Differential Neutron Flux in Atmosphere at Various Geophysical Conditions

A. Zanini[1], C. Ongaro[2], E. Durisi[3], L. Visca[3], S. DeAgostini[3], F. Fasolo[3], M. Pelliccioni[4], O. Saavedra[5]
(1) INFN-Sez Torino, Via P.Giuria 1, 10125 Torino, (Italy)
(2) Otto, P.zza Vittorio Veneto 14, 10123 Torino, (Italy)
(3) Experimental Physics Department, University of Torino, Via P.Giuria 1, 10125 Torino, (Italy)
(4) LNF, Via E. Fermi 40, 00044 Frascati, (Italy)
(5) General Physics Department, University of Torino, Via P.Giuria 1, 10125 Torino, (Italy)

Abstract

The intensity and composition of cosmic radiation at atmosphere altitudes up to 30 km o.s.l. are modulated by solar activity and strongly depend on geophysical characteristics and atmosphere parameters. An accurate evaluation of secondary neutron energy spectra may constitute a valuable contribution to a better knowledge of the primary cosmic ray intensity. Moreover, because of neutron high Relative Biological Effectiveness (RBE), a correct assessment of the neutron component allows an improved estimate of the risk associated to a human exposure to ionizing radiation arising from cosmic rays. In addition, neutron intensity and energy distribution is strictly correlated to atmospheric composition. In this work the results of different experiments, concerning neutron integral and differential measurements at various altitudes and latitudes, are presented.

Introduction

The radiation environment around the Earth is due to the interaction of primary galactic cosmic rays (GCR) with nuclei constituting the atmosphere. Primary particles, entering into the upper layers of the atmosphere mainly interact with Oxygen and Nitrogen nuclei and produce a secondary shower, consisting of different particles such as protons, neutrons and mesons. The secondary particle production is balanced by absorption in air and leads to a variation of ionizing particle flux with altitude. The secondary shower characteristics depends on geophysical coordinates, solar activity and atmosphere composition. Recently the possible role of cosmic ray intensity variation in the present global warming has also been considered. In fact observations by satellite suggest that cosmic rays play an important role in the climate, showing a correlation between cosmic ray

pp. 4291–4294

intensity and the fraction of the Earth covered by clouds. Among the components of the secondary shower, a special attention should be payed to neutron field distribution, because the neutron fluence strongly depends on atmospheric composition and characteristics, and, neutrons give an important contribution to the total dose in human exposure to cosmic radiation environment.

The results of different experiments concerning neutron spectra at various altitudes and latitudes are presented (Matterhorn, 46°N, 3480 m o.s.l., Chacaltaya 16°S, 5230 m o.s.l., Alitalia Flights 10500m o.s.l., ASI (Space Italian Agency) Transmediterranean Balloon flights, 15000, 28000, 30000 m).

1. Experimental methods

Experimental techniques. The complexity of the experimental neutron spectra and dose evaluation – wide energy range and dependence on many parameters – requires the development of appropriate techniques.

A complete experimental system, based on passive detectors, is realized in two energy ranges: A. 100 keV-100 GeV (extended), B. 10 keV - 20 MeV (limited).

A. The extended energy range detector system is constituted by passive detectors with different energy thresholds and responses: Bubble Dosimeter BD100R (100keV-20MeV), Polycarbonate detector, foils (1MeV-150MeV), Polycarbonate detector bottles (1MeV-150MeV), Fission detector 209Bi layers (100MeV-hundreds of GeV)[3]. The experimental data have been processed with a special version of the unfolding code BUNTO [4].

B. The BDS[1] spectrometer with an adapted version of the BUNTO unfolding code is used like limited energy range detector system; it is constituted by six types of bubble detectors, which differ in energy thresholds and responses.

Because the extended system requires long exposure time to get reasonable statistic in the high energy region, in several cases, where a first information is needed in shorter time, the limited system, integrated by MC simulation, can be useful.

Monte Carlo simulations. Two MC codes (GEANT 3.2 and FLUKA) have been used to simulate the hadronic cascade and the interaction between primary protons and atmosphere at various altitudes and latitudes. In figure 1. (left), the secondary radiation separated into the main components is represented, in terms of ambient dose equivalent rate H* vs altitude (Northern latitude 6.0 GV, minimum solar activity 465 MV). In figure 1. (right), the relative importance of the neutron component to respect to the total dose is clear.

In figure 2. the results of various experiments, collected in North and South hemisphere and at different altitudes, are presented in terms of integral neutron fluence rate vs. altitude. Taking into account the differences between experimental conditions and simulation parameters, the comparison between the experimental and simulated vertical profiles shows an overall agreement.

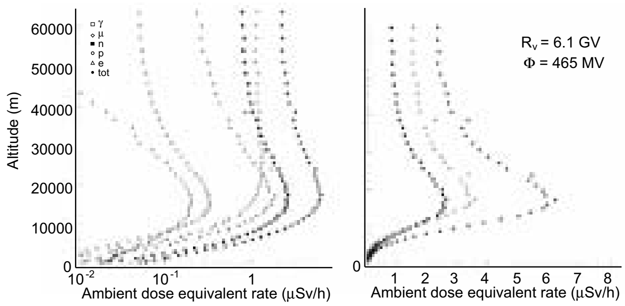

Fig. 1. Neutron vertical profiles: H* Fluka simulation (left); H* Neutron contribution vs total (right).

