Topical: Dust from Astronauts and Space Habitats (DASH): Implications on Long Term Space Missions

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This topical research paper addresses the effects of the spaceflight environment on microbiology, chemistry, and particulate exposures from dust generated onboard a spacecraft or in a habitat.

Abstract: Dust is present in all human occupied indoor environments

Inhalation of dust is a major source of human exposure to microbes and chemicals in the indoor environment, including on the International Space Station (ISS). Despite over 20 years of continuous operation of the ISS, we do not yet have a comprehensive understanding of how Dust from Astronauts and Space Habitats (DASH) impacts the health of astronauts, the integrity of materials onboard, or on planetary protection. DASH also creates a significant amount of waste. **Therefore, understanding the nature, contents, and reuse possibilities can further enhance sustainability of long-duration missions.**

DASH can be used as a matrix to assess overall health of a spacecraft or habitat

Dust is a representative composite matrix consisting of small particles from the wide variety of sources within an indoor environment, including dead skin cells, lint from clothing, food waste, material components, and other small fragments of all the materials comprising the cabin environment. DASH collected from passive air samplers on the ISS has been characterized with Earth-based analyses, revealing particulates from materials onboard [1], various chemicals present [2, 3], and a unique microbiome [4]. This makes DASH a useful monitoring tool to assess the overall composition of contaminants to which astronauts may potentially be exposed, including both chemicals and microbes. Currently, DASH on the ISS is vacuumed from the HEPA filter screens and other air intakes of the ventilation system as part of the astronaut crew's weekly chores, utilizing the most expensive resource available in human spaceflight, namely crew-time. Vacuum bags containing DASH are occasionally returned to Earth for archival purposes and for very limited analyses for one or two specific contaminants. This is a framework that is feasible for human spaceflight in low earth orbit (LEO). However, as missions take crews further from Earth to occupy planetary surface and orbiting habitats extending duration of human missions in space, there is a critical need to expand these assessment and analytical techniques and transition from ground-based monitoring to onboard/onsite analyses. Collection of DASH aboard a spacecraft can complement surface swab and air sampling, which are currently part of the microbial monitoring technology roadmap at NASA. In fact, the capability to analyze DASH onboard can simplify this monitoring by first testing DASH and conducting further analyses with swabs/air only if theses test results indicate further analyses are warranted. **Developing methods to monitor DASH onboard spacecraft for chemicals, microorganisms, and particulates could maintain astronaut health, ensure spacecraft/habitat integrity, and give information on microbial community composition to aid in planetary protection (Figure 1).**

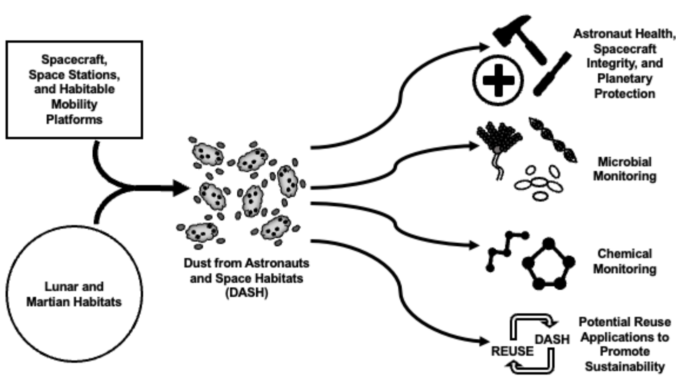

Figure 1: Dust from Astronauts and Space Habitats (DASH) can be used to monitor overall health of the indoor environment associated with long-term human occupied spacecraft and habitats

