MARS SURFACE IONIZING RADIATION ENVIRONMENT: NEED FOR VALIDATION.

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Introduction: Protection against the hazards from exposure to ionizing radiation remains an unresolved issue in the Human Exploration and Development of Space (HEDS) enterprise [1]. The major uncertainty is the lack of data on biological response to galactic cosmic ray (GCR) exposures but even a full understanding of the physical interaction of GCR with shielding and body tissues is not yet available and has a potentially large impact on mission costs [2]. “The general opinion is that the initial flights should be short-stay missions performed as fast as possible (so-called ‘Sprint’ missions) to minimize crew exposure to the zero-g and space radiation environment, to ease requirements on system reliability, and to enhance the probability of mission success.” [1] The short-stay missions tend to have long transit times and may not be the best option due to the relatively long exposure to zero-g and ionizing radiation [1]. On the other-hand the short-transit missions tend to have long stays on the surface requiring an adequate knowledge of the surface radiation environment to estimate risks and to design shield configurations. Our knowledge of the surface environment is theoretically based and suffers from an incomplete understanding of the physical interactions of GCR with the Martian atmosphere, Martian surface, and intervening shield materials. An important component of Mars surface robotic exploration is the opportunity to test our understanding of the Mars surface environment.

The Mars surface environment is generated by the interaction of Galactic Cosmic Rays (GCR) and Solar Particle Events (SPEs) with the Mars atmosphere and Mars surface materials. In these interactions, multiple charged ions are reduced in size and secondary particles are generated, including neutrons. Upon impact with the Martian surface, the character of the interactions changes as a result of the differing nuclear constituents of the surface materials. Among the surface environment are many neutrons diffusing from the Martian surface and especially prominent are energetic neutrons with energies up to a few hundred MeV. Testing of these computational results is first supported by ongoing experiments at the Brookhaven National Laboratory but equally important is the validation to the extent possible by measurements on the Martian surface. Such surface measurements are limited by power and weight requirements of the specific mission and simplified instrumentation by necessity lacks the full discernment of particle type and spectra as is possible with laboratory experimental equipment. Yet, the surface measurements are precise and a necessary requisite to validate our understanding of the surface environment. At the very minimum, the surface measurements need to provide some spectral information on the charged component and limited spectral information on the neutron environment. Of absolute necessity is the precise knowledge of the detector response functions for absolute comparisons between the computational model of the surface environment and the detector measurements on the surface [3].

Computational Model: The Mars 2001 mission has a planned launch date of April 2001 with an expected landing for a 90 day mission on the Mars surface in Jan. 2002 (about one to two years after Solar Cycle 23 maximum). We use the projected Badhwar-O’Neill model [4,5] for GCR and the estimated Feb. 23, 1956 SPE model (the largest directly observed event) [6] as boundary conditions at the top of the Martian atmosphere. We assume the Martian atmosphere to be CO2 and distributed according to the COSPAR low-density model [7]. The Martian surface is taken as regolith (58.2% SiO2, 23.7% Fe2O3, 10.8% MgO, 7.3% CaO) with minimal differences in transport properties from Martian bedrock [8]. The transport code used to describe the interaction of the space environment with the Martian atmosphere and surface is the HZETRN code [2], which has been recently improved in the description of angular dependent neutron transport and corresponding boundary conditions [9].

The interplanetary environment at Mars excluding the low-energy anomalous cosmic rays is shown in fig. 1. The GCR environment is for the months of Jan. to Mar. of 2002 representing the expected 90-day surface mission. We have assumed an isotropic interplanetary diffusion coefficient with a r radial dependence. The SPE considered is the Feb. 23, 1956 event and the particles arrived over a several hour period. The radial dependence of SPE is controversial and we have assumed the SPE flux intensities are the same as for Earth. Although the multiple charged ions are of lower intensity their effects are magnified by their large charge. The SPE can dominate the GCR environment if one occurs. There is only a small probability of an event like the Feb. 23, 1956 event occurring.

Mars Surface Environment: The surface environment generated by the GCR is shown in fig. 2(a). The highly charged ions are attenuated by the interaction with the Martian atmosphere contributing to the lighter ion fields and neutrons. Impact with the Martian surface generates a backward flux of neutrons extending to a few hundred MeV as seen in the figure. Due to the higher atomic weight elements of the regolith (and bedrock) the backward neutron flux is appreciable compared to the forward propagating component produced in collision with atmospheric components. This effect is also seen in the surface environment generated by a high energy SPE as that which occurred on Feb. 23, 1956 as shown in fig. 2(b). The spectral distribution in LET(Si) as a function of regolith shielding is given in fig. 3. These results are available as graphs and tables at http://SIREST.larc.nasa.gov.

