Development of Challenge Aerosols for testing Filters in Spacecraft Air Revitalization Systems

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Outline

Will primarily be discussing HEPA filtration because that is what has been traditionally used in space vehicles including ISS

- HEPA – High Efficiency Particle Air

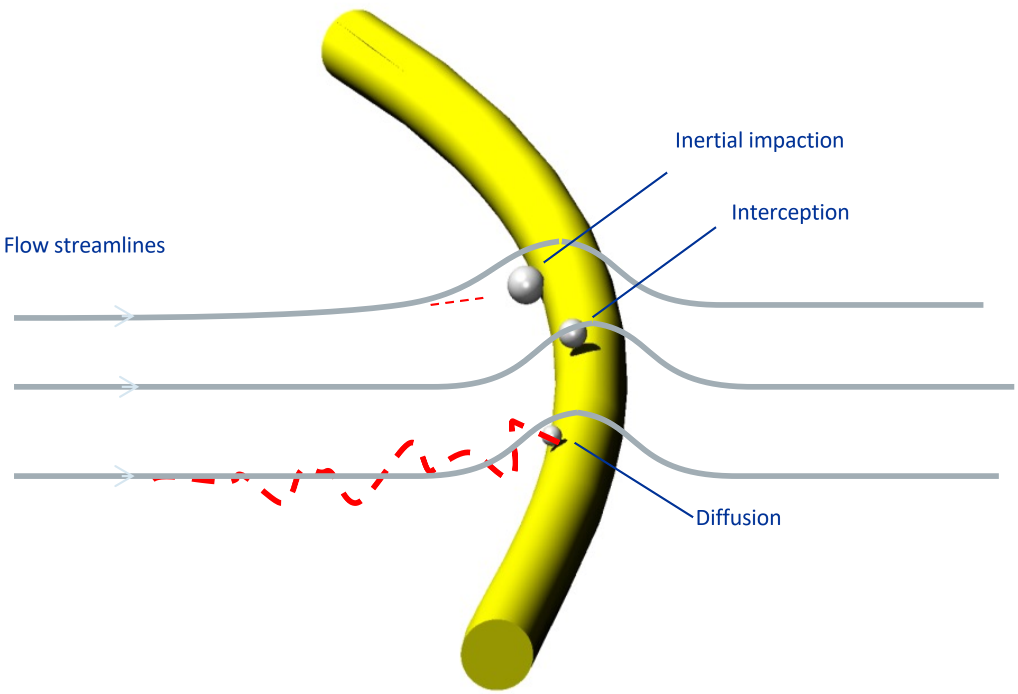
Filtration Background

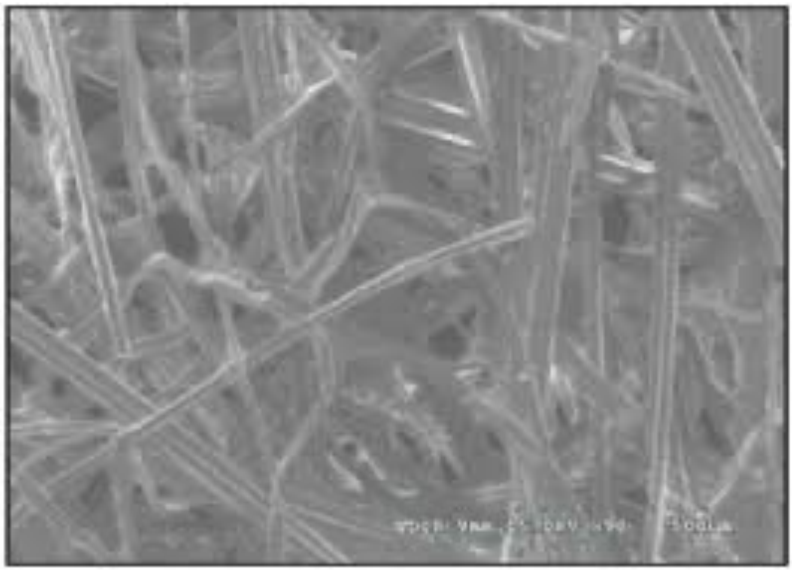
Existing Air Filtration Standards and Aerosol Generation