Microbial growth can occur in DASH

The dust onboard the ISS and other spacecraft contain an entire unique microbiome. Most of these microorganisms are not inherently harmful to the crew or the spacecraft. However, the potential for exponential growth of these microorganisms could lead to unsafe conditions if sufficient moisture accumulates. Microbial function could change due to long-term exposure to changing environmental conditions on long duration missions outside of LEO. These changes in the microbial community need to be elucidated to mitigate potential risks that may compromise crew health and performance, or the physical degradation of mission critical materials and systems [5]. On Earth, when dust is exposed to elevated relative humidity (RH) conditions, there are sufficient nutrients to facilitate significant fungal growth (Figure 2) [6, 7]. This is true for variations in RH exposure, such as a short burst of elevated RH followed by low RH conditions (~ < 50%) as shown by modeling fungal growth with the time-of-wetness (TOW) framework [8]. We also need to understand the importance of other environmental conditions, including temperature, carbon dioxide (CO_2), pressure, radiation, and microgravity, on microbial growth. To date, most microbiome studies aboard the ISS have focused on microbial characterization including the Microbial Tracking 1, 2, and 3 projects. Some recent studies have focused on ISS dust, comparing microbial load on various particle sizes [9] and comparing microbial composition to clean rooms at NASA Jet Propulsion Laboratory (JPL) [10]. In general, microbial samples are returned to Earth where they are quantified using culture-based [11] or molecular-based techniques such as quantitative polymerase chain reaction (qPCR) [12]. Although capability exists on the ISS to sequence microbial communities [13] and amplify DNA [14], more work needs to be done to streamline this process onboard a spacecraft or habitat. However, little work has been performed to understand how DASH can be utilized as a monitoring system for potential pathogens, or to provide early detection of harmful or useful microbial functions from the organisms present. **Quantifying, identifying, and elucidating functions of microorganism present in DASH in various environmental conditions that may be present on a long duration mission is important for astronaut health, integrity of spacecrafts/habits, and planetary protection.**

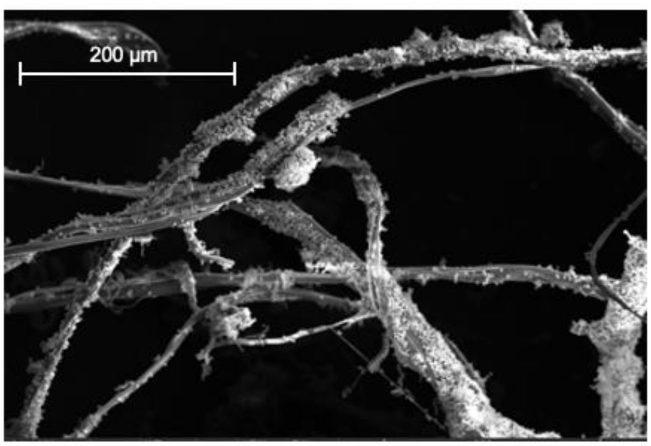

Figure 2: Scanning Electron Microscopy (SEM) image of fungal growth and dust collected from the ISS HEPA filtration cover after incubation at 100% relative humidity for 2 weeks. No microbial growth was observed via SEM in this dust until it was exposed to elevated relative humidity conditions, which would mimic a ventilation system failure or other unanticipated event with elevated relative humidity.

Environmental conditions during habitat dormancy may alter DASH composition

Future Mars and Lunar surface missions currently plan to utilize an orbital space station, such as The Gateway, as a location from which to implement surface missions down to a pre-established habitat such as an *Artemis* base camp. Initially, the Gateway will have periods of dormancy between human missions to the Lunar surface. In subsequent missions, surface habitats will have periods of dormancy until a sustainable human presence can be established. Environmental conditions in the habitat may be intentionally altered during this dormancy period to conserve power and increase longevity. Understanding how DASH will react during these dormant periods of altered environmental conditions (e.g., temperature, relative humidity, and ventilation rate) is essential for a complete understanding of the environment in which returning crews will operate, the impacts to hardware longevity, and other possible unintended consequences encountered through an understandable desire to conserve resources. This point is particularly important with respect to the potential of unintended microbial growth. Even during human occupancy, when spacecraft conditions are closely monitored, the presence of isolated pockets of moisture or increased relative humidity on localized scales can lead to fungal growth in dust or on other surfaces. On a dormant spacecraft or habitat microbial growth may not be discovered onboard until the crew returns. This can potentially lead to degradation of materials or production of allergens or toxins by proliferating microorganisms. **Understanding what happens to DASH during Earth-based simulated dormancy periods can inform environmental condition parameters in habitats when the crew is not present and prevent sub-optimal conditions in habitat while crew is not onboard.**

