MITIGATING LUNAR DUST HAZARDS: UNDERSTANDING TOXICITY AND ADVANCING SUSTAINABLE FILTRATION. A. Cameron[1,2,*], M. Song[1,*], J. Laskowska[1], T. Tetley[1], J.J. Cilliers[3], J.N. Rasera[3],
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Introduction: Lunar regolith dust remains a significant challenge for long-duration missions, having abraded equipment and caused respiratory irritation during Apollo. These fine, electrostatically charged particles adhere to surfaces and easily become airborne, increasing the risk of inhalation. As NASA's Artemis programme anticipates multi-week lunar stays with frequent EVAs, robust dust mitigation is paramount for astronaut health and habitat sustainability. Although standard HEPA filters are efficient, their frequent clogging and the cost of resupply undermine long-term viability. Consequently, two parallel studies were conducted: one evaluating the cytotoxic effects of lunar dust simulants on human respiratory cells, and another studying the potential of various pre-filters derived from recycled, repurposed or locally produced materials to reduce dust ingress. Both efforts converge on mitigating dust hazards in future lunar habitats.

Methods: *Toxicity:* In this study, we assessed cytotoxic responses in both immortalised alveolar epithelial (TT1) cells and macrophage-like THP-1 cells, following exposure to multiple lunar dust simulants (LMS-1D, LHS-1D), crystalline quartz, and zinc oxide at concentrations ranging from 0 to 200 µg/mL. To isolate the <5 µm fraction, particles were dispersed in water to allow >5µm particles to sediment out. The supernatant was then siphoned off and serially diluted to produce the desired exposure concentrations. The cells were exposed for 24 hours. Cell viability was quantified via MTT (3-(4,5-Dimethylthiazol-2-yl)-2,5-Diphenyltetrazolium Bromide) and LDH (lactate dehydrogenase) assays. To measure ROS (reactive oxygen species) levels within the cells, microscopic images were captured following exposure to DHE (dihydroethidium) dye. These methods enable the observation of cytotoxic effects and responses triggered by the dust particles.

Sustainable Filtration: To build on earlier findings demonstrating the pre-filtration potential locally derived or recycled materials, this study introduces a newly acquired Palas RBG 1000 Aerosol Generator (Fig. 1) for improved repeatability. LHS-1D dust was compacted to a bulk density of 1 g/cm³ by tamping 4.5 g of simulant into the aerosolisation system. Each scoping test ran for two minutes, injecting around 0.18 g of dust, at a nominal fill rate of 35 mm/h and 0.6 bar inlet pressure, yielding an approximate filter face velocity (FFV) of 2.09 m/s with a dust load of ~5390 mg/m^3 [1]. Dust that accumulated in the front tubing was carefully tapped out six times into a dedicated collection cylinder, which helped maintain a consistent start mass for each run while preserving any dust that had stabilized within the system. Between tests, the primary piping was not deep cleaned to conserve steady-state conditions. Post-run filter efficiency was quantified by comparing the filter's mass gain to the total mass change of the system, alongside tracking changes in pressure drop to assess breathability during loading.

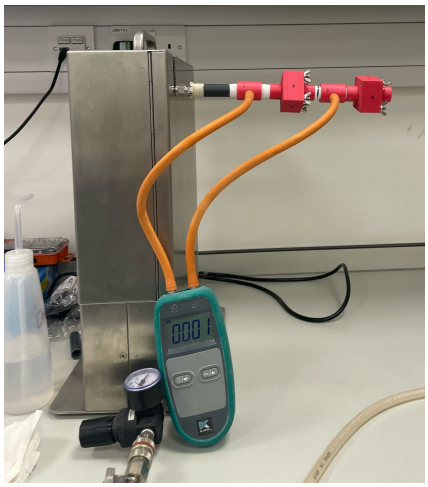

Fig. 1: Experimental filtration apparatus for testing pre-filters under simulated lunar dust exposure.

Preliminary Results: *Toxicity:* With the THP-1 macrophage-like cells, the MTT assay showed notable increases in metabolic activity with higher dust loads, most prominently for LMS-1D (Fig. 2). This trend suggests a heightened state of cellular stress and potentially enhanced phagocytic engagement, as macrophages intensify their efforts to internalise and degrade dust particles. Assays of alveolar epithelial (TT1) cells in earlier work similarly found elevated responses at modest exposure levels, hinting that both primary defence (macrophages) and structural lung cells can be activated by lunar dust. These observations imply that these particles may drive toxicity by boosting mitochondrial activity and provoking inflammatory pathways in lung-relevant cell types. Further cell exposure studies are presently underway, and will permit validation of these findings through robust statistical analysis.