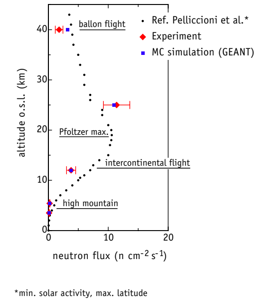

Fig. 2. Neutron vertical profiles: experimental neutron fluence.

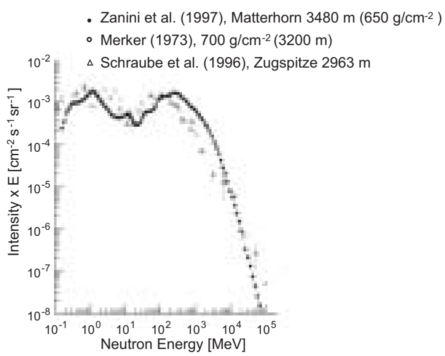

Fig. 3. Extended range: experimental neutron spectrum at Matterhorn ($46° N$, 3480 m a.s.l., 6GV, by author permission[2]).

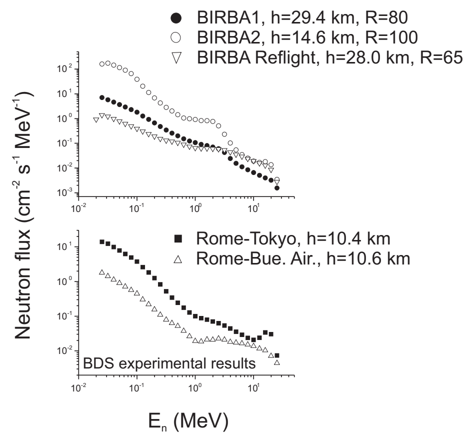

Fig. 4. Limited range: experimental neutron fluence; latitude effects (low), altitude effects (up).

2. Results

Neutron spectra analysis. As an example, a neutron spectrum obtained with the extended system is shown in figure 3. (left). This method allows an accurate reconstruction of the two characteristic peaks (evaporative and knock-on).[2] The BDS system (limited range) has been used in experimental conditions in which the exposure time was short: this is the case of flights on aircrafts (1015MV and 924MV; 8hrs) and on stratospheric balloons (ASI Trapani-Siviglia flight, Wolf number 100, 80, 65; 22hrs). The very simple system allows in both cases the evaluation of the neutron fluence differences between polar and equatorial flight paths (aircraft, fig. 3. low), and between different altitudes and solar activities (balloon flights, fig. 4. up).

Correlation with atmosphere parameters Finally an attempt to evaluate the cor-

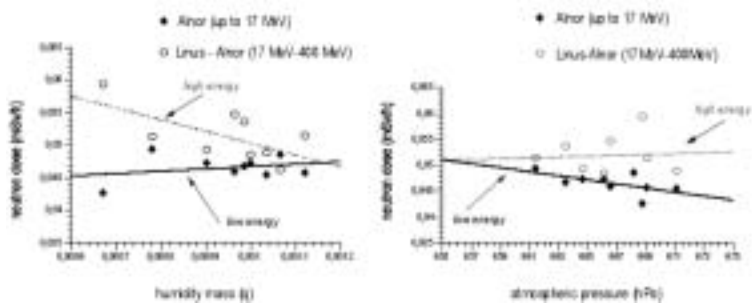

Fig. 5. Neutron ambient dose equivalent and cloud cover. Low energy range (0.025 eV-20 MeV): the dose increases with humidity mass; high energy range (20 MeV-400 MeV): the dose decreases with the increase of the humidity mass, as expected because of thermalization processes with clouds.

relation between cosmic ray intensity and atmosphere parameters has been performed at Matterhorn laboratory, by means of a traditional rem-counter ALNOR (thermal to 20 MeV) and an extended rem counter LINUS (up to 400 MeV). Neutron ambient dose equivalent has been measured in wet and dry atmospheric conditions and at different pressure values. The results are shown in figure 5.
It can be observed that at lower energies (0.025eV-20 MeV), the dose increases with the increase of the humidity mass, whereas at higher energies (20 MeV-400 MeV) the dose decreases with the increase of the humidity mass, as expected because of thermalization processes with clouds.

3. Conclusion

The detector system, both in extended and in limited energy range, seems to be suitable for neutron spectrometry in different cosmic ray fields; due to the reduced size and simple experimental set up, it could represent the unique tool for all the applications that require space and weight reduction, and absence of electronic equipment: for example intercontinental flights, balloon flights and on board space vehicles.

4. References

1. BTI, HWY 17, Chalk River, Ontario, Canada.
2. Grieder P.K.F. 2001, in Cosmic Ray at Hearth, ed. Elsevier, 126-127.
3. Tommasino L. et al. 1995, Rad. Prot. Dos., 59, 299-302.
4. Zanini A. et al. 2001, Il Nuovo Cimento, Vol 24-C, 691-697.