MEASUREMENT OF PRIMARY COSMIC AND X-RADIATION IN THE SOUTH AMERICAN ANOMALY AT AN ALTITUDE OF 90 KM.

Part I: Measurement of the Primary Cosmic Radiation Intensity

by

N.E. Becerra and H.S. Ghielmetti

Centro Nacional de Radiación Cósmica
Buenos Aires, Argentina

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APPENDIX 2.3.

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1. INTRODUCTION

On December 16, 1967 an Argentine ORION II rocket was launched carrying an instrumented payload composed of four GEIGER-MÜLLER counters and one NaI(Tl) scintillator. Although the main object of the experiment was the measurement of the X-ray flux and spectrum near the top of the atmosphere, the information obtained from the GM counters made it possible to measure the integral intensity of the primary cosmic radiation above the local geomagnetic cut-off.

2. RESULTS OF THE ROCKET FLIGHT

The rocket was launched from Chamical (30° 22' S; 66° 17' W), province of La Rioja, Argentina, where the vertical geomagnetic cut-off is 12.0 GV. The rocket reached a maximum altitude of 90 km, the total duration of the flight being 300 sec.

The detectors of charged particles were four GEIGER-MÜLLER counters, Victoreen 1B85, mounted parallel to the rocket axis (Fig. 1). The mean projected area $\bar{A}$ for each counter is 11.9 cm^2 for isotropic radiation, its efficiency ϵ for charged particles detection being 0.96 (KEPPLER, 1965).

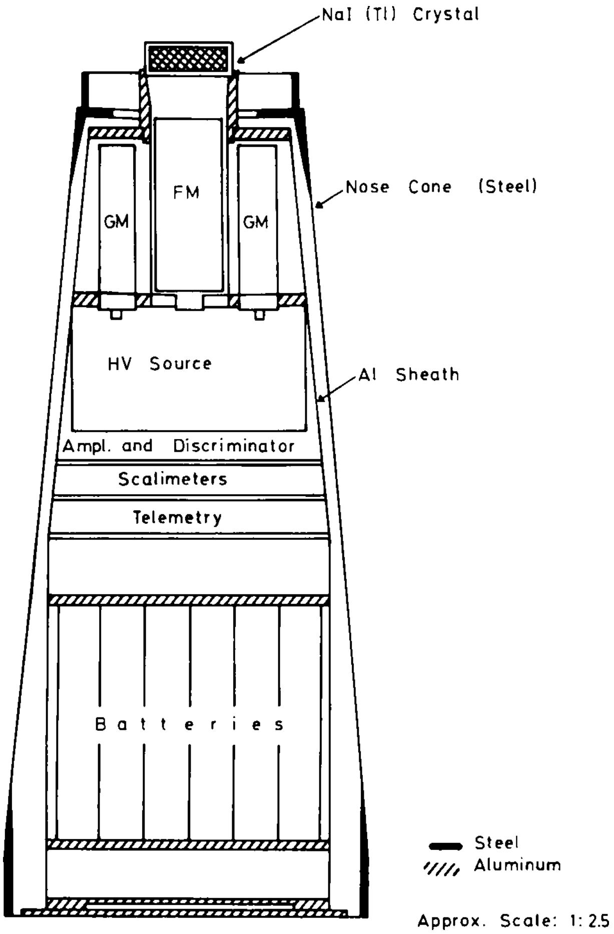


Fig. 1 Outline of the payload which shows the placement of the detectors and the part of the nose cone which remains after the separation of its upper part.

The rocket trajectory (atmospheric depths versus time diagram), derived from the information supplied by an MPS-19 radar, is given in Fig. 2. The conversion of altitude (km) to atmospheric depth (g cm^{-2}) was carried out using the model of the mean atmosphere between 30 and 300 km given in COSPAR International Reference Atmosphere (CIRA, 1965). This model is particularly suited for Chamical latitude.

Fig. 3a shows the counting rate of the counters as a function of time, and Fig. 3b the counting rate measured above the 40 km level, which is given as a function of the atmospheric depth in the upward as well as the downward branch of the flight. From this figure, it is observed that the counting rate remains essentially constant, from approximately 3 g cm^{-2} up to the minimum atmospheric depth reached; this can be explained as a result of the high energy of the detected