Composite Aerosols

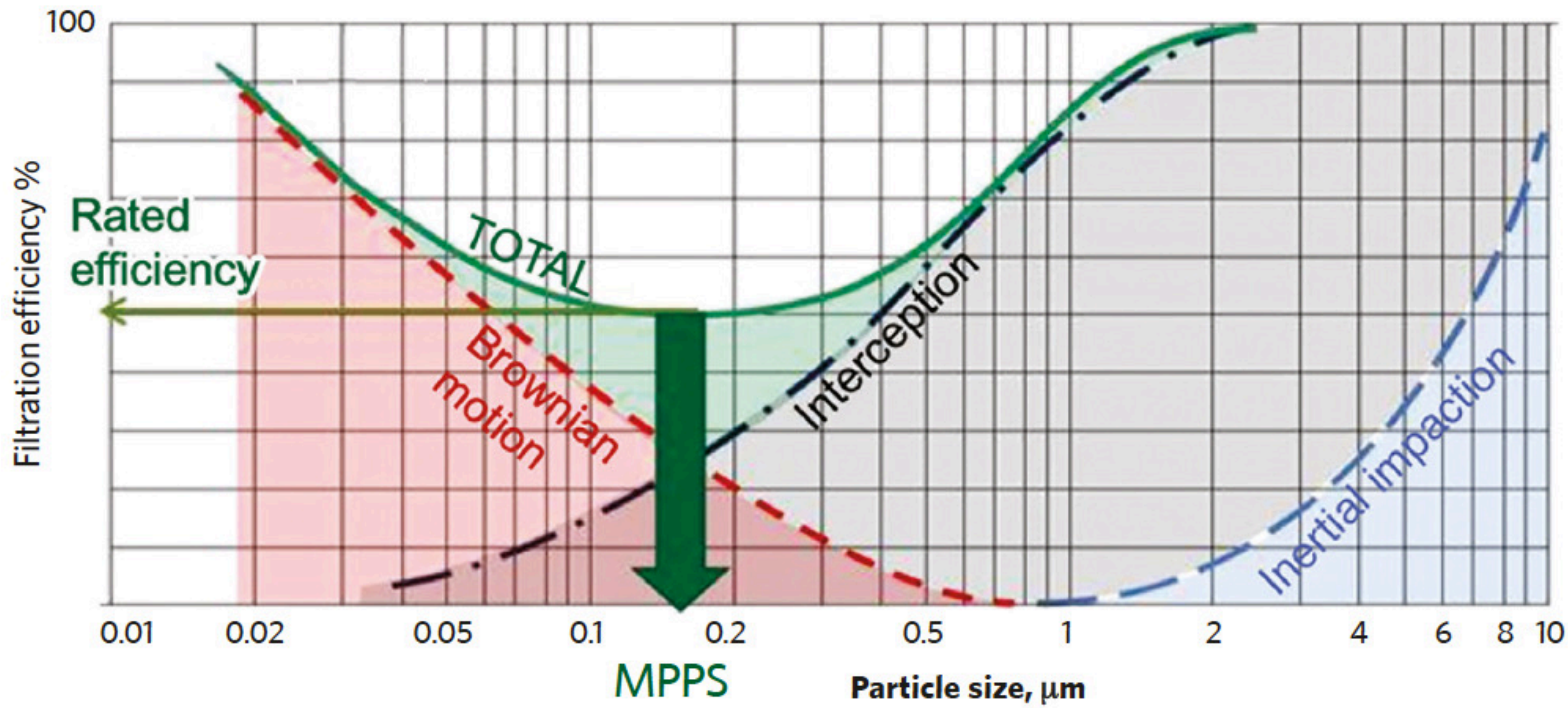
- Ultrafine
- Fine
- Large and Fibrous Particles

Fiber Filter Capture





Most Penetrating Particle Size (MPPS)



For example, the Bacterial Filter Element from ISS are 99.97% efficient for 0.3 micron particulate at 70 CFM and ambient pressure

Filter Standards

Mil-Standard 282

- Became industry standard for HEPA efficiency upon 1956 update
- Was thought to be monodisperse at 0.3 µm
- Was later to be polydisperse around 0.23 µm
- Has since been broadened to allow hot and cold dispersion methods and other oils

IEST-RP-CC001.5

- Adds leak testing specification to baseline testing of every HEPA filter
- Specifies construction material, filter performance (including allowable pressure drops)

IEST-RP-CC007.2 provides similar testing guidance for ULPA filters

ASHRAE 52.2-2017 is a standard including general efficiency air filters but adds suggestions for test duct design and requirements for flow velocity and aerosol distribution uniformity

Challenge Aerosols - Efficiency

Oil-based challenge aerosols

Oil challenge aerosols were specifically designed to test or certify performance of high efficiency filters at or near their least efficient particle size or MPPS

This is in part to allow low exposure during rapid and non-destructive testing of each filter element before release to the customer

