CHARGED PARTICLE DOSE MEASUREMENTS BY THE ODYSSEY/MARIE INSTRUMENT IN MARS ORBIT AND MODEL CALCULATIONS.

T. F. Cleghorn[1], P. B. Saganti[2], C. Zeitlin[3], and F. A. Cucinotta[1]

[1] NASA Johnson Space Center, 2101 NASA Road 1, Houston, TX, 77058
[2] Prairie View A&M University Prairie View TX. 77446
[3] NSBRI, 1 Baylor Plaza, Houston, TX 77030

Introduction: Knowledge of the space radiation environment is crucial both for human space exploration, and robotic space missions. It is likely that human explorers will return to the moon, and then go to Mars within the next thirty years. The radiation environment that they will encounter is a significant obstacle to future exploration, and must be dealt with successfully before long-term human missions outside of the magnetosphere can take place. Shielding technologies and materials must be developed to lower the dose and dose equivalent that human beings will receive on such missions. To begin this development, a fairly complete and accurate understanding of the space environment must be obtained. The major components of the space particle radiation environment that are most hazardous to humans are: galactic cosmic rays (GCR), the particles contained in solar particle events, (SPE), and secondary particles generated in material in the spacecraft itself. The intensity of the GCR varies by roughly a factor of two over the eleven-year solar cycle, inversely with the level of solar activity. These GCR particles are fully stripped nuclei, predominantly protons and helium, but also significant numbers of heavier ions, including carbon, oxygen, and iron. Since the ionization caused by nuclei passing through matter is proportional to the square of its charge Z, the dose contribution from these heavier nuclei is significant. In addition, the energy spectra of these ions are "hard", i.e.: they are very penetrating. The solar particles, on the other hand, are less penetrating, and most SPE are composed predominately of protons. Unfortunately, SPE can occur at any time during the solar activity cycle, and can contain extraordinarily large numbers of particles, which can mean very high doses at and near the surface of the material upon which they impinge. In addition, whereas GCR arrive isotropically from all directions, SPE can be highly directional beams. The material around a particle detector can influence the measured dose from an SPE, and the detector can even miss the SPE entirely if the detector happens to be pointed in the wrong direction. It is thus necessary to measure both of these components accurately in order to get a clear understanding of the cosmic ray particle environment, and to develop adequate shielding for long duration space missions. The Odyssey spacecraft, which has been in Mars orbit since September, 2001 has onboard a charged particle radiation detector (MARIE), which measures the cosmic ray particles between energies ~30 and ~150 MeV/nucleon, as well as some higher energy particles. The charge range is between protons, (Z=1) and neon,

(Z=10). The MARIE instrument has been described elsewhere [1,2].

The Data: The MARIE instrument operated continuously between March 13, 2002, and October 28, 2003, except for the period when Mars and Earth were in solar opposition. During this twenty month period, approximately 12 solar particle events were observed by the MARIE instrument, the last of which, on October 26/28, 2003, caused the instrument to cease functioning. This large event illustrates the vulnerability of space hardware to the radiation environment. Not only did MARIE shut down, but a number of other spacecraft, and even ground-based systems, were affected as well. In addition to this large event, several other major SPE were observed. The events prior to March 2003 have been discussed elsewhere [3,4]. Subsequent to February 2003, there were three additional SPE observed by MARIE. These events occurred on: March 18-20, May 28 - June 3 and October 26-28. A short period of detector saturation occurred in the May/June event, as well as the saturation and instrument engineering parameter anomalies during the October event.

Results: The dose rate due to the GCR was calculated to range between ~18 and ~ 24 millirads per day. This represents the surface dose rate at the top detector of the particle telescope. The minimum energy required for a GCR proton to reach this detector and to trigger the coincidence counter is ~30 MeV. This is slightly lower than the minimum energy required for particles to penetrate to the inside of a typical manned spacecraft in low earth orbit in significant numbers so as to be hazardous to humans. Large solar particle events seen by MARIE, however, can reach 1-2 rads, and the October 26/28, 2003 event has been estimated to be $\geq$ 7 rads. Dose estimates for some other spacecraft are even higher for this event.

Conclusions: There are two major charged particle radiation hazards for future space explorers. Shielding against the large SPE doses can be done fairly easily, due to the lower energies of the particles. However, the omnipresent lower flux of high energy GCR particles represents a more difficult shielding problem. These fluxes can be modeled with some success by programs such as HZETRN [5,6], which use neutron monitor data as input, however more accurate shielding models are still under development. Ideally, high hydrogen content material, e.g.: water or polyethylene, provides the best protection from the penetrating nuclei. However launching sufficient quantities of this type of material would be prohibitively heavy and expensive. High Z shielding material is actually counter-productive, in terms of the protection which it provides. Long duration human space missions will require not only a solution to the shielding problem, but additional work on biological counter-measures, and above all, lowering the exposure times with faster spacecraft.

References: [1] Zeitlin, C., et al; *Adv. Space Res. October, 2002* (in press 2004). [2] Cleghorn, T.F., et al, *LPSC XXXIII* Odyssey #5 (2002), [3] Cleghorn, T.F., et al. *Adv. Space Res. October 2002* (in press, 2004) [4] Cleghorn, T.F.,et al, *LPSC XXXIV*, Odyssey #3 (2003) [5] Wilson, J.W., et al.; Transport Methods and Interactions for Space Radiations *NASA RP 1257*, (1991) [6] Saganti, P., et al, *Adv. Space Res.*, *October 2002* (in press, 2004)