НАУКИ О ЗЕМЛЕ

Factors influence on atmospheric concentrations of beryllium-7 (^{7}Be) in the Chernobyl zone

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Факторы, влияющие на концентрацию бериллия-7 (^{7}Be) в атмосфере Чернобыльской зоны

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Abstract: *the paper presents the results of monitoring of ^{7}Be concentration in the surface atmospheric layer of Chernobyl for the period from July 2005 to May 2010. The features of influence of factors such as rainfall, storm activity, temperature and wind speed on the concentration of the isotope were examined. It was shown that significant impact on variation of ^{7}Be concentrations have a flux of thermal neutrons produced during thunderstorms and intensification of vertical exchange in the troposphere.*
Аннотация: *в статье представлены результаты мониторинга концентрации ^{7}Be в приземном слое атмосферы Чернобыльской зоны в период с июня 2005 по май 2010. Исследовано влияние осадков, грозовой активности, температуры и скорости ветра на концентрацию изотопа. Было показано, что существенное влияние на изменчивость концентрации ^{7}Be имеет поток тепловых нейтронов, образующихся в течение гроз и интенсификация процесса вертикального обмена в тропосфере.*

Keywords: *beryllium-7 (^{7}Be), thunderstorm activity, meteorological parameters, Chernobyl zone.*
Ключевые слова: *бериллий-7(^{7}Be), индекс грозовой активности, метеопараметры, Чернобыльская зона.*

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Introduction. Beryllium-7 (^{7}Be) is radionuclide (T½ = 53.3 days) of cosmogenic origin. A lot of attention is paid to the study of spatial-temporal variability of concentrations of this radionuclide in the atmosphere. This is because it is used to solve a number of tasks: assessment of stratospheric air masses intrusion in the surface layer of the atmosphere [1]; the influence of transport paths and precipitation on the composition of marine aerosol particles [2]; vertical transport of aerosols in the troposphere [3]; evaluation of SO_2 dry deposition from the atmosphere to the Earth surface [4], etc.

Spatial-temporal variability of concentrations of this isotope in the surface layer of the atmosphere is determined by the variability dynamics of the components that regulate ^{7}Be balance in each of the regions under consideration. Increases in ^{7}Be concentration occur due to the processes causing its formation, and as a result of advective transport of air masses.

^{7}Be concentration in the surface layer decreases because of radioactive decomposition of its atoms, deposition and washout of aerosol particles, which contain it on the underlying surface, and advective transport of air masses.

^{7}Be is formed in the atmosphere as a result of interaction of the nuclei of the major air components with protons and neutrons according to the reactions: ^{14}N (n,3p5n)^{7} Be, $^{14}N(p,4p4n)^{7}Be$, $^{16}O(p,5p5n)^{7}Be$.

Most of ^{7}Be is formed during interaction of nitrogen atoms with secondary thermal neutrons, which are the product of the interaction of cosmic rays with nuclei of atoms that make up the atmosphere of the Earth. Since the flow of galactic and extragalactic cosmic rays is modulated by the changes in the flow of solar wind, variations in solar activity are a significant factor in variability of the flux of secondary neutrons [5].

About 70% of ^{7}Be atoms are produced in the stratosphere. Some of these atoms get into the troposphere because of different processes. In the troposphere, ^{7}Be is formed under the same reactions as in the stratosphere, but thermal neutrons in these reactions may include particles, which occur under other processes. It is observed that at the altitudes up to 10-15 km above the surface, the downward thermal neutron flux is considerably smaller than the upward flow. Therefore, neutrons of other, non-space origin may exist in the troposphere. One of the sources of neutrons in the atmosphere can be reaction of atomic nuclei of certain elements (beryllium, boron, cadmium, fluorine, lithium, carbon, etc.) with alpha particles arising from radioactive decomposition of radon isotopes ^{219}Rn, ^{220}Rn, ^{222}Rn and their decomposition products. Since the rate of radon emanation from soils in the warm season is significantly higher than that in the cold season, the flow of the emerging thermal neutrons, and hence ^{7}Be concentration should positively correlate with the temperature in the surface layer and reach its maximum in July-August. On the other hand, positive correlation between the change in ^{7}Be concentration and temperature in the surface layer can be explained by intensification of the process of vertical mixing in the troposphere [6].