Solid aerosols

NaCl are used for applications where a liquid aerosol compromises media such as N-95 masks

Polystyrene Latex Spheres – mainly for ULPA testing. Allows tight particle size distribution at or near MPPS to reducing loading

Challenge Aerosol - Loading

Loading as a means of testing filter lifetime performance

ISO 12301-1 defines the general use Arizona Road Dust

- Selected as a loading challenge to internal combustion engines
  - in construction and farm equipment
- Includes mineral specification

ASHRAE challenge aerosol

- ISO 12301-1 dust and added linters

Sensible model for their environment

However, road dust would not be a practical challenge for clean room filters or other specialized applications

Our Conditions – Variable Gravity

NASA's upcoming missions include at least three distinct gravity environments

Earth

Lunar and Martian reduced gravities

Zero gravity of low earth orbit and transit missions

Sumlin and Meyer point out that on the moon in still air, 1 μm particles will stay aloft for up to a week and 20 nm particles will remain lofted for up to 3 years.

This will require active removal to avoid human irritation or health effects

Our Conditions – Variable Pressure

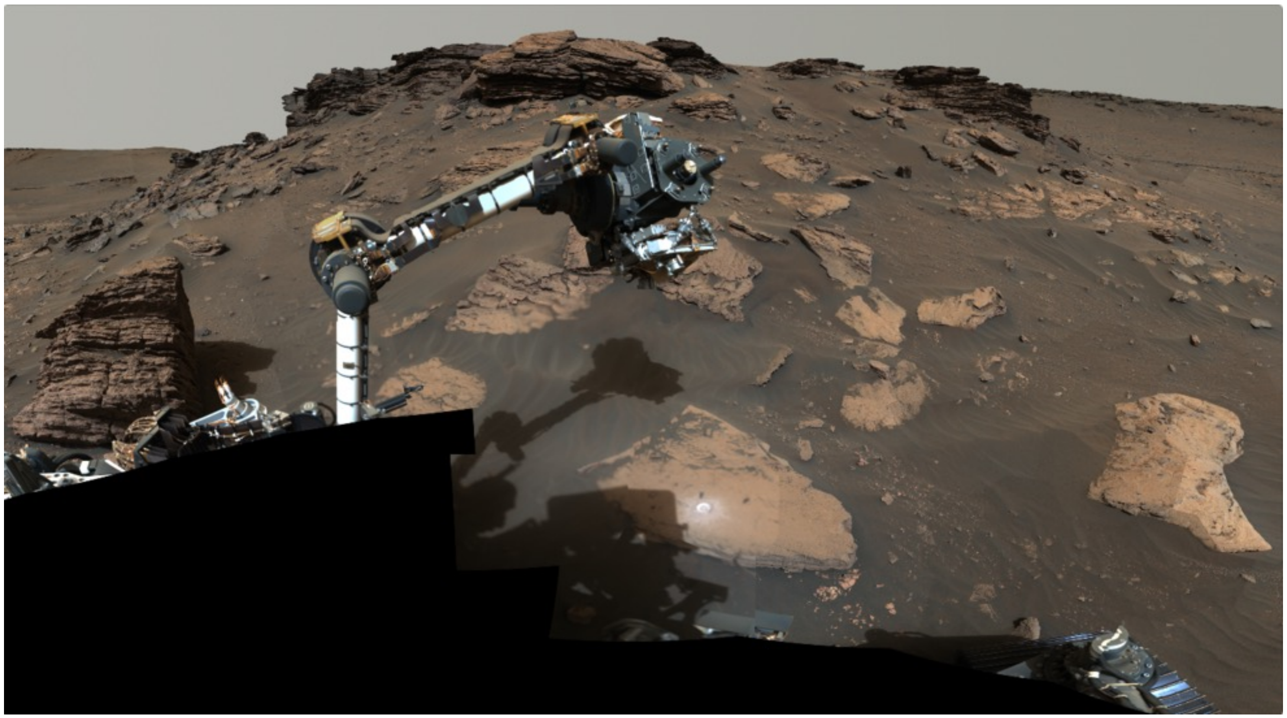
Habitable Cabin pressures

Varied from 14.7 to 8.2 psi

Lunar and Martian surface

0 and 0.95 psi

MOXIE on Perseverance



Our Conditions – Sources of PM

Particulate Matter identification on Space Shuttle and ISS

Closed system – ongoing research

Long periods of zero gravity – with no sedimentation

Added expected challenge of lunar dust

Agui and Stocker report that 227g/suit/EVA should be expected

7% is predicted to aerosolize in Lunar cabins

This aerosolization rate would be expected to change significantly when transported of of the Lunar surface, HALO