Exploring how DASH can be repurposed for sustainable uses

During long-term crewed space missions, there will be a constant supply of DASH. Cleaning of DASH will create a significant amount of waste, which will be in vacuum bags. The logistical challenges of storage on the ISS are substantial, and the overall volume of storage needed to facilitate handling of unusable waste occupies valuable space inside of any spacecraft or habitat. Most of the vacuum bags containing DASH from the ISS are typically trashed in unmanned non-reusable vehicles along with other waste, which burns up in the atmosphere. This is costly and future work aims to have mostly reusable vehicles so this disposal practice will not always be available for LEO missions. For missions beyond LEO, the ability to dispose of waste through these methods will not be an option. Consequently, developing ways in which to prevent microbial growth in DASH during storage, or scenarios that employ novel reuse applications for the unique matrix of microorganisms, particulates, and chemicals that make up DASH are all important areas of research. For example, if microbes are present in DASH that are capable of degrading spacecraft materials, these could potentially be used to help create a bioreactor to break down unwanted materials waste, such as plastics [15], organic compounds [16], or heavy metals[17]. DASH may therefore be a key component to further creation of a sustainable logistics and material cycle that includes other waste onboard. **Discovering a way to utilize DASH waste for other useful purposes during a mission will reduce DASH and potentially other waste products and create a sustainable cycle that can alleviate the need for further materials or processes to deal with these waste types.**

Earth-based applications

Understanding the composition and functions of microbial communities in DASH can lead to many potential Earth-based applications. The unique gravity, radiation, CO_2, reduced cabin pressure, and other conditions on a spacecraft or surface habitat may activate novel metabolic pathways and provide compounds that are useful to pharmaceutical [18] or industrial purposes [19]. In addition, developing streamlined, compact, and autonomous processes that would be required for analyzing RNA or DNA in a space environment would be beneficial to many Earth-based researchers from medical to environmental microbiology study areas. Successfully developing techniques to monitor DASH in space habitats for environmental contaminants can be applied to Earth-based processes such as monitoring for viral agents (e.g., SARS-CoV-2) in buildings with vulnerable populations [20] or monitoring other isolated indoor environments such as remote research outposts or submarines for contaminants that could impact occupant health. **Developing novel and efficient methods for microbial and chemical analyses in DASH can improve Earth-based monitoring for contaminants to better protect occupants in resident and commercial indoor environments.**

Recommendations

Recommendation #1: Understand how microbial, chemical, and particulate components of DASH will react in a wide variety of changing environmental conditions that may be experienced during a long-duration crewed space mission. Dust collected from the ISS can be used to understand these effects through incubations at varying radiation levels, relative humidity conditions, CO_2 concentration in the air, and gravity conditions.

Recommendation #2: Develop molecular based DNA/RNA extraction and quantification protocols that can be performed onboard a spacecraft or habitat which are essential for a sustainable, safe indoor environment for the crew. To date, most microbial and chemical analyses related to DASH from the ISS are performed by Earth-based laboratories. Once beyond LEO, sending samples back to Earth for analyses will not be as feasible and even now the return trip may affect the microbial communities present in DASH. Developing on-board capability will provide rapid and more accurate results for contaminants contained in DASH that will inform the crew of the real-time conditions of their environment.

Recommendation #3: Determine potential reuse cases for DASH to reduce volume and mass of this waste type that needs to be stored in the limited space onboard a habitat and spacecraft. Discovering useful microbial functions via RNA analyses, such as material degradation, can provide a purpose for DASH that will be generated and collected in large quantities during a long duration crewed mission.

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