THE MOON'S SURFACE MAY BE A SELF-STERILIZING ENVIRONMENT FOR TERRESTRIAL MICROORGANISMS. Andrew C. Schuerger¹ and David J. Smith, ¹ Dept. of Plant Pathology, University of Florida, Bldg. M6-1025, Kennedy Space Center, FL 32899; acschuerger@ifas.ufl.edu, ², Spaceport Technology Division, NASA, Mail Code KTE-3, Kennedy Space Center, FL 32899; david.j.smith-3@nasa.gov.

Introduction: Microbial surveys of robotic and crewed vehicles prior to launch have documented a wide diversity of microorganisms present on space-craft surfaces [1,2,3]. Bioloads on vehicles have been estimated using traditional culture-based assays, and have yielded between 1 x 10⁴ and 2 x 10⁸ viable mesophilic bacterial species per vehicle [4,5]. Recovered microorganisms were composed of approximately 80% non-spore forming bacterial, 10% spore-forming bacterial, and 10% eukaryotic species [3,4,5].

Although a significant number of papers have appeared in the literature on the microbial diversity of spacecraft prior to launch [1,2,3,4], very little literature exists on how terrestrial microorganisms might survive the journey to the lunar surface, or how long they might survive on the Moon. One notable exception is the study by Mitchell and Ellis [6] that described the recovery of a single colony of Streptococcus mitis from foam insulation that was deeply embedded within the Surveyor III camera and recovered from the lunar surface by Apollo 12 astronauts. Based on this single report, the possible survival of at least one terrestrial microbe on the lunar surface for 2.5 years has been adopted by the astrobiology community as proven fact. However, in a paper by Knittel et al. [7], published at the same conference report as the Mitchell and Ellis paper [6], a second team of microbiologists were unable to recover viable terrestrial microorganisms from Surveyor III wire cabling.

The primary objective of the study was to expose a common spacecraft contaminant, *Bacillus subtilis*, to low-pressure and high temperature lunar conditions to predict if terrestrial microorganisms can persist on spacecraft surfaces on the Moon. A model for the inactivation of terrestrial microorganisms on the lunar surface has been developed.

Methods: The microbial bioloads of spacecraft from documented lunar spacecraft [1,2,3,4,5] were used to estimate the microbial bioload of 48 spacecraft to have landed or crashed on the Moon. Then based on published reports on the effects of ultra-high vacuum on microbial survival [see reviews 1,3,4], inactivation kinetics were modeled for *Bacillus subtilis*, non-spore forming eubacteria, and eukaryotic species.

A series of new lab experiments were conducted in high-temperature ovens and a Moon simulation chamber to investigate the survival rates of *B. subtilis* under temperatures up to 100 C and in combination with high levels of vacuum ($1 \times 10^{-6} \text{ mb}$).

Results: Although UV irradiation was not studied, it is the most biocidal factor for terrestrial microorganisms on external surfaces of spacecraft [1.2]. Based on published literature [see reviews 1,3], most, and perhaps all, terrestrial microorganisms on sun-exposed external surfaces would be inactivated within one lunar day after landing.

The viable microbial bioload for all spacecraft predicted to have landed on the lunar surface is 9.52 x 10^{12} spores, and the per-vehicle average (for 48 spacecraft) was 1.98 x 10^{11} viable microorganisms per vehicle. These estimates are several orders of magnitude higher than earlier published reports because the earlier reports under-sampled and under-estimated nonculturable, eukaryotic, archaea, and extremophilic species on spacecraft.

Inactivation kinetics for *B. subtilis* for low-pressure alone suggests that 0.5% of landed spore-forming bacteria may survive to the present day, if shielded from solar UV irradiation and insulated from high temperatures. In contrast, non-spore forming bacterial and fungal species are likely to lose up to two orders of magnitude of viability per lunar day from high vacuum effects alone.

Thermal stresses would accelerate the loss of viability for landed spores or cells. Results of interactive studies between low-pressure and high temperature suggest that these two factors interact synergistically and are likely to inactivate all microbial species adhered to spacecraft surfaces heated above 70 C, within one lunar day. It is predicated that between 50 and 66% of landed or crashed spacecraft surfaces reach at least 70 C during the lunar day.

Results suggest that the lunar surface is a self-sterilizing environment that will likely leave no microbial survivors on spacecraft surfaces within 2-3 years after landing. Implications for lunar astrobiology will be discussed.

References: [1] Schuerger, A. C. et al. (2003) *Icarus*, 165, 253-276. [2] Schuerger, A. C. et al. (2006) *Icarus*, 181, 52-62. [3] Taylor, G. R. (1974) *Ann. Rev. Microbiol.* 28, 121-137. [4] Dillon, R. T. et al. (1973) *Space Life Sci.* 4, 180-199. [5] Favero, M. S. (1971) *Environ. Biol. Medicine* 1, 27-36. [6] Mitchell, F. J. and Ellis, W. L. (1971) 2nd Lunar Sci. Conf. 3, 2721-2733. [7] Knittel, M. D. et al. (1973) 2nd Lunar Sci. Conf. 3, 2715-2719.