Lunar Dust and Lunar Simulant Activation, Monitoring, Solution, and Cellular Toxicity Properties

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Introduction

During the Apollo missions, many undesirable situations were encountered that must be mitigated prior to returning humans to the moon. Lunar dust (that part of the lunar regolith less than 20 µm in diameter) was found to produce several problems with mechanical equipment and could have conceivably produced harmful physiological effects for the astronauts.[1] In fact, the abrasive nature of the dust was found to cause malfunctions of various joints and seals of the spacecraft and suits. Additionally, though efforts were made to exclude lunar dust from the cabin of the lunar module, a significant amount of dust nonetheless found its way inside. With the increased gravity correlated with ascent from the lunar surface, much of the fine fraction of this dust began to float and was inhaled by the astronauts. The short visits to the Moon during Apollo lessen exposure to the dust, but the plan for future lunar stays of up to six months demands that methods be developed to minimize the risk of dust inhalation. The guidelines for what constitutes "safe" exposure will guide the development of engineering controls aimed at preventing the presence of dust in the lunar habitat.

Due to the lack of an atmosphere, there is nothing to protect the lunar soil from ultraviolet radiation, solar wind, and meteorite impacts. These processes could all serve to "activate" the soil, or produce reactive surface species. However, upon their return to Earth, samples obtained during the Apollo missions were inadvertently exposed to the ambient atmosphere, as the dust caused the knife-edge indium seals of the "rock boxes" to fail.[2] Therefore, in order to understand the possible toxic effects of the reactive dust, it is necessary to "reactivate" the dust, using methods that simulate those processes in space.

We have previously developed a method for monitoring the activity of ground lunar soil and lunar simulant.[3] Using the production of hydroxyl radicals in solution as a marker, a fluorescent species is produced that can be measured to determine relative activities. For instance, as can be seen in Figure 1, the activity of ground Apollo soil is ~ 3 times that of ground lunar simulant and ~ 10 times that of ground quartz. The development of this test is important, as it is inexpensive and can be transferred into a portable sensor. Electron paramagnetic resonance (EPR) spectroscopy can also be used for this purpose. However, it is costly and bulky, and not appropriate for a simple monitoring system. Even so, EPR can provide valuable evidence of hydroxyl radical production, as has been shown previously.[4] We present some initial results on the production of radical species in solution using EPR spin-trap experiments.

Placing lunar dust in solution could lead to effects on mechanical and physiological systems, as well as other biological systems. For instance, while it is known that lunar dust is highly abrasive and causes a variety of problems with suits and equipment during Apollo, it is unknown as to how these properties might be affected in the presence of water or other liquids. It is possible that the dust may release minerals (e.g., metallic nanophase Fe) into solution that could speed corrosion or rust. Also, as lunar dust produces hydroxyl radicals (and possibly other reactive oxygen species) in solution, these radicals could also lead to the breakdown of suit or habitat materials. In the body (i.e., in lung solution), the effects could be two-fold. First, if the dust or dust solutions, it may release an excess of elements (such as nanophase metallic Fe) that are necessary for bodily functions but only in certain concentration ranges. For lunar dust, the presence of nanophase iron being released into the body is a concern. Secondly, the hydroxyl radicals or other reactive oxygen species produced by the dust in solution could conceivably interact with cells, leading to various problems. A number of previous studies have been performed to determine the various species released by lunar dust and lunar simulant.[5,6] These studies have measured the response of ground lunar soil and lunar simulant to exposure to ground soil and ground simulant.

Materials and Methods

Test materials: Quartz samples (Mn-USSi) with diameters below 15 µm were provided by U.S. Silica. Lunar simulant (JSC-1A-vf) was obtained from Dr. James Carter at the University of Texas at Dallas. This simulant was designed to be similar to low-titanium, mature lunar mare regolith with 90% of the particles less than 13 µm. The lunar dust used for these studies was an Apollo 16 soil (62241) provided by Dr. Larry Taylor at the University of Tennessee-Knoxville. This particular sample was a mature highland soil with a size distribution between 3 µm – 450 µm.

Methods: Powdered samples of quartz-lunar soil mixtures were added to quartz-lunar simulant mixtures with a mortar and pestle for 10 minutes stopping every 2 minutes to scrape the sides to ensure consistent grinding.

Fluorescence testing procedure: Ground and unground material were added to 100 µM fluorescein disodium (32000 µM) in 100 µL of PBS. The mixtures were allowed to interact for 1 hour before being filtered. The fluorescence spectrum of the filtered solution was obtained using a Perkin-Elmer LS50B spectrometer.

EPR testing procedure: For spin-trap experiments, 300 mg of simulated lunar dust or simulant was added to 10 mL of 2-methyl-2-nitroso-propane (MNP)/acetonitrile solution in a 10 mL conical tube for testing.

Dissolution testing: Buffer solutions of pH 4.0, 5.3, and 8.7 were prepared using citrate and citrate-phosphate buffers. 0.5 mg JSC-1A-vf was added to 20 mL of solution for 72 hours while rotating. The mixtures were filtered and analyzed using ICP-MS.

Conclusions

This work has shown the effects of grinding on the activation level of lunar dust, the changes in dissolution properties of lunar simulant, and the production of cytokines by cellular systems. Grinding of lunar dust leads to the production of radicals in solution and increased dissolution of lunar simulant in buffers of different pH. Additionally, ground lunar simulant has been shown to promote the production of IL-6 and IL-8, pro-inflammatory cytokines, by alveolar epithelial cells. These results provide evidence of the need for further studies on these materials prior to reaching the lunar surface.

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References:

Figure 1: Emission spectra of ground and unground Apollo 16 soil (62241) with ground JSC-1A-vf and ground Mn-USSi 15. The concentration of dust was 1.8 mg/mL.

Figure 2: EPR spectra of a 100 mM MNP solution after exposure to ground quartz (Mn-USSi, bottom), lunar simulant (JSC-1A-vf, middle), and Apollo 16 lunar dust (62241, top). The lunar dust and lunar simulant were ground for 10 minutes, while the quartz was ground for 30 minutes. The asterisk denotes the position of the spin adduct, Mn-MNP (Mn(II)).

Figure 3: Production of IL-6 and IL-8 by A549 alveolar epithelial cells exposed to ground lunar simulant, JSC-1A-vf.

Figure 4: Production of IL-6 and IL-8 by A549 alveolar epithelial cells exposed to ground lunar simulant, JSC-1A-vf.

Figure 5: Production of IL-6 and IL-8 by A549 alveolar epithelial cells exposed to ground lunar simulant, JSC-1A-vf.

Figure 6: Production of IL-6 and IL-8 by A549 alveolar epithelial cells exposed to ground lunar simulant, JSC-1A-vf.

Figure 7: Production of IL-6 and IL-8 by A549 alveolar epithelial cells exposed to ground lunar simulant, JSC-1A-vf.

Figure 8: Production of IL-6 and IL-8 by A549 alveolar epithelial cells exposed to ground lunar simulant, JSC-1A-vf.