ISTITUTO NAZIONALE DI FISICA NUCLEARE

Sezione di Catania

INFN/AE-04/14

22 December 2004

ARE SMALL SINGLE GEIGER COUNTERS ABLE TO SHOW UP COSMIC DAILY VARIATION EFFECTS? A CASE STUDY FOR EDUCATIONAL INVESTIGATIONS

Paola La Rocca[1] and Francesco Riggi[1,2]

[1)] Dipartimento di Fisica e Astronomia, Università di Catania, Via Santa Sofia 64, I-95123 Catania, Italy

[2)] INFN-Sezione di Catania, Catania, Italy

Abstract

Data measured with a small Geiger counter for a period of approximately three months were analyzed to search for daily variation effects, after proper correction for the influence of the atmospheric pressure. Harmonic dial analysis for each individual day was carried out. The ratio of the measured flux between selected intervals within the 24 hours was also investigated. Methods and results are presented in the framework of educational studies involving high-school teams.

PACS.: 01.40.Ej, 29.40.-n, 96.40.-z

*Published by **SIS–Pubblicazioni***

Laboratori Nazionali di Frascati

1 INTRODUCTION

Cosmic-ray intensity variations within 24-hours periods have been investigated at sea level since a long time [1,2]. It is generally accepted that on average the intensity along the day is higher than in the night, and the amplitude of such variation is in the order of 0.2 % for single ion chambers, while it is slightly higher for counter telescopes and for neutron detectors. However, the amplitude and phase of the daily variation of the cosmic-ray intensity are not constant over long periods, and both may undergo periodic as well as non-periodic variations. The experimental study of such diurnal variations has been the object of detailed investigations several decades ago [3-7], together with the analysis of the variations correlated to exceptional events, such as magnetic storms or large solar flares.

The diurnal variation consists of several components, not only related to solar phenomena (co-rotation of cosmic-ray particles with the Sun) but also to the complex interplay between the Sun and the magnetic field around the Earth. The early studies of the daily variation allowed to exclude that such variation could be the result of residual atmospheric effects.

The general features of the mean daily variations, extracted from yearly measurements, show a larger effect for the nucleon component, and a smaller amplitude for the meson component. As far as the amplitude and phase of the maximum are concerned, they strongly depend on the location of the measuring station. The variation may depend upon the latitude, since this may result in a different threshold rigidity. Some altitude effect has also been observed. As a consequence, sets of data having their phase of maximum which may differ by several hours have been reported [1]. The acceptance of the detector plays also a major role to determine the amplitude and phase of the observed variation. Investigations carried out with counter telescopes defining particular orientations (vertical or with a zenith angle of 30° from the vertical, pointing to North, South, East or West directions), showed indeed a maximum shifted by several hours [1]. Moreover, for each given location, the amplitude and phase of the diurnal variation may change by large amounts when such effect is monitored for long periods, of the order of years. Measurements done with a counter telescope, allowing at the same time to get data from a zenithal angle of 30° with respect to the vertical, both for the North and South orientations, showed that such large variation of the amplitude and phase are not simultaneous [1].

For such reasons, even though the main aspects of such variations have been largely investigated and understood in the past, the problem is still open to local scale studies, where the influence of the geographical location, its altitude and the particular geometry/acceptance of the detection apparatus may produce results not easily predictable. For instance the investigation of diurnal variations in the cosmic ray flux underground, which was pioneered a long time ago [8,9] is still today a common task of all large underground detectors [10-12].

Quantitative studies of such variations, even at the sea level, require professional monitoring stations which should be operated for long periods and with high statistics. However, the interest in obtaining even restricted sets of data and carrying out their analysis and interpretation may give rise to useful educational projects at the high-school or even university level. Such studies may also become part of comprehensive approaches to environmental physics, with the intervention of peoples from different research area.

Along this line we made an attempt to investigate to what extent could a detector as simple as a single, small-volume, Geiger counter be able to show up evidence for diurnal variations in the measured cosmic-ray flux. It must be stressed that in such case the overall acceptance of the detection set-up is several orders of magnitudes lower than those usually employed, and on top of that its geometry does not allow for specific selection of the orientation of the incoming cosmic rays. On the other hand, the availability of small Geiger counters could allow high-school teams to join very easily to similar projects, whereas scintillation detectors usually require more expensive set-up and skillness to be operated. This study is then intended as a test case to provide useful analysis hints and preliminary data to a team wishing to collaborate to shared investigations in the field.