As follows from [7], thunderstorms can be another source of thermal neutrons in the troposphere. Paper [7] proposes a mechanism to explain the neutrons emerging above the thundercloud by photonuclear reactions, which occur due to interaction of the nitrogen and oxygen atomic nuclei with bremsstrahlung radiation of the flux of escaping electrons reaching relativistic velocities [8]. This idea gave rise to a theory [9,10] relating the neutron production during thunderstorms to emergence of huge upward atmospheric discharges (sprites, jets etc. [11]) where bremsstrahlung of relativistic escaping electrons is formed. Thus, the sources of thermal neutrons participating in ^{7}Be formation may include thunderstorms, which vary considerably in intensity and frequency of occurrence.

^{7}Be is connected with submicron size aerosols, and it is deposited with them on the earth surface by “wet” and “dry” deposition [12]. Most of ^{7}Be in moderate climate zones gets to the earth surface with “wet” deposition [1]. Taking this into account, changes in the characteristics of precipitation in a certain area make a significant factor decreasing the concentration of this substance in the lowest atmospheric layer.

^{7}Be balance dynamics in different regions can also be influenced by changes in the wind regime typical of this region. Not only can it cause secondary pollution with radioactive dust from the surface, but also horizontal migration of the substance between the neighboring regions.

Thus we can assume that variability of concentrations of ^{7}Be and some other cosmogenic radionuclides in the surface layer can be under the significant influence of non-space factors. First of all, these are changes in local weather conditions affecting both receipt and expenditure of their material balances. Such features may include mean monthly values of temperature and wind speed in the surface layer, the amount of atmospheric precipitation, and the index of thunderstorm activity, which is calculated as a number of thunderstorms occurring over the point of observation per a particular month. Despite the fact that variability of ^{7}Be concentrations has been monitored since 1950-ies [13], its connection with non-space factors is still under-studied.

Given the above, the object of this research is changes in ^7Be concentration, changes in the index of thunderstorm activity, temperature, wind speed in the surface layer in Chernobyl.

The subject of the research is the role of non-space sources of cosmogenic radionuclides in the changes of their concentrations in the lowest atmospheric layer, illustrated by ^7Be in the region.

The aim of the research is to identify the effects of variations of index of thunderstorm activity, temperature, wind speed on seasonal changes in ^7Be concentrations in Chernobyl.

Material and method. ^7Be concentration was measured by an equipment complex which consisted of an air filtration unit and gamma-ray spectrometer. The air filtration unit includes a fan and a filter holder which hosts a microfiber filter FPP-15-1.5. The air was being filtered for three to seven days. Filter activity was measured by a gamma-spectrometer with a semiconductor Ge-Li detector. ^7Be activity was determined by 477 keV line. The measurement error did not exceed 10%. For the period from July 2005 to May 2010 305 samples were selected and analyzed (Fig. 1). According to the obtained results, ^7Be concentration in the surface layer during the period of research ranged from 0.18 to 8.0 mBq/m3, the mean value was 3.0 ± 0.3 mBq/m3.

Meteo data were obtained at the meteorological station near the point of sampling. Data on the index of thunderstorm activity were obtained from the National centers for environmental information (http://www.ngdc.noaa.gov).