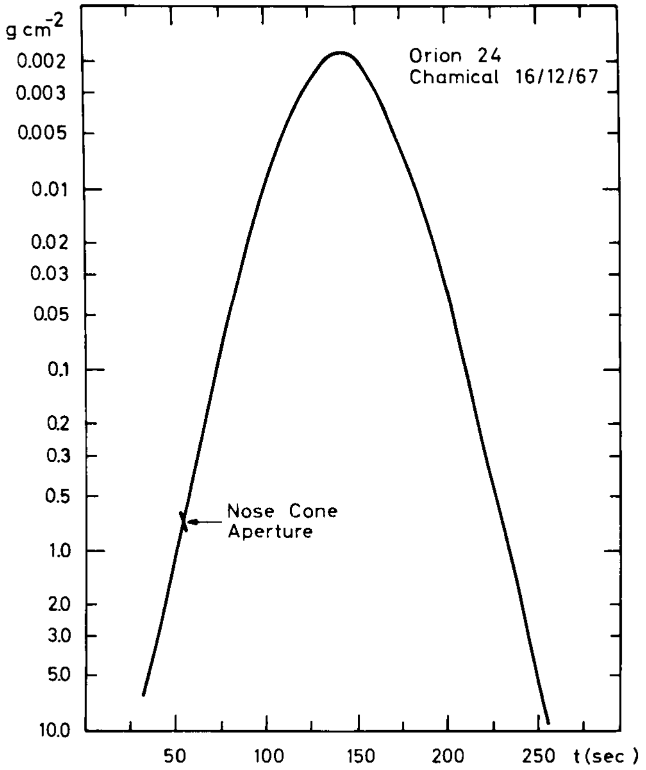
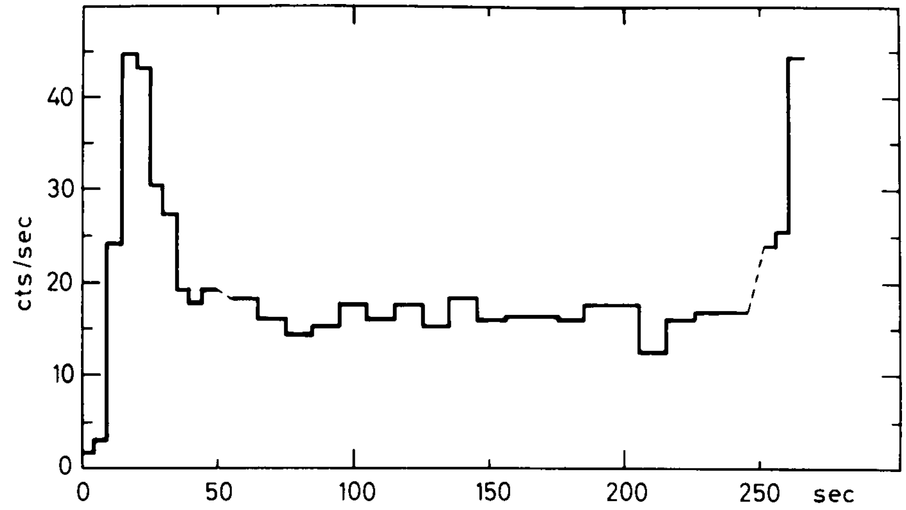


Fig. 2 Atmospheric depth versus time curve for the rocket flight, according to the information received by an MPS-19 radar.

particles and its consequent low absorption in the mass of air interposed. However, for the determination of the primary intensity, we used the counting rate averaged over 30 sec around the apogee, that is, when the atmospheric depth was lower than some 2 · 10^{-3} g cm^{-2}. This value, (4.13 ± 0.18) cts sec^{-1}, does not statistically differ from the general average (4.05 ± 0.07) cts sec^{-1} taken over 190 sec.

The total intensity measured near the apogee includes primary cosmic radiation, essentially composed of protons and α-particles, plus reentrant as well as splash albedo radiation. Therefore, in order to derive the first one, the contribution from the total atmospheric albedo must be substracted.

The counter used may be considered omnidirectional with a good approximation, since the extreme values of the projected area do not differ by more than 15 % from the mean value. On the other hand, the high energy of the incident particles makes neglectable in a first approximation the absorptive material of the steel wall of approximately



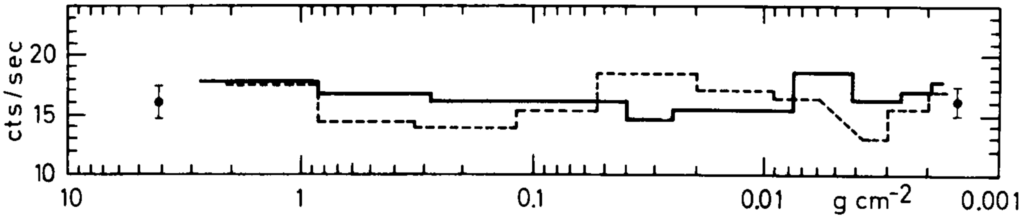


Fig. 3a Counting rate of the four GEIGER-MÜLLER counters as a function of time (upper part).

