What Questions Should We Ask About The Health Effects Of Mars Dust? Lessons From The Lunar Dust Experience.

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Introduction: The first samples of dust from the Moon were returned to Earth aboard the Apollo 11 Command Module on July 24, 1969. Subsequent manned Apollo missions, as well as the robotic Soviet Luna series [1] added to the collection. Accounts of the Apollo astronauts raised the possibility of potential health problems from dust even on their short periods on the lunar surface, but a serious investigation of the toxicological effects of the samples of dust did not commence in earnest until NASA began to consider a return to the Moon. A series of workshops held on the topic at NASA Headquarters and various NASA centers started in 2004, culminating in the NASA Engineering and Safety Center (NESC) Lunar Dust Workshop held at Ames Research Center in 2007 [2]. The subsequent work on experimental toxicological effects of lunar dust using simulants and actual Apollo samples was led by the NASA Office of the Chief Toxicologist at the Lyndon Johnson Space Center in Houston (JSC) with significant contributions on the topic made by the lunar dust lab at Ames Research Center (ARC), as well as at Glenn Research Center (GRC) and other NASA facilities and universities. A comprehensive compilation of findings from this initial phase of research has been published [3], and includes some references to possible Mars dust effects. The present abstract summarizes and contrasts what we've learned from lunar dust research with what we know about Mars dust simulants and data from in situ robotic examinations on Mars, and gives some initial thoughts on what we will need to learn about Mars dust in order to assure safe manned missions in the future, and appropriate handling on Earth of any Mars soil sample return materials.

Toxicological Essentials of Lunar Dust: From studies on actual lunar dust (Figure 1), lunar dust simulants, and terrestrial dust known to be toxic, some key findings have been established about lunar dust, which are listed along with significant terrestrial analogues in the Table.

To summarize, lunar dust mineralogic properties suggests toxicity in that it displays a high size fraction in the respirable range, a jagged morphology, high surface to volume ratio, and likely high surface chemical reactivity, and contains heavy metals, all of which could contribute to toxicity. Experiments show that it generates an inflammatory response in experimental animals. Consequently, a preliminary toxicologic exposure limit has been established for lunar dust of 0.5 mg/m3, which is intermediate in toxicity between freshly fractured silica dust and "nusance" dusts such as titanium oxide. However, virtually nothing is known about the long-term effects of pulmonary and other modes of exposure to lunar dust. This is an important focus of concern because some terrestrial analogues such as silica (quartz) dust cause major chronic pulmonary disease, and this has profound implications for the human exploration of space and planetary environments.

Studies of lunar dust may be extrapolated to the nature of dusts from other airless bodies such as large asteroids where, like on the moon, the impact of micrometeorites is the predominant process producing dust. However, planets with even thin atmospheres such as Mars are likely to produce very different types of dust due to chemical interactions and particle weathering (Figure 2). The distinction between these dusts and the impact on mitigation strategies will influence research efforts and mission designs for some time to come.

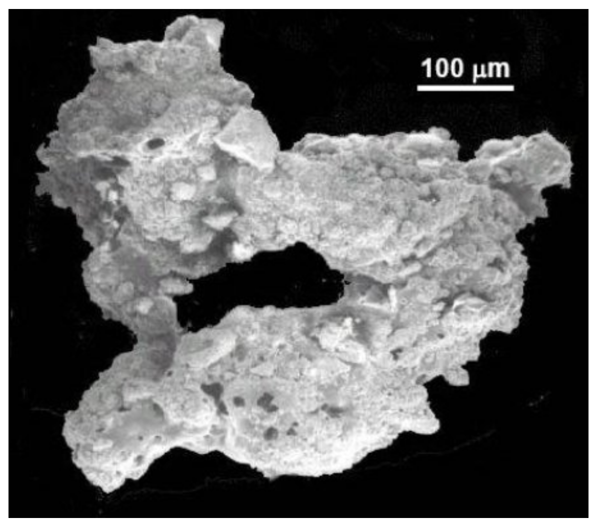

Figure 1. A large lunar dust agglutinate particle, displaying jagged morphology and high surface to volume ratio. (image credit: David S. McKay, NASA/JSC)

Apollo Mission Dust Impact and Possible Relevance to Mars Missions: The 2015 NASA Human Research Program evidence report on celestial dusts includes reports of Apollo astronaut experiences with lunar dust exposure and equipment effects. Dust contamination on surfaces of EVA suits was extensive, and allowed dust to gain entry to the atmosphere of mission vehicles. This became a significant problem during the return to Earth when the Lunar Excursion Module returned to microgravity and dust became airborne in the vehicle. Apollo crew report difficulty with dust in their eyes and entering their upper respiratory tracts, producing impairment of vision and itation of the sinuses. All these issues will apply to Mars dust management, but because of what we know of the divergent chemistries of the two dusts, Mars dust is highly oxidized may be more acutely irritating to mucus membranes of the respiratory tract and other systems, and less likely to be passivated by entry into the crew cabin atmospheres.

