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Comparative analysis of long-term gamma-background measurements by different detectors in the Chornobyl Exclusion Zone

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Regular variations of gamma-background intensity were revealed in sets of measurements of background dose rate in exclusion zone around Chornobyl atomic station. Daily and approximately 5-6 days variations are especially noticeable among them. To prove that revealed variations are not caused by meteorological conditions or by peculiarities of the equipment, the signals from two different detection systems which work simultaneously have been analyzed. The conclusion was made that the complex of the observed regularities is impossible to explain by trivial reasons like meteorological conditions or by equipment effects.

Key words: gamma background, monitoring, regular variations, daily variations.

Introduction

The radioactive contamination of a great territory was the result of the accident on the 4-th energy unit of Chornobyl NPP (ChNPP) in 1986. Currently the Automated System of a Radiation Control (ASRC) is functioning in 30-km exclusion zone around ChNPP, with the help of which the level of a gamma-background is controlled. The results of measurements are regularly sent to a server. As a result, there is a database of many-years regular measurements, that gives the possibility to analyze tendencies of changes, etc.

Analyzing so long-term measurements it turned out ([Skorbun et al., 2018](#); [Skorbun et al., 2018 \(2\)](#); [Skorbun et al., 2019](#); [Skorbun et al., 2020](#)), that there are quite noticeable variations of gamma-background values which require the explanations. First of all, these are regular daily variations of a signal intensity – values of gamma background dose rates – , which at the first sight

can be caused by the changes of meteorological conditions, that should be taken into account while carrying out the measurements.

In our previous works ([Skorbun et al, 2019](#); [Skorbun et al, 2020](#)) the different possible causes for appearance of such effects were analyzed: instrumental factors, connected with power supply ones, the possibility of mistaken analysis, and influence of meteorological conditions (temperature). This paper is one more attempt of the authors to identify trivial causes for observed effects (periodicities) appearance. With this aim the comparative analysis of signals from two detection subsystems was carried out. They work simultaneously in the ASRC, but they are different in construction. It was expected that these constructive differences would reveal in signals as a different response of the equipment to different influence factors.

Variations of gamma-background values, which look like an amplitude modulation often have the noise level. Therefore, the fact of revealing low-intensity regularities like periodicities in a signal (which ideally must be poissonian noisy band), can be easily doubted. But the effects of signal modulations in May 2018 turned out to be so large that the signal itself looks like a slightly noised sinusoid. In the example of such a signal it is easier not only to estimate the peculiarities of the revealed periodicities, but to prove a reliability of their existence as a whole.

Short characteristics of the measurement system

The ASRC structure contains two subsystems based on the use of different types of detecting blocks. Collection and transfer of data are automated in both subsystems.

One of them is based on the use of BDMG-08p type detector, manufactured by “Piatigorskii plant “Impulse”, (at the time of setting up it was a Soviet Union production). Detecting blocks (BD) have modifications BDMG-08p-03, BDMG-08p-04, BDMG-08p, which are distinguished by the diapason of doze rate measurement, and sensible detecting elements (but all detecting elements are Geiger-Mueller counters). The level of intrinsic noise is from 0.2 to 2.0 s⁻¹. Parameters of an output signal from BD (according to technical documentation): polarity – positive; amplitude – not less than 3.5 V; pulse duration – from 2.0 to 3.5 mks.

Detectors transform a dose rate of a gamma emission in a statistical sequence of electric pulses, number of which in a time unit is proportional to dose rate. Later on in a special program transformer PP2 are converted to the form convenient to transmit through communication channels. The corresponding programs for measurement channel work are also formed in PP2.

Then the information comes to a microprocessor desk for information collection and display. There the information is accumulated, minimal, maximal and mean values during 15 min are determined, which are sent to a computer. In this subsystem the data are sent through wire communication channels.

