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Nuclear Physics B Proceedings Supplement 00 (2015) 1–3

**Nuclear Physics B
Proceedings
Supplement**

Cosmic Rays Induced Background Radiation on Board of Commercial Flights

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Abstract

The aim of this work is to determine the total integrated flux of cosmic radiation which a commercial aircraft is exposed to along specific flight trajectories. To study the radiation background during a flight and its modulation by effects such as altitude, latitude, exposure time and transient magnetospheric events, we perform simulations based on *Magnetocosmics* and *CORSIKA* codes, the former designed to calculate the geomagnetic effects on cosmic rays propagation and the latter allows us to simulate the development of extended air showers in the atmosphere. In this first work, by considering the total flux of cosmic rays from 5 GeV to 1 PeV, we obtained the expected integrated flux of secondary particles on board of a commercial airplane during the Bogotá-Buenos Aires trip by point-to-point numerical integration.

Keywords: Cosmic rays, Background Radiation, Commercial Flights

1. Introduction

A nearly constant flux of particles of Solar, Galactic or Extragalactic origin arrives to the near-Earth environment. These particles, known as *cosmic rays* (CR), reach our planet with energies that vary over a wide range, beginning at 10^5 eV for solar wind particles and ending beyond 10^{20} eV for extragalactic cosmic rays. The lower energy CR are deflected by the Earth magnetosphere, but as the particles energy becomes higher, they can go through the magnetosphere and thus, they are able to penetrate into the atmosphere. When one of this *primaries* collides with a constituent nucleus of the air (typically a nitrogen atom), a cascade of *secondary particles*, called an *Extensive Air Shower* (EAS), is generated.

As the altitude increases, the atmosphere protective layer becomes thinner and less dense, and this is the main reason to consider the incidence of cosmic radiation over a commercial aircraft flying between 10 km to 12 km, since at those levels the background radiation produced by secondary particles is much higher than at ground level. Besides altitude, there are other factors that may affect the dose received by the airplane elec-

tronics, the passengers and the aircraft crew, such as the geomagnetic coordinates of the plane trajectory, different space weather conditions, and of course the exposure.

This phenomenon has been investigated only in the last two decades and it has become an occupational health issue in some countries (see, for example [1]). To calculate the number of particles incident over an aircraft flying along different routes, simulations will be performed using *Magnetocosmics* and *CORSIKA*. *CORSIKA* (COsmic Ray SIMulations for KASCADE) [2] is a detailed Monte Carlo program to study the evolution and properties of extensive air showers in the atmosphere. *Magnetocosmics* [3], is a code based on Geant4 [4, 5] that allows the calculation of charged particles trajectories through different geomagnetic field models.

1.1. Rigidity of a particle

The motion of a charged particle through a magnetic field is described by the relativistic Lorentz equation of motion, that conserves the magnitude of the momentum p , and therefore the energy of the particle. After some transformations, it can be written as $\frac{d\hat{\mathbf{v}}}{ds} = \frac{q}{pc} \hat{\mathbf{v}} \times \hat{\mathbf{B}}$,

where $\hat{\mathbf{l}}_v$ is a unitary vector pointing in the direction of the momentum and s is the path length along the particle trajectory. With this, the rigidity of the particle is defined by:

$$R = \frac{pc}{q}, \quad (1)$$

and it is a measure of the resistance of the particle to the bending of its trajectory by the magnetic field.

1.2. Geomagnetic Rigidity Cut-off

The International Geomagnetic Reference Field (IGRF) [6] is an internationally agreed and widely used mathematical model of the Earth magnetic field up to $5R_\oplus$. In this model, the magnetic field vector is given by $\vec{\mathbf{B}} = -\vec{\nabla}V$, where V is the so called magnetic potential. Each constituent model of the IGRF is a set of spherical harmonics of degree n and order m , representing a solution to Laplace's equation for the magnetic potential arising from sources inside the Earth at a given epoch. These harmonics are associated with the Gauss coefficients g_n^m and h_n^m , and are updated every five years by the International Association of Geomagnetism and Aeronomy working group [6].

Beyond five Earth radii, the Earth magnetic field is increasingly affected by the solar wind interaction with the Earth magnetosphere. These distortions can be described by several external source fields originated on different magnetospheric current systems. The Tsyganenko model[7] is a semi-empirical best-fit representation for the magnetic field, based on a large number of satellite observations (IMP, HEOS, ISEE, POLAR, Geotail, etc) [8]. The model includes the contributions from external magnetospheric sources such as the ring current, the magnetotail current system, the magnetopause currents and the large-scale system of field-aligned currents.

By virtue of the geomagnetic field, it is usual to define the **rigidity cut-off** R_c of a cosmic ray to the lower rigidity of an incoming charged particle above which it can penetrate the Earth magnetosphere and reach a specific position at some altitude on the Earth. The rigidity cut-off is directional, i.e., it depends on the Earth location of the observational point (characterized by the local altitude h , latitude φ and longitude λ), and the arrival direction of the particle (given by the particle zenith, θ , and azimuthal, ϕ , angles): $R_c = R_c(h, \varphi, \lambda, \theta, \phi)$.