2 EXPERIMENTAL SET-UP

The experimental set-up used in the present experiment has been already described [13]. Measurements of atmospheric pressure and cosmic muon flux were performed by the use of a small Geiger counter and a barometric sensor. Both were connected through an interface to a PC for acquisition and display of the data.

Measurements were carried out under a concrete roof at the last floor of the Physics Department of the University of Catania. The geographical coordinates of the set-up were 37° 31’ 29” N, 15° 4’ 19” E. The Geiger counting rate was about 0.3 Hz. The data were collected in 30 minutes step, which gave approximately 550 counts in each bin. The total amount of events collected in the experiment was in the order of 2.5×10^6.

The Geiger counter is sensitive to cosmics originating from any orientation. The average thickness of the concrete roof, taking into account the angular distribution of cosmic muons, was about 100 g/cm^2. However, due to the geometry of the surrounding environment, the amount of shielding offered by the concrete roof and by the walls is not symmetric with respect to the azimuthal angle. Because of the roof, the shield is mainly concentrated in a cone along the vertical, while towards the East direction is much smaller and it is negligible approximately in the West direction. This could be of some concern as far as the daily variations are being investigated, since the Sun is viewed from the counter through a larger shield in the late morning and in the early afternoon (local time), and without any shield in the evening. The measurement period extended approximately from mid April to mid July, which at our latitude could enhance the effect, due to the relatively late sunset.

Some power failures, and the need to have exactly periods of 24 hours without any break, reduced the data set to 82 days which were analysed to search for daily variations.

Before to proceed to any analysis of the daily variations, we checked that during the overall period of data taking there were no catastrophic events (large solar flares, Forbush decreases,…) which could strongly influence the measured flux and would suggest to exclude those periods from the analysis. For the neutron flux we referred to the Oulu (Finland) [14] and Moscow [15] neutron stations, which continuously report the measured data in small time steps. Only a slow variation of the measured flux was seen during such period, whose amplitude is in the order of 1 %.

The data were also corrected for atmospheric effects according to a procedure described elsewhere [13]. A barometric coefficient of 0.051 %/mbar was used throughout. Even if in our case the corrections are not large, such procedure is essential, since the daily variations we are searching for are very small, and the atmospheric pressure itself undergoes a daily cycle.

Moreover, since small-amplitudes, long term variations may occur on a time scale of the order of months (as checked from the neutron monitor stations, see above), we carried out our analysis within each individual day by normalisation of the hourly flux to the average daily flux. In such a way only minor variations are expected due to other possible influences, which should hopefully average out when relatively long periods are considered. To simplify the analysis, the data were arranged into a single matrix 82x48 whose rows and columns are the 48 time intervals and the 82 days, containing the counts per 30 minutes or the ratio between the actual number of counts and the daily average.

3 RESULTS AND ANALYSIS

3.1 Harmonic Dial Analysis

According to the harmonic dial analysis [16,17] the amplitude and phase of the first harmonic (24 hours wave) along a series of data (one day or a small number of days) can be extracted by the usual Fourier analysis. By writing the time variation as:

$$f(t) = A_0 + R \sin(\omega t + \phi)$$

which can be also expressed by:

$$f(t) = A_0 + a \sin(\omega t) + b \cos(\omega t)$$

where $a = R \cos(\phi)$ and $b = R \sin(\phi)$, the amplitude R will be given by

$$R = (a^2 + b^2)^{-}$$

with a phase of the maximum given by

$$\Phi = \tan^{-1}(b/a)$$

If the time series is sampled at discrete time steps, the coefficients *a* and *b* are evaluated by

$$a = \frac{2}{N} \sum_{i=1}^{N} R_i \cos(2\pi t_i / 24)$$

$$b = \frac{2}{N} \sum_{i=1}^{N} R_i sin(2\pi t_i / 24)$$

with the time t in hours, and N is the number of measurements along the 24-hours period.

Building an imaginary 24-hours clock dial, each point in this plot will represent the tip of a hand pointing to the hour of maximum and having a length proportional to the amplitude. If this is done for each individual day, the scatter plot of such points will create a cloud, whose centre-of-mass will indicate the average time of maximum and the mean amplitude.