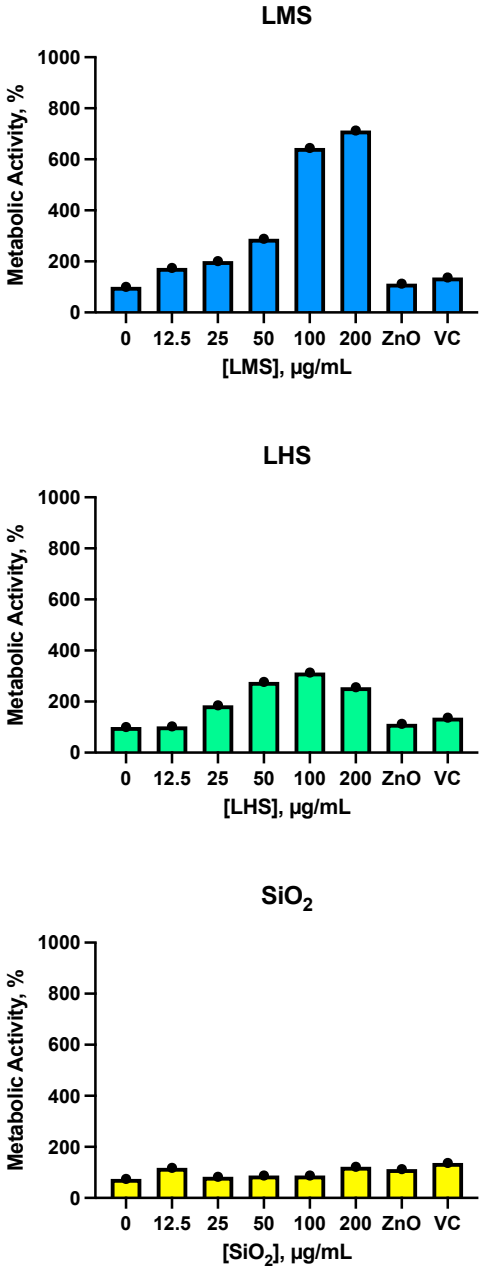

Fig. 2: Preliminary MTT assay results after 24h exposure with THP-1 macrophage-like cells.

Sustainable Filtration: Preliminary data confirm that basalt-fibre pre-filters continue to exhibit high capture efficiency at manageable pressure drops (Fig. 3), echoing past outcomes. Notably, certain materials that previously appeared suboptimal—such as spun-bound polypropylene and wool felt—demonstrated unexpectedly strong performance, while an organic candidate, sphagnum moss, also proved promising for dust capture. This experimental campaign is ongoing; the next stage will focus on down-selecting materials that combine robust filtration with in-situ production or recycling potential, ensuring a sustainable and resilient dust mitigation strategy for long-duration lunar missions.

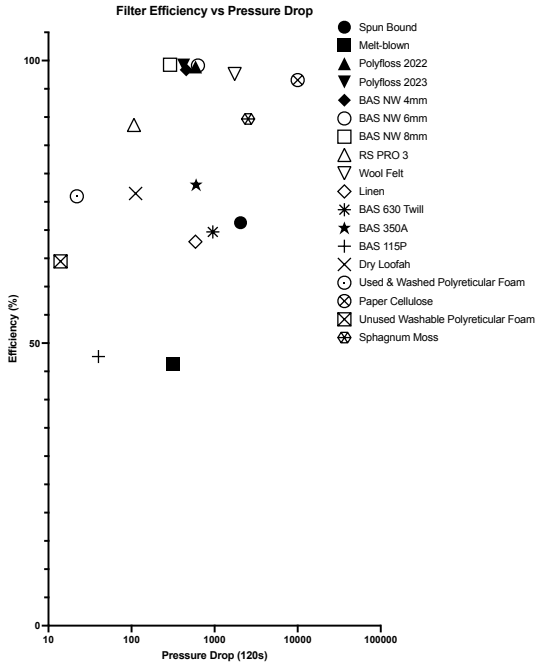

Fig. 3: Filter efficiency versus pressure drop for 19 materials.

Future Integration: These two research avenues will inform each other: the filtration system will provide "filtered" vs. "unfiltered" dust samples to test on THP-1 and TT1 cells, directly evaluating how effective the pre-filters are at removing biologically harmful particles. By correlating filter efficiency with cellular toxicity outcomes, we aim to optimize filter designs for maximal health protection.

Conclusion: Mitigating lunar dust hazards requires a synergistic understanding of the dust's biological effects and the development of robust countermeasures. This work contributes on both fronts by elucidating the toxicological impact of lunar dust simulants on human respiratory immune cells and by pioneering a sustainable dust filtration solution. The findings will help guide the design of life support systems that minimise crew exposure to hazardous dust, an essential step toward safe and sustainable long-term lunar habitats. By leveraging in-situ materials for filtration and addressing dust toxicity, future lunar missions can better protect astronaut health and maintain habitat functionality, turning one of the Moon's greatest challenges into a manageable risk.

References: [1] J.H. Agui and D.P. Stocker (2009) *Nasa Lunar Dust Filtration and Separations Workshop Report*.