Fig. 3b Counting rate of the four GEIGER-MÜLLER counters above 40 km as a function of atmospheric depth (lower part).

1.0 g cm^{-2}, corresponding to the range of 24 MeV protons and roughly 100 MeV α-particles.

The total counting rate for each counter if given by

$$N_t = \int_{\Omega_p} \epsilon I_p(\theta,\varphi) A(\theta,\varphi) d\Omega + \int_{\Omega_r} \epsilon I_r(\theta,\varphi) A(\theta,\varphi) d\Omega + \int_{\Omega_s} \epsilon I_s(\theta,\varphi) A(\theta,\varphi) d\Omega$$

where $A(\theta,\varphi)$ is the counter area projected perpendicularly to the incidence direction (θ,φ). I_p, I_r and I_s are the unidirectional intensities of the total primary radiation, and of the reentrant and splash albedo, respectively. The integrations are made on the effective solid angles for the three types of radiation.

Although between 50 and 90 km above sea level the solid angle covered by the Earth is somehow smaller than a hemisphere (5.50 and 5.23 steradians), the remaining angle under the horizontal plane is covered by the atmosphere. Therefore it may be a good approximation to consider that the primary radiation is incident only from the upper hemisphere ($\Omega_p = 2\pi$) and the splash albedo, from the lower hemisphere ($\Omega_s = 2\pi$). It is more difficult to estimate Ω_r and lacking a better evidence we shall also take it as 2π. With these approximations we are able to calculate the primary intensity, for assuming isotropy for the three types of radiation, it is:

$$N_t = 2\pi\,\epsilon\bar{A}(I_p+I_r+I_s) = 2\pi\,\epsilon\bar{A}(1_p+\Phi_{rs}I_t)$$

where I_t is the measured total intensity, given by $N_t(2\pi\,\epsilon\bar{A})^{-1}$ and Φ_{rs} is the fraction corresponding to both components of the albedo.

Obviously, Φ_{rs} cannot be calculated from the present experiment and we shall therefore use WEBBER's results (1967). Using some albedo measurements he gives the variation curve for Φ_{rs} between the geomagnetic pole and the equator. For Chamical's geomagnetic latitude (19°S), $\Phi_{rs} = 0.65$ and the correction becomes important.

Finally, the value of the integral intensity $I_p = (1 - \Phi_{rs})\, I_t$ for the primary particles of magnetic rigidity higher than the Chamical cut-off is $(2.02 \pm 0.30) \cdot 10^{-2}$ part$(\text{cm}^2 \text{ sec ster})^{-1}$, the I_t measured is $(5.75 \pm 0.28) \cdot 10^{-2}$ part$(\text{cm}^2 \text{ sec ster})^{-1}$.

It is interesting to compare this value with the total integral spectrum $I_p\ (> P) = 0.79\ P^{-1.5}$ derived by WEBBER and ORMES (1965) for the sum of the primary protons and α-particles and particularly with the results of a balloon measurement carried out by them in July 1964 from Tucumán, Argentina, (geomagnetic cut-off: 12.1 GV) at some 400 km north-east of Chamical. Fig. 4 shows this comparison and an excellent agreement between both measurements is observed.

Furthermore, this shows that the level of solar modulation at the time of both measurements (July 1964 and December 1967) was entirely comparable, at least for the high energies considered.

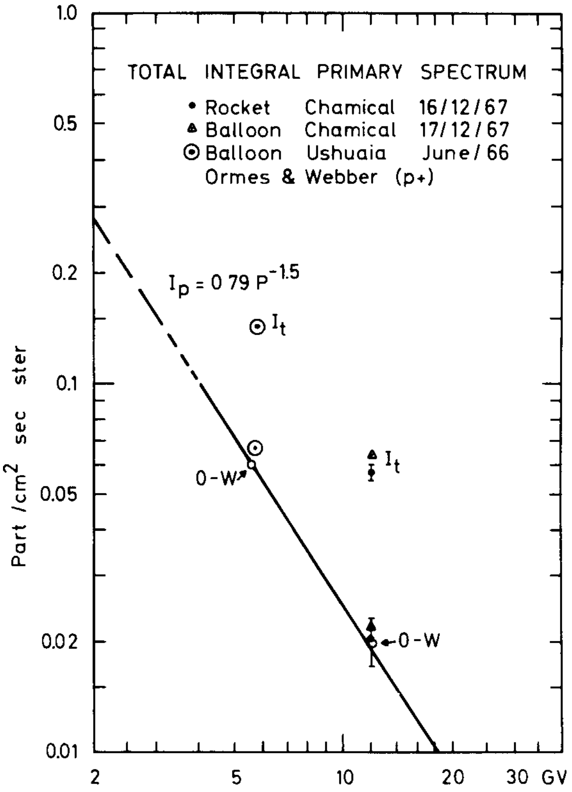


Fig. 4 Total primary integral spectrum. The value measured by the rocket and the values obtained by extrapolation of balloon measurements (with albedo corrections) are enclosed.

