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Gamma-rays and ionizing component during thunderstorms at Gran Sasso

M. Aglietta[1,2], B. Alessandro[2], P. Antonioli[5], F. Arneodo[4], L. Bergamasco[2,3], M. Bertaina[2,3], M. Brunetti[7], C. Castagnoli[2], A. Castellina[1,2], D. Cattani[9], S. Cecchini[8,5], A. Chiavassa[2,3], G. Cini[2,3], B. D'Ettorre Piazzoli[6], G. Di Sciascio[6], W. Fulgione[1,2], P. Galeotti[2,3], M. Galli[9], P. L. Ghia[1,2], G. Giovannini[9], M. Iacovacci[6], G. Mannocchi[1,2], C. Morello[1,2], G. Navarra[2,3], A. Pagliarin[9], O. Saavedra[2,3], G. C. Trinchero[1,2], P. Vallania[1,2], S. Vernetto[1,2] and C. Vigorito[1,2]

[1]*Istituto di Cosmo-Geofisica del CNR, Torino, Italy*

[2]*Istituto Nazionale di Fisica Nucleare, Torino, Italy*

[3]*Dipartimento di Fisica Generale dell' Università, Torino, Italy*

[4]*Dipartimento di Fisica dell' Università and INFN-LNGS, L' Aquila, Italy*

[5]*Istituto Nazionale di Fisica Nucleare, Bologna, Italy*

[6]*Dipartimento di Scienze Fisiche dell' Università and INFN, Napoli, Italy*

[7]*Istituto SAO, CNR, Bologna, Italy*

[8]*Istituto TESRE, CNR, Bologna, Italy*

[9]*Dipartimento di Fisica dell'Università degli studi di Bologna, Italy*

Abstract

A study of the temporal variations of the environmental radiation (secondary cosmic rays and airborne radionuclides) is presented. The data are provided by a NaI detector, sensitive to gamma-rays of energy $E >$0.1 MeV and by the EASTOP air shower array, sensitive to particles of energy $E >$2.5 MeV and $E >$25 MeV and detecting Extensive Air Showers generated by cosmic rays of energy above 100 TeV.

In conditions of perturbed weather significant increases of the counting rates have been observed by both detectors. In the energy range $E <$3 MeV, increases of duration of a few hours are correlated with rainfalls. Short duration increases ($\sim$10 minutes), occurring during thunderstorms, are observed also at higher energies and are accompanied by a a significant increase in the air showers counting rate.

1 Introduction

A monitoring measurement of the temporal variations of environmental airborne radionuclides and secondary cosmic rays due to atmospheric effects is performed at the EASTOP station of the Gran Sasso Laboratories, at an altitude of 2000 m above the sea level. In order to study a wideenergy range we used both a NaI scintillator detector, sensitive to gamma-rays of energy $E >$100 KeV, and the EASTOP air shower array, operating in single particle mode and in coincidence mode (i.e. EAS mode). In the following we will mainly discuss a peculiar event, occurred during conditions of perturbed weather.

2 NaI scintillator data

The detector consists of a cylindrical NaI(Tl) monocrystal (10$\times$20$\oslash$ cm) with sides and bottom shielded by 1.0 cm Pb, 0.2 mm Cu and 0.3 mm Al (Cecchini et al. 1997a). During four months of operation (from July 5 to November 4 1996) the following data sets have been obtained:

a) Counting rate per minute in the energy range 0.4 - 20 MeV (referred here as "Ratemeter", and including both radioactivity and secondary cosmic rays);

b) Counting rate per hour in the energy range 0.1-2.8 MeV (radioactivity + secondary cosmic rays);

c) Counting rate per hour in the energy range 3-10 MeV (secondary cosmic rays); these data are corrected for the atmospheric pressure effect, the barometric coefficient being $\beta = -(0.50 \pm 0.04)\%$/mbar.

In a few occasions of perturbed weather significant increases in the counting rates have been observed in all data sets. In Fig.1 an event with particular interesting features, occurred on July 11, is shown. The Ratemeter (data *a*) shows a fast increase, lastings $\sim$10 minutes, of magnitude exceeding 20%, superimposed to a slower

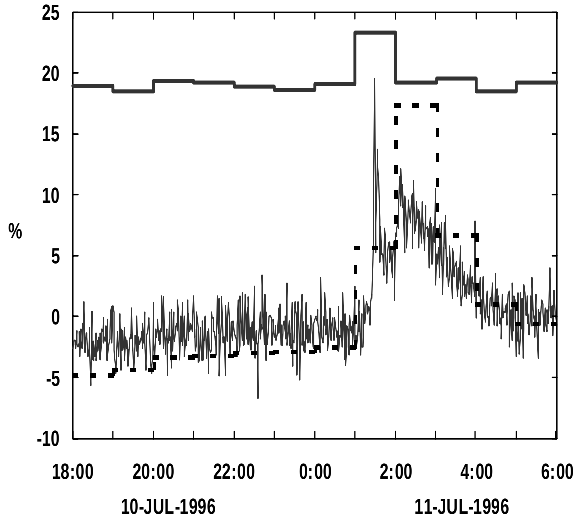

Figure 1: NaI scintillator data during the July 11 event. Thin line: percent increase of the counts per minute at energy $E > 0.4$ MeV (ratemeter); thick dashed line: hourly counting rates in the energy range 0.1-2.8 MeV; thick countinuous line: hourly counting rate in the energy range 3-10 MeV.

