Sample Return of Pristine Lunar Dust to Enable the Design of New Simulants and Activation Protocols for Astronaut Health

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Background

Artemis programme success relies on several ambitious Science Goals that include the need for "*investigating and mitigating exploration risk to humans*". Since the Apollo era, lunar dust toxicity has been one of the major concerns for future lunar exploration. The Artemis III mission to the Moon's South Pole will again expose the two-member crew to lunar dust. The peculiar lunar environmental conditions may radically modify the physico-chemical properties of the dust particle surface and this in turn may enhance the reactivity of particulates encountering biomolecules and tissues upon inhalation. Low-valance state iron (Fe^{2+} and Fe^0), which is thermodynamically favoured by the non-oxidizing lunar environment, occurs in all lunar rocks. Nanophase iron (np-Fe^0) is generated during impingement of micrometeorites on the lunar surface and occurs in the form of nanometric grains that are deposited on the rims of agglutinitic glass. Furthermore, the lunar dust is continuously irradiated by space radiation (cosmic ray, solar wind events) that may induce electron defects, ion implantation and alteration of the redox state of metal ions.[1]

Several studies on the interaction between toxic minerals and human lungs demonstrated the peculiar role of reduced iron ions exposed at the mineral surface of inhaled particles.[2] Specifically, the presence of np-Fe^0 is one of the causes for the high reactivity of lunar dust[3] and is thought to be responsible for the lunar dust inflammatory effect. Oxidative activity of mineral dusts is widely accepted as one of the key factors contributing to lung inflammation. The formation of particle-derived reactive oxygen species (ROS), including superoxide ($\bullet O_2^-$), hydrogen peroxide (H_2O_2), and hydroxyl radicals ($\bullet OH$), is known to induce, when the amount of ROS overcomes the antioxidant cell defenses, oxidative stress in cell, abnormal proliferation, and tissue damage.

The assessment of the impact of lunar dust on human health needs to take into account the enhanced reactivity of lunar dust in the experimental design of toxicological researches. Recently, the second NASA Engineering and Safety Center (NESC) workshop on lunar dust (Houston, Feb 2020) gave clear indications that "there is a need for a standardized lunar simulant for rigorous assessment of toxicity relevant to upcoming lunar missions" and rated this gap in the dust assessment as a "top priority" for

[1] Durante, M., and F. A. Cucinotta. 2011.
[2] Gazzano, E. et al.. 2007; Turci, F. et al., 2011
[3] Wallace, W. T. et al. 2010

defining the impact of lunar dust on human health. To fill this gap, it is necessary to preserve the original chemical characteristics of the samples collected on the Moon surface.

Why should sample return of lunar dust in a pristine state be considered a priority?

Samples from Apollo missions have been extensively characterized and their toxicity assessed by Lunar Airborne Dust Toxicity Assessment Group (LADTAG). Nevertheless, Apollo dust samples returned to Earth were not in the enhanced reactive chemical condition induced by the lunar environment, when astronauts were, and again will soon be, exposed to them. Current knowledge has been established using those materials and carries with it a considerable uncertainty due to the modifications that likely occurred to the toxicity-relevant physicochemical properties of particle surfaces. Some samples were returned in sealed containers under vacuum, but after ~50 years there are concerns regarding the preservation of their surface reactive state. As a consequence, the *in-situ* study of the reactivity of lunar dust will be required to design ground-based studies that reactivate the dust to restore the effects of the lunar environment. Such an experiment is proposed in a companion white paper "*In situ toxicological investigation of lunar dust reactivity to design new simulants and activation protocols for astronaut health*". This white paper presents the need for the return of samples of lunar dust, preserved in a pristine state, which will serve as both a backup to the *in situ* measurements of reactivity on the lunar surface, and provide such material for more extensive studies of surface reactivity than are possible on the lunar surface. Experiments designed to provide an accurate quantitative assessment of the chemical reactivity of lunar dust in its native state will serve as a reference point to study the mechanisms involved in the lunar dust surface reactivity in terrestrial laboratories and ultimately to understand their potential toxicity.

Artemis III should include a means to sample lunar dust obtained from a site distant from the landing site (and thus avoiding the effects of rocket plumes) with an emphasis on collecting material in the respirable range (smaller than ~10 µm diameter). Such samples should be collected in containers designed to be sealed on the lunar surface under non-reactive atmosphere (e.g., Ar positive pressure) and should maintain those conditions for transportation back to Earth. Subsequent studies using pristine lunar dust samples will provide an accurate reference for future toxicological studies using either reactivated[4] simulants or reactivated curated lunar samples. Specifically, mechanical milling in a non-oxidative atmosphere will be used to simulate micrometeorite impact on the Moon and ion implantation and transition metal ion reduction will be carried out at high energy radiation facilities to mimic the effect of solar wind. The direct comparison of the reactivity of lunar dust on the lunar surface with the reactivity of both activated simulants and activated curated lunar dust will provide information necessary to directly address the existing knowledge gap highlighted in the recent NESC workshop.

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[4] Loftus, D. J., E. M. Tranfield, J. C. Rask, and C. McCrosssin. 2008. *The chemical reactivity of lunar dust relevant to human exploration of the Moon*, NASA Ames Research Center, USA; Wallace, W. T., L. A. Taylor, Y. Liu, B. L. Cooper, D. S. McKAY, B. Chen, and A. S. Jeevarajan. 2009. "Lunar dust and lunar simulant activation and monitoring." *Meteoritics & planetary science* **44**(7): 961-970; Turci, F., I. Corazzari, G. Alberto, G. Martra, and B. Fubini. 2015. "Free-radical chemistry as a means to evaluate lunar dust health hazard in view of future missions to the moon." *Astrobiology* **15**(5): 371-380.