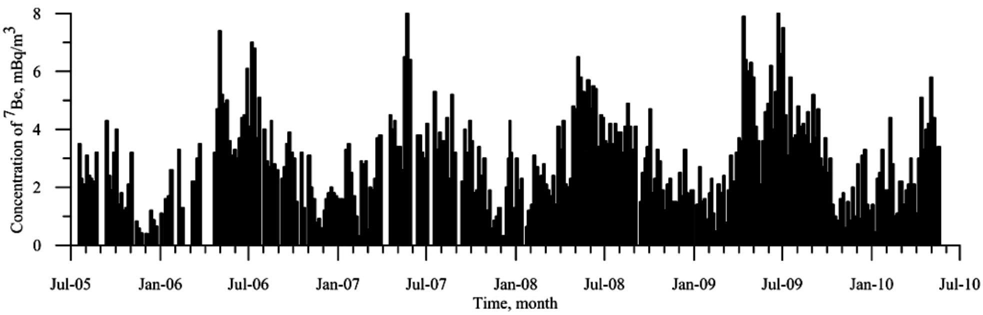

Fig. 1. Temporal variability of ^7Be concentration

SOLAR index is one of the parameters characterizing solar activity. It is determined as a flux of solar radio emission at the wavelength of 10.7 cm. An important feature of this index is that it can register under any cloud condition and at any point on land. As a result, the time series of its mean monthly values for the period from 1950 given in (http://www.ngdc.noaa.gov) have the smallest errors.

Fig. 2 shows the temporal variability of mean annual values of this index for the period from 1950 to 2010, based on the data of National centers for environmental information.

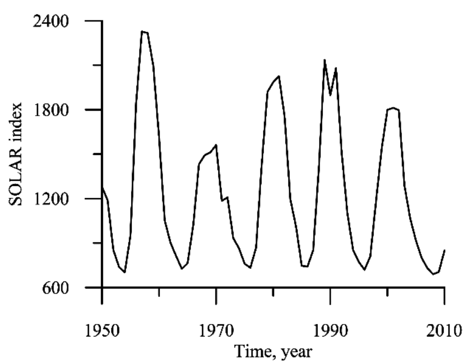

Fig. 2. Temporal variability of mean annual values of the SOLAR index

As it follows from Fig. 2, since 1950-ies the values of this index of solar activity varied within wide limits, but the longest period when SOLAR value remained virtually unchanged corresponds to the transition from 23 to 24 cycle (from 2005 to 2010). During this time period, solar activity was at its minimum, thus the flux of cosmic rays participating in ^{7}Be formation remained almost unchanged and was close to its maximum level.

Paper [14] establishes correlations allowing to consider the effect of reduced concentrations of micro-elements in the aerosol layer which occurs when precipitation of average intensity passes through it. This allows to use these correlations, annual variations of monthly concentrations of the studied micro-elements in the surface layer obtained from observations, and annual variations of monthly rainfall amounts falling on the corresponding area, and to estimate values of their initial concentrations in this layer which would occur if there was no precipitation for each month. It is evident that the values of these characteristics are proportional to the amounts of radionuclides in the surface layer per month from all sources minus those which underwent radioactive decomposition and those wrought by and gone with the wind. Given this, annual variations of this feature were used to evaluate the role of the studied non-space sources.

In order to calculate its value we calculated the averaged annual variations of monthly rainfall amounts for the specified period.

The mentioned dependence is compared with similarly averaged annual monthly variations of temperature in the lowest atmospheric layer, wind speed and index of thunderstorm activity.

Results and discussion. Fig. 3 shows temporal variability of mean monthly values of the SOLAR index, and ^{7}Be concentrations measured in the surface layer above the city of Chernobyl.

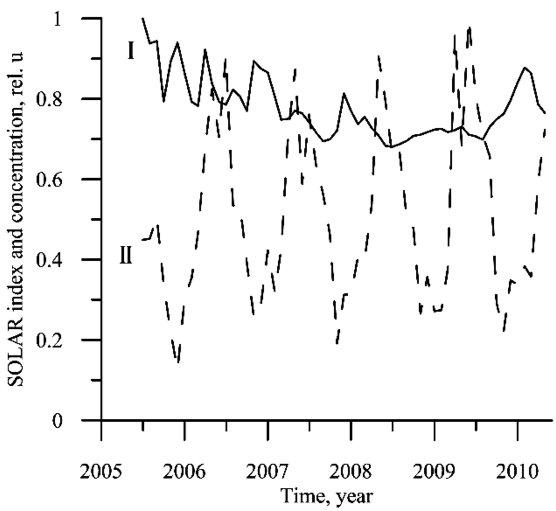

Fig. 3. Temporal variability of the SOLAR index values normalized to their upper bounds (I) and ^{7}Be mean monthly concentrations (II)

According to Fig. 3, during the studied period, no connection between solar activity variations and changes in ^{7}Be mean monthly concentrations in the surface layer over Chernobyl was identified.

