulses count rate variability is caused by cosmic rays among other possible influences has not been discussed in the literature, perhaps because of the widespread belief that they are relatively small. However, a correct analysis shows that this is not quite the case. It has long been known [6] that cosmic rays at ground level consist of high-energy and low-energy components, where the low-energy component, which is the subject of this paper, has an energy of up to 3 MeV. The problem is that it is not so easy to isolate the contribution of cosmic rays from other factors.

After entering the Earth's atmosphere, the primary high-energy cosmic ray particle generates secondary neutrons, muons, electrons, gamma-rays, and other particles. When we talk about the natural radiation background, in reality, we are talking about measuring gamma-rays with energy up to 3 MeV. In order to make it possible to compare the results of different measurements, it is necessary to be sure that we are talking about the same thing. And not about relative assessments, but about absolute ones. Today, such a parameter can be the dose estimate and, accordingly, the parameter that is measured is the dose rate of the radiation field. This measured signal consists of two main parts: gamma-radiation from terrestrial radionuclides and ones that came from outer space. Contributions from other components of the radiation background remain outside the scope of such estimates.

Estimates found in the literature vary widely. As a basis for consideration, it is possible to take the estimates of official organizations, in which the contribution to the dose from cosmic rays is estimated as a percentage of the measured natural dose rate [7 - 9]. The cosmic ray dose estimates are made in the range from 5 to 17 % of the measured (total) natural background, which are registered by ordinary gamma-spectrometers or counters.

The lower limit of sensitivity of such equipment is approximately 30 keV – the beginning of the action of the photo-absorption mechanism. The low-energy component is of interest mainly in connection with its contribution to the dose, both at ground level and, for example, increasing the dose during high-altitude aircraft flights [10]. We emphasize that in this approach only the low-energy gamma-background is measured, and the contribution to the dose of other particles, primarily electrons, can only be theoretical.

However, there are direct standard ways of estimating the low-energy cosmic component, which consists of measuring the dose rate after shielding the radiation from the upper hemisphere with a powerful (10 - 15 cm) lead shield. In such direct measurements, when the detector was shielded [11], 0.015 mSv/year = 1.7 nSv/h was obtained.

And, finally, direct measurements are possible in the absence of the terrestrial gamma-background – these are measurements over the water surface. Fig. 1 shows a very impressive result of such measurements taken from [11]. Measurements in [11] showed that the rate of gamma-rays counting above the ground level and above water (Danube River, far from the shores, where there is no terrestrial gamma-background) differs by approximately two-three times only.

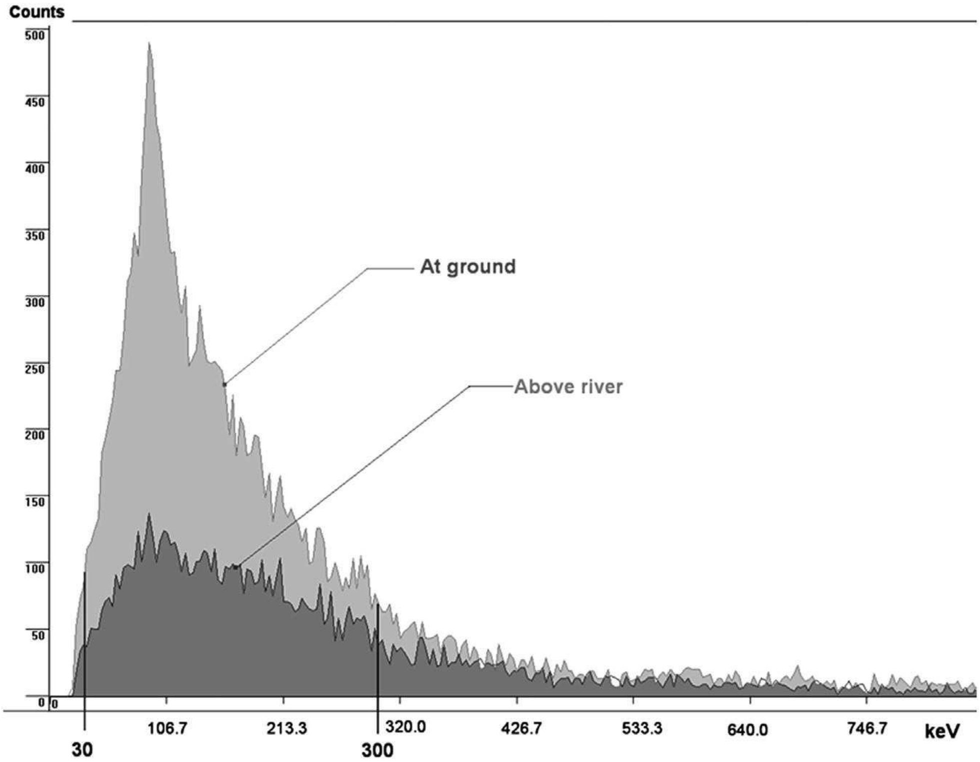

Fig. 1. Gamma-spectrum of the low-energy component of the gamma-background on the surface of the earth and above water (Fig. 6 from [11]).