Later the subsystem for radiation background measurements, on the base of more modern detectors like Gamma TRACER of the Genitron Instrument GmbH, Germany production (with Geiger-Mueller counters also), was mounted. The Gamma TRACER is a detector, which is intended for permanent registration of dose rate of gamma emission. The energy-efficient technology ensures the use of a Gamma TRACER during five years without maintenance. The measurement results can also be read off through an interactive infrared port. The detectors are completed by USW module SkiLink for wireless transfer of data through radio channels.

How different are these subsystems? The purpose of the subsystems is identical: to measure gamma emission dose rate. The sensitive elements have the same principle of work as well: they are the gas discharge Geiger-Mueller counters, the work of which are based on transformation of gamma emission dose rate into sequence of statistically distributed in time electrical pulses. The counters permit to generate the pulses with amplitude up to tenth volts.

But these BD have different methods to transfer the data to secondary equipment. BDMG-08p uses the cable, through which the pulses are passed (parameters of pulses are given above). GammaTRACER uses a radio channel at frequencies 410-490 MHz or also a cable. In our case GammaTRACER is attached to secondary equipment with the help of a radio channel, the information – the integral number of pulses in a unit of time – is coded and passed to a receiver. Intensity of bit errors is less than 10^{-10} . It corresponds to one “erroneous” transmitted value for 10 years at each hour data transmission.

As far as these are two constructively different electronic measurement circuits, then it was possible to expect that influence of such factors, as electromagnetic disturbances, humidity, temperature, etc. will be displayed in signal in different ways, that makes it possible to make some conclusions about the causes of revealed periodicities.

Experimental data and methods of analysis

In this work the measurement results which we received by detectors of two pointed subsystems at the observed post Mashevo, placed inside 30-km exclusion zone around ChNPP are considered. The data from the two subsystems were transformed in every hour signals.

It should also be noted that the main contributor in a signal is ^{137}Cs , which as of today is the main gamma-pollutant of a territory in 30-km exclusion zone around ChNPP, that Fig. 1 demonstrates.

The long sets of gamma-background measurements have been analyzed in order to find periodical changes in them. Such methods as wavelet analysis and Fourier analysis were used.

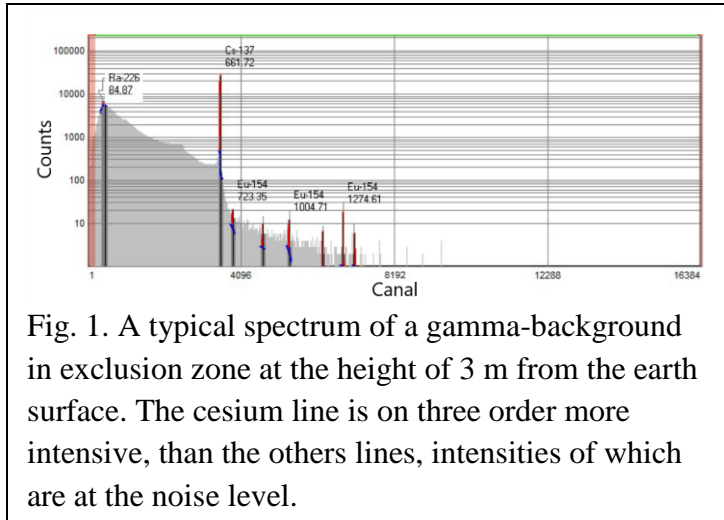


Fig. 1. A typical spectrum of a gamma-background in exclusion zone at the height of 3 m from the earth surface. The cesium line is on three order more intensive, than the others lines, intensities of which are at the noise level.

Wavelet analysis, as well as a Fourier analysis means expansion of a signal (that is some function) on the set of frequencies ([Astaf'eva, 1996](#); [Torrence C., Compo G. P., 1998](#)). In Fourier analysis the signal is considered as a sum of sinusoids over all interval of measurement time. In contrast to this, wavelet transformation analyzes the separate parts of a signal (for a given

interval of time). Such procedure can be considered as a calculation of correlation between a given part of a signal and some limited in time function, which is named wavelet and which contains the given frequency. Changing the frequency spectrum of a wavelet, it is possible to calculate correlation between a given part of a signal with wavelets of different frequencies and to find the frequency, correlation for which will be the largest one.