Furthermore, on the moon the amount of dust entering habitation compartments and ensuing problems seem to have been somewhat landing site-dependent, with Apollo 14 reporting less dust cloud formation on landing and also fewer subsequent problems with dust inside the vehicles. However, because all evidence points to extensive distribution of fine dust due to global-scale dust storms, at least for Mars the smaller (and likely respirable) particles may be uniformly distributed across potential landing sites [3].

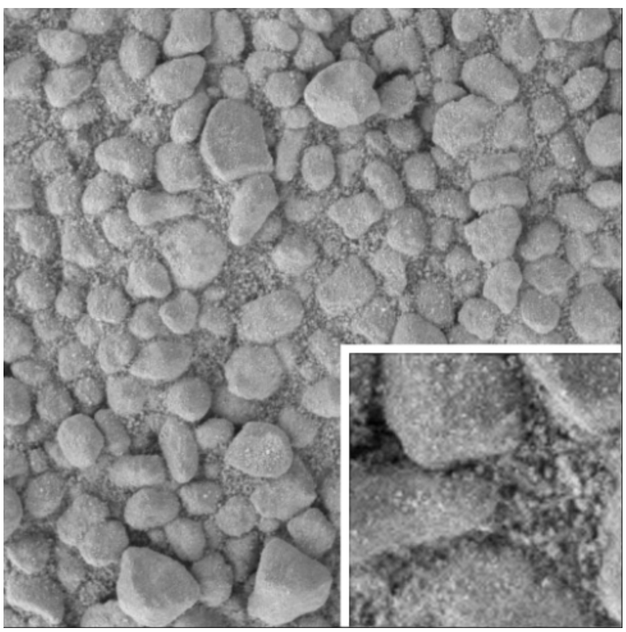

Figure 2. Mars soil imaged by the Mars Exploration Rover Opportunity, showing the rounded, weathered grains. Much smaller fine grains are seen in the inset. The larger view captures an area on the ground of approximately 2cm x 2cm. (edited from http://www.marsroverblog.com/lanikai-under-the-microscope.html)

Regardless, manned Mars mission designers will have benefited from the Apollo experience and from all the science that has been performed on samples in the repository.

Dust problems on the Moon were unexpected, and could have been mission limiting if surface operations had lasted longer. While we do not have the advantage of curated dust samples from Mars, we know enough of the general chemistry from in situ measurements (including from Viking missions), from SNC Mars meteorites, and from subsequent remote sensing to know that Mars dust will be of a fundamentally different minerology than lunar dust. While lunar dust may be seen as glass-like, Mars dust is based on salts that are highly oxidized. In fact, because of the high oxidation, Mars dust has been compared to powdered bleach.

From what we know of the toxicology of such terrestrial commercial analogues, because of its highly oxidized state, Mars dust might be suspected to cause rapid inflammatory reactions in the upper airways and digestive tracts of crew members. In sufficient dose of dust, these reactions may be serious and even mission-threatening.

Mars dust is known to contain heavy metals that can be highly toxic, but it remains uncertain in what concentrations or chemical state these metals may be. The highly oxidized state of Mars dust can convert otherwise benign materials into toxic forms. For example, it remains an open question how much of the chromium known to be in the Martian soil is the highly toxic hexavalent form, which may be produced by the oxidative environment. This led the National Research Council to recommend that testing for this toxin be included on a robotic precursor mission [6].

There is now enough knowledge, and thanks to the Apollo missions, even direct human contact experience with celestial dusts to frame key questions that will direct research into human health effects and ultimately mitigation strategies.

Questions to address Mars dust health effects: The 2007 NESC Lunar Dust Workshop Medical Splinter Group [2] formulated questions regarding lunar dust risk, most of which fully apply to Mars dust. These questions can consititute a starting point for Mars Dust health effects discussions to generate recommendations for toxicologic research and mitigation efforts:

A. What is the full range of routes/anatomical sites of dust exposure that we need to be concerned about?

B. What characteristics/properties of lunar dust make it a hazard to crewmember health?

C. What is the full range of possible medical, physiological and pathological processes/ responses that we need to consider as a consequence of lunar dust exposure?

D. Which medical/physiological processes are reversible? If reversible, what is the time course? Which processes are irreversible?

E. What operational scenarios need to be considered to provide a framework for envisioning lunar dust exposure to astronauts?

