MAPPING BIOLOGICALLY RELEVANT RADIATION DOSE AROUND THE LUNAR SOUTH POLE.

P. H. Phipps[1,2,*], T. J. Stubbs[2], M. D. Looper[3], H. E. Spence[4], and L. W. Townsend[5]. [1]University of Maryland, Baltimore County, Baltimore, MD, USA [2]NASA Goddard Space Flight Center, Greenbelt, MD, USA, [3]The Aerospace Corporation, El Segundo, CA, USA, [4]University of New Hampshire, Durham, NH, USA, [5]University of Tennessee, Knoxville, TN, USA. *phphipps@umbc.edu

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 low, steady flux of GCRs with intermittent SEP events that have substantially higher fluxes. During solar minimum, GCRs are higher in flux while SEP events are less common. On the other hand, during solar maximum SEP events occur more frequently and GCR fluxes are lower. This is due to variations in solar activity with the Solar Cycle. GCRs have characteristic energies spanning from 1 MeV to 10s of GeV [2]. SEPs, however, have much lower energy ranges of 50 keV to 100s of MeV.

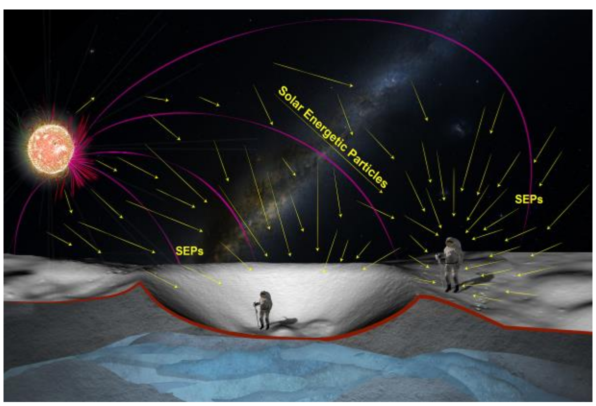

Figure 1: *Illustration of how natural shielding from surrounding terrain effects radiation exposure at the lunar surface in and around a crater during a solar energetic particle (SEP) event. Inside the crater, the high elevation of the crater walls blocks SEPs incident at shallow angles.*

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 radiation dosage depends on the surrounding terrain for any location on the surface, so it can vary substantially from point to point. We focus on a region of the lunar South Pole which covers potential future Artemis base camps [3] (Figure 2). Of particular concern will be radiation exposure of biological systems, such as astronauts.

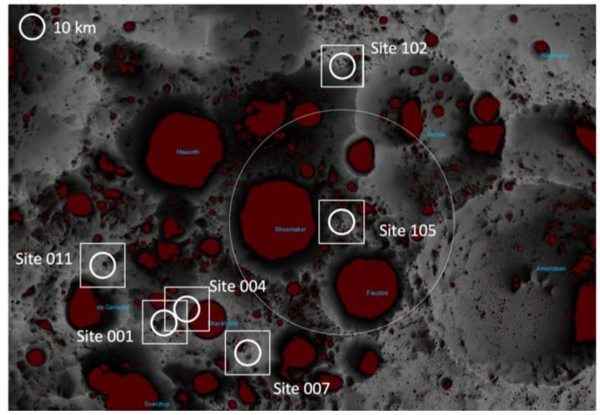

Figure 2: *Location of potential Artemis base camps around the lunar South Pole where we will predict radiation exposure.*

Methods: We use Geant4 Monte Carlo simulations [4] to compute the dose response for spherical targets composed of water (H_2O), as proxies for biological systems. These targets are surrounded by shells of aluminum of varying thickness to approximate effect of localized shielding (*e.g.*, space suit ≡ 1 mm Al). To determine dose from primary space radiation (*e.g.*, in rads), we convolve the dose responses with representative GCR and SEP spectra [5].

To determine the effect of shielding from surrounding terrain at potential Artemis base camps, we consider 5° around the South Pole using the 64 pixel per degree digital elevation model (DEM) from the Lunar Orbiter Laser Altimeter (LOLA). We calculate the local horizon to determine the solid angle of the visible sky. This is combined with our dose estimates to create a map of biologically relevant radiation dose around the lunar South Pole.

Discussion: Biological scaling factors can be used with these dose maps and compared to specific NASA exposure limits (*e.g.*, lens and heart). Such radiation dose maps can help mitigate exposure when selecting sites for permanent habitats, as well as choosing routes and 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]