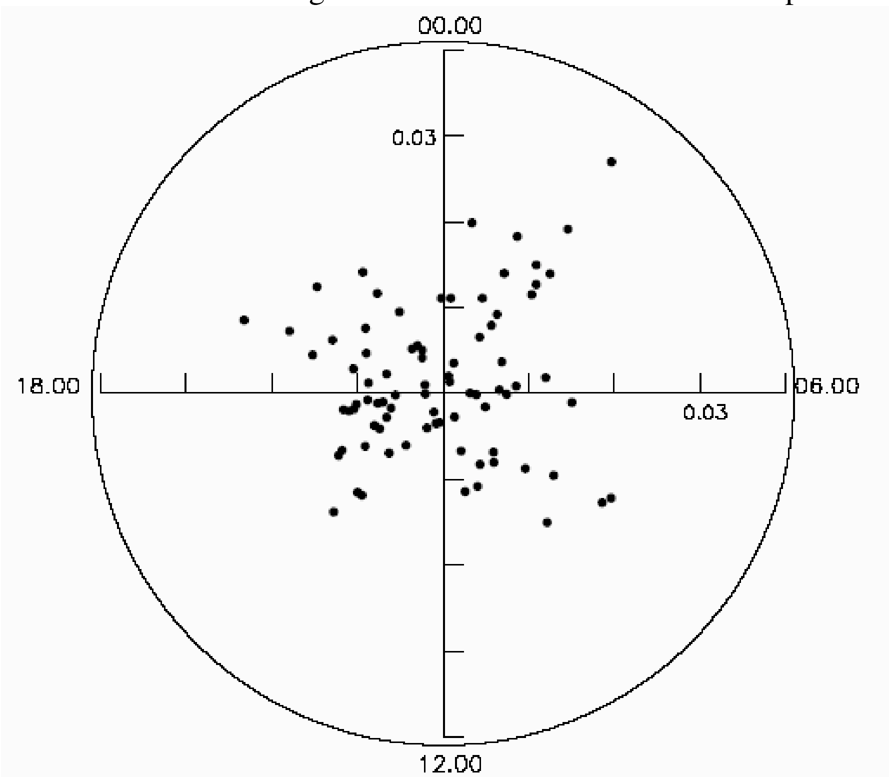

Fig.1: 24-hour harmonic dial, as extracted from the 82 days data set measured in the present investigation.

Such analysis was carried out for each of the individual 82 days selected from the data set, and the result is shown in fig.1.

As it can be seen, the day-to-day fluctuations are large, both for the amplitude and its phase, resulting in a scatter plot where it can hardly be seen a well defined behaviour. However, this is usually obtained even in high-statistics experiments. The centre-of-mass of this collection of data points is 0.0016 (that is 0.16%) and phase Φ = 22.3 hours (solar local time). The dispersion of the data may be understood from the standard deviation of the distances of the individual points with respect to the centre-of-mass, given by

$$\sigma_R = \sqrt{\frac{\sum_{i=1}^{N}[(x_i - x_m)^2 + (y_i - y_m)^2]}{N-1}}$$

where x and y are the cartesian coordinates corresponding to the polar (R, Φ) coordinates. We got $\sigma_R = 0.0127$. The standard deviation of the mean turns out to be 0.0014 for R.

The trend of the daily variation, as extracted from an average of all the individual days