ISS015E17168

Complexity of filters

For space missions, different choices dominate the selection of filters

Reduced mass and maintenance dominate

Long life and regeneration instead of replacement are desired

Different types of filters can be considered because long term benefits dominate instead of initial cost

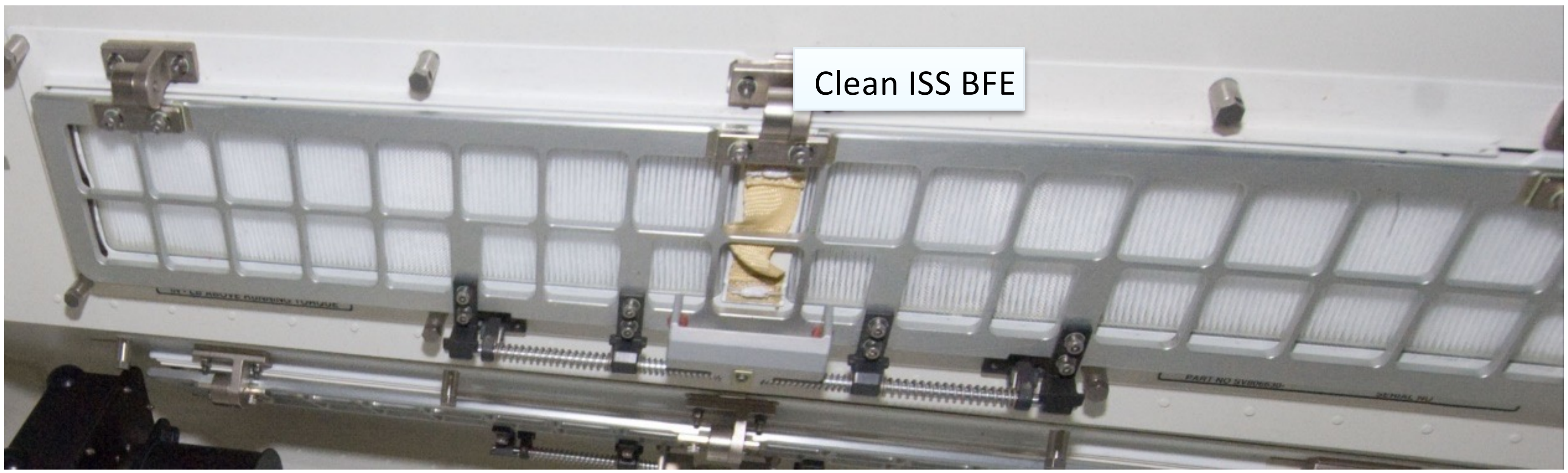
Vortex

Electro-static precipitators

Pre-filters are going to be key in removing larger particles

Pre-filters and Non-media filters

Large particulate has an outsized effect on high efficiency filters
Pre-filters are commonly used to maintain useful lifetime of higher efficiency filters



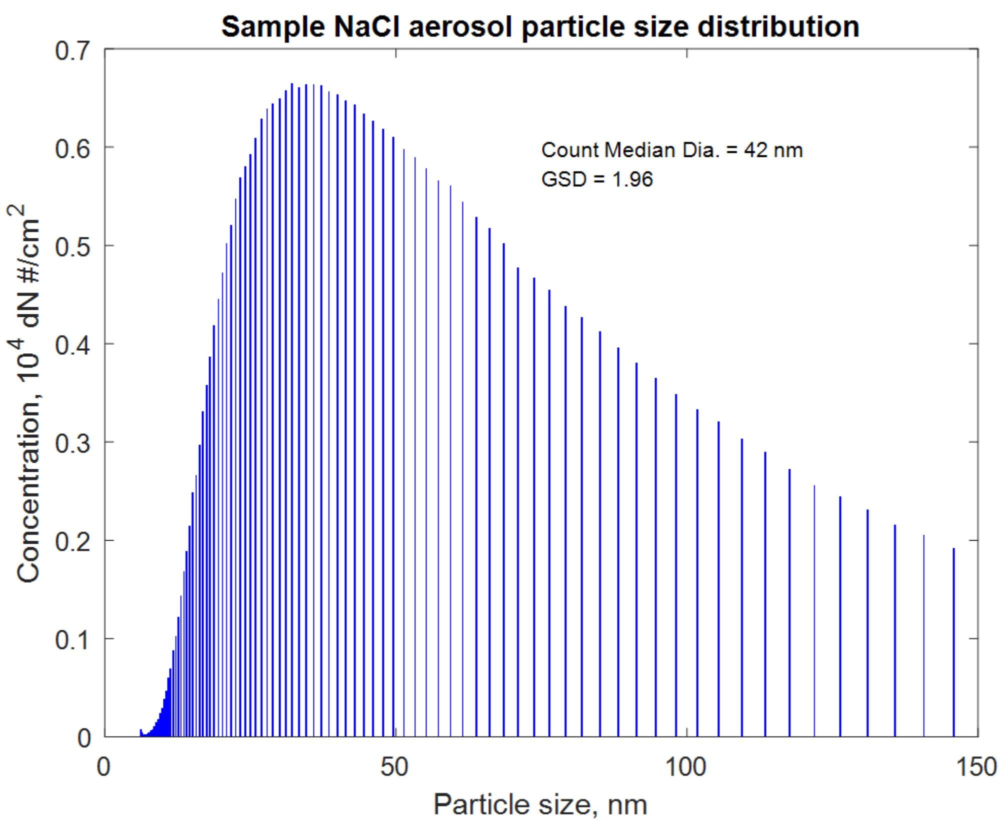
Electrostatic precipitators, vortex filters and other non-media filters are suited for capture of different sized particles but are also susceptible to odd shapes such as fibers and flakes