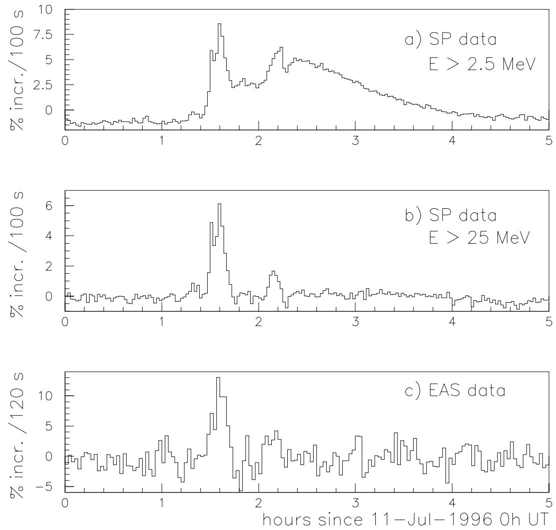

Figure 2: EASTOP data during the July 11 event: *a)* percent increase of the single particle counting rate for detector energy $E >$2.5 MeV; *b)* single particle counting rate at $E >$25 MeV; *c)* Extensive Air Shower rate.

and smoother one, lasting few hours. It is interesting to note the different behaviours of the hourly counting rates in the two different energy ranges: between 0.1 and 2.8 MeV (data *b)* it follows the Ratemeter curves, while in the 3-10 MeV range (data *c)* it shows an increase only at the time of the first peak, demonstrating that the long duration increase is a lower energy effect. These data suggest that the short duration increase and the longer one, even if both produced in conditions of perturbed weather, could have a different origin.

3 EASTOP data

The EASTOP electromagnetic detector is made of 35 plastic scintillators (each of area 10 m^2 and thickness 4 cm) spread over an area of $\sim$10^5 m^2 (Aglietta et al. 1988). Two data set are considered here:

1) SP data: the single particle counting rate of any individual scintillator recorded every 100 seconds.

2) EAS data: Extensive Air Showers generated by cosmic rays of energy $E \geq 100$ TeV; the trigger condition requires at least 5 contiguous detectors hit in a time coincidence of 300 ns; the trigger rate is about 28 s^{-1}.

Each detector operates at an energy threshold $E_{th} = 3.0 \pm 0.5$ MeV. Ten out of the 35 detectors have an additional wooden cover that increases the energy threshold of charged particles to $E_{th} \sim$ 25 MeV. The average SP counting rate is $n_c \sim$ 500 and 400 m^{-2} s^{-1} respectively for "external" and "covered" detectors.

1) The SP counting rate is mostly due to secondary particles (muons and electrons) generated in the atmosphere by low energy primary cosmic rays and is modulated by the atmospheric pressure, the 24 hours anisotropy and the solar activity. Besides these modulations, significant increases in the SP counting rate are observed in coincidence with rainfalls and thunderstorms. The increase usually starts with the beginning of the rain and reaches a magnitude of the order of $\sim$5-15$\%$ in a time of $\sim$ 0.5-1 hour; when the rain stops the

counting rate returns to its normal value with a slow decay, lasting few hours.

In Fig.2 (curves *a* and *b*), the SP counting rate of two EASTOP detectors are shown during the increase occurred on July 11 1996, under discussion. Plot *a*, corresponding to an "external" detector, shows the same temporal behaviour as the Ratemeter, while plot *b* corresponding to a "covered" detector only shows two short duration peaks. These observations agree with the NaI detector data and confirm the obverved difference in the energy range between long duration and short duration increases.

2) Concerning EAS data, a significant excess in the air shower counting rate is observed in coincidence with the short duration peaks (see Fig.2c). During the first peak the increase reaches a magnitude of more than 10% and lasts $\sim$ 10 minutes. All events recorded during the increase consist of well reconstructed air showers and show no unusual characteristics. An interesting feature is the arrival directions of the excess showers, about perpendicular to the ground at the EASTOP site (i.e. an irregular mountain slope of about 15° oriented to South).

