GALACTIC COSMIC RAY PROTON RADIATION DOSAGE NEAR A SIMPLE LUNAR CRATER.

P. H. Phipps[1], T. J. Stubbs[2], M. D. Looper[3], and H. E. Spence[4], [1]University of Maryland, Baltimore County, Baltimore, Maryland, USA (email: phphipps@umbc.edu), [2]NASA's Goddard Space Flight Center, Greenbelt, Maryland, USA, [3]The Aerospace Corporation, El Segundo, CA, USA, [4]Institute for the Study of Earth, Oceans, and Space, University of New Hampshire, Durham, New Hampshire, USA.

Introduction: The Moon has a harsh radiation environment that poses significant challenges to future science and exploration activities. Exposure hazards from space radiation are primarily due to galactic cosmic rays (GCRs) and solar energetic particles (SEPs) that are incident at the lunar surface from all directions. The Lunar Reconnaissance Orbiter's (LRO) Cosmic Ray Telescope for Effects of Radiation (CRaTER) instrument has been observing space radiation around the Moon since 2009 [1]. The CRaTER observations show a steady rate of GCR flux with intermittent SEP events that have much higher fluxes. During solar minimum the GCR have a higher flux rate while the SEP events are less common. On the other hand, during solar maximum the SEP events have a higher rate but the GCR flux is lower. This is due to variations in solar activity. GCRs have characteristic energies spanning from 1 MeV to 10s of GeV [2]. SEPs, however, have much lower energy ranges of 50 keV to 10 GeV.

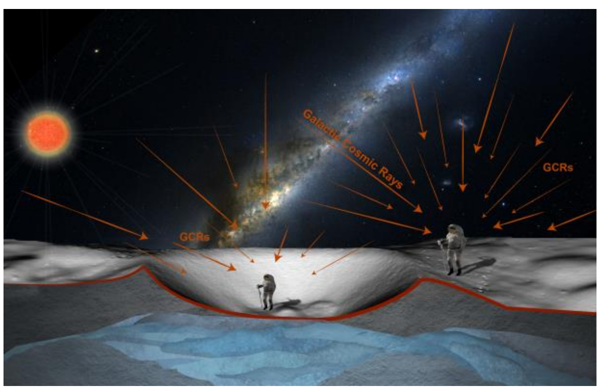

Figure 1: Schematic of the radiation exposure at the lunar surface in and around a crater.

The level of exposure at a given location on the Moon is dependent on the amount of space radiation incident from above the local horizon (Figure 1). This means that, radiation dosage depends on the surrounding terrain for any location on the surface, so it can vary substantially from point to point. Here we consider the radiation exposure around simple lunar craters that are representative of the types of landforms that will be encountered by future landed missions (e.g., the Artemis program) [3]. Of particular concern will be radiation exposure to biological targets, such as astronauts, and to critical electronic systems.

Methods: We use Geant4 Monte Carlo simulations [4] to compute the dose response for spherical targets composed of water (H_2O) and silicon (Si), as proxies for biological and electronic systems respectively. These targets are surrounded by shells of aluminum of varying thickness to approximate the influence of localized shielding from space suits, rovers, and habitats. The dose response, in rad cm^2 sr, from the Geant4 modeling is shown in Figure 2. To determine the dose rates from primary space radiation (e.g., in rads per year), we convolve the Geant4-computed dose responses with representative GCR spectra from Badhwar-O'Neill 2010 [5] (as shown in Figure 3).

To determine the topographical affects we create a crater 20 km crater similar to Shackleton crater at the lunar South Pole (top Figure 3). Measuring the local

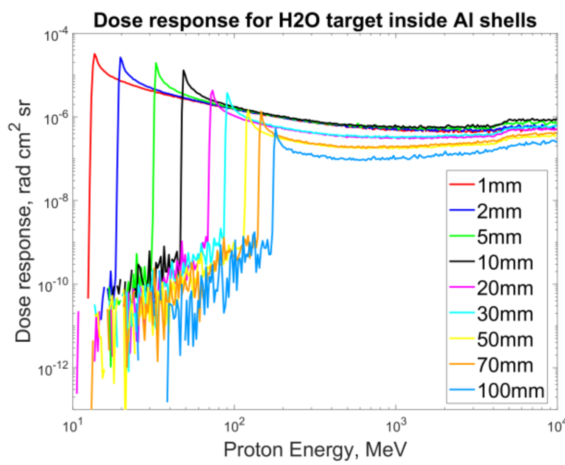

Figure 2: Dose response in H_2O targets inside Al shells.

