ULTRAVIOLET IRRADIATION ON THE SURFACE OF MARS: IMPLICATIONS FOR EVA ACTIVITIES DURING FUTURE HUMAN MISSIONS. A. C. Schuerger, University of Florida, Space Life Sciences Lab, Kennedy Space Center, FL 32899; email: schuerg@ufl.edu.

Introduction: Robotic and piloted spacecraft are launched from Earth with finite levels of microbial contamination that are composed of species similar to the cleanroom environments within which the vehicles are assembled. After entering the harsh environment of interplanetary space, the microorganisms on the vented surfaces of spacecraft are subjected to biocidal factors that immediately begin to reduce the viable bioloads and species diversity of the launched vehicles. Based on published literature [see reviews by 1,2,3,4], between 50-70% of spore-forming bacteria, and up to 2 logs of non-spore forming species, may be inactivated during the 6-8 month cruise phase to Mars due to the solar UV irradiation (external surfaces), low pressure, and high desiccating conditions in interplanetary space.

The harsh conditions found on the surface of Mars are only slightly more conducive to the survival of terrestrial microorganisms than are found in interplanetary space. Even the launched bioloads found within pressurized human habitats in Earth-Mars transit vehicles will be exposed to conditions that are likely to reduce the species diversity of microorganisms within the human life support systems [2]. The reductions in biomass and species diversity of the launched bioloads on and within spacecraft are likely to simplify the forward contamination issues related to human expeditions on Mars by limiting the numbers of viable cells that might be dislodged from spacecraft surfaces and dispersed onto the martian terrain.

The objectives of the current study are to characterize the UV flux on Mars, predict microbial survival under martian conditions, and model the likelihood of microbial contamination of the local terrain during future crewed missions.

Methods: Experiments have been conducted under simulated martian conditions using a Mars Simulation Chamber (MSC) [described in 5] to determine the effects of solar UV irradiation, low pressure, gas composition, and low temperature on the survival of diverse *Bacillus* spp. The MSC system can accurately simulate five key components of the surface environment of Mars including: (a) pressures down to 0.1 mb, (b) UVC, UVB, and UVA irradiation from 190 to 400 nm, (c) dust loading in the atmosphere from optical depths of 0.1 (low-dust sky) to 3.5 (global dust storm) using a series of neutral density filters, (d) temperatures from –100 to 30 ^{o}C, and (e) atmospheric mixtures composed of the top five gases in the martian atmosphere [CO_2 (95.53%), N_2 (2.7%), Ar (1.6%), O_2 (0.13%) and H_2O (0.03%).

Results: The UV flux on equatorial Mars has been modeled by several teams [e.g., 1,6,7] and yields approximate fluence rates for UVA (400-320 nm) , UVB (320-280 nm), and UVC (280-200 nm) of 38, 8, and 3 W/m^2 at the mean orbital distance from the sun. These fluence rates are then decreased or increased by ~18% at aphelion and perihelion, respectiveluy, during the martian orbit. The 7 mbar atmosphere of Mars fully attenuates the UV photons below 190 nm due to absorption by the CO_2 atmosphere [8]. Thus, strong biocidal UVC irradiation is present at the marian surface.

The martian UV flux was listed by Schuerger et al. [9] as the strongest of 17 biocidal factors on Mars that include: (1) solar UV irradiation, (2) extreme desiccation, (3) low pressure (1-14 mbar), (4) anoxic CO_2 atmosphere, (5) extremely low temperatures (global average of -61 ^{o}C), (6) solar particle events, (7) galactic cosmic rays, (8) UV-glow discharges from blowing dust, (9) solar UV-induced volatile oxidants (e.g., O_2^-, O^-, H_2O_2, NOx, O_3), (10) globally distributed oxidizing soils, (11) extremely high salt levels (e.g., $MgCl_2$, NaCl, $FeSO_4$, and $MgSO_4$) in surficial soils at some sites on Mars, (12) high concentrations of heavy metals in martian soils, (13) likely acidic conditions in martian regolith, (14) perchlorates in at least some soils, (15) lack of defined energy sources free of UV irradiation, (16) no known source of available nitrogen and carbon, and (17) no obvious redox couples for microbial metabolism. These biocidal factors are consistent with other studies [10,11] that modeled conditions likely to be inhibitory to the growth of terrestrial life on Mars.