No less interesting is the question of the form of the gamma-spectrum of cosmic radiation. For example, it was shown in [12], as in Fig. 1, that the spectrum of the low-energy component has an appearance, similar to the usual Compton continuum in the spectra of scintillation gamma-spectrometers: a broad peak from 30 keV to 300 - 400 keV with a maximum in the region of 90 - 100 keV. In real measurements, this spectrum of cosmic radiation is superimposed on a similar Compton continuum of radiation from natural terrestrial radionuclides.

If not all components of this “low-energy cosmic background”, then at least a gamma-part of them, close to the level of the terrestrial radiation gamma-background, ends its existence due to Compton scattering, has an energy of the order of 30 - 400 keV and can be recorded by gamma-spectrometers and counters. This is the energy range in which ASRC also works.

2. Experiment

Let's look at the ASRC data from the cosmic rays’ point of view. There is a fairly long series of results of regular observations of the gamma-background level in the 30-km zone around the Chornobyl Nuclear Power Plant.

For measurement were used:

1. BDMG-04 and GammaTRACER detectors for measuring dose characteristics. The range of equivalent dose rate measurements is from $0.05\cdot10^{-6}$ to 10 Sv/h and from $1.0\cdot10^{-7}$ to 10 Sv/h, respectively. Gamma-radiation energy range is from 0.06 to 2.0 MeV for both types. Limits of permissible basic relative error of gamma-radiation equivalent dose rate measurement at confidence probability P = 0.95 do not exceed $\pm(15 + 2.0\cdot10^{-6}/A_x)$ % (for both types) where A_x is the measured value.

2. Canberra gamma-radiation spectrometer with OSPREY analyzer and 4ABR-1.5x1.5 detector. Genic-2000 Inspector software. Resolution is <3 %. Energy range is 0 - 2500 keV.