Validation Issues: Model validation has followed two paths. The basic interaction models are validated in laboratory experiments using monoenergetic ion beams and high-resolution detectors for which specific particle types and energies can be measured [10, 11]. These are combined in the transport equation and integrated for the specific boundary conditions [12]. These solutions are then tested in the space environment on specific spacecraft with simplified detection equipment. For example, a test of the HZETRN results on Shuttle is shown in fig. 4. The TEPC detectors were developed to measure LET distributions of radiation fields but are limited by detector geometry, fluctuations in energy loss, and diffusive processes. Only by knowledge of the detector response can meaningful comparisons with measurements be made. Details are given by Shinn et al. [3]. The simplified detection systems in most spacecraft measurements will require detailed knowledge of the detector response to each radiation component for a meaningful validation. Even then, one would hope to have some degree of separation of particle type in either the detector spectral response or as difference between differing detectors. In the case of neutrons, it would be desirable to differentiate between those generated in the atmosphere and the backward propagating neutrons produced in the surface. Not only would this allow the validation of the basic model but it has important implications for shielding technology on the Martian surface.

Concluding Remarks: The Martian surface environment integrated over the Mars 2001 mission has been evaluated. A large SPE could dominate the environment exceeding the accumulated GCR environment in a few hours. A prominant feature of the surface environment evaluation is the large number of neutrons produced as secondaries in the atmosphere and Martian surface materials. The backward propagating neutrons from the GCR are predicted to dominate those produced in the atmosphere below 20 MeV. The backward propagating neutrons from the SPE are predicted to be nearly equal in number to those produced in the atmosphere. The GCR LET spectrum can be modified above 150 keV/micron by the addition of regolith shielding with little change in the lower LET components. In distinction, the SPE LET spectrum is mainly attenuated at the lowest LET values with little affect on the highest LET components.

References: [1] Hoffman S. J. and Kaplan D. I. (1997) NASA SP 6107. [2] Wilson J. W. et al. (1997) NASA CP 3360. [3] Shinn J. L. et al. (1998) IEEE Nucl. Sci. 45, 2711-2719. [4] Badhwar G. D. et al. (1994) Radiat. Res. 138, 201-208. [5] Wilson J. W. NASA TP-1999-209369. [6] Foelsche et al. (1974) NASA TN D-7715. [7] Simonsen L. C. et al. (1997) NASA CP 3360. [8] Kim M. Y. et al. NASA TP 1998-208724. [9] Clowdsley M. S. et al. (1999) NASA TP 3335. [10] Miller J. (1997) NASA CP 3360. [11] Heilbronn L. (1997) NASA CP 3360. [12] Wilson J. W. et al. (1991) NASA RP 1257.

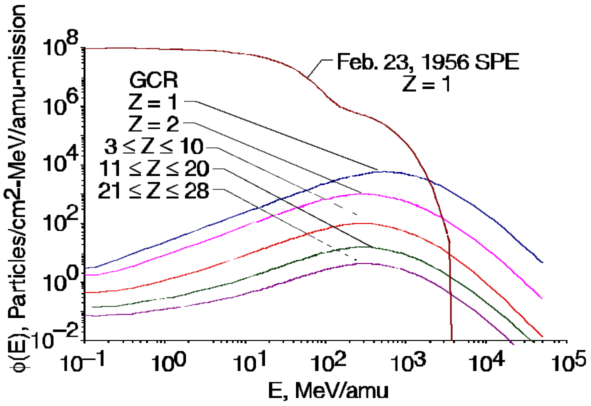

Figure 1. Local interplanetary environment model for surface 2001 mission.

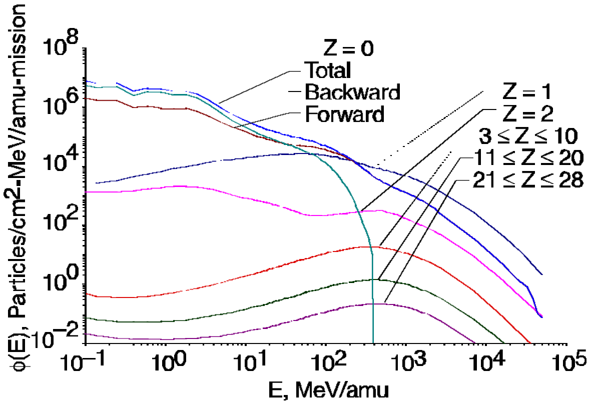

Figure 2a. Mars 2001 surface environment (GCR).

