IMPERIAL

Mitigating Lunar Dust Hazards: Understanding Toxicity and Advancing Sustainable Filtration

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Introduction

Lunar regolith dust poses a significant challenge for long-duration missions. During Apollo, it was found to abrade equipment and cause respiratory irritation (**"lunar hay fever"**).

This work presents two parallel studies aiming to:

1. Evaluate the cytotoxic effects of lunar dust simulants (LDS) on human pulmonary alveolar cells; and,
2. Study sustainable air pre-filters derived from recycled, repurposed or locally produced materials.

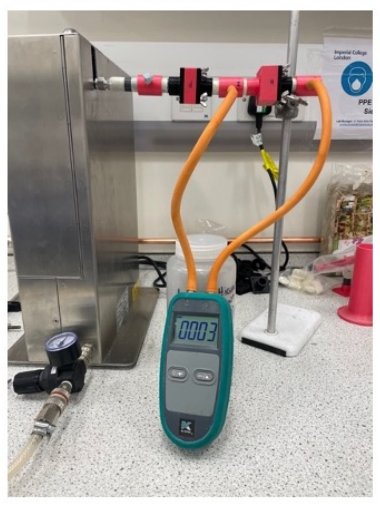
Methods

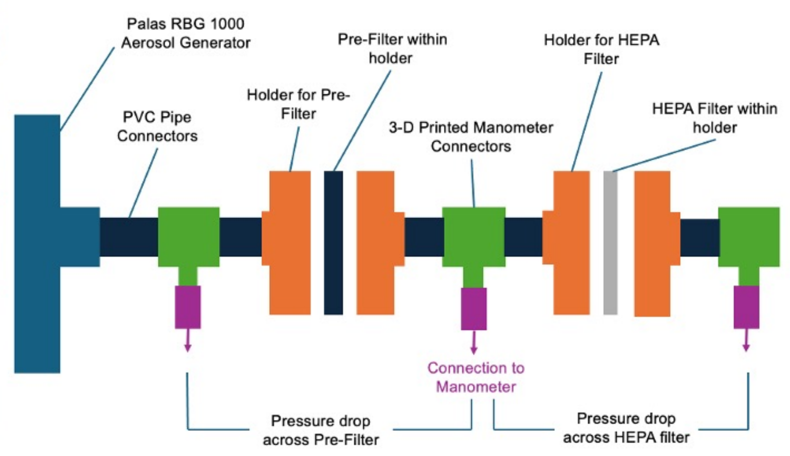
Toxicity:

Human pulmonary alveolar epithelial (**TT1**) and macrophage-like (**THP-1**) cells were exposed to **LMS-1D** and **LHS-1D**, and **quartz** at concentrations of 0–200μg/mL for 24 hours. **ZnO** was the positive control, and deionised water was a vehicle control (VC).

Test	Result
MTT Assay (3-(4,5-Dimethylthiazol-2-yl)-2,5-Diphenyltetrazolium Bromide)	Mitochondrial activity and cell viability
LDH Assay (lactate dehydrogenase)	Membrane integrity and cell viability
DHE (Dihydroethidium) stain and confocal microscopy	Intracellular reactive oxygen species (ROS) generation

Sustainable Filtration:





Parameter	Value	Detail
LHS-1D density	1g/cm³	4.5g simulant tamped to 29mm
Feed rate	35mm/h	Air density ~5390mg/m³ [1]
Inlet pressure	0.6 bar	Filter face velocity 2.09m/s
Brush speed	910rpm	Range 595-1270rpm
Endpoint	+498Pa	Increase from clean HEPA pressure drop

Results & Discussion

Toxicity:

Mitochondrial activity increased in THP-1 cells with higher dust loads (Fig. 1). This trend may suggest a heightened state of cellular stress and enhanced phagocytic engagement, in attempt to internalise and degrade dust particles. TT1 cells showed no change in mitochondrial activity.

Both cells showed minimal LDH release (Fig. 2). This indicates plasma membrane integrity remained intact and cell viability was maintained.

