Changes in low energy neutron count rate near ground level associated with weather phenomena

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Abstract

Measurements of neutron count rate at ground level were performed with a single lead- and moderator-free He-3 tube detector. This detector has been collecting data intermittently since October 2008 and is located at ground level in São José dos Campos, Brazil. In this paper, we report events when a significant increase in the neutron count rate was recorded. These events seem to be correlated with changes in local weather conditions such as cloud coverage or rainfall. We also report the observation of a single event that seems to be indicative of the production of a burst of neutrons by a lightning discharge near the detector.

Introduction

The characterization of the terrestrial neutron flux is of importance since the presence of neutrons in the environment is ubiquitous. Neutrons may be produced by primary cosmic rays (Grieder, 2001), during seismic activities (Kuzhevskij et al., 2003), some authors have measured (Shah et al., 1983; Kuzhevskii, 2004), and others have calculated (Babich, 2007; Babich et al. 2008) the generation of neutrons associated with lightning discharges. Also, the ground-level neutron flux may be influenced by weather conditions (Lockwood and Yingst, 1956; Mishev and Stamenov, 2008). Based on this diversity of phenomena, one is led to the conclusion that the ground-level neutron flux can be used as a probe to investigate several physical processes and phenomena. There are about 50 monitor stations (Eroshenko, 2008) located in diverse regions of the planet. These stations are usually devoted to the study of cosmic rays, and some of them have been collecting data on neutron flux for many decades; they are usually located at high altitudes and their detectors consist of bulky and expensive equipment (e.g., Stoker et al., 2000).

In order to provide an affordable alternative to the detection of neutrons, and also to collect valuable data at low altitudes and study the variation of the neutron flux at ground level, we propose the use of single lead- and moderator-free He-3 tube detectors. We have been measuring the ground-level flux of neutron with this type of detector for several months now; in this paper we present some preliminary results and establish possible correlations between recorded events and weather phenomena.

Instrument

The detector used in this study is a commerciall proportional counter. It consists of a standard He-3 cylindrical tube (area, 70 cm²; type 25291; Ludlum, USA) with a central anode wire, pressurized to increase detection probability (pressure, 5 MPa) and fed by a compact high voltage power supply (operating voltage, 1450 V). Figure 1 shows the tube detector together with the power supply.

Figure 1: He-3 neutron tube detector and high voltage power supply used to monitor neutron flux.

The principle of neutron detection is illustrated by the reaction (Knoll, 2000)

$$n + {}^{3}He \rightarrow {}^{3}H + p + 764\ kev \qquad (1)$$

The released energy (764 keV) is mainly carried away as kinetic energy of the daughter products. In the case of a proportional counter, each fission reaction (1) results in a charge spike which is amplified and detected by the electronic circuit. Neutron registration efficiency of such detector tube is inversely proportional to the neutron energy, reaching about 80% for thermal neutrons. He-3 detectors are highly sensitive to thermal neutrons. Since we are interested in registering the absolute flux of neutrons originating from different sources and not only the ones produced by cosmic rays, the detector tube was not covered with lead, nor moderators, such as paraffin or polyethylene, were used; lead producers have the effect of multiplying the number of incoming neutrons, and moderators filter out low energy neutrons present in the environment.

The interface between the detector tube and the computer uses a high-pass diode-protected JFET low noise circuit, which amplifies the input signals from the detector tube; these signals are passed to a CMOS threshold detector; the signals are then amplified and passed to an output silicon transistor, which generates a square wave from rail to rail. All cables, including the coaxial cable connecting the detector tube to the interfacing circuitry, are shielded and grounded.

The detector used in this study was calibrated in a nuclear instrumentation laboratory using NIM Ortec 452 Spectroscopy instruments (Instituto de Estudos Avançados, São José dos Campos, Brazil) and an Am-Be source. In the experimental set-up used, counts were integrated in one-minute intervals.

Measurements

Since this is a preliminary study, data is presented here in a raw format, as they were collected by the detector. No barometric correction of the neutron count rate was performed as we deemed it unnecessary at this stage of our work; we estimate that under normal conditions, the atmospheric correction would amount to about 5% (see Lockwood and Yingst, 1956).

Series of neutron counts have been collected intermittently since October 2008 in the city of São José dos Campos (23° 11′ 11″S, 45° 52′ 43″ W, 600 m above sea level), Brazil (Figure 2). During measurements, the detector was located inside a one-floor thin brick building.

Figure 2: Location of the city of São José dos Campos (SJC), Brazil.

Data were collected under different meteorological conditions, such as clear sky, drizzle, rainy periods, and lightning storms. Examples of count rates measured under these conditions follows.

Figure 3 shows an example of the data collected during a period of clear skies (minimal cloud coverage). From the results shown in this figure, one observes that the neutron count rate oscillates between 0 and 2 neutrons per minute (n/min) for most of the time; count rates higher than 2 n/min may be attributed to statistical fluctuations of the background count. The 15-minute average, in this case, shows that the background is rather flat. The mean count rate for the period of measurement shown in Figure 3 was 0.67 n/min.

