


Nanoparticles Sampling inside the International Space Station

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Abstract

Nanoparticles were collected inside the International Space Station (ISS) with a thermophoretic sampler named Diapason (DTM Technologies, Modena, Italy), a device based on thermophoresis, a phenomenon whereby small particles suspended in a gas with a temperature gradient move towards the lower temperature region. Particles measuring from a few nanometers up to about 2 μm were deposited on transmission electron microscope grids and examined under a transmission electron microscope. The particles sampled were prevalently agglomerates of primary particles. Many of the aggregates examined were made up of multiple elements, prevalently Ca, Al, Si, K, Ca, Na, S, Ni and Ti. The preliminary results showed that the Diapason thermophoretic sampler works satisfactorily even in microgravity conditions and allows the measurement of ultrafine particles, which are the most dangerous for human health.

Keywords

Aerosol, Brownian Motion, Diapason, Gravitational Deposition, Microgravity, Nanoparticle, Thermophoresis, Thermophoretic Sampler

1. Introduction

Aerosol is the suspension in the gas of solid or liquid particles measuring from a few nanometers to tens of microns. Aerosol contains either primary particles, which are directly emitted into the atmosphere, or gaseous precursors that, on contact with the atmosphere, are transformed either by nucleation, condensation, coagulation or photochemical generation into secondary particles [1].

Primary sources may be either natural (e.g., marine biological particles, forest fires, mineral dust, etc.) or anthropogenic (vehicular, aerial and sea traffic, biomass burning, industrial emissions) [2].

Aerosols vary in size and composition according to the sources of contamination. About 10% of the total aerosol in the atmosphere is generated by human activity, whereas the remaining 90% is naturally generated [3].

Particulate matter (PM) in the atmosphere is classified according to its aerodynamic diameter into ultrafine particles (UFP_s), with a diameter less than 100 nm (also called nanoparticles); fine particles, with a diameter between 0.1 and 2.5 μm. These and ultrafine particles are known as PM_{2.5}; coarse particles have diameters greater than the PM_{2.5}.

PM₁₀ denotes all ambient particular matter (*i.e.*, ultra-fine, fine and coarse particles) having a diameter of 10 μm or less. They are sometimes termed “thoracic” particles since they are not blocked by the initial defences of the nose and throat and penetrate beyond the larynx to deposit along the thoracic airways [4] [5].

By far, the largest number of particles in the atmosphere falls into the ultrafine size range, which, although dominating the surface area of particulate pollution, contributes little to the PM mass.

Nanoparticles (NPs) arise largely from primary combustion emissions (vehicular exhaust, airplane engines, forest fires, industrial emission etc.) and from secondary particles produced by gas-to-particle conversion processes. NPs are present and produced also by living organisms ranging in size from microorganisms, such as bacteria, algae and viruses, to complex organisms, such as plants, insects, birds, animals and humans.

As regards their effects on health, UFPs are easily transported via nasal and oral routes through the respiratory system, and deposited by Brownian motion in the lung, penetrating the pulmonary alveoli, and subsequently various other organs of the human body, such as the brain, causing a range of disorders, including cardiovascular and neurological diseases. The health effects of UFP are prevalently studied on Earth at atmospheric pressure. Very few studies have been conducted on their effects in low gravity conditions, such as inside a space station.

Astronauts on the ISS spend all of their time in a confined environment that abounds with aerosol sources: the occupants’ activities, personal hygiene practices, emissions from building materials, on-board electronic equipment, living organisms, etc. In microgravity conditions, aerosol composition and size distribution differ from those on Earth, primarily on account of the different sources, but also due to the mechanisms by which aerosols are removed.

Pollution is not uniform within the ISS because it depends on the experimental activity carried out in the various areas of the space station and on the large volume of the ISS, approximately 900 m³.

In the atmosphere, coarser particulate matter is removed by gravitational settling while smaller particles may be removed by Brownian diffusion, coagulation or thermophoresis [6] [7]. In microgravity conditions, particles do not settle, resulting in coarse particles remaining airborne. In addition, microgravity causes a variation of aerosol deposition in the human respiratory system compared to atmospheric pressure [8].

On Earth, aerosols $> 0.5 \mu\text{m}$ are deposited in the respiratory tract through sedimentation and impaction due to gravity. In microgravity conditions, gravitational particle sedimentation in the lung is reduced. Once deposited in the lung via Brownian motion, NPs may translocate into the bloodstream to other organs, presenting a higher risk for human health. NP sampling is used to ascertain composition, concentration, size distribution, and emission sources on the ISS; therefore, it is imperative to understand whether these aerosols have a significant impact on astronaut health.

In addition to particulate, inorganic gases (CH_4 , H_2 , CO), volatile organic contaminants (halocarbons, aldehydes, aromatics, alcohols, etc.) and bioaerosols should also be monitored to ensure good air quality inside the ISS. This topic is, however, beyond the scope of this paper.

2. Experimental

This paper details the NP measurements performed inside the ISS as part of the agreement between the National Aeronautics and Space Administration (NASA) and DTM Technologies (Modena, Italy). A device (named Diapason) was designed and built by DTM for sampling airborne NPs ranging from a few nanometers to 2 microns. Very small (length 160 mm, width 120 mm, height 45 mm) and low weight (225 g), the Diapason functions on two 1.5 V rechargeable batteries. Sampling can last as long as 12 h without recharging the batteries.

A prototype of the Diapason was successfully tested within the framework of the NASA flight opportunities programme on 21 June 2013 during a 13-minute sub-orbital flight on UP Aerospace's SpaceLoft XL vehicle launched from Spaceport America in New Mexico.

Results showed that particles from a few nanometers up to about $2 \mu\text{m}$ were successfully captured on all grids. SEM images of the substrate were observed on each grid, and the particles collected were successfully examined. Post-flight inspection of the payload did not reveal any fracture or failure to the instrument.

The Diapason is based on thermophoresis, a phenomenon whereby small particles suspended in a gas with a temperature gradient move towards the region of lower temperature. Thermophoretic velocity depends on various parameters, such as temperature gradient, kinematic viscosity, thermal conductivity, and gas pressure, but also on the physical parameters of the particles themselves, *i.e.*, their diameter and thermal conductivity.

The smaller the aerosol diameter, the greater the thermophoretic force, a phenomenon that facilitates the deposition of ultrafine particles. Furthermore, the microgravity conditions inside the ISS mean that there is no gravity-induced particle deposition of aerosol on the Diapason.

The instrument consists essentially of two flat metallic lamina, 20 mm long and 6 mm wide, placed at a distance of 1 mm from each other to create a small channel between the two. A micro-fan forces air to flow through this small gap. One lamina, fixed to the housing, is heated by an electrical resistor (Polyimide thermofoil

heater), while the lamina where the particles are deposited on metallic TEM grids (3 mm diameter) is kept at the steady ambient temperature of the space station. The temperature difference between the two lamina at a distance of 1 mm is about 15°C, *i.e.*, the temperature gradient is 15°C/mm (Figure 1, Figure 2). Figure 3 shows the grids located on a lamina. Figure 4 shows an astronaut near the “small” Diapason in the U.S. Laboratory aboard the ISS.



Figure 1. Diapason sampler (exterior view).