Increased dust exposure enhanced intracellular ROS generation (Fig. 3). This may suggest that LDS induces a cytotoxic response through oxidative stress-related cell signalling or injury.

MTT Assay Results

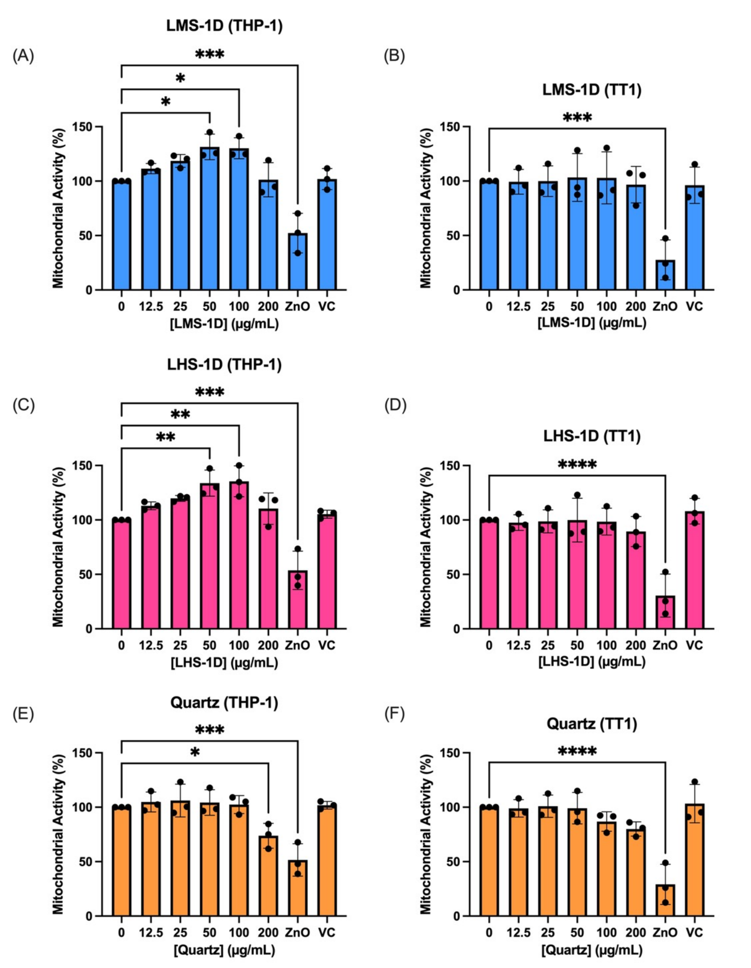


Figure 1 MTT assay results following 24-hour exposure.
Data show percentage of mitochondrial activity compared to untreated cells defining 100% activity. Bars show the mean and error bars denote standard error of the mean. VC = vehicle control (deionised water) *P<0.05, **P<0.01, ***P<0.0001, ****P<0.00001.

