MODELS FOR THE LUNAR RADIATION ENVIRONMENT: ORBIT, SURFACE, SUBSURFACE, WITH AN APPLICATION TO LUNAR POLAR LOCATIONS.

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Introduction: Radiation protection is one of the two NASA highest concerns priorities [1]. In view of manned missions targeted to the Moon [2], for which radiation exposure is one of the greatest challenges to be tackled [3], it is of paramount importance to be able to determine radiation fluxes and doses at any time on, above and below the lunar surface [4]. With this goal in mind, models of radiation environment due to Galactic Cosmic Rays (GCR) and Solar Particle Events (SPE) on the Moon have been developed, and fluxes and spectra hereby computed [5]. The work is described [6] as models of incoming cosmic ray [7-9] and solar primary particles [6] impinging on the lunar surface, transported through the subsurface layers, with backscattering taken into account, and interacting with some targets described as material layers. Time dependent models for incoming particles for both GCR and SPE are those used in previous analyses as well as in NASA radiation analysis engineering applications [10]. The lunar surface and subsurface has been modeled as regolith and bedrock, with structure and composition taken from the results of the instruments of the Luna, Ranger, Lunar Surveyor and Apollo missions, as well as from ground-based radiophysical measurements (see discussion in [4-6], [10]). The lunar-like atmosphereless body surface models are used to develop models for the surfaces of Martian satellites Phobos and Deimos [11].

Results: In order to compare results from different transport techniques, particle transport computations have been performed with both deterministic (HZETRN) [12] and Monte Carlo (FLUKA) [13] codes with adaptations for planetary surfaces geometry for the soil composition and structure of the Apollo 12 Oceanus Procellarum landing site [14,15], with a good agreement between the results from the two techniques [6,10]: GCR-induced backscattered neutrons are present at least up to a depth of 5 m in the regolith, whereas after 80 cm depth within regolith there are no neutrons due to SPE [6,10]. Moreover, fluxes, spectra, LET and doses for many kinds of particles, namely protons, neutrons, alpha particles, heavy ions, pions, muons etc., for various other lunar soil and rock compositions have been obtained with the deterministic particle transport technique [6]. Results have in particular been obtained for orbital scenarios, for surface (i.e. landers, habitats and rover) scenarios, for subsurface scenarios, and for lunar polar locations, with regards to ways to infer and detect locally the presence of water and/or volatiles. The results from this work can only be compared in literature with previous versions of the same models or with very simplistic models [4-6,10], as also mentioned in [16]. These models will be tested against spacecraft instruments data (e.g. RADOM onboard the CHANDRAYAAN-1 spacecraft from ISRO) in the near future.

Conclusions: Models for the radiation environment to be found on the Moon (on, above and below the surface) due to GCR, SPE and backscattering effects have been developed. A good agreement has been found between results from deterministic and Monte Carlo transport techniques. The quite large differences in the time and effort involved between the deterministic and Monte Carlo approaches deeply favor the use of the deterministic approach in computations for scientific and technological space radiation analysis. This approach looks promising for lunar polar locations studies. These models will be tested with the data from spacecraft instruments in the future.

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