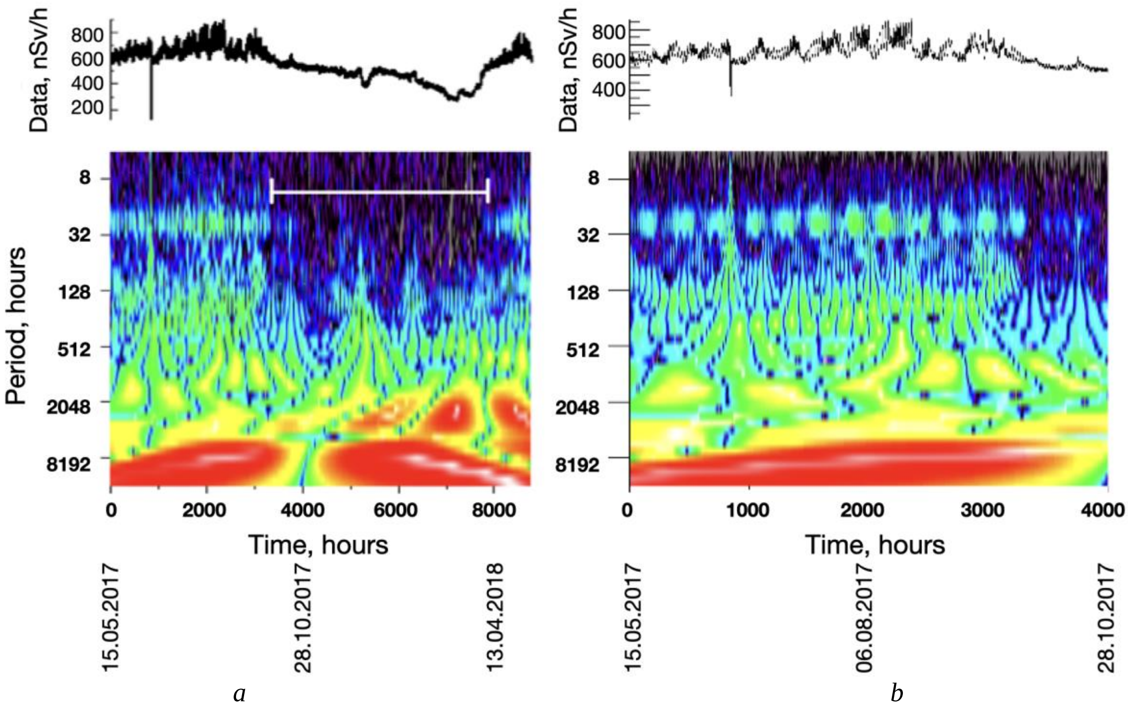

Fig. 2. A signal and a picture of the coefficients of its wavelet expansion. Observation post "Pripyat". Starts on 15.05.2017, ends on 15.05.2018. Gaussian wavelet. *a* – the total signal for the year, from 15.05.2017 till 15.05.2018. The solid light line in the Figure on the left shows the time range when signs (spots) of the daily sinusoid are practically absent (from September 2017 till April 2018). *b* – a part of this signal from 0 : 4000 h (from May 2017 till October 2017), where both the band of the daily movement and the modulation by the "sawtooth" signal are clearly visible when the amplitude of the daily small peaks gradually increases within 7 - 9 days and then drops sharply. (See color Figure on the journal website.)

It can be concluded that the main effects, detected in ASRC signals, are observed in one way or another during the following astronomical phenomena (Fig. 2):

1. There is a daily course of the signal (rotation of the Earth around its own axis). The minimum of the modulating sinusoid is at 05 - 07, and the maximum is at 17 - 19 Kyiv time (and not at 12:00 and 00:00, as it would be if the source were the Sun), see 1 - 4.

2. The diurnal course is observed mainly in the summer months – this can be connected with the movement of the Earth in Space.

3. There are "failures" in the uniformity of the diurnal course – the peculiarities of radiation from an external source.

4. The modulation of the ASRC signal in the form of "saw teeth" – radiation from an external source [4, 6] is observed.

5. Periodicity of several days (4-5-6-7-8 days) occurs irregularly.

6. There are the results of wavelet analysis, which show the correspondence of changes in the ASRC signal to the phases of the Moon (August 2015, 2016) [13].

3. Model of the source and the presence of the GC and other directions

The phenomenon of the existence of a diurnal course, that is, regular daily changes in the ASRC signals, is the first among the series of unexpected periodicity effects. It is obvious that the daily course is connected with the rotation of the Earth around its axis. The explanation seems obvious – it is hardware, including the influence of weather conditions, and the effects of changing measurement conditions during the day and night. However, if we point out that earlier [1 - 4] it was shown that the appearance of the diurnal cycle cannot be explained by hardware effects, then the question arises again about the causes for the appearance of such periodicity. And, of course, first of all, it should be remembered that this is not the first observation of the variability of radioactive decay signals (see [5]). From this, the idea arises, that there is some external factor (radiation, field), the magnitude of which is shielded by the Earth. Secondly, this hypothesis is supported by the existence in the series of measurements of the radioactive decay rate of many periodicities, including solar and stellar daily periods, revealed in the works of Schnoll [14, 15], which clearly indicates the connection of the detected in [14, 15] effects with the stars system, that is, with the factor, which is generally outside the boundaries of the solar system. Note, that this effect (the existence of solar and sidereal daily periods) cannot be observed in ASRC signals, because the resolution of ASRC data in the best case = 15 min, and the difference between solar and sidereal daily periods is 4 min.

The existence of “sawtooth” effects in the ASRC signal and some other multi-day periodicities allows us to propose a model of an external factor that will include almost all of the specified effects. This is the model of cosmic ray detection.

It follows from the model that these periodicities reflect the dynamics of cosmic rays and/or the sources that emit them. So, the considered model is based on the hypothesis that there is an astrophysical object that, by emitting cosmic rays (that is, those rays that ultimately create a low-energy gamma-background), affects the ASRC signals:

diurnal changes are caused by the shielding of this source by the Earth due to rotation around its own axis;

seasonality can be attributed to the fact that, due to the slight inclination of this object, the source does not rise above the horizon in the period from October - November till May;

modulation in the form of “saw teeth” in such a model can occur if an astrophysical object changes the intensity of its radiation, which increases linearly for several days, and then sharply falls (pulsates), which leads to a modulation of the diurnal periodicity;

the right ascension (RA) of this source (“cosmophysical factor”) is close to the RA ~ 17 ÷ 19 h local time (the time of appearance of the maxima of signal changes).