As a result of such calculations the two-dimensional matrix of wavelet-transform coefficients are created. In this matrix the largest coefficients will be in those time moments, when there are the largest correlations between the given parts of a signal and the wavelet. Such matrix can be depicted as an 2D-image, horizontal axis of which is the time, and vertical axis is the period of possible periodic component, and in which color or gray tints depend on coefficient values. If in the signal there is a prominent periodic constituent, even only in some limited time interval from long-time measurements, in the image of wavelet coefficient the set of regularly horizontally positioned spots appears. The distance between these spots is proportional to a period. The used Gaussian wavelet equally represents maxima and minima of a sinusoid, therefore in shown images the distance between such spots corresponds to a half-period.

In the given below analysis the distances between regularly placed spots are estimated. The exactness or uncertainty of such a procedure depends on the exactness of finding the center of a spot, that is from the size and the form of the spots. In our case an error in determination of spot “center” position does not exceed ± 2 units of horizontal axis for diurnal variations, that in reality corresponds to ± 1.5 hours.

Results

The results of a wavelet analysis of regular one-hour (number of pulses for an hour) measurements of a gamma background for GammaTRACER is shown in Fig. 2. The upper graph in Fig. 2a is noise-like set of measurements (gamma background level), which must be analyzed. A two-dimension image below represents a series of spots, the color or tint of which represent the values of wavelet coefficients for that upper signal, for different time moments. Across the horizontal is a time in hours; vertical axis is a half-period in the units of a horizontal axis. In the Fig. 2b the same matrix is shown as a three-dimensional image where on a vertical axis the values of the coefficients are shown.

As it was mentioned above, the signal taken for analyzing is not entirely usual for signals of an ASRC system, because it does not look like a noise band, in which it is necessary to find hidden peculiarities, but it looks like a noisy, but distinctly defined sinusoid, the cause of its appearance is necessary to investigate. Therefore, it is expected that wavelet analysis gives the possibility to determine its period, and also time moment of its minima and maxima etc., with increased reliability.

Fig. 2a fully confirms the expected result. Horizontal set of spots corresponds to the period of 24 hours. It is obvious that its cause is Earth rotation. But besides daily period there is modulation of daily sinusoid. In Fig. 2b the occurrence of three “humps” in the full set of diurnal peaks are clearly seen. The period of such a modulation is easy to determine by counting the number of peaks between humps. The mean number is approximately 10-11 half-periods, that is period of an amplitude modulation of daily variations is equal approximately 5-6 days.

Analogical analysis for BDMG-08 is shown in Fig. 3.

