Study of Forbush decreases and lunar cycles effects in the thermal neutron flux registered near the Earth surface by means of “Neutron” setup data

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Abstract. The experimental data on thermal neutron flux registered by the “Neutron” setup (MEPhI, Moscow) on the Earth's surface for the period from May 2015 to February 2019 were analyzed. The effects of Forbush decrease (FD) and the lunar cycles were studied. The comparison with the results of FD studies in data of two other setups: the Moscow neutron monitor (MNM) and the muon hodoscope URAGAN (MEPhI, Moscow) was made. Comparison showed that the FD amplitudes of “Neutron” are comparable with those of MNM (on average, less by about 30%), and about 1.5 times more than for MH URAGAN. The counting rate recovery of “Neutron” detectors is much faster than for MNM and MH URAGAN.

1. Introduction
The neutron flux observed near the Earth surface has two main different sources. The first one is created as a result of cosmic ray particle interactions with nuclei of the atmosphere that generate a huge shower of secondary particles (extensive air shower: EAS). The second source of neutrons was confirmed by the group of B.M. Kuzhevckij [1], the neutrons are generated through the interaction of α-particles, emitted by the naturel radioactive gas (radon isotopes), with nuclei of the elements of the atmosphere or the ground. On the neutron flux near the surface of the Earth influence variety of effects: changes in the flux of cosmic rays, meteorological parameters (the atmospheric pressure and temperature near the detector), the Sun and the Moon, the tectonic activity of the Earth crust, weather conditions (amount of precipitation), etc. In this work two effects were studied: the Furshbus decrease (FD) and the impact of the Moon movement around the Earth. The FD is a sudden decrease of the counting rate, caused by a powerful activity of the Sun that produces interplanetary coronal mass ejections (ICMEs). The Moon acts on the Earth by its gravitational force, especially when the Moon, the Earth and the Sun are aligned and the tidal forces from Moon and Sun are added up. The Moon procure an increase of the counting rate, by stimulation if the emanation of the radon isotopes at the Earth surface. This work was done in the Experimental complex NEVOD [2], by analyzing the data on the thermal neutron counting rate collected on the “Neutron” setup [3].

2. Description of the “Neutron” setup
The “Neutron” setup is designed to monitor the neutron background near the Earth surface. It consists of four identical scintillation detectors, which have a pyramidal metal housing and are located inside
the NEVOD building at different altitudes from the ground surface (-3 m to 10.5 m). The setup operates since 2010 in a continuous mode and records the thermal neutron counting rate every five minutes. The location of each detector within the building is presented in the figure 1.

![Figure 1. Layout of neutron detectors of the “Neutron” setup (a) and photo of the detector (b).](image)

The long operation time of the setup was sufficient to prove its effectiveness and reliability. These advantages are due to the use of a special inorganic scintillator in the form of a granular alloy of ZnS(Ag) and LiF, enriched up to 90% in the $^6$Li isotope. The average thickness of the scintillator is only 30 mg/cm$^2$ and the area is 0.75 m$^2$. This scintillator is viewed by a FEU-200 photomultiplier.

3. Methods of data analysis
A long-term data of thermal neutron counting rate from May 2015 to February 2019 were analyzed. Corrections for the barometric effect were evaluated and introduced by month. 20 FDs were found, for each of them the FD amplitude and recovery time were estimated. A comparison with the results of the FD studies with two other setups: the Moscow neutron monitor (MNM) [4] and the muon hodoscope (MH) URAGAN (MEPhI, Moscow) [5] was done.

To find the amplitude of FD, a method based on step-by-step averaging of the counting rate before and after FD in different time intervals was used. Three days of counting rate before and after FD at first were corrected for the slope (with the help of linear approximation), then were averaged over 1, 2, and 3 days. Therefore, a set of 36 different amplitude estimates were obtained and their average value was taken as the amplitude of the Forbush effect [6]. The figure 2 shows the different parameters of a typical FD event; the displayed event was registered by “Neutron” setup (2nd detector) on 08 September 2017.

![Figure 2. Illustration of Forbush decrease parameters for a typical event registered on 08 September 2017 by the second detector of the “Neutron” setup.](image)
The epoch superposition method was used to study different lunar waves (in this work just two waves were studied: the semidiurnal tidal wave (M2) and the synodic month wave). It consists in summing of many overlapped periods, i.e. the counting rate of the first hour of the first period was summed up with that of the first hour of the second period, and so on, then the data were divided by the number of experimental points that fell into the corresponding interval.

4. Experimental results and discussions

4.1. Forbush decrease results

The comparison of a powerful FD event registered on 22 June 2015 by the setups MNM, MH URAGAN and “Neutron” is presented in figure 3. A good agreement between data of these three setups is observed. This event is a “cascade” event (two FDs where the first one is directly followed by the second one, the counting rate after the 1st FD doesn’t have time to recover). For such event, the amplitude of the 1st FD can be estimated, but not the recovery time.

![Figure 3. Comparison of the FD event registered on 22 June 2015 by the setups: the second detector of “Neutron”, MNM, and MH URAGAN.](image1)

The comparison of FD analysis results from the data of the 2nd detector of the “Neutron” setup with results from MNM and MH URAGAN is presented in figure 4. The amplitudes of FDs measured by the “Neutron” setup detectors are comparable with those of MNM (on average, less by about 30% for 1st, 2nd and 4th detectors, and about 50% for the 3rd detector), and about 1.5 times more than for the muon hodoscope URAGAN. The counting rate recovery of the four detectors of the “Neutron” setup is much faster than for MNM and MH URAGAN.

![Figure 4. Comparison of the amplitudes and the recovery times of FDs registered by the second detector of the “Neutron” setup, MNM and MH URAGAN.](image2)
4.2. Lunar effect results

The semidiurnal tidal wave (M2) was obtained by the data of 1st detector with a clear peak (amplitude ~0.32%), that corresponds to the upper culmination around midday (figure 5). The second peak of upper culmination (at midnight) does not appear. For the other three detectors this wave is not visible, its absence can be explained by a stronger effect of changes in the weather, soil temperature, soil moisture, etc. The synodic lunar month wave (1st harmonic) was obtained by the data of 2nd and 4th detectors with an amplitude of 0.8% and 0.6% respectively during the full moon (figure 6). For the other detectors the effect is less seen. Its absence is essentially due to the detectors placement within the NEVOD building and its shielding effect. A similar wave was found by Yu.V. Stenkin et al [7] with a higher amplitude (~1%), the difference is possibly due to the location of their detector at an altitude of 4300 m above sea level against 170 m in our work, and the type of soil.

![Figure 5. Semidiurnal tidal wave (M2).](image1)

![Figure 6. Synodic lunar month wave. Black circle – new moon; white circle – full moon.](image2)

5. Conclusion

The search for the response of “Neutron” setup detectors to Forbush decrease effect during a long period (05.2015 – 02.2019) was done. 20 FDs events were found. Comparison between different FDs studies showed that the FD amplitudes of “Neutron” are comparable with those of MNM, and about 1.5 times more than for muon hodoscope URAGAN. The counting rate recovery of “Neutron” setup is much faster than for MNM and MH URAGAN. The effect of lunar cycles was observed and confirmed the existence of the M2 and 1st harmonics. The semidiurnal tidal wave obtained by the data of the 1st detector located in the building basement gives maximum increase (~0.32%) of counting rate at the middle day (upper culmination) compared with the other detectors. The synodic month wave was found for the 2nd and 4th detectors with amplitudes 0.8% and 0.6% respectively during the full moon. For the other detectors, the effect is less seen.

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