3. COMPARISONS WITH BALLOON MEASUREMENTS

Another interesting result of the measurement carried out is the comparison of the total intensity of the particles measured by the rocket above the atmosphere with the value obtained by extrapolation to 0 g cm^{-2} of the total intensity measured with a balloon-borne GM counter.

To fit and extrapolate the counting rate measured in the atmosphere by GM counters similar to those used in the rocket, our group has been using several years an expression of the form

$$C(x) = A \exp(-x/86) - B \exp(-x/L),$$

where C(x) is the counting rate at a depth of x g cm^{-2} and A, B, and L are parameters determined for each flight (GHIELMETTI et al., 1964).

This fitting has proved excellent for depths between approximately 600 g cm^{-2} and the minimum reached by the balloon. Furthermore, it is valid for flights made near the equator as well as for the middle latitudes and those near the poles. It is therefore an interesting opportunity to compare an extrapolated value at the top of the atmosphere, $C(x = 0) = A - B$, with the value measured directly. In a flight carried out from Chamical, the day after the rocket experiment, the balloon reached a minimum atmospheric depth of 4.0 g cm^{-2}. The fitting curve for the balloon flight is shown in Fig. 5. The extrapolated value at the top of the atmosphere is $C(x = 0) = 4.6$ cts sec^{-1}, which corresponds to a unidirectional total intensity of $6.4 \cdot 10^{-2}$ part (cm^2 sec $ster)^{-1}$, that is, it differs from the value measured by the rocket at some 2 mg cm^{-2}, by no more than 10 %.

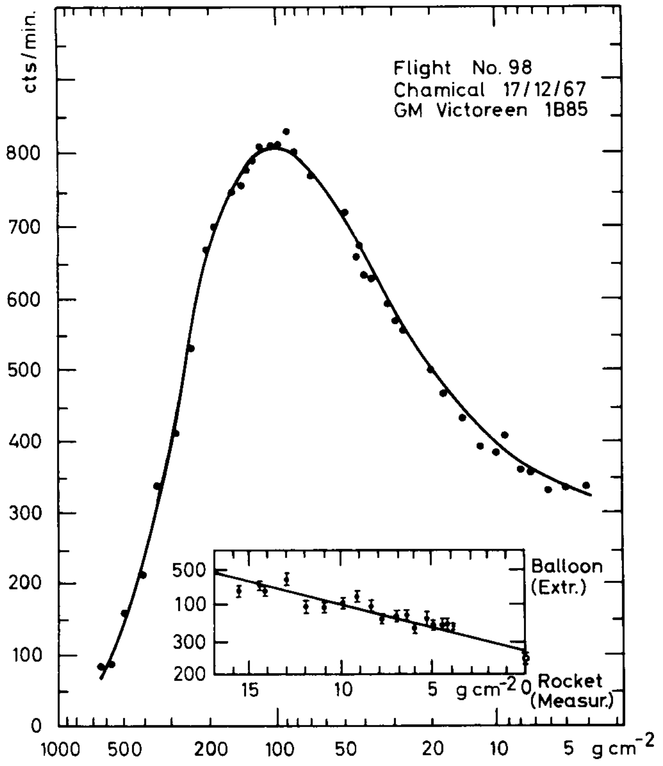


Fig. 5 Balloon measurement carried out from Chamical on December 17, 1967. The fitting curve $A \exp(-x/86) - B \exp(-x/L)$ is included. The values measured and those computed below 15 g cm^{-2} are shown in the inset.

A former balloon flight, also carried out from Chamical in June 1964, gave an extrapolated value of 4.2 cts sec^{-1} which, together with what was said before, proves the little variation in the modulation degree of the primary radiation for high energies during the period between 1964 and 1967.

Fig. 4 also includes the primary intensity derived from the extrapolated value of a flight carried out from Ushuaia (geomagnetic cut-off: 5.7 GV) in May 1966. The correction for albedo has been made taking $\Phi_{rs} = 0.53$ for Ushuaia geomagnetic latitude (43°S). This value has also been derived from the curves produced by WEBBER (1967).

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