LDH Assay Results

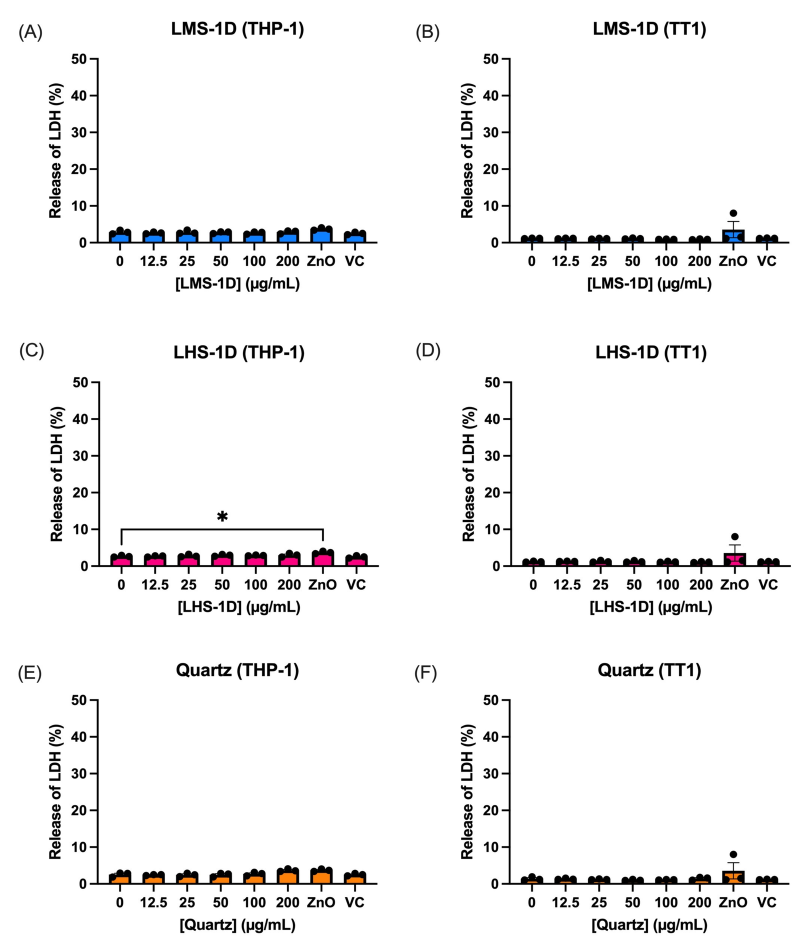


Figure 2 LDH assay results following 24-hour exposure.
Data show percentage of LDH release compared to a LDH positive control defining 100% release. Bars show the mean and error bars denote standard error of the mean. VC = vehicle control (deionised water). *P<0.05.

DHE Staining

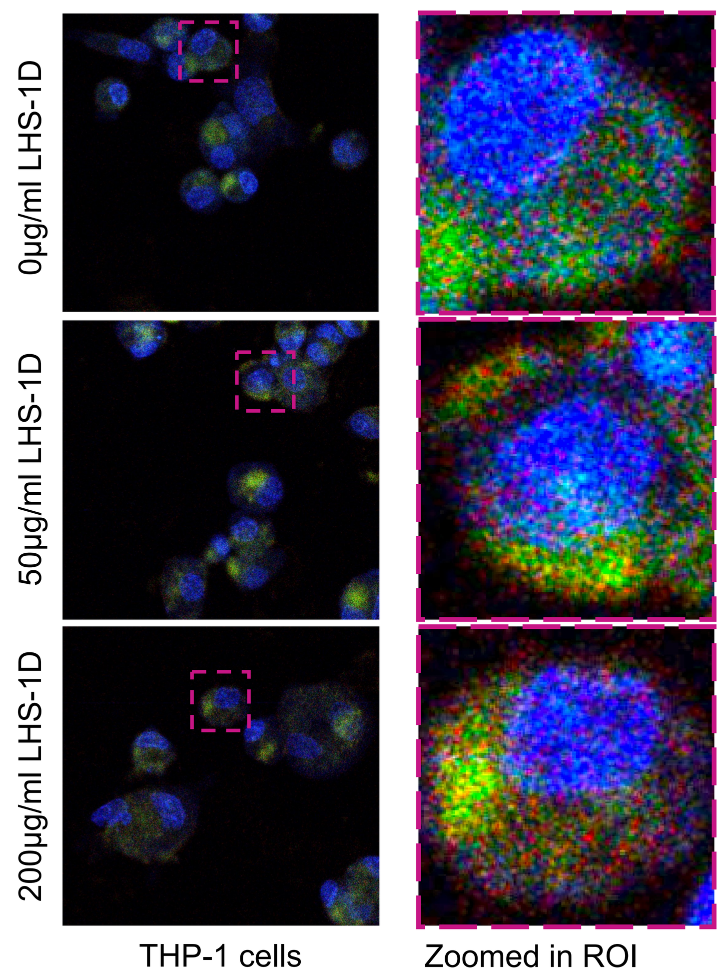


Figure 3 Confocal microscope images of THP-1 cells exposed to LHS-1D for 24 hours.
Superoxide radicals (ROS) are shown as red. Images are taken at ×40 magnification with a zoomed in region of interest (ROI).

