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To cite this version:

HAL Id: lirmm-01234455
https://hal-lirmm.ccsd.cnrs.fr/lirmm-01234455
Submitted on 26 Nov 2015

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Use of CCD to Detect Terrestrial Cosmic Rays at Ground Level: Altitude vs. Underground Experiments, Modeling and Numerical Monte Carlo Simulation

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Abstract—In this work, we used a commercial charge-coupled device (CCD) camera to detect and monitor terrestrial cosmic rays at ground level. Multi-site characterization has been performed at sea level (Marseille), underground (Modane Underground Laboratory) and at mountain altitude (Aiguille du Midi–Chamonix Mont-Blanc at ~5,780 m of altitude) to separate the atmospheric and alpha particle emitter’s contributions in the CCD response. An additional experiment at avionics altitude during a long-haul flight has been also conducted. Experiment results demonstrate the importance of the alpha contamination in the CCD response at ground level and its sensitivity to charged particles. Experimental data as a function of CCD orientation also suggests an anisotropy of the particle flux for which the device is sensitive. A complete computational modeling of the CCD imager has been conducted, based on a simplified 3D CCD architecture deduced from a reverse engineering study using electron microscopy and physico-chemical analysis. Monte Carlo simulations evidence the major contribution of low energy (below a few MeV) protons and muons in the CCD response. Comparison between experiments and simulation shows a good agreement at ground level, fully validated at avionics altitudes with a much higher particle flux and a different particle cocktail composition.

Index Terms—Alpha-particle emitters, atmospheric neutrons, avionics measurements, Charge-Coupled Devices (CCD), Monte Carlo simulation, muons, protons, terrestrial cosmic rays, underground test.

Manuscript received July 11, 2014, revised September 16, 2014; accepted October 17, 2014. Date of publication November 12, 2014, date of current version December 11, 2014. This work has been supported by the French National Research Agency under Project ANR-09-BLAN-0155-01 (HAMLET project).

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Digital Object Identifier 10.1109/TNS.2014.2365038