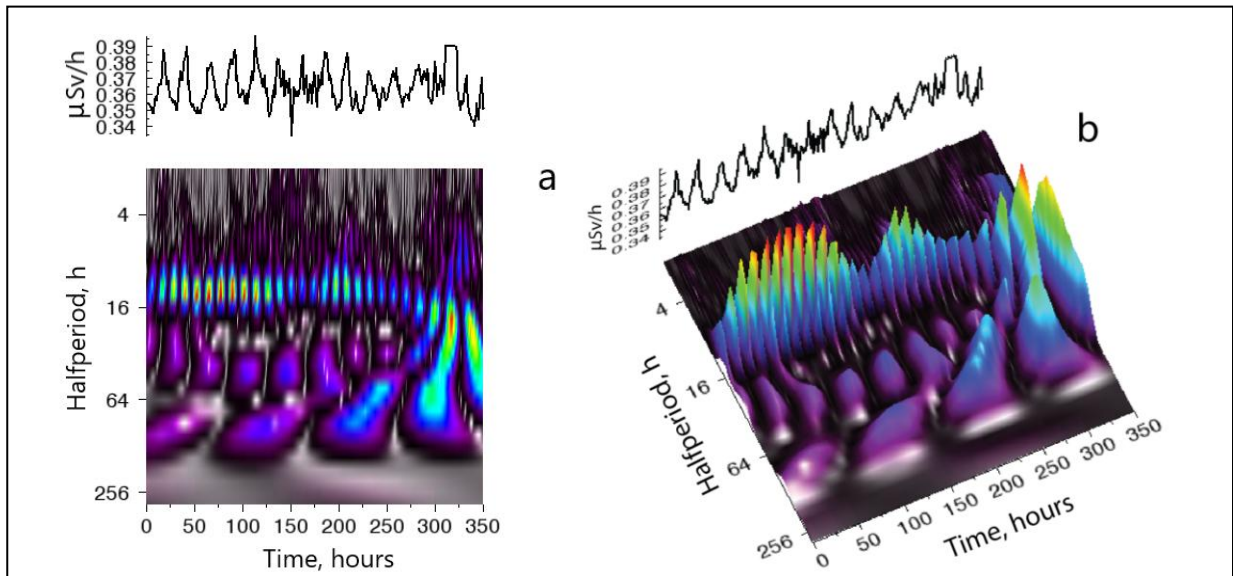


Fig. 3. Results of a wavelet transformation for BDMG-08p, 01-15/05/2018, Mashevo. The signal amplitude is given in microsieverts. Gaussian wavelet of 10 order.

If the Morlet wavelet is used, then it is possible to distinguish between positions of sinusoid maxima and minima, that is to determine their positions in time. In that way it was shown that for both detectors maximal coefficients of a daily set is related to 17-18 hours of a day, and minimal coefficient to 05-06 hours of local time morning.

Discussion

As far as the aim of the work was to establish reliability of revealed periodic phenomena in