Sustainable Filtration:

Basalt-fibres and Polyfloss exhibited high efficiencies at lower pressure drops (Fig. 4), indicating reduced energy requirements. Organic materials performed less efficiently and consistently.

Basalt 6mm indicated most EVAs carried out per HEPA filter, 868 EVAs (Fig. 5). Estimates varied between similarly efficient pre-filters.

Pre-filter materials indicated variable rates and relationships for HEPA loading (Fig 6). The best fit for global regressions varied between pre-filters.

Efficiency vs Pressure Drop

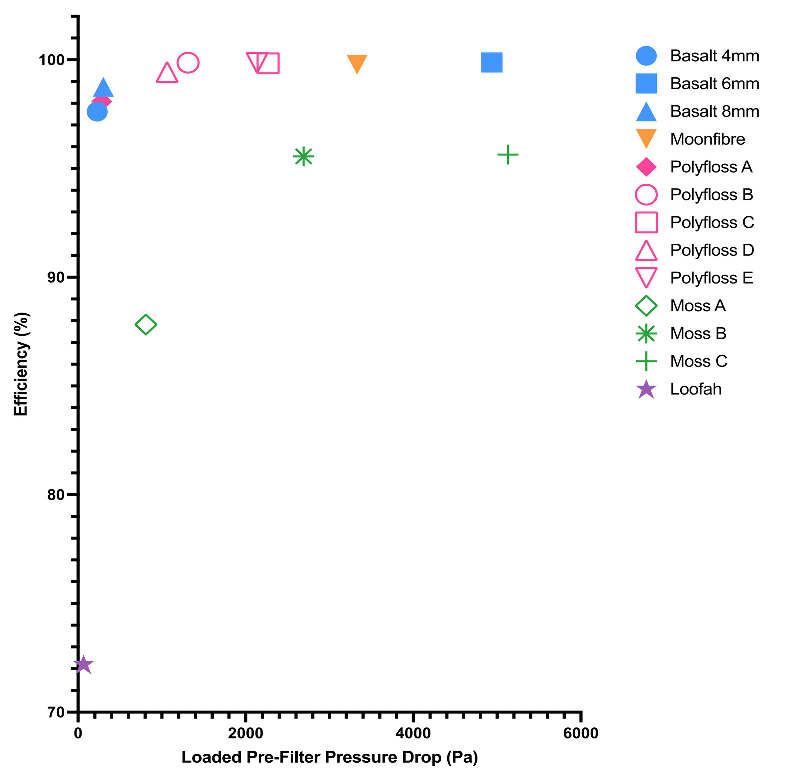


Figure 4 Pre-filter efficiency related to pressure drop.
Prefilters exhibiting a high efficiency compared to a low pressure drop (relating to lower system energy requirements) are most ideal; this is the top left quadrant of the graph.