In a few other occasions similar events have been observed. All of them have a similar behaviour: a short duration (10-15 minutes) increase of the air showers counting rate, superimposed to a slower increase of the single particle one (the shower increase always occurs when the single particle counting rate is still raising). In one occasion an operator could report the local weather conditions during an air showers increase and he verified that a thunderstorm was in progress, with lightnings and hail fall. It is worth to note that these events are quite rare, while the long duration increases in the single particle counting rate appear to be strongly correlated with rainfalls.

4 Discussion

In summary, two different types of counting rate increases have been observed in our measurements:

- **Type A**: an increase directly related to rainfalls, observed in the energy range $E < 3$ MeV; it lasts a few hours and has a slow decrease.

- **Type B**: a short duration ($\sim$10 minutes) increase, observed also at energies $E > 3$ MeV, usually superimposed to a slow increase of type A. This type of event is accompanied by a significant excess of the air shower counting rate.

A possible explanation of type A events could be related to the gamma ray emission from radioactive aerosols transported to the ground by the rain, as Radon daughters (that, as it is well known, constitute condensation nuclei for raindrops).

This "washout" effect interpretation is supported by the results obtained from the difference between the spectrum measured during the increase and the spectrum in normal conditions. In Fig.3, showing such difference spectrum with the identification of the photoelectric peaks, the contribution of gamma decays from Radon daughters is visible.

Similar events were observed during a measurement on board of M/N Italica, along the Ravenna - Terra Nova Bay - Ravenna course of the XI Italian expedition to Antarctica. In that occasion, with the aid of a meteorological station, it was possible to pinpoint the coincidence of precipitations with increments in the detector counting rate and ascribe them to gamma emission from Radon daughters (Cecchini et al. 1997b).

Concerning the origin of type B events, atmospheric pressure effects can be excluded since the data are corrected for pressure variations. Furthermore the phenomena appear to differ significantly from what observed by Fazzini et al. (1968) in similar occasions, interpreted as a temperature effect. An increase of the primary cosmic rays flux is excluded as well by contemporary measurements by the neutron monitors at Rome and Jungfraujoch.

A possible origin can be due to the effect of strong atmospheric electric fields on the propagation of the secondary cosmic rays particles. Variations of the single particle counting rate (of energy $E > 20$ MeV and $E > 80$ MeV) have been observed by the BAKSAN air shower array in correlation with electric field variations during thunderstorms (Alexeenko et al, 1985). They show the same time duration as the present events, while the amplitudes are smaller (less than 3%) and with both signs (i.e. increases and decreases are observed, while

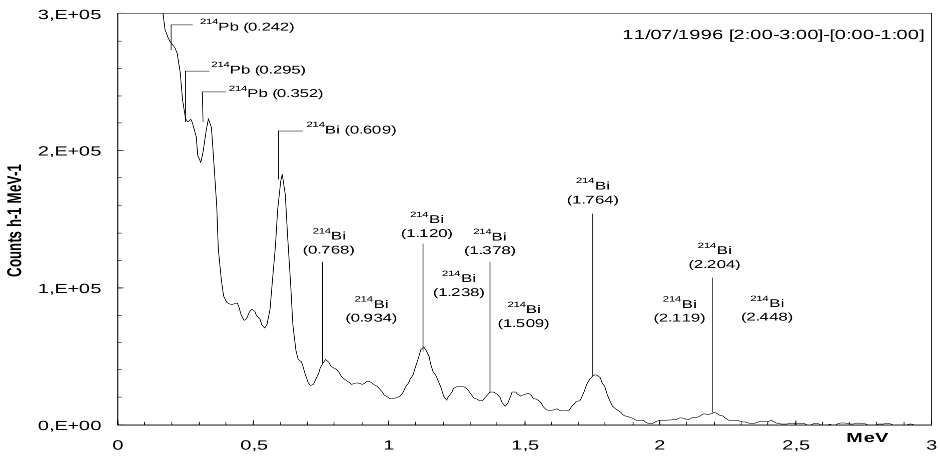

Figure 3: Difference between the spectrum obtained during the counting rate increase occured on July 11 and the spectrum obtained in normal conditions. The gamma-ray photoelectric peaks of the Radon daughters are well identified.

only increases are observed in the present data). According to Dorman (1997) these variations should be due to effects of the electric field on the muon component.

The electric field could as well affect the electron component and possibly modify the air shower counting rate. The acceleration of electrons and the consequent increase of bremsstrahlung radiation have been studied in several works (Wilson 1925, Shaw 1967, Parks et al.1981, McCarty and Parks 1985, Gurevich et al. 1992, Eack et al. 1996, Eack and Beasley 1996, Suszcynsky and Roussel-Dupre 1996 and references therein).

According to Gurevich et al. (1999) the EAS electrons can be accelerated by electric fields of magnitude $E_c >$ 1-2 KV cm^{-1} and initiate an "avalanche" process producing more and more fast electrons by collisions with air molecules. The process would be more effective on larger and more energetic air showers. Such effect would increase the size of air showers and consequently increase the rate of the events observed over a given detection threshold.

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