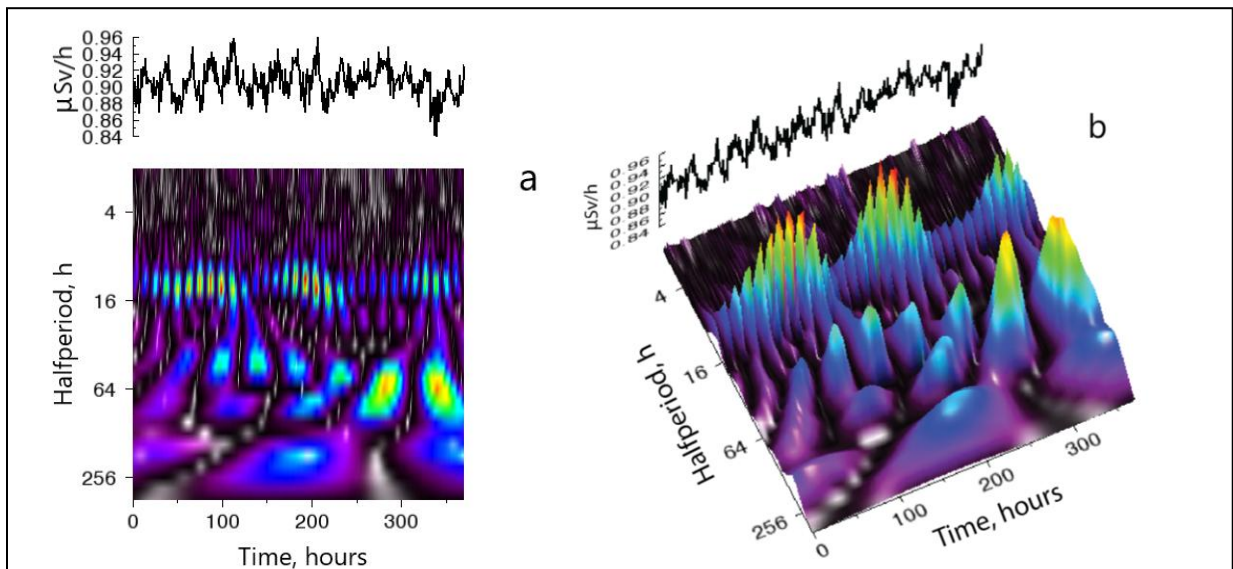


Fig. 2. Results of a wavelet transformation for GammaTracer, 01-15/05/2018, Mashevo. The signal amplitude is given in microsieverts. Gaussian wavelet of 10 order.

signals of gamma-background measurements, the discussion will consist of two parts. Taking into account the results of parallel measurements by two independent detection subsystems, the possibility to reject a hypothesis about instrumental cases of revealed peculiarities will be discussed, and also to make some conclusions from the analysis of the observed facts.

Taking into consideration constructive distinctions of the subsystems, it was likely to expect in the BDMG-08p data more “clear” manifestations of periodicities, if to assume that they are connected with meteorological conditions (the level of meteorological conditions are equal for both subsystems); or with peculiarities of the equipment work (a communication cable in BDMG-08p can be an antenna for receiving of electromagnetic and electrostatic disturbances, and it is more sensitive to these disturbances, then radio channel). But we do not see distinctions in the results of wavelet analysis for these two subsystems. It points out that revealed periodicities are not the demonstration of the constructive peculiarities of the equipment and its work, but reflect behaviors of the outer influence factor.

Periodical changes of the signals of the ASRC system in general can be caused by three factors: 1 – changes of equipment work under meteorological influences; 2 – changes of the state of a source (screening by the water or snow), because a gamma emission from polluted surrounded territory is registered; 3 – receiving additional or modulating signals from extraterrestrial space.

Usually the results of gamma background measurements represent practically noise signal, distorted by a seasonal change. Therefore, the question arises about reliability of these signal analyzing and, correspondingly, about reliability of the periodical changes discovered.

In ([Skorbun et al., 2018](#); [Skorbun et al., 2018 \(2\)](#); [Skorbun et al., 2019](#)), comparing data from different observation posts it was shown that observed periodicities are not the result of occasional properties of these noise signals. And on the basis of the results presented here, due to the fact that the time interval (May 2018) was discovered by chance, where the changes exceed $\pm 10\%$, a conclusion can be made that such big changes cannot be explained by the meteorological conditions: the equipment was specially created for the work in open air, it is metrologically checked and admitted to work, and its characteristics cannot be changed so strongly. Besides, the influence of detectors heating was checked experimentally [3] during regular metrological checking, and it was shown that heating leads only to small (1-1.5 %) reduction of the effectiveness. At the same time the experimental data are changed in a phase with the temperature changes, and values of the variations are much greater than expected ones.

It is obvious that occurrence of the daily periodicities is connected with daily Earth rotation around its axis. If as a result of such a rotation the meteorological conditions are changed (variations of a temperature, humidity etc.), then such effects must depend on a day length and on a season. But this is not so. In all analyzed data signal ([Skorbun et al., 2018](#); [Skorbun et al., 2018 \(2\)](#); [Skorbun et al., 2019](#)) minima are observed at 05-07 am, and maxima – at 5-7 pm. Moreover, from time to time the sharp changes of moments of maxima-minima appearance are observed, which return to back during 2-3 days. Because this is not an equipment glitch, the most logical explanation of such an effect is an assumption about sharp changes in the outer source, emission from which modulates our signal.

Due to the fact that the source of gamma radiation is a polluted (mainly by ^{137}Cs) surrounding territory, it is possible to assume that similar effect of periodical changes can be caused by variations of humidity – flooding of soil, where the radioactive ^{137}Cs mainly is placed, by the water or snow, that lead to screening of the emission. Observation of pointed periodicities in signals, received in autumn –winter period rejects such a cause, say nothing of that there are no so regular and large changes in the humidity variations.