Fig. 4 shows annual variations of monthly ^{7}Be concentrations in the surface layer over Chernobyl obtained from observations, as well as annual variations of monthly precipitation sums normalized to their upper bounds.

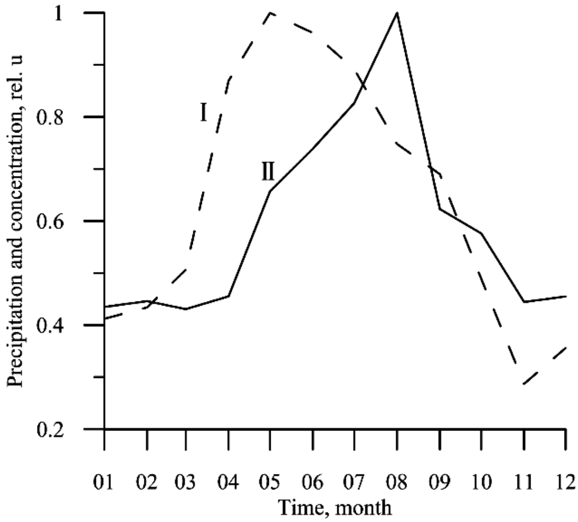

Fig. 4. Intra-annual variability of monthly precipitation sums normalized to their upper bounds (I) and ^{7}Be concentration in the atmosphere (II)

According to Fig. 4, the maximum intensity of aerosol washout effect from the surface layer above Chernobyl is observed in August, while ^{7}Be mean monthly concentrations reach their maximum values in May.

As a result of compensation of the washout effect for each month according to the method above, we have obtained mean monthly values of ^{7}Be initial concentrations .

Fig. 5 shows annual variations of ^{7}Be initial concentrations calculated accorting to this methid in the surface layer over Chernobyl, as well as index of thunderstorm activity, normalized to their upper bounds.

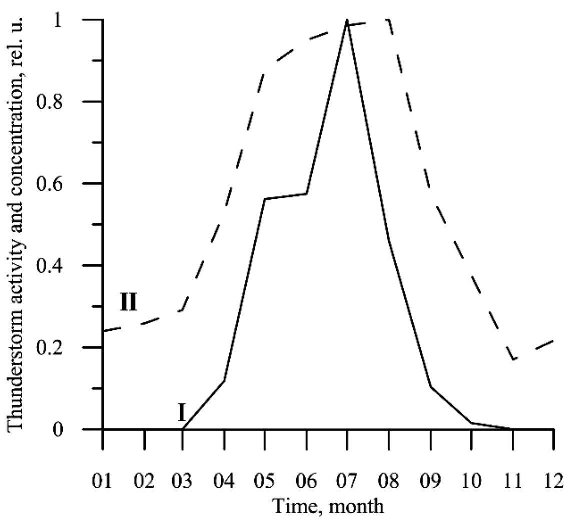

Fig. 5. Intra-annual variability of thunderstorm activity indices normalized to the corresponding upper bounds (I) and ^{7}Be mean monthly concentration (II)

As it follows from Fig. 5, the maxima values of both dependencies almost coincide. The maximum value of the index of thunderstorm activity over Chernobyl corresponds to July and the maximum value of ^{7}Be mean monthly initial concentration corresponds to August.

Fig. 6 shows annual variations of ^{7}Be initial concentrations in the surface layer over Chernobyl, and mean monthly temperature of this region.

