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A characterization of the moon radiation environment for radiation analysis

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Abstract

The radiation environment found on the surface of the Moon is shown and applied to different possible lunar mission scenarios. Models for the primary particle environment to be found on the Moon due to galactic cosmic rays (GCR) and solar particle events (SPE) have been used, with solar modulation and surface backscattering patterns taken into account. The surface itself has been modeled as regolith and bedrock. Particle transport has been performed with both deterministic and Monte Carlo approaches. A good agreement is found between the two methods.

Keywords: Moon radiation environment; Lunar mission scenarios; Galactic cosmic rays; Solar particle events; HZETRN deterministic space radiation transport code

1. Introduction

On January 14, 2004 President George Bush set up a new vision for NASA. He articulated agency's vision for space exploration in the 21st Century, encompassing broad range of human and robotic missions including missions to Moon, Mars and beyond. As a result, there is a focus on long duration space missions. NASA, as ever, is committed to the safety of the missions and the crew. There is an overwhelming emphasis on the reliability issues for the mission and the habitat. The cost effective design of the spacecraft demands a very stringent requirement on the optimization process. Exposure from the hazards of severe space radiation in deep space long duration missions is an operational constraint. Thus protection from the hazards of severe space radiation is of paramount importance for new vision. It is envisioned to have long duration human presence in Moon for deep space exploration. Therefore, there is a compelling need to know the radiation environment in space, on the surface of Moon and lunar regolith aimed at long duration human presence in Moon (see discussions in Wilson et al., 1997, 2003; De Angelis et al., 2002a,c, 2004).

The ionizing radiation environment is fundamentally of two sources, the galactic cosmic rays (GCR) entering the solar system from local interstellar space and the particles associated with acceleration across the transition boundary from a large scale coronal mass ejection (CME) into the local interplanetary media (Reames, 1999) and also possible acceleration in the solar surface during a large disturbance (Shea and Smart, 1993). These solar related particles are discrete events associated with solar activity and are referred to as solar particle events (SPE). From a human protection perspective, the low-energy components such as anomalous cosmic rays (ACR) resulting from the acceleration of interstellar plasma across the shock boundary at the edge of the solar system and associated high-speed solar storm particles are unimportant. Mostly

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the most energetic SPE able to be detected by ground-based neutron monitors on the Earth are of importance to humans in space (Wilson et al., 1999a). Both the GCR and SPE sources are modified by the interplanetary fields during their propagation within the solar system. The expanding solar wind provides a strong convective current balancing the inward drift of GCR causing a general decrease of the GCR intensity in approaching the sun, which changes in degree in proportion to solar activity. SPE propagation allows some expansion along the sectored interplanetary magnetic field allowing a decrease in intensity at larger distances. There is some evidence that the CME shock driven events weaken slowly over a few AU from the sun (Reames, 1999).

These sources are greatly modified near planetary bodies or large satellites (Wilson et al., 2000, 2003). Interaction with such large bodies effectively shields against the local space environmental components. In addition to the effect of shielding, secondary radiations are induced by collision of GCR and SPE with the body surface materials and/or atmosphere, adding to the local radiation field. Neutrons are a most conspicuous component since their short lifetime (11 min) limits their propagation from their collisional source and they are not a normal part of the deep space environment except for the induced field near a large body. If the body has a magnetic field, the dipole component makes an effective magnetic bottle in which the neutron charged decay products (electron and proton) could be trapped forming a belt of ionizing radiation centered on the magnetic equator such as seen for the Earth and Jupiter. In addition to the relatively stable trapped protons and electrons, the magnetic field interacts with the interplanetary plasma forming a bow shock and magnetic tail through which the interplanetary media is accelerated through inward radial diffusion leading to precipitation near the magnetic poles. In addition, the magnetic fields deflect energetic charged particles entering into magnetic equatorial regions so those particles of the interplanetary environment reach the planetary surface mainly near the magnetic poles.

This work reviews previous Langley activity on the lunar radiation environment (De Angelis et al., 2002a,b,c, 2004; Clowdsley et al., 2003; Wilson et al., 2003) and goes on to provide new characterization of the moon environment for radiation analysis using the deterministic approach. The moon profile (De Angelis et al., 2002a,b,c, 2004) is based on a detailed description of the lunar regolith and rocks from both the physical and chemical point of view as from a single lunar location, namely the Oceanus Procellarum landing site of the Apollo 12 mission, with the same chemical composition adopted for the whole Moon for both surface and rock layers, chosen as an average of the Apollo 12 surface samples taken at the Oceanus Procellarum landing site.

2. Environmental models

In this section the environmental models used are shown. First discussed is the SPE model and assumptions used, next is the GCR model (Badhwar and O'Neill, 1996). These Langley base models are used in our environmental models (e.g. Wilson et al., 1997, 2003; De Angelis et al., 2002a,b,c, 2004; Clowdsley et al., 2003).

2.1. Solar particle events

Solar particle events are composed mostly of protons and the rest of this paper concerns only the proton component.

2.1.1. Solar proton propagation

Solar proton events have been recorded at the earth since 1942 although the detection technique varied considerably over the last 50 years. Although solar flare process is assumed to be the source of SPE, recent studies indicate (Reames, 1999) that coronal mass ejection (CME) may be the source of SPE. It is almost a customary to refer to SPE as meaning from the solar flare, and as major solar flares are associated with CME, in this paper we would use 'solar winds' and CME interchangeably in the discussions of SPE. Solar winds are super ionized plasma coming from the corona of the sun. Solar propagation of SPE is closely intertwined (Meyer et al., 1956) with the magnetic topology of the interplanetary medium. The plasma flows radically from the sun. The interplanetary magnetic fields from the sun to earth 'appear' to be curved in the Archimedean spiral nature. The energy density of this plasma is much larger than the energy density of the interplanetary magnetic field, so for all practical purposes, it is assumed that the interplanetary magnetic field within the plasma is 'frozen'. The solar protons appear to propagate into the interplanetary medium through two independent phases. The first is the diffusion from the CME site through the corona to the 'foot' of the idealized Archimedean spiral path formed by the interplanetary magnetic field line between the sun and the detection point. The second phase is the propagation in the interplanetary medium from the sun to the detection point along the interplanetary magnetic field lines. The intensity is higher, rises faster and is for shorter duration if the point of observation is located along the interplanetary field line from the point of ejection in the sun at other locations the intensity is lower rises and decreases slowly and is therefore for longer durations.

2.1.2. Solar proton event characteristics

Solar proton events as measured at the orbit of the earth have common characteristics of a propagation delay between the onset of the solar flare/CME in electromagnetic emission and the onset of the particle increase, a rapid increase to the maximum intensity and a slow decay to the background (Shea and Smart, 1993). For a solar flare on the western portion of the sun, the solar particle flux usually rises and decays fairly rapidly compared to solar flare on the eastern hemisphere of the sun. In addition to the solar protons from the flare/CME that are visually observed from the earth, approximately 20 percent of