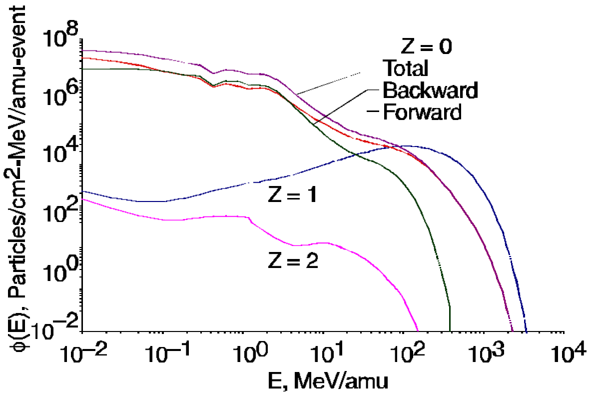

Figure 2b. Mars 2001 surface environment (SPE).

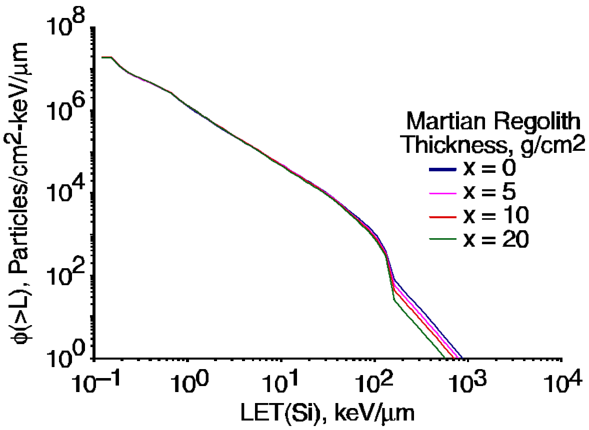

Figure 3a. LET (in silicon) spectra of GCR as function of depth in regolith.

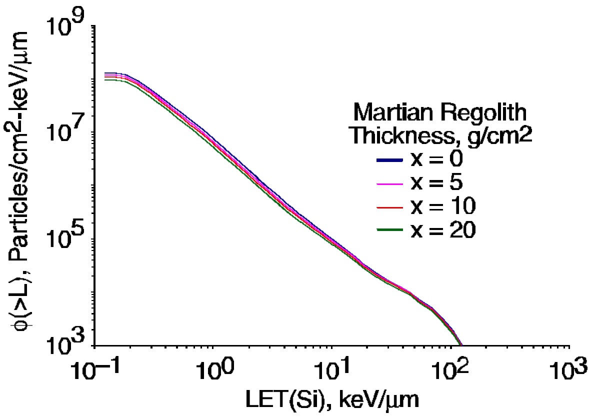

Figure 3b. LET (in silicon) spectra of Feb. 23, 1956 SPE as function of depth in regolith.

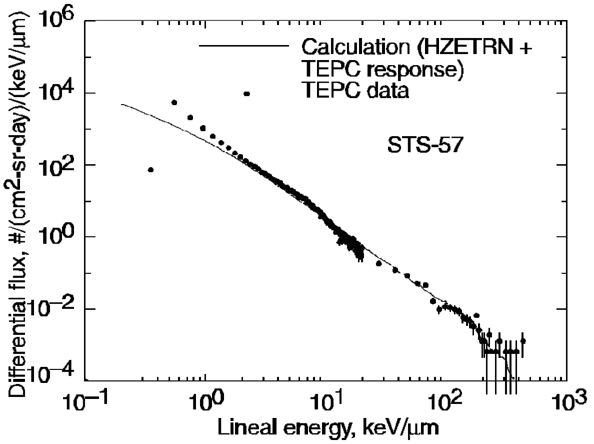

Figure 4a. Measured and calculated lineal energy spectra induced by galactic cosmic rays in a 252 nmi × 28.5° orbit in June 1993 aboard STS-57.

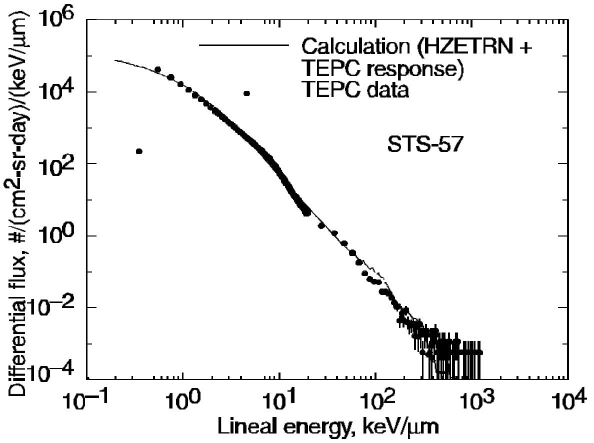

Figure 4b. Measured and calculated lineal energy spectra induced by trapped protons in a 252 nmi × 28.5° orbit in June 1993 aboard STS-57.