Composite Aerosol - Ultrafine

Filters for future space missions will still need to deal with the regular nuisance of respirable PM2.5 and PM10 particles

These are the focus of the Industrial Filter standards described earlier

Perry, Perry and Coston and Meyer have all published works detailing the debris collected in vacuum bags and in different active and passive samplers



Composite Aerosol - Fine

Large scale introductions of lunar dust are expected in any mission that goes to the moon or interacts with any that do

HALO for example

Lunar dust is pervasive and jagged in a way that increases concern for equipment damage

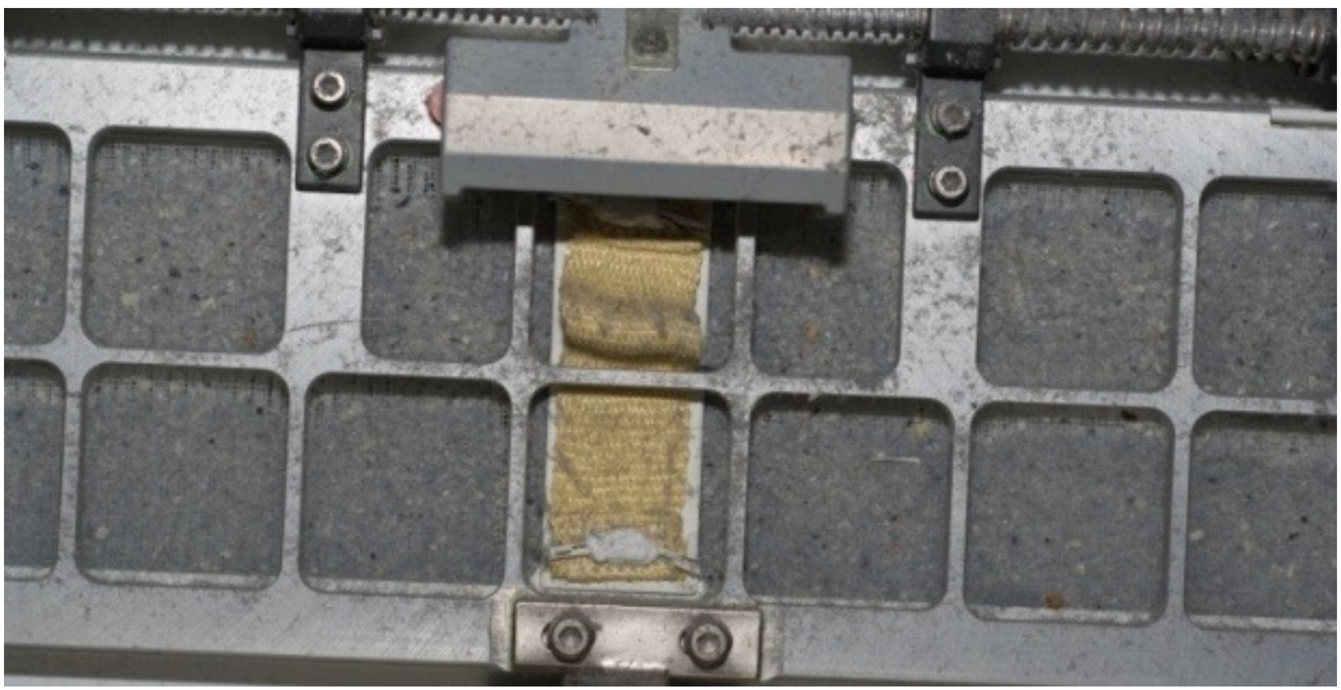
Lunar dust also is initially charged which leads to it getting easily dispersed but not easily removed from astronauts and their Lunar suits