F. What are the "expected" modes/sites of crew member exposure to lunar dust, given the nominal operational scenarios envisioned?

G. What do we need to consider in terms of "unexpected" modes of crew member exposure?

H. Can we anticipate that 1/6th gravity, radiation, and other special space environmental effects (possible reduced atmospheric pressure, reduced ppO2) may have an exacerbating/multiplicative health impact on the physiological/medical effects of lunar dust?

I. What simple techniques for crew member "clinical status evaluation" in response to lunar dust exposure are already available, and what advanced technologies might be needed?

J. What countermeasures do we need to consider providing to remediate at least some of the effects of lunar dust exposure, both anticipated and unanticipated?

K. What treatment of lunar dust-induced disease do we need to anticipate and test?

L. To what extent are the planned "classical" toxicology studies sufficient to define all of the potential medical/physiological impacts of lunar dust exposure? What supplemental studies need to be incorporated into the roster of work that is already slated to be tackled? Where are the knowledge gaps that currently contribute to the uncertainties in lunar dust toxicity? How are those gaps best filled with targeted research?

M. What custom/special supportive facilities/technologies/methods need to be developed in order to preserve, transport, and administer lunar dust research materials: E.g. Native lunar dust and high-fidelity simulants will passivated during transport and delivery, reducing the relevance of any testing of this material.

N. What safety procedures must be developed for handling lunar dust samples in analytical laboratories? Lunar dust and high-fidelity simulants are laboratory materials for which material safety data sheets and other safety protocols need to be developed in advance of handling in lunar and terrestrial laboratories.

O. What is the appropriate panel of mineral particulate control materials to be used for research into the toxicity of lunar dust?

P. What are the dust risk interfaces between EVA suits and the human body? Risk of untoward cutaneous effects from lunar dust entry into the suit depends on body site-specific factors in combination with suit factors.

Conclusion: Nearly all of the areas of prior inquiry into lunar dust health effects are relevant to work that needs to be performed on Mars dust, dust simulants, and terrestrial analogs. Therefore, it is recommended that research programs for health effects of Mars dust be based on the 2007 NESC Lunar Dust Workshop.

References:

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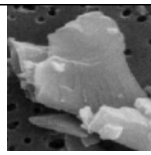
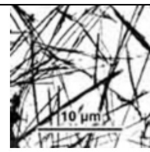
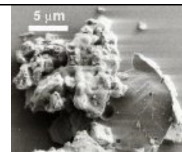
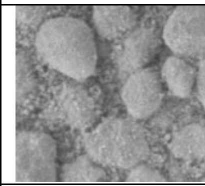
Table. Comparison of Toxicologic Properties of Terrestrial Toxic Dusts, Lunar Dust, and Mars Dust.

	Silica	**Asbestos**	**Lunar Dust**	**Powdered bleach** (Calcium hypochlorite and other components.)	**Mars Dust**
Major Risk	Pulmonary fibrosis	Lung cancer	Unknown	Upper airway and digestive track inflammation; severed edema: ingestion or inhalation may be fatal.[4]	Unknown
Appearance.					
Particle Size Distribution	Known in a wide variety of industrial settings.	Known in a wide varieity of industrial settings.	Known for multiple Apollo landing sites.	Size profiles for commercial products are proprietary.	Unknown.
Respirable size fraction	High	High	High (2%) [3]	Low, due to manufacturing process. However, chlorine gas may be generated which can reach the alveoli.	Unknown
P.E.L.	0.1 mg/m3 (quartz)	0.1 fiber/ cc air/ 8 hr.	0.5 mg/m3 (episodic over 6 months)	Variable due to differences in ingredients of commercial formulations.	Unknown
Re-entrant morphology?	Yes	Yes	Yes	Low, due to manufacturing process.	Low, due to weathering.
Surface/Volume Ratio	High	High	Very high in the agglutinate fraction	Low	Low due to weathering.
Surface reactivity	High in fresh-fractured	Low due to atmospheric exposure	High, in situ, due to vacuum and radiation	High due to oxidative chemistry.	Probably high due to oxidative chemistry.
Heavy metal content.	Variable	Low in pure material.	Variable due to landing site	Low, due to manufacturing process.	Possible toxic concentrations, e.g. hexavalent chromium.
Acute toxicity.	High	Low	Mild	High	Unknown
Chronic toxicity	High	High	Unknown	Low	Unknown
Other comment	May cause subacute injury in high concentrations.	Requires water for formation. Not found on Moon.	Suspected to be rapidly passivated on exposure to atmosphere.	Chlorine generated on exposure to water.	Probably passivates in moist atmospheres. May release chlorine gas on exposure to acidic solutions.