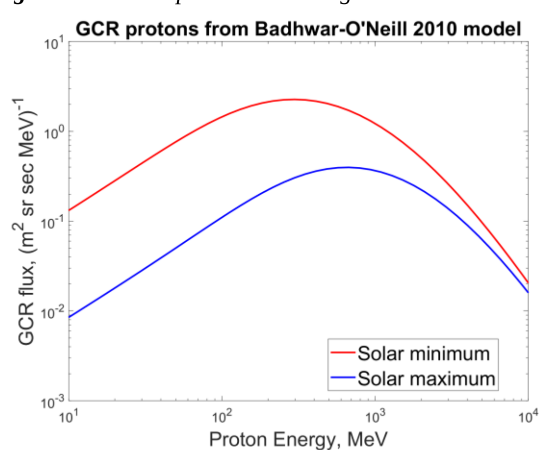

Figure 3: GCR flux from the Badhwar-O'Neill 2010 GCR spectrum.

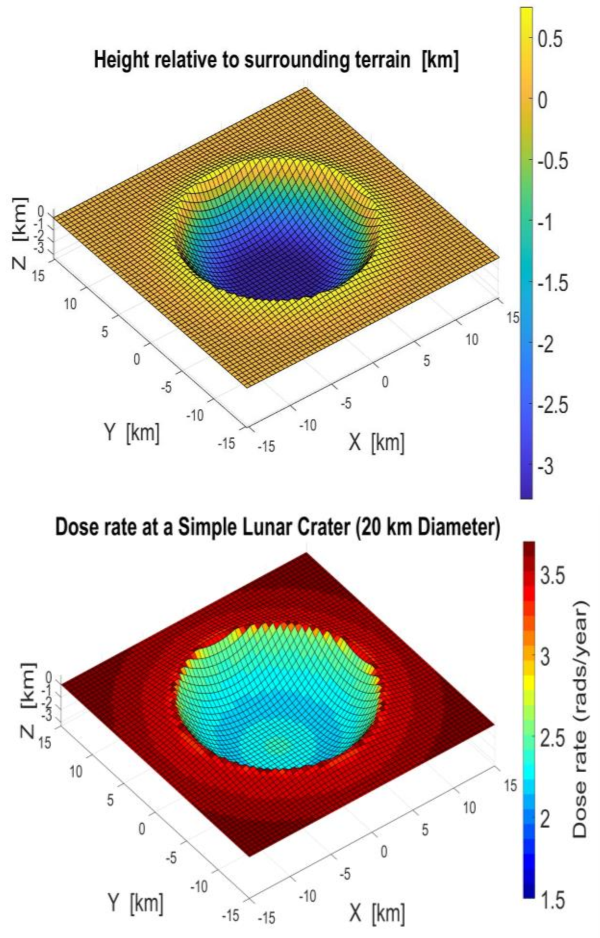

Figure 4: *Radiation exposure at a simple lunar crater. (top) Crater shape and height. (bottom) GCR dose rate in H2O for each grid point in rads/year*

horizon for each location on a grid we calculate the solid angle of the sky visible. This fraction can be multiplied by the dose rates determined from the Geant4 convolution with GCR spectrum. This gives the dose rate received from GCR primary protons at each surface point (bottom of Figure 3).

Preliminary Results: The total GCR primary proton dose rate, over the entire 4π of the sky, assuming 5 mm Al shielding is shown in the second column of Table 1 for both Si and H_2O and solar minimum and solar maximum. The minimum values, scaled by the solid angle of the sky for inside the crater, are shown in the third column of Table 1. The values scaled by the sky solid angle for a location similar to Artemis Base Camp 004 [3], which would be just outside the crater rim of the crater shown in Figure 4, are shown in the fourth column of Table 1.

Discussion and Conclusions: In comparison with dose received on a planar surface, we find that the dose rate of radiation can be reduced by at least 40 percent for regions inside craters, while for areas outside the crater rim it can be reduced by at least 10 percent.

	Si		**H_2O**	
	Solar Min	Solar Max	Solar Min	Solar Max
4 π dose rate	0.59	0.18	0.85	0.25
Minimum lunar surface dose rate	0.18	0.053	0.25	0.074
Artemis Base Camp 004	0.26	0.078	0.37	0.11
Radiation exposure limits	---		139	

Table 1: *GCR primary proton dose rate values. Dose rate in mrads/hr 1rad = 0.01Gy = 0.007 Sv*

Although, GCR dose rates calculated around the crater are well below the dose rate exposure limits of 139 mrad/hr (for 100 rad lens 30 day exposure limits [6], last column in Table 1). These are important considerations when selecting sites for permanent habitats, as well as for choosing routes and for contingency planning during surface operations.

References: [1] Schwadron, N. A., et al. (2018) *Space Weather*, *16*, 289–303. [2] Case, A. W., et al. (2013), *Space Weather*, 11, 361– 368. [3] NASA's Lunar Exploration Program Overview (Sept 2020) NP-2020-05-2853-HQ. [4] Allison, J., et al. (2006) IEEE Trans. Nucl. Sci., 53 (1), 270–278. [5] O'Neill, P. M. (2010) IEEE Trans. Nucl. Sci., 57, 3148–3153. [6] NASA Space Flight Human Standards, NASA-STD-3001.