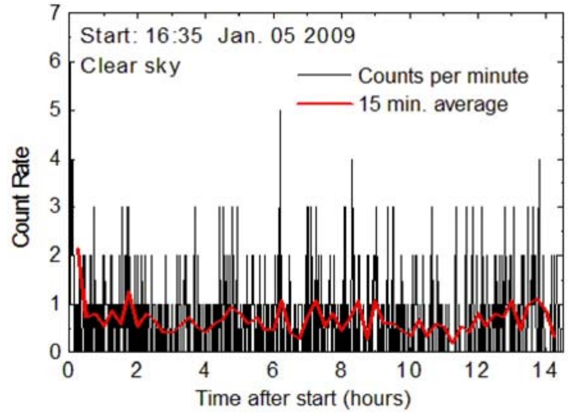

Figure 3: Neutron count rate measured in cloudless day. Measurements at one minute interval (black) and 15-minute average (red).

The count rate measured during a drizzly and overcast day is shown in Figure 4.

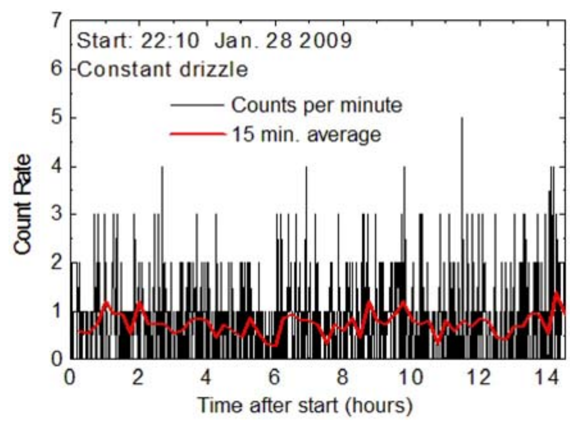

Figure 4: Neutron count rate measured in a cloudy and drizzly day. Measurements at one minute interval (black) and 15-minute average (red).

In this case, one observes that the count rate also fluctuated, for most of the time, between 0 and 2 n/min. The mean count rate for this period was 0.76 n/min. The 15-min average was also rather flat, similar to what was measured during a period with clear skies, Figure 3.

An example of the effects of a rainy period on the neutron count rate is shown in Figure 5. It is evident that during a period of constant rain there was a significant increase in the count rate. The mean count rate for the period shown in Figure 5 was 1.0 n/min, obviously higher than the two preceding examples due to the increase in the count rate associated to the rain.

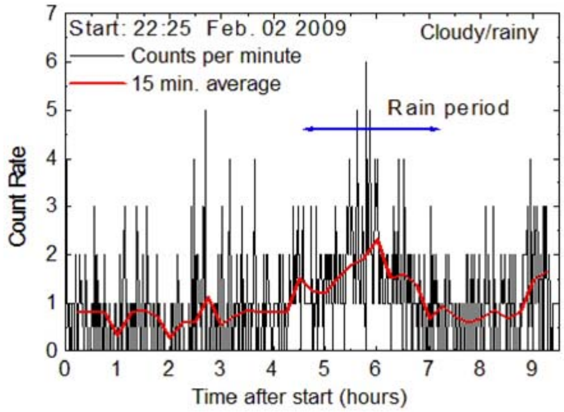

Figure 5: Neutron count rate measured during a cloudy and rainy day. Measurements at one minute interval (black) and 15-minute average (red). The blue horizontal line indicates a period of constant rain.

Finally, in Figure 6 is shown what may be a special event. During a lightning storm, a burst of neutrons was recorded almost at the same time that a lightning discharge occurred in the vicinity of the detector (< 0.5 km).

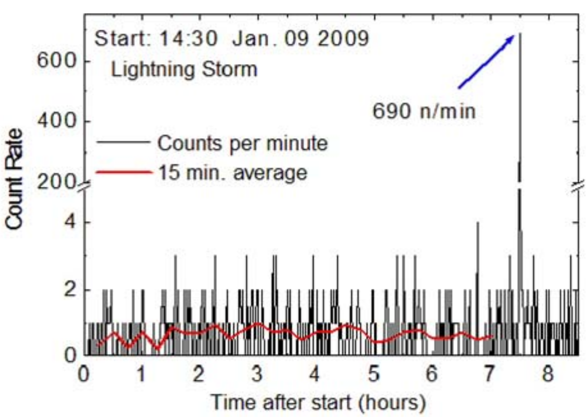

Figure 6: Neutron burst detected during a lightning storm. Measurements at one minute interval (black) and 15-minute average (red). The neutron burst occurred at 21:45 h of January 9, 2009.

The count rate in this event increased within a very short time to a large value. Since the software was set to integrate the neutron count in intervals of one minute, the peak value of the burst as recorded was 690 n/min. The whole event lasted less than 2 minutes, as recorded by the detection software. The mean neutron count rate before the event was 0.65 n/min, similar to the result shown in Figure 5. Also, the 15-minute average was flat.