Conclusions

1. With the aim to check that revealed in the signals of ASRC of Chernobyl exclusion zone, periodical changes in a gamma-background intensity are not occasional, the measurement results which were received from two independent subsystems of detecting on the Mashevo observation post were analyzed. The measurement channels are checked and certified by metrological service, they are exploited by qualified personnel, therefore the measurements results must be considered as correct and reliable ones. Observation of the periodical constituents simultaneously in the two independent measuring subsystems irrefutably prove the existence of such effect.

2. Sensitivity of detecting blocks and channels of the ASRC in general to outer influence factors like detector heating, parameters of power supply nets ~ 220 V, and to electrostatic and electromagnetic fields is much less than the revealed effect. The possibility that observed diurnal variations of a gamma background signal intensity is due to detector heating was investigated in the previous work [Skorbun et al., 2019](#), where it was shown that observed effects are not explained by this outer factor.

3. An effect of diurnal variations of a signal intensity, in the chosen interval of observations is big enough, it is seen with naked eyes and values of variations is about $\pm 10\%$. This is much more than the level of a noise component of registered signal. Moreover, such big variations largely exceed allowable diapasons of variations, pointed in the passport of the equipment.

4. Comparison of data from two different measuring subsystems (and for different observation posts ([Skorbun et al., 2018 \(2\)](#); [Skorbun et al, 2019](#))) leads to a conclusion that observed diurnal periodicity is not occasional. The nature of such changes of an intensity remains unclear. In a literature (see, for instance, the review in [Parkhomov, 2011](#)) where multiple observations of diurnal, monthly and years changes of radioactive decay intensity were described. But it should be accentuated, that in contrast to work [Sturrock et al., 2017](#), in which the revealed diurnal and other variation of radon decay velocity are directly connected with the processes on the Sun, on the base of our data we cannot make such a conclusion. First of all, because the maximal and minimal signal values we observed approximately at 5 PM and 5 AM correspondingly. But not at noon and midnight, as in [Sturrock et al., 2017](#), when Sun's influence is maximal and minimal correspondingly.

5. In the graphs of analyzed signals, and in images of their wavelet coefficients, it is possible to see an evident reduction of modulation intensity and some interruptions in the diurnal regularity, which are failed to connect with peculiarity of an equipment work or with the meteorological conditions. Therefore, a revealed period of a modulation in 5-6 days also must be recognized as a real physical phenomenon of the outer influence. As the most evident earth's influence factor on the ASRC data, an influence of a natural synoptic process can be taken, which has a variability of 5-7 days [Ukrainian hydrometeorological center, 2011](#). But fulfilled above analysis rejects meteorological conditions as an influence factor.

Therefore, the question remains, if in our case the changes of ^{137}Cs decay velocity under influence of outer actions are observed, or ASRC system detectors receive an additional "secondary" emission, which originates from the Sun or other cosmic sources. As far as authors know, the generated by cosmic rays secondary gamma emission constitutes only a small part of a natural gamma-background [Cinelli et al, 2017](#), whereas we deal with signals from polluted territory, intensity of which can be on two-three order higher, then on "clear" territories. In this situation the contribution of cosmic rays in a standard understanding of this phenomenon is expected as

extremely small. Thus, reasoning from the above analysis, where a meteorological influence is rejected, the authors tend to consider the ideas of ([Rokityansky, 1999](#); [Shnoll, 2014](#)), where on the base of extensive experimental examples the hypothesis about existing of some global cosmic factor, whose influence on all earth's processes is suggested.

6. The revealed periodical changes of a gamma background noise signal directly influence measurement results, which received under carrying out the control of a radiation state with the use of ASRC, and must be taken into account at calculations of uncertainties of the received results and forecasting of radiation state in the Chornobyl exclusion zone.

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