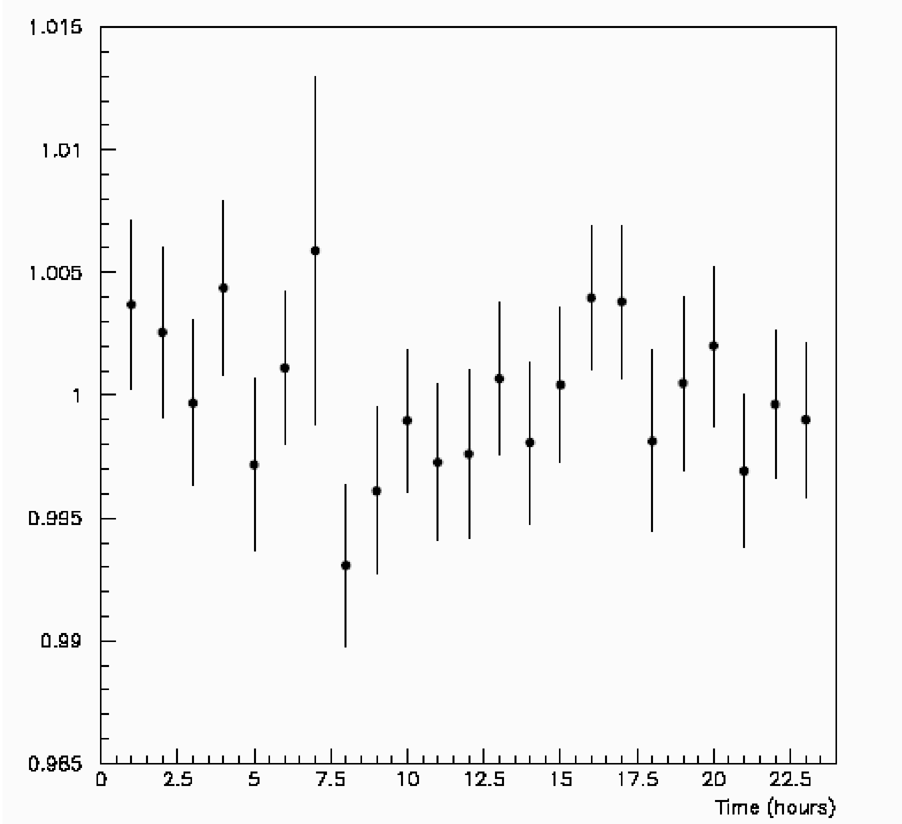

Fig.2: Diurnal variation of the cosmic ray flux, reported as the ratio between the flux measured in 1-hour interval and its daily average value.

is reported in fig.2. This shows some evidence for a maximum located in the late afternoon and for a second maximum early in the morning. However, the statistical fluctuations are large, and do not allow to extract a definite trend. The data could also be compatible with a semidiurnal periodic variation, as observed in many experiments [18].

3.2 Sliding analysis of selected time intervals

In order to better understand the observed small variations along the day, the ratio between the mean hourly flux measured in a given time interval along the day and the corresponding mean flux in the rest of the day was evaluated. Such quantity is slightly different with respect to the previous one, since it tends to enhance or depress the particular interval chosen, excluding it from the average.

The simplest ratio which can be defined is the Day/Night ratio, which can be defined as the ratio between the mean flux along 12 day hours (for instance from 08 a.m. to 08 p.m. local time) and the corresponding night interval. This ratio in our case turns out to be slightly smaller than 1 (approximately 0.998 ± 0.001).

Solar Local Time (hours)

Such value however does not bring in itself much information, except for very clean experimental situations, where the geometry/shielding of the apparatus are well defined, and the statistical errors negligible. Not being the case here, we preferred to plot this ratio by shifting the centroid of the time interval in steps of 30 minutes (sliding analysis). The result is

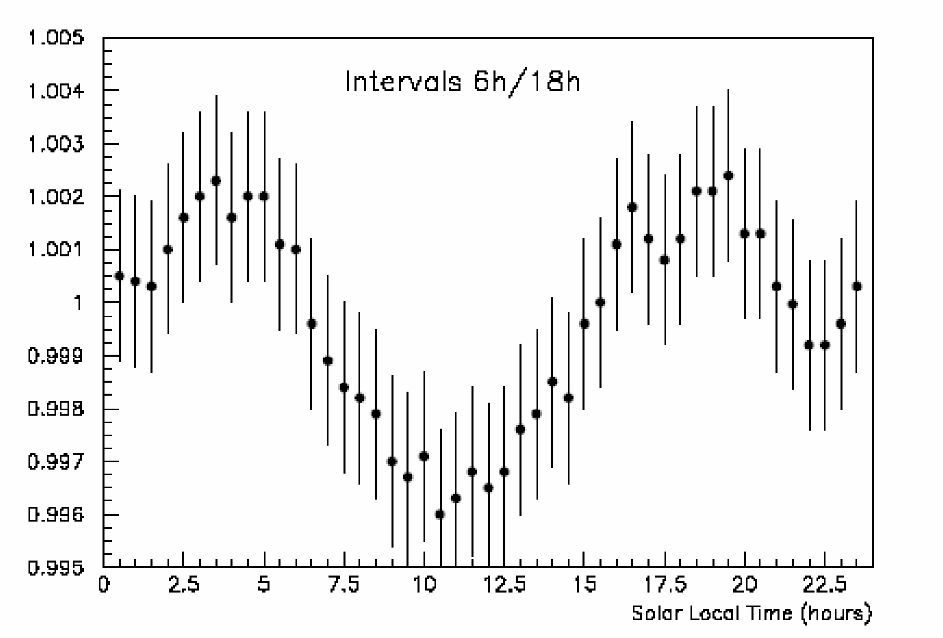

Fig.3: Ratio between the average flux along 12 consecutive hours and the corresponding flux along the remaining 12 hours, as a function of the time corresponding to the center of the selected interval

