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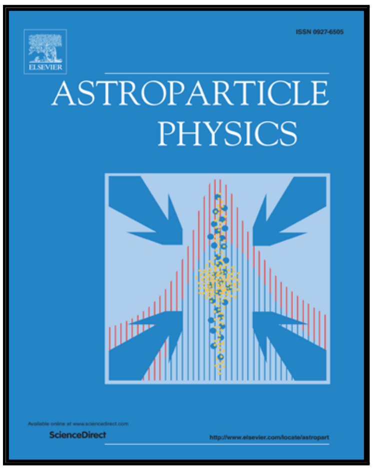

Analysis of the angular distribution of cosmic-ray-induced particles in the atmosphere based on Monte Carlo simulations including the influence of the Earth's magnetic field

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Analysis of the angular distribution of cosmic-ray-induced particles in the atmosphere based on Monte Carlo simulations including the influence of the Earth's magnetic field

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Abstract – **Several applications exist that calculate cosmic-ray-induced particle (CRIP) spectra as a function of the altitude in the atmosphere. In general, the Earth's magnetic field is only used to modulate the primary cosmic radiation that arrives at the top of the atmosphere, but it can also modulate low-energy charged particles at flight altitudes. The effects of the Earth's magnetic field on the angular distributions of CRIP transport in the atmosphere should be quantified, because it furnishes important data for the development of applications for aircrew radiation protection, onboard dosimetry and the simulation of irradiation of sensitive equipment and particle detector systems used at ground level, flight and atmospheric balloon altitudes.**

In this work we calculate the angular distribution of the cosmic-ray-induced particles (CRIP) for altitudes from ground level up to 80 km using an application based on Geant4 developed in previous works. In order to quantify the effects of the Earth's magnetic field (EMF) on the angular distribution of the CRIP, the calculations were carried out both including the EMF in the South Atlantic Magnetic region and omitting it. A part of these results were compared with analytical calculations of the ratio between the mean free path of the primary particles from the cosmic radiation and the deflection radii at different altitudes in the atmosphere. The albedos of neutrons and protons at 80 km were estimated and compared with the QARM and ATMORAD codes, which ignore the Earth's magnetic field.

Index Terms – **Monte Carlo method simulation, South Atlantic Magnetic Anomaly, Flight altitude, angular distribution of the extensive air shower.**

I. Introduction

Cosmic radiation is a generic term usually attributed to several components of radiation of terrestrial and extraterrestrial origins [1]. The extraterrestrial primary cosmic radiation coming from galactic and extra-galactic sources (i.e. supernovae, quasars, etc) or solar emissions and interplanetary medium is assumed to have an almost isotropic angular distribution. When the primary cosmic radiation interacts with the atmosphere or is deflected by the Earth's magnetic field (EMF), it gives origin to secondary cosmic-ray-induced particles (CRIP) which consist of several types of particles, including photons, electrons, neutrons, pions, muons, etc. with angular distributions which depend on the type of particle, energy and geomagnetic latitude and altitude.

Quantifying the angular distribution of cosmic-ray-induced particles as a function of energy and altitude is needed to simulate the effects of the cosmic radiation in onboard electronic devices of aircrafts and the effective dose on aircrews and the response of particle detectors. This kind of simulation is usually performed with an isotropic or semi-isotropic incident flux at all energies, which sometimes does not correspond to the reality. There are several codes that quantify the fluence rate of particles as a function of altitude, for a specific altitude range and dates [2][7][8]. However, almost none of these codes furnishes the angular distributions and all of them ignore the Earth's magnetic field at low attitude in the atmosphere.

Regarding the specific case of the aircrew, measures of radiation protection are based on sets of conversion coefficients that make the link between the double differential fluence distributions (energy and direction) of each incident particle to the radiological quantities of interest [9][10]. Usually, the angular distribution of cosmic radiation for determining the ambient dose equivalent or the effective dose in aircraft environment is considered to be isotropically distributed, that is, the fluence per unit of solid angle is independent of the direction of incidence. This premise is called into doubt by several authors, especially for the high-energy components (above 100 MeV) that tend to have marked directionality. In Ref. [9], the conversion coefficients were calculated for a set of irradiation geometries of interest for CRIP dosimetry (isotropic, semi-isotropic, from the top), but, in fact, none of these represent totally the real behavior of the atmospheric radiation field. The ICRU, in its recommendation number 84 [11] used a hemispherical incident (semi-isotropic) geometry. However, Ref. [12] shows that an isotropic geometry is still the most adequate to reproduce the effective dose received by crews, using the

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