2. Background Radiation on Board

To calculate the expected flux of secondary particles in any place along the plane trajectory, we use a method

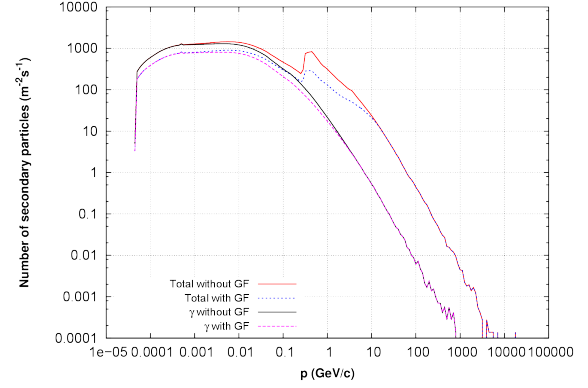


Figure 1: Differential spectrum of the secondary particles flux at 14.74°S 67.27°W and an altitude of 11 km a.s.l. The effect of the geomagnetic field on the flux (dashed lines) is clearly visible on the low energy photon flux, when compared with the flux obtained when no rigidity cut-off is considered (solid lines).

based on the simulation of the complete flux of primaries within a given range of energy [9], that includes the effect of the rigidity cut-off at different locations in the Earth, that we summarize here:

1. Simulation of showers at different altitudes using *CORSIKA*. Features of injected primaries at the top of the atmosphere:
 - Primary nuclei injected: $1 \leq Z_p \leq 26$, $1 \leq A_p \leq 56$
 - Very low initial rigidity cut-off rigidity: $R_c = 4GV$
 - Energy and arrival direction: $(R_c \times Z_p) \leq (E_p/GeV) \leq 10^6$, $0^\circ \leq \theta_p \leq 90^\circ$, $0^\circ \leq \phi_p \leq 360^\circ$
 - Simulation time: $t = 7200s$ (primary particles flux is constant and isotropic)
2. Selection and discretization of routes.
3. Computation of rigidity cut-offs for each point in the trajectory using *Magnetocosmics*.
4. Filter secondary particles by the primary rigidities and the rigidity cut-off computed for each point of the trajectory: all those showers generated by primary particles with rigidities below the cut-off are simply discarded.
5. Computation of the total amount of particles that hit the aircraft, by point-to-point integration of the flux of secondaries along the flight trajectory.

As an example of the possible results obtained by this method, we show in figure 1 the differential momentum

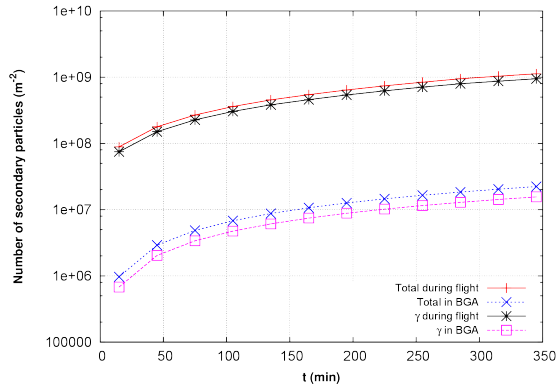


Figure 2: Integrated flux of particles (red plus signs) and only photons (black asterisks) as a function of time for the flight BOG-EZE, without taken into account the fuselage shield and the effects produced by takeoff and landing. As a comparison, we show the total integrated flux (blue crosses) and photons (magenta squares) for the same calculation but staying the same time at the city of Bucaramanga (Colombia), at an altitude of 1 km a.s.l. There is up to two orders of magnitude in the integrated exposure between those two considered cases.

spectrum of secondary particles flux obtained when the geomagnetic effect is taken into account, as compared with the flux when no geomagnetic rigidity cut-off is considered. As expected, a considerable reduction of the flux of low energy particles is observed, as the high flux of low energy primaries is strongly diminished and even forbidden due to the effect of geomagnetic field.

3. First results

In this work we chose the trajectory of the flight AR1360 BOG-EZE (Bogotá-Buenos Aires), and can be seen elsewhere¹. This route was divided into 12 intervals of equal flight time and the flux of secondaries along each of them was assumed to be constant and equal to the flux in the midpoint. The shield due to the flight fuselage and the effects of takeoff and landing on the flux was not included in this preliminary analysis (i.e., the aircraft was supposed to fly at a constant altitude of 11 km along the whole trajectory). For each one of this intermediate points, the geomagnetic rigidity cut-off was calculated by using the method described in the previous section. The result of this calculation can be seen in figure 2, where we show the integrated flux of total particles and photons as a function of time expected on board of a commercial flight. As a comparison, in the same figure we show the integrated flux expected for the same calculation but staying for the same

time at the city of Bucaramanga (Colombia) at an altitude of 1000 m a.s.l. In the same figure the effect of the atmospheric absorption on the EM component is clearly visible as a diminish of the photon flux at Bucaramanga when compared with the total flux respect to the diminution at 11 km a.s.l..

4. Conclusions and acknowledgements

The simulations performed show that at flight level, the integrated number of secondary particles is up to two orders of magnitude greater than at 1000 m a.s.l. When calculating the integrated flux, geomagnetic effects must be taken into account since they reduce the number of primary particles that generate showers. To make more accurate calculations, the shielding due to aircraft's fuselage and the effect of takeoff and landing will be included in the following round of calculations. This calculations also allow us to precisely calculate the expected flux variations due to space weather phenomena, such as the observed changes in the flux of primaries during transient geomagnetic disturbances and the corresponding change in the flux of secondaries. The authors of this work thank the support of COL-CIENCIAS grant 617/2014.

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¹ See for example <http://www.flightradar24.com/data/flights/ar1360/>