It is also expected to appear in large periodic doses

Composite Aerosol – Large Debris

Perry and Coston, and Meyer (2014) have reported that hair and fibers
- make up 25-50% of the mass in vacuum bags returned from ISS

Meyer (2014) relates that will generate up to 90 mg/hr of skin cells
- An assessment of Space Shuttle particles show that skin flakes or squames clearly dominate the particle number count



8 days accumulation

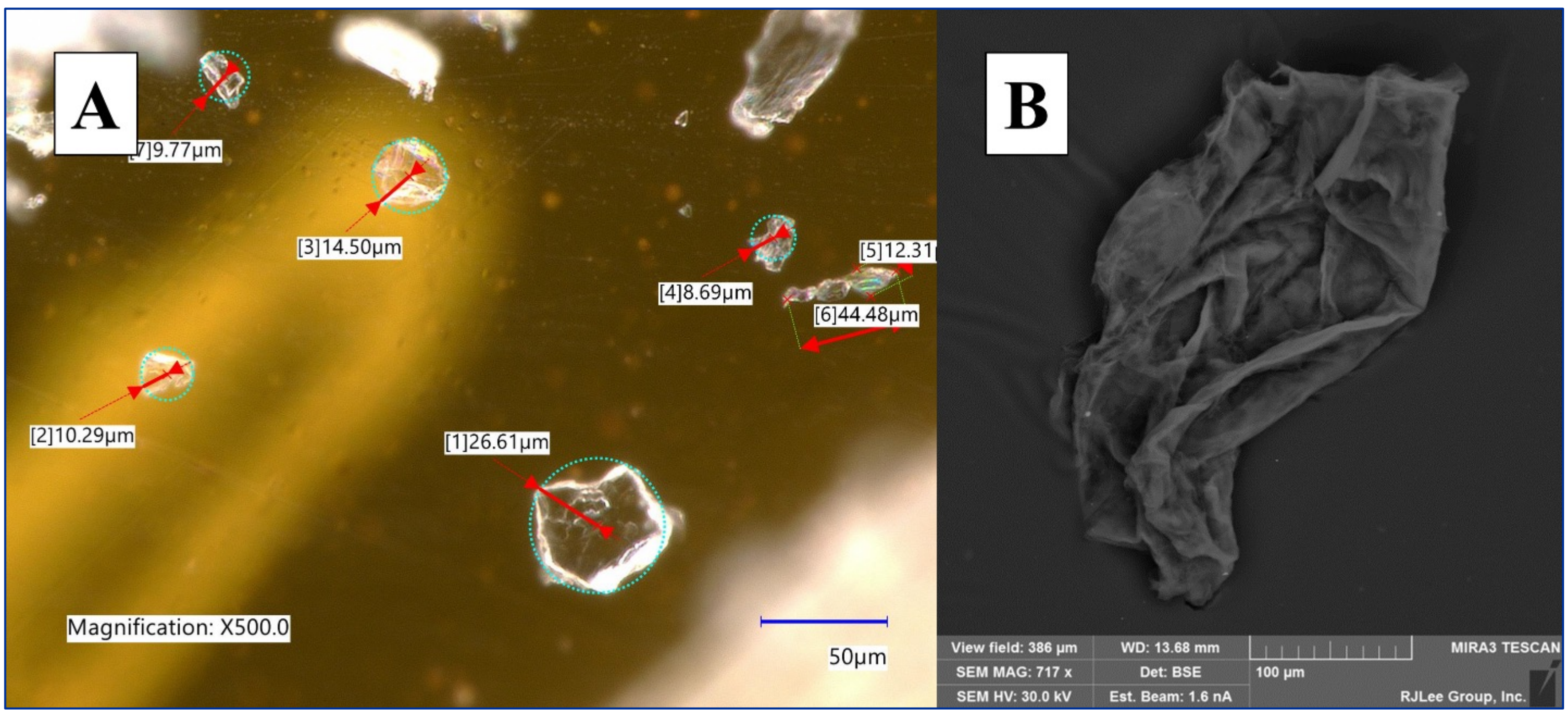
Composite Aerosol – Skin Cells

Meyer (2014) reports that skin cells range from 300 nm to 40 µm with an average of 14 µm