Such a source must meet the requirement that the intensity of its influence on the detector on the Earth must exceed the influence of other possible sources, for example, located further away. Among the candidates known to the author, the Sun meets these requirements; the center of our Galaxy (GC) (the Sagittarius constellation RA = 17 h 46 min); such directions as the apex of the Sun (RA = = 18 h 28 min); and cosmological vector potential RA = 19.3 ÷ 19.63 h) [16]. The interval of 17 ÷ 19 h best corresponds to two directions: the constellations Sagittarius (GC) and the Cygnus (the apex of the Sun). Others clearly fall outside the data scatter. In addition, as marked in Fig. 2 region of no diurnal periodicity, from approximately September - October till April - May, corresponds to the period when the constellation Sagittarius does not rise above the horizon [17], which allows a choice to be made in favor of the GC (Milky Way).

4. Discussion

The cosmic ray hypothesis includes mechanisms to explain all the observed effects, but, firstly, its acceptance requires many assumptions, and secondly, the quantitative estimates are agreed upon only by an order of magnitude.

Quantitative estimates. In this model, there is some gamma-background, which gives a more or less stable signal. If man-made pollution is not taken into account, then it can be assumed that the natural terrestrial gamma-background at the location of ASRC (Kyiv region, Ukraine) is 5 - 10 μR/h = (44 ÷ 88) nSv/h. A contribution from cosmic rays will be added (compared) to it.

In [18] at sea level, the dose from cosmic rays is estimated as 0.27 mSv/year, which corresponds to the dose rate of $0.27{:}365{:}24 = 3.08\cdot10^{-5}$ mSv/h = = 30.8 nSv/h. In [8] the average dose rate from cosmic rays for the territory of Europe is approximately 300 μSv/year = 0.0342 μSv/h = 34 nSv/h. In [19, section 1] they take that cosmic rays’ part in the natural dose is about 1/3 of the total dose.

But in measurements with lead shielded detector only 1.5 nSv/h was obtained for the dose rate from cosmic rays in [12], and 1.7 nSv/h in [11].

As one can see, the values are very different and it is difficult to compare them due to the fact that in the case of indirect measurements, a lot of averaging is done in such estimates, there is a dependence on mathematical models, geography, etc. The paper [9] provides an analysis of the variability of the contribution of various factors over some territory, where there are both plains and mountainous regions, and the ratio between the dose from terrestrial radionuclides and cosmic radiation is assumed to be 50 % : 50 %.

Therefore, the magnitude of the possible contribution of cosmic rays to the ASRC signals should lie within the limits of the estimates made above, that is, from 1.5 to 34 nSv/h. If we take 16 % [20] as the maximum possible value of the contribution from cosmic rays for our conditions, then we expect that the dose rate from cosmic rays will be (44 ÷ 88 nSv/h)·16 % ≈ 7 ÷ 14 nSv/h.

From Fig. 2, it is possible to directly estimate the value of variability in ASRC signals. It reaches a maximum of 200 nSv/h, which is much higher than the limits defined above for the intensity of cosmic rays.

Peculiarities of measurements. In reality, the peculiarity of the ASRC situation is the geometry of measurements when signals arrive at the detector from all sides, and not directly from above. If we consider the scheme of the formation of an atmospheric shower [21], generated by a high-energy particle of cosmic rays, it becomes clear that at the very end of this process, the low-energy component will be transformed by Compton scattering of gamma-quanta and electrons and ultimately disappear in the process of photo-absorption, which corresponds to the region ~30 keV. Moreover, at this stage, when the formation of new secondary particles is already energetically impossible, the gamma-ray scattering will already go in all directions [11], and not from top to bottom in the direction of movement of the primary particle.

According to passport data, ASRC detectors are sensitive in the 50 - 3000 keV region. In addition, they do not have special lead screens. That is, it is obvious that they are sensitive to the low-energy component of cosmic radiation, which forms an already continuous 30 - 300 keV background.

Assumptions in the model. The possibility of the influence of meteorological factors on the equipment and on the source, the influence of radon exhalation, the neutrino hypothesis, and the influence of atmospheric pressure on cosmic rays is rejected due to the smallness of the expected effects. The basis for this is a large number of publications on this topic, which show that the influence of these factors can be considered small.

