MODELING OF THE MOON RADIATION ENVIRONMENT AT THE ALTITUDE OF THE INDIAN CHANDRAYYAN-1 SATELLITE AND A COMPARISON WITH THE RADOM EXPERIMENT DATA

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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 groundbased 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 satellite Phobos [11]. Also the radiation environment for the transit phase from the Earth to the Moon have been modeled. These results for the Moon Radiation Environment as well as for the cruise phase have been obtained in the framework of the RADOM investigation that is onboard the CHANDRAYAAN-1 mission by the Indian Space Agency ISRO. The RADOM investigation and preliminary results are described in another LPSC 2009 paper by Ts.P. Dachev.

Results - Moon: 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 (see Fig. 1 and 2) [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 have been then rescaled to be tested against spacecraft instruments data (e.g. RADOM onboard the CHANDRAYAAN-1 spacecraft from ISRO). The models have been set to a 100 km altitude circular orbit, to the actual mission time frame (both punctual and averaged data), and to the actual environmental shielding inside the spacecraft. The detailed comparison between models and data is currently underway, along with better trajectory analyses. As a

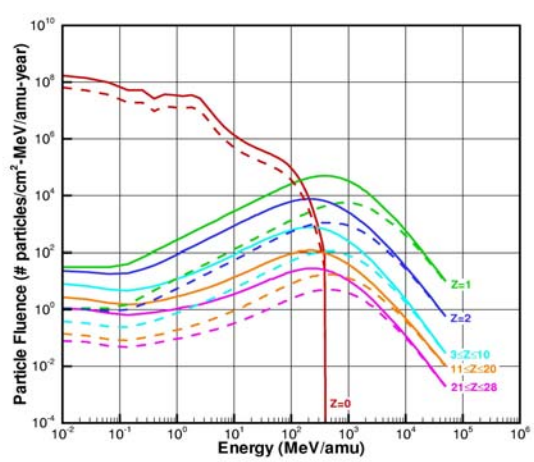

Fig. 1. GCR particle environment during the 1977 solar minimum (full lines) and the 1990 solar maximum (dashed lines) at an altitude of 100 km above the lunar surface (results from the deterministic technique).

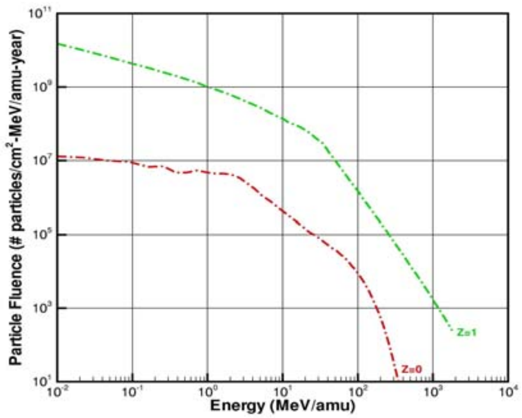

Fig. 2. The radiation environment at 100 km altitude from the lunar surface due to the September 1989 SPE (results from the deterministic technique).

preliminary comparison, RADOM data at 100 km altitude around the Moon give a mean flux for 100 MeV protons of 2.29 particles/cm^2.sec with a mean dose of 8.77 μGy/h. If for the comparison the above model is used, rescaled for CHANDRAYAAN-1 orbital conditions, with a shielding pattern of 0.45 g/cm^2 on the 2π solid angle before the detector and more shielding (10 g/cm^2) on the other 2π solid angle at the back side of the detector, a value for 100 MeV protons of 2.55 particles/cm^2.sec is this way obtained.

Results – Cruise Phase: A tool for radiation shielding analysis developed for manned deep space missions [17] has been used. The tool allows obtaining radiation dose and dose rates for different interplanetary mission scenarios, composed of at least one out of three main segments, namely the launch and the interplanetary cruise phase, the planetary approach /departure and orbit insertion/escape phase, and the planetary surface phase. For each individual phase the respective radiation environment is taken into account, along with its variations with time. Only Galactic Cosmic Rays (GCR) and Solar Particle Events (SPE) are considered during the interplanetary cruise phase, trapped radiation belts, where present, are also considered in the planetary approach phase, and the planetary environments (atmospheres, where present, and surfaces) effects are taken into account in the third phase. Some examples of analysis results for space missions are given in [18].

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 comparisons studies with spacecraft data. These models are being tested with the data from RADOM experiment onboard the CHANDRAYAAN-1 spacecraft.

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