The aerodynamic size and shape of flaked skin is difficult to reproduce

Lab efforts have focused on identifying and sizing thin flaky biological materials, such as garlic (below) and onion skin and vellum

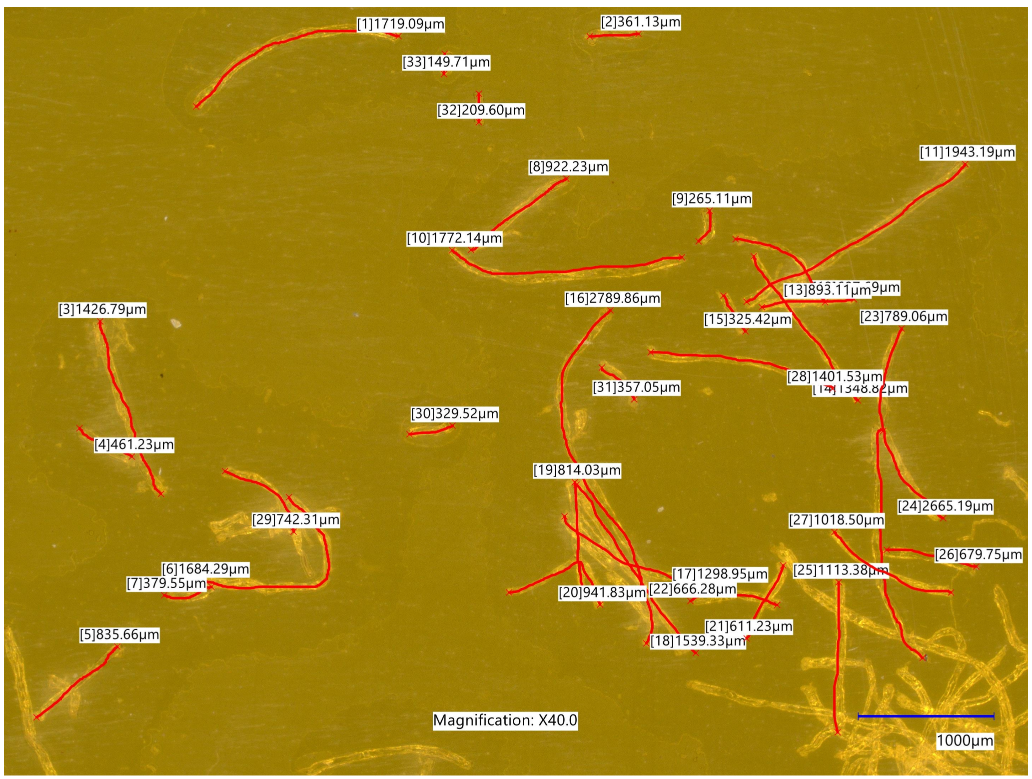
Efforts to locate useful amounts of anonymous skin cells as ongoing

