LUNAR DUST SEPARATION FOR TOXICOLOGY STUDIES.

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Introduction: We have developed a method for extracting respirable dust (<2.5 µm) from Apollo lunar soils. This method meets stringent requirements that the soil must be kept dry, exposed only to pure nitrogen, and must conserve and recover the maximum amount of both respirable dust and coarser soil. In addition, we have developed a method for grinding coarser lunar soil to produce sufficient respirable soil for animal toxicity testing while preserving the freshly exposed grain surfaces in a pristine state.

Figure 1. Dust separation system housed in a dry nitrogen glove box.

Background: During the Apollo missions, crewmembers were briefly exposed to dust in the lunar module, brought in after extravehicular activity. When the lunar ascent module returned to micro-gravity, the dust that had settled on the floor now floated into the air, causing eye discomfort and occasional respiratory symptoms. When the dust became bothersome, the crew donned their helmets and waited for the air revitalization system to remove the dust.

Because our goal is to set an exposure standard for 6 months of episodic exposure to lunar dust for crew on the lunar surface, these brief exposures of a few days are not conclusive. Based on experience with industrial minerals such as sandblasting quartz, an exposure of several months may cause serious damage, while a short exposure may cause none. The detailed characteristics of sub-micrometer lunar dust are only poorly known, and this is the size range of particles that are of greatest concern.

Surface Activation of Lunar Grains: Studies conducted by [1] have emphasized that the toxic impact of quartz is related to surface reactivity. However, lunar dust is expected to have higher surface reactivity than does freshly ground quartz because of several concurrent processes: (a) Micrometeorite bombardment creates fresh fracture surfaces, where unsatisfied bonds occur. Lunar dust is the product of repeated fracturing and comminution from meteorite impacts. Pressure pulses from impact can produce shock effects, dislocations, and phase changes in the grain surface material; (b) Individual particles are subject to intense UV radiation which is energetic enough to break additional bonds and thereby increase the potential reactivity of grain surfaces; (c) Regolith grains are also subject to particulate radiation from solar wind and solar flare events (Figure 2) which can damage the surface and near-surface regions down to several tens or even hundreds of nanometers [2, 3]. The probable result is that the grain surfaces and outermost regions may have enhanced reactivity with human tissue.

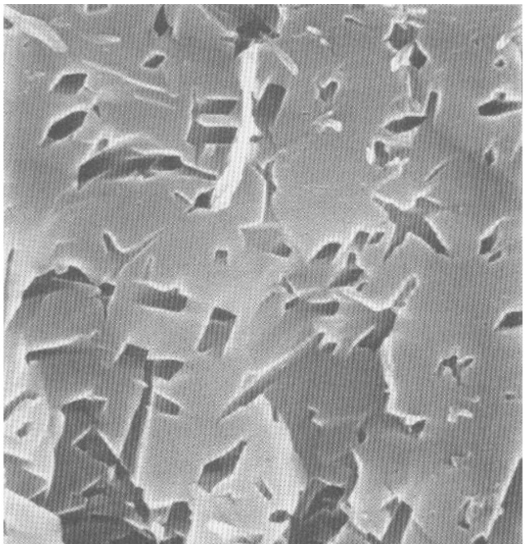

Figure 2. Solar-flare damaged lunar grain.

In addition, lunar dust contains metallic nano-size iron. This is due largely to vaporization of the soil induced by micro-meteorite impact, with subsequent deposition of the vapors as impact glass filled with myriads of nanophase metallic Fe grains (3-33 nm). Some native iron may also be formed by hydrogen reduction (via solar-wind protons) of this melt. The effect of the nanophase iron on human tissue and cells is yet to be determined; such material does not occur on Earth and humans have not developed any specific evolutionary ability to deal with it.

Dry Separation is Required: Because of the processes just described, lunar soil grains are likely to be highly reactive [4]. Grinding of lunar simulant can create a similar reactivity, which is greatly reduced ("passivated") over the course of a few hours by contact with humidity and atmospheric oxygen [4]. As our objective is to determine the native reactivity of lunar dust, we must minimize any changes in reactivity caused by the size separation process. Because of the potential strong reaction with water, and possibly other fluids, the separation of lunar dust must be done either in vacuum or in a dry inert gas atmosphere. We have chosen to perform all separation procedures in an ultrapure dry nitrogen atmosphere. Because dry sieving is typically not very effective at releasing the respirable dust particles that are adhered to larger grains, we developed a system that is more efficient than typical dry separation methods and from which all of the lunar material can be recovered.

Fluidized Bed: Fluidized beds are most commonly used for chemical processing [5], but the principal of operation makes them a useful option for a dust separation system. Because fluidization stirs and roils the material extensively, it can remove the smaller particles that would otherwise remain adhered to the larger particles.

Our fluidized bed was developed at JSC, originally for use as an *in-situ* resource utilization (ISRU) demonstration unit. Modifications to the original component include the addition of a cup-shaped filter holder at the bottom, which prevents material from being caught in the corner space between the bottom of the walls of the bed and its floor. Previous work has shown that these "dead" spots would eventually lead to channeling, in which fluidization stops and the gas forms a channel to the top of the bed [6]. The modification has resulted in continuous fluidization behavior for the entire duration of four hours used in separation runs.

Settling Flask/Impactor: The fluidized bed is followed by a settling flask, in which the input is directed via a tube to the bottom of the flask. The settling flask presents a large volume to the air stream of the separation system. The sudden expansion of size at the flask reduces the speed of the dust-filled airstream and thus heavier particles will settle out. Smaller particles will remain in the air stream and flow around the tube, then drift upwards in the air stream to the top of the flask, and are carried out to the next component—the cyclone.

Cyclone: A cyclone separator consists of a cylindrical shell with a tangential inlet through which dust-laden gas enters, an exit pipe for discharging the processed gas, and a conical base for discharge of oversized particles. A dual vortex is created inside the cyclone because of its geometry, and this separates coarse soil from fine dust. The main vortex spirals downward and carries most of the coarser dust particles. The inner vortex, created near the bottom of the cyclone, spirals upward and carries finer dust particles [7]. The cut size (the size of particle that is passed through the exit pipe) is a function not only of the design of the cyclone, but also of the gas flow rate. Gravity plays only a small part, and a non-intuitive result is obtained in which lower flow rates release larger particles through the exit, while higher flow rates pass smaller particles.

Filter: The membrane filter is the final component in the system, and is the point at which the product dust is collected. Filters are one of the most efficient methods of separating dust from a gas stream, with collection efficiencies of more than 99% for very fine particulates, and they are thus appropriate for the final step in the process, where further separation is not required.

A membrane filter with a pore size of 0.05 μm is used, which as been found to be robust—a single filter is used throughout a four-hour system operation without loss of flow.

Conclusion: The method that has been developed to separate lunar dust of respirable size can be used for many other purposes, and can be modified to handle larger or smaller quantities of material. Follow-on uses for this system include lunar ISRU for hydrogen extraction [8] and terrestrial waste clean-up [9].

References:

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