Mars chamber results and modeling [1,12,13] suggest that sun-exposed surfaces of spacecraft will be sterilized within a few tens-of-minutes to several hours on the first sol on Mars if the vehicles land under normal clear-sky conditions (optical depths < 0.5). Pressure was found to have a minor effect, and gas composition and temperature were found to have no effect on spore survival under simulated martian conditions [1]. In one example (Fig. 1), the survivability between a UV-resistant bacterium (*Bacillus pumilus* SAFR-032) and a UV-sensitive bacterium (*B. subtilis* 42HS1) exposed to a simulated Mars-normal equatorial UV flux indicated that most *Bacillus* spp. on sun-exposed surfaces are likely to be inactivated by greater than 6 orders-of magnitude within 180 min on sol 1 after landing [12]. Surface contaminants on the undersides of rovers and landers are also likely to be quickly inactivated by solar UV due to reflected UV photons off of the surrounding terrain, but the process is approximate-

ly 10-15 times slower due to the low (~3%) UV reflectivity of the regolith [13]. Furthermore, UV penetration into surface defects on spacecraft materials has been modeled (Figs. 2 and 3) [14], and results suggest that even with embedded spores, UV photons (arrows in Figs. 2 and 3) will reach the microbial cells leading to the eventual accumulation of a lethal UV dose. The only conditions in which UV irradiation cannot act on the landed bioloads are conditions in which the microrbial cells are in fully contained internal components of a rover (e.g., the computer CPU, internal payloads), are covered by UV-attenuating materials, or in which multi-layered microbial aggregates form protective layers over embedded cells [14].

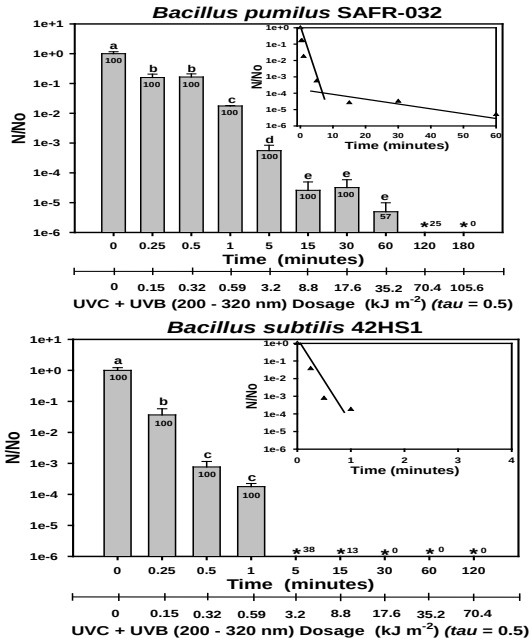

Fig. 1. Both the UV-resistant *B. pumilus* SAFR-032 (top) and UV-sensitive *B. subtilis* 42HS1 (bottom) strains were inactivated within 180 min under an equatorial Mars-normal UV flux (adapted from Schuerger et al. [12]).

Fig. 2. UV photons (arrows) can reach microbial cells (black ovals) embedded within pits, cracks, and defects on spacecraft materials (adapted from Schuerger et al. [16])

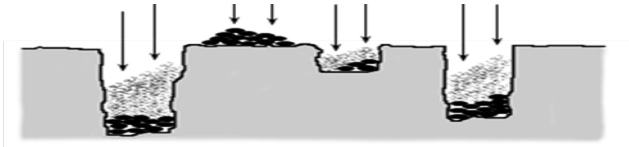

Fig. 3. UV can be attneuated by multi-layers of cells or by UV absorbing dusts, greases, etc. (adapted from Schuerger et al. [16]).

Discussion: Results suggest that a portion of the launched bioloads on spacecraft will be inactivated by the interplanetary environment before reaching Mars, a portion will be inactivated on sun-exposed surfaces of landed spacecraft within a few hours on sol 1, and survivors that are shielded from solar UV irradiation but exposed to the low pressure and low temperature of Mars may have significant difficulties growing under the environmental conditions found on the surface. However, Schuerger and colleagues [9, 14, 15] have demonstrated that at least seven genera of bacteria have members that can grow under martian conditions of 7 mbar, 0 ^{o}C, and CO_2-enriched anoxic atmospheres. Thus, we must remain cautious in concluding that the combination of 17 biocidal factors are alone capable of preventing the forward contamination of Mars.

Knowledge Gaps. The following are examples of planetary protection knowledge gaps that could be addressed with future ground and ISS research. (1) Can spacecraft coatings be designed that will decrease the aggregation of multi-layered microbial colonies during prelaunch processessing, and thus, enhance the UV biocidal effects on Mars? (2) Can spacesuits be designed that mitigate the adhesion of fine-grained surficaial fines in order to minimize the shielding effects of solar UV irradiation? (3) What is the difference between human spacesuit/habitat venting versus outgassing, and can viable cells be released by either processes? (4) How do microbial ecosystems change within human habitats over time, and can protocols be implemented that mititgate the survival of terrestrial microorganisms that might be released to the martian environment during EVAs? And (5), biocidal kill curves under martain conditions are required for a much wider diversity of terrestrial microorganisms than Bacillus spp. in order to accurately model the survival, growth, and adaption of the microbes on Mars?

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