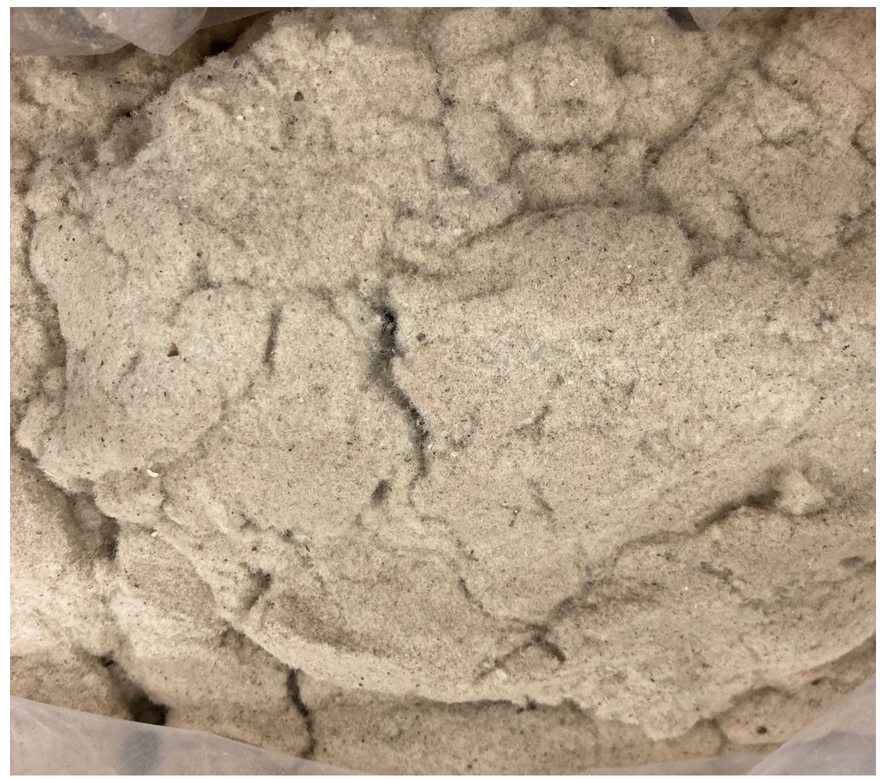


Composite Aerosol - Fibers

Because of the high incidence of fibers and their high aspect ratio, fibers are a unique and necessary challenge to any filter system. Average lengths have been reported to be 12.9 µm

We are working to cut our own fibers in a rotary mill and looking at commercially available ASHRAE cotton linters





Discussion

Formulation of the composite aerosol

Each filtration environment could require a unique formulation

Not all particle types are easy to deal with, so may require a separate dispersal method

An example would be mixing of lunar dust with fibrous particles

- Fibers are known to clump together
- Some lunar simulants, specifically NU-LHT, also agglomerate

ASHRAE Test dust #2 is a mix of 93.5 wt% ISO Fine Test Dust with 6.5 wt% chopped cotton linters

Discussion

Testing with a large particle size distribution composite aerosol

We have outlined an idealized bi or tri-modal distribution of separate but important aerosol populations

If each aerosol type requires a separate dispersal system, this becomes increasing difficult to meter out consistently and continuously

Creative solutions can be made if it is determined what the specific testing needs are

As detailed in paper ICES 2023 paper 200, we loaded a full scale Gateway-HALO filer with NU-LHT-2M simulant for long periods but performed efficiency measurements with a fine distribution of NaCl aerosol

Discussion

Large particle size composite aerosols for efficiency tests

With the prevalence of hair and lack of gravitational settling for some NASA missions, large aerosols and appropriate removal techniques will need to be used

There are no good commercially available dispersal techniques or measurement because these are not of routine concern on Earth

We typically test large particles gravimetrically because mass balances are so sensitive

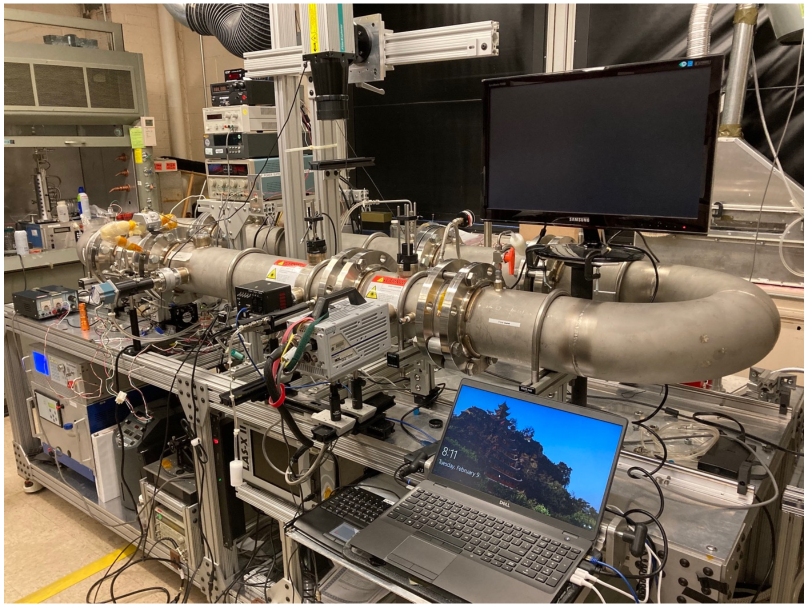
Discussion

Testing under spacecraft reduced pressure environment conditions

To test at sub ambient pressures special closed system test stands need to be developed

Many particle dispersal devices rely on pressurized air to disperse particulate matter

Many particle detection and size measurement devices are designed for ambient pressures



Discussion

Other considerations

Given the unique environments that these filters will operate in, very large items, such as loose hardware, tools and cookies could be considered as practical challenges

Lunar simulants are also known to be abrasive
- Our experience with Lunar simulants has not shown increased filter media damage
- Though we have had issues with dispersal and particle measurement devices

Conclusion

Different missions are going to require tailored challenge aerosols

These should still be based on current industrial standards with additions for new and novel concerns for space applications

We have made an argument that these samples may become quite complicated

- Multi-modal distributions
- May require separate distribution devices for each component

References

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