Estimated EVA Usage

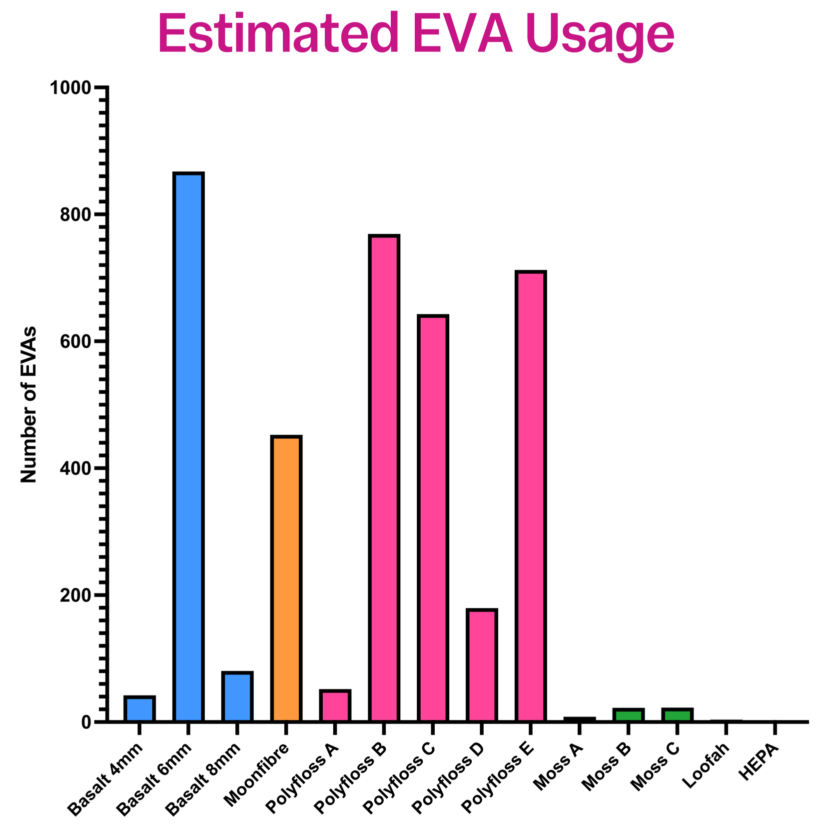


Figure 5 Estimated HEPA filter longevity for number of EVAs carried out.
Data utilises mean pre-filter efficiencies (%) based on 1 HEPA filter usage per EVA.

Rate of HEPA Loading

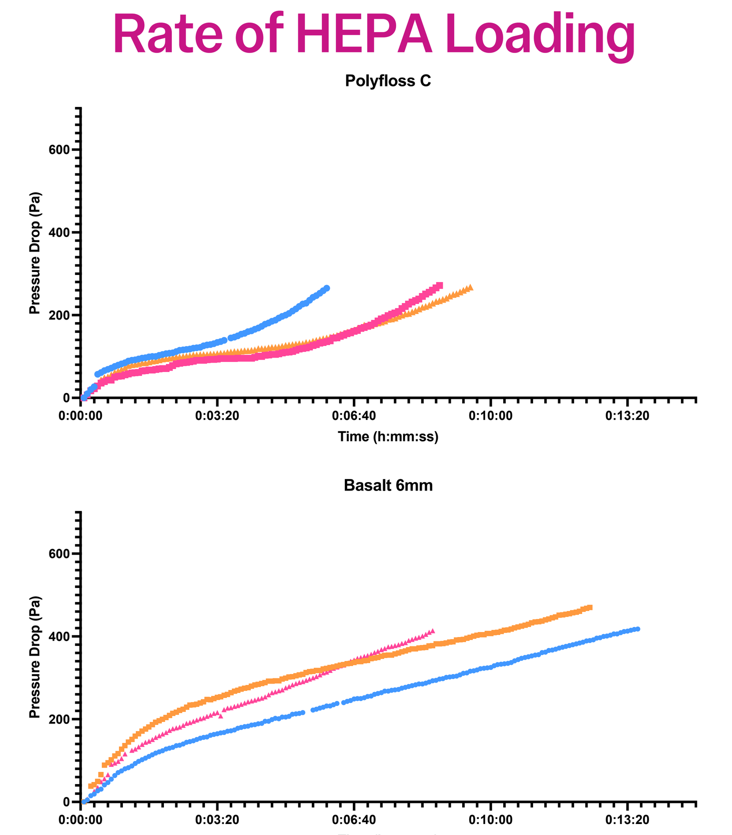


Figure 6 HEPA filter pressure drops measured over the experiment.
Pressure drops are normalised according to the 5s reading for each pre-filter.

Future Integration

The toxicity study provides a valuable framework for future experiments. The filtration system will provide "filtered" vs. "unfiltered" dust samples to test on THP-1 and TT1 cells, evaluating pre-filter effectiveness in removing biologically harmful particles and allowing optimisation of filter design.

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 LDS on human pulmonary alveolar cells and by pioneering a sustainable dust filtration solution. These will help guide designing life support systems, minimis crew exposure to hazardous dust, an essential step toward safe and sustainable long-term lunar habitats.

References

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