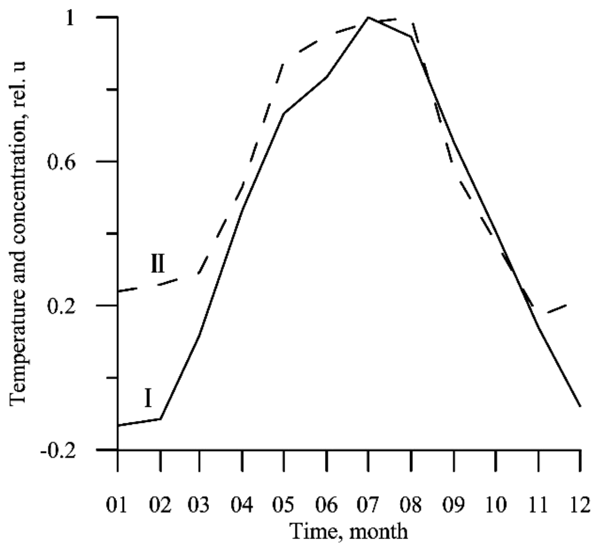

Fig. 6. Intra-annual variability of mean monthly temperature in the surface layer normalized to the corresponding upper bounds (I) and ^{7}Be mean monthly concentration (II)

According to Fig. 6, the maxima of both dependences almost coincide, too. The maximum mean monthly temperature in the surface layer over Chernobyl corresponds to July, while the maximum mean monthly ^{7}Be initial concentration corresponds to August.

Fig. 7 shows the annual variations of ^{7}Be initial concentrations in the surface layer over Chernobyl, and mean monthly wind speeds in the region.

The dependances shown in Fig. 7 are opposite. The maximum mean monthly wind speeds in the surface layer over Chernobyl represent January, while the maximum mean monthly ^{7}Be initial concentration represents August. This suggests that the increase in mean monthly ^{7}Be initial concentration in August cannot be caused by the increased flow of radioactive dust risen from the underlying surface by the wind. The effect of horizontal migration of ^{7}Be is also minimal in August.

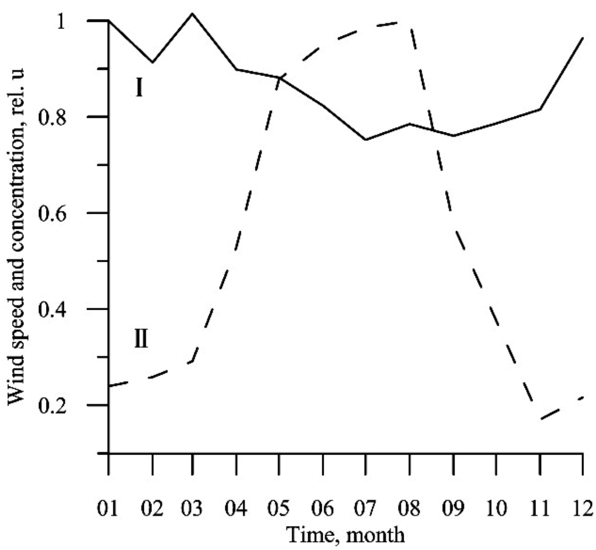

Fig. 7. Intra-annual variability of mean monthly wind speeds in the surface layer normalized to the corresponding upper bounds (I) and ^{7}Be mean monthly concentration (II)

Conclusions. Maximum concentration of ^{7}Be in the surface layer in Chernobyl region is observed in spring and summer while minimum concentration is observed in autumn. Even in the years when the fluxes of secondary neutrons involved in ^{7}Be formation in the surface layer reach their maximum, changes in the concentrations of this radionuclide are largely influenced by the flows of thermal neutrons generated during thunderstorms, and vertical exchange in the troposphere. The effect of radioactive dust raised by wind or transported from neighboring regions on changes in ^{7}Be concentration is insignificant. Formation of some other cosmogenic radionuclides is attended by the same thermal neutrons. Thus the conclusions obtained for ^{7}Be can be generalized to them.

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