In Figure 7 is shown lightning strikes that were recorded in a period of 1 hour in the area surrounding the location of the detector during time measurements of the day 09 of january, 2009.

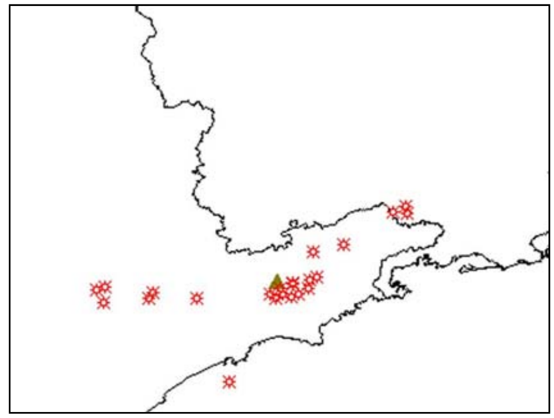

Figure 7: Lightning strikes recorded from 21:15 to 22:15 h of Jan. 09, 2009. The triangle indicates the position of the detector. The horizontal dimension of the image is 550 km, approximately. (Courtesy of R. Holtzworth, World Wide Lightning Location Network.)

Discussion

The natural neutron background at low altitudes is mainly the result of two physical processes: in the first one, neutrons are produced as a by-product of the decay of radon and other radioactive elements present on the Earth's crust; alpha particles emitted by these elements interact with the nuclei of the constituents of the atmosphere resulting in the emission of neutrons; in the second process, the most important one, neutrons are produced by the interaction of primary cosmic rays with the nuclei of the constituents of the atmosphere.

Neutrons can also be produced as a result of human activities related to nuclear technologies, during seismic activity when larger-than-normal quantities of radon gas may be released, and, recently, lightning discharges have also been proposed as a source of neutrons..

In this study, only natural sources of neutrons are considered since the detector was neither located near any artificial source nor in the vicinity of any active geological feature. Thus, the background count rate can only be attributed to neutrons produced by cosmic rays and decay of radioactive elements in Earth's crust. Changes in the count rate are then the result of the influence of weather conditions or modulation of cosmic rays by phenomena of extraterrestrial origins such as solar activity. As far as the solar activity is concerned, the previous months have been rather quiet, with the Sun displaying minimal activity and low sunspot number. Moreover, since we recorded data for short periods of time (< 1 day) fluctuations related to the rotation of the Sun are not important. Therefore, the observed changes in the neutron count rate in this study were mostly caused by weather phenomena.

Based on this information we can discuss the data presented here. Comparison of the results in Figures 3 and 4 indicates that the increase in cloud coverage and, consequently, the increase in the water content of the atmosphere, affected the neutron count rate. This increase can be explained by a decrease in the atmospheric pressure during atmospheric disturbances since the distance traveled by neutrons in the atmosphere is dependent on its density. Also, water (more specifically, the hydrogen in the water molecule) is a moderator that thermalizes the energy of neutrons produced by primary cosmic rays, thus increasing their probability of being detected. This latter effect is possibly what caused most of the change in the count rate observed in Figure 5; a significant increase in the number of detected neutrons coincided with a period of continuous rain when the water content of the atmosphere is high.

Figure 6 shows a rare event: a burst of neutrons which coincided with a lightning strike within a short distance of the detector (< 1.0 km). This event was witnessed by one of the authors (I.M.Martin) who was present at the laboratory when it occurred. Figure 7 is evidence that in this particular day the area surrounding the location of detector was hit many times and during a short period of time by a large number of lightning strikes. Since all electronic equipment, detector tube, cables and connectors were shielded and well insulated, and no other transient effects were observed, we are led to believe that the observed burst of neutrons was produced by a lightning. This is a type of phenomenon that has already been reported in the literature and predicted by theoretical studies (Babich, 2007; Babich et al. 2008). To the best of our knowledge, this is the first time that such event has been recorded in Brazil.

Conclusion

The study of atmospheric neutrons is relevant due to the various physical processes involved in their generation. The neutron count rate can serve as a proxy to study primary rays, be used in studies that relate changes in the climate with fluctuations in the cosmic ray flux, employed as a probe in geophysical applications; and, recently special attention have been focused on the measurement of neutron flux at high and low altitudes due the problems they can cause to electronic equipment, and the their effects on the health of the crew of airplanes.

Therefore it is important the use of alternative and inexpensive methods to monitor the neutron flux at ground level. In our study we used a simple He-3 tube detector to monitor the count rate and were able to register how this rate was affected by the weather phenomena. In addition, we were fortunate to record the production of a burst of neutrons by a lightning strike.

In the near future, we plan to extend this study using several detectors with larger area to increase the counting rate efficiency and to perform counting experiment at other locations in order to gain a better understanding of the neutron flux field. Our experiment will also be extended in order to measure the production of neutrons by lightning since this may an alternative route to a better understanding of plasma physics of lightning on Earth's atmosphere.

Acknowledgments

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