shown in fig. 3, which reports the ratio between the mean flux along 12 consecutive hours and the corresponding mean flux along the remaining 12 hours, as a function of the time corresponding to the center of the selected interval. From such plot a trend is apparent as a function of the solar local time, with a minimum in the late morning and a broad maximum at late evening. The amount of such variation is in the order of 0.2%. The same analysis was done selecting smaller intervals to build the numerator of such ratio, in order to better define the observed trend, although at the expense of larger statistical errors. The results are shown in fig.4 (for the ratio between time intervals of 6 hours and 18 hours) and in fig. 5 (time intervals 2 h/22 h). In fig.4 the evening maximum is now better observed around h. 17-18 local time, which was masked in the previous plot due to the large interval chosen. Moreover a second maximum appears early in the morning. The same basically can also be seen in fig.5. However, for this shorter interval, statistical errors are larger and even small variations from day to day start to become important.

The interpretation of such results is not straightforward, due to the discussed limitations of the set-up. However, the data are clearly incompatible with a constant trend along the day, and some indication of a periodic behaviour along the day is clearly seen. While the afternoon maximum may be related to the negligible amount of shielding toward the West direction, the indication of a second maximum early in the morning is at present not clear, and could require additional investigation under different conditions.

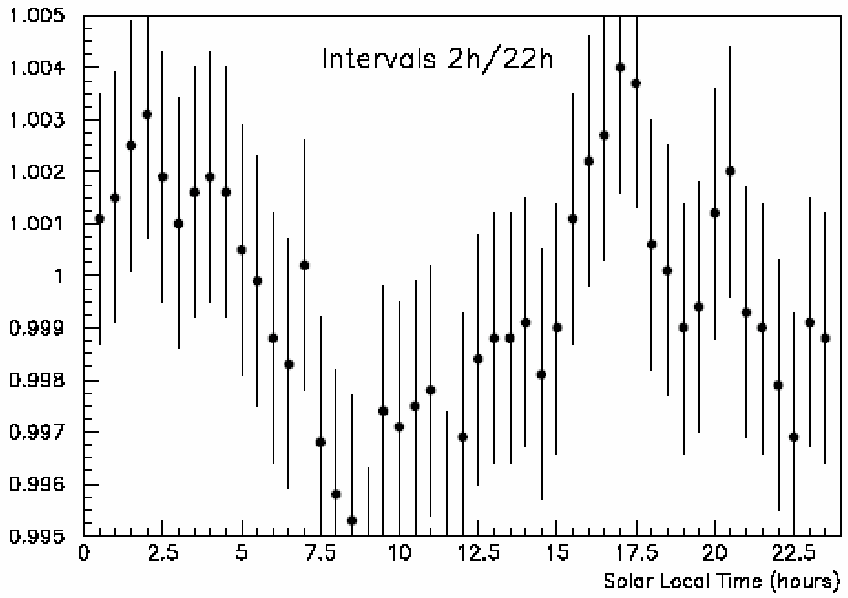

Fig.4: As in Fig.3, for the ratio between 6 hours and 18 hours.

