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Diurnal Variations of Energetic Particle Radiation Dose Measured by the Mars Science Laboratory Radiation Assessment Detector

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The Radiation Assessment Detector (RAD) on board the Mars Science Laboratory (MSL) rover Curiosity has collected data on the interplanetary radiation environment during cruise from Earth to Mars and at the surface of Mars since its landing in August 2012. RAD's particle detection capabilities are achieved with a solid-state detector (SSD) stack (A, B, C), a CsI(Tl) scintillator (D), and a plastic scintillator (E) for neutron detection. The D and E detectors are surrounded by an anticoincidence shield (F), also made of plastic scintillator. All scintillators are optically coupled to silicon diodes which convert scintillation light to electrons. RAD is capable of measuring both Galactic Cosmic Rays (GCRs) thought to be produced by supernovae outside the heliosphere and Solar Energetic Particles (SEPs). GCRs are relativistic particles (100 MeV/nuc to >10 GeV/nuc) composed of roughly 89% protons, 10% alpha particles (He), and 1% heavier nuclei [1]. Because of their high energies and continuous nature, GCRs are the dominant source of background radiation at the Martian surface, and are responsible for the production of secondary particles (notably neutrons) via complex interactions in the atmosphere and regolith. SEPs are produced by coronal mass ejections. These intermittent storms are most likely to occur near solar maximum and typical fluxes are dominated by protons with energies lower than 100 MeV/nuc. Unlike the GCR flux, the SEP flux can vary by five or more orders of magnitude over timescales of a day.

Even under a constant flux of energetic particle radiation at the top of the atmosphere, the radiation dose at the surface should vary as a function of surface elevation [2]. This variation is directly related to the change in the shielding provided by the total atmospheric mass column, which is to a very good approximation directly related to surface pressure. Thus, the flux of primary energetic particles should increase with altitude, all other things being equal.

At present, MSL has been at a nearly constant altitude of $\sim$-4.4 km MOLA so that no elevation-induced changes are expected and none have been observed. However, any process that changes the column mass of atmosphere should change the dose at the surface. On Mars there are two major processes that substantially change column atmospheric mass. The first is the seasonal condensation cycle during which $\sim$25% of the dominant atmospheric constituent (CO_2) condenses onto the winter pole. This seasonal signal is very strong and has been observed by surface pressure measurements from the Viking Landers up through MSL [3,4]. The second major process is related to the thermal tide. The direct heating of the Martian atmosphere by the Sun produces global scale waves that redistribute mass [5]. The two most dominant tidal modes are the diurnal and semidiurnal tide. Together, the thermal tide can produce a variation of 10-15% over a Martian day (sol).

Here, we report on the dose measured by the RAD E detector and the variation of this dose over the diurnal cycle. Further, we show that the variation in the E dose rate is very likely due to the variation of column mass, as measured by the pressure sensor on the Rover Environmental Monitoring Station (REMS), driven by the thermal tide. While changes in dose were expected from changes in altitude or season, the discovery of a diurnal variation was not anticipated, although it should have been reasonably expected in hindsight.