But if we accept the hypothesis about the influence of cosmic rays on the ASRC data, it becomes necessary to assume the existence of cosmic sources with certain properties, which seem to be absent today. In our case, it is required that in the GC, there is a sufficiently intense source of cosmic rays with dynamics, detected in the ASRC signals. In the studies known to the author, at best there are attempts to find correlations with cycles of the Sun's activity, and in all cases, there are no long regular series of background measurements, similar to the data of ASRC, only in which the presence of weak periodic components can be found.

Obviously, some part of the ASRC signal is due to the reception of cosmic rays, which, at least partially, explain the observed variability. We will consider proving that the ASRC signals include low-energy cosmic gamma-rays, which are a component of the near-surface gamma-ray background. The low-energy gamma-component is the result of the transformation of the primary cosmic rays at the stage, when the energy of the secondary particles is already lower than the energy, when in the process of collisions, new particles with lower energies can be formed, and therefore the further process of energy loss to final absorption is only Compton scattering. It seems that as a result of multiple Compton scattering, gamma-quanta lose their “memory” of the characteristics of the primary particle. However, it follows from our results that they carry information about the total flow of energy that comes to the Earth with cosmic rays. In other words, in further studies of the nature of periodicities in ASRC signals, the idea that ASRC signals reflect the total energy flow of cosmic rays can be a working hypothesis. Since this is a total effect, it may faint appearing in the data of muon or neutron monitors, which (data) characterize only a part of the flow of secondary particles, generated by the parent high-energy particle, but it may appear in the total data of ASRC. In this model, it is necessary to consider the total effect of at least two bright sources of influence in the signals: the Sun and the GC. Moreover, their relative contribution can be changed: both in our data and in [22] data, it is noted that the magnitude of the observed changes in different years is different.

However, from the other side, for example, it is hard to guess the existence of a cosmic source, which would ensure shown in Fig. 2 variability of 200 nSv/h, and which had not previously been detected in the GC. In the model of cosmic rays, to explain the monthly periodicities, the idea of changing pressure through the lunar tides in the atmosphere emerges. However, judging by the literature, the magnitude of such effects is so small, that identifying them is not a simple task. And in any case, the influence of these tides was not detected, when corrections for pressure were made at cosmic rays investigations.

5. Conclusion

Analysis of a long-term regular series of measurements of signals from the ASRC in the Chornobyl exclusion zone, revealed many features, that are related to certain astronomical phenomena:

the presence of periodic components, primarily these are regular diurnal changes;

the detected effects are seasonal: they are observed in the summer months and are practically absent from September till April;

it was found that the amplitude of these diurnal changes is superimposed with modulation, which leads to a signal in the form of “saw teeth”;

maximum diurnal shifts occur at 5 - 7 p.m. local time;

the results are reproduced at several independent measurement posts.

Theoretically, cosmic rays, which come to the Earth, have all the necessary physical mechanisms to explain the variability of ASRC signals. Both as the cosmic rays themselves, and the parameters of their passing through the atmosphere. But still, the influence of such parameters was not observed. It is possible that this difference in quantitative estimations can be removed in the future by showing that the low-energy component accumulates the cosmic rays of all energies, passing through the atmosphere, especially from the Sun.

Depending on the further development of the search for mechanisms involving ASRC signals variability, as a result of our investigation either unknown sources of cosmic rays, or new mechanisms for the formation of low-energy components will be adopted. In both cases, it will be confirmed that the ASRC is a specific astrophysical observatory.

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КОСМІЧНІ ПРОМЕНІ ЯК МОЖЛИВЕ ДЖЕРЕЛО ПЕРІОДИЧНИХ КОМПОНЕНТ У СИГНАЛАХ ГАММА-ФОНУ

Аналіз довготривалих регулярних серій вимірювань сигналів від автоматизованої системи контролю радіаційного стану (АСКРС) у Чорнобильській зоні відчуження виявив у них багато особливостей, які відтворюються для різних постів спостережень і які розглядаються із загальної позиції впливу космічних факторів. Мається на увазі, що ці особливості явно пов'язані з деякими астрономічними явищами. Запропоновано модель, що описує всі перераховані явища, а саме: можливість проявів впливу космічних променів. Такий механізм досі не розглядався як можлива причина змінності сигналів радіоактивного фону взагалі і в сигналах АСКРС зокрема. Можливо, тому, що його внесок вважається малим.

Ключові слова: гамма-фон, Чорнобильська зона відчуження, варіабельність швидкості лічення, космічні промені.

Надійшла / Received 28.12.2023