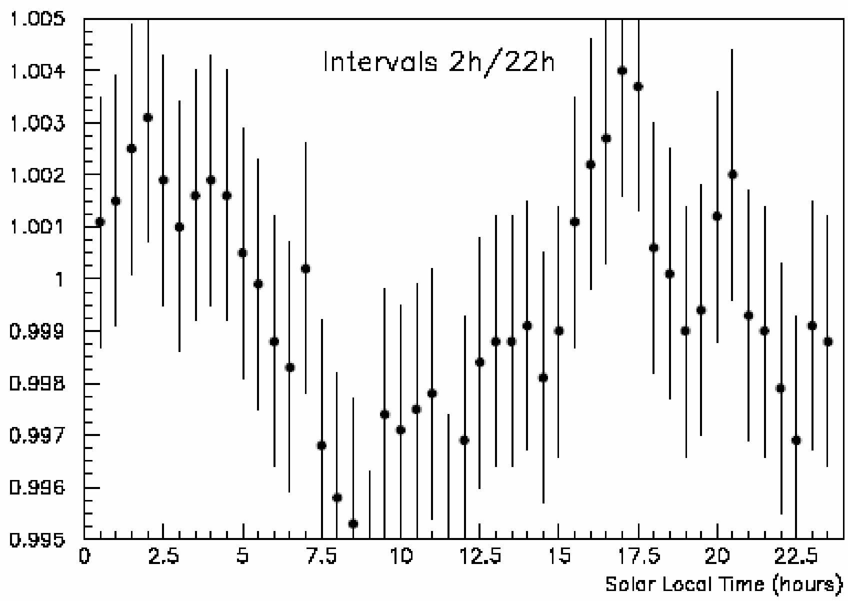

Fig.5: As in Fig.3, for a ratio between intervals of 2 hours and 22 hours.

It must be observed that the effects of the atmospheric conditions may play an important role, even after correcting for the barometric coefficient. As an example, because of decay effects, the muon sea level intensity is related to the height of production. A higher temperature is associated to muons being produced at a higher altitude, with a corresponding decrease of the observed flux. In absence of strong atmospheric fronts or troughs, the daily counts have been observed to be smaller than the nightly counts, due to temperature effects [19]. In other cases, the role of semidiurnal variations have been found to be as important as the diurnal cycles, showing a strong positive correlation with that in the atmospheric pressure [18].

4 CONCLUDING REMARKS

The use of a small Geiger counter, operated for a relatively long period, may allow the observation of even the small diurnal variations of cosmic rays, which are in the order of 0.1-0.3 %. The fluctuations from day to day have been found to be very large, as it is usually observed in professional experiments with large area counters and huge statistics. However, statistical analyses carried out for a sufficiently large number of observational days (in the order of a hundred or more) are able to show up some trend. The detailed interpretation of such data is made difficult by the inclusive nature of the observations, which are obtained by a very simple set-up, not allowing to select neither well defined orientations of the incoming cosmics nor a uniform composition of the hard and soft components, due to the amount of shielding around the detector. Since the investigation was only intended as a test for further educational studies by high school teams, many improvements could be imagined to what already obtained. As an example, even with a single counter, a better choice of the detector location could define a uniform amount of shielding around it, allowing to disentangle the effect of the flux variation along the day from that of the disuniformity due to the shielding. The possibility of using two small Geiger counters in coincidence is usually ruled out in such case, since the statistical errors associated to the small number of expected coincidences would not allow the observation of a 0.2 % effect even after long runs. In terms of possible collaborations between several participating teams, an increase in statistics could be obtained by adding the data obtained from several groups operating on a local area with a similar set-up.

5 REFERENCES

(1) A.E. Sandström, Cosmic Ray Physics, North-Holland, Amsterdam, 1965.
(2) L. I. Dorman, Cosmic Rays. Variations and space explorations, North–Holland, Amsterdam, 1974.
(3) J.L.Thompson, Phys. Rev. 54(1938)93.
(4) J.L.Thomson, Phys.Rev.55(1939)11.
(5) E.O.Wollan, Rev.Mod. Phys. 11(1939)160.
(6) J.W.Firor et al., Phys. Rev.94(1954)1031.
(7) R.P.Kane, Phys.Rev.98(1955)130.
(8) D.Barrett et al., Phys. Rev. 95(1954)1571.
(9) N.Sherman, Phys.Rev.89(1953),25.
(10) See e.g. Gran Sasso experiments at http://www.lngs.infn.it/
(11) L3+C Collaboration, http://l3cosmics.cern.ch:8000/
(12) H.Besier et al. (ALEPH Collaboration), Nuclear Instruments and Methods A454 (2000)201.
(13) B.Famoso, P.La Rocca and F.Riggi, Report INFN/AE_04/13 (2004).
(14) Oulu Neutron Station, http://cosmicrays.oulu.fi/
(15) Moscow Neutron Monitor, http://helios.izmiran.rssi.ru/cosray/main.htm.
(16) J.Bartels, Terr.Mag. 37(1932)291.
(17) J.Bartels, Terr. Mag. 40(1935)1.
(18) P.Nicolson and V.Sarabhai, Proc. Phys. Soc. 60(1948)509.
(19) H.M.Mok and K.M.Cheng, Proc. of the 10th Int. Congress of the Int. Radiation Protection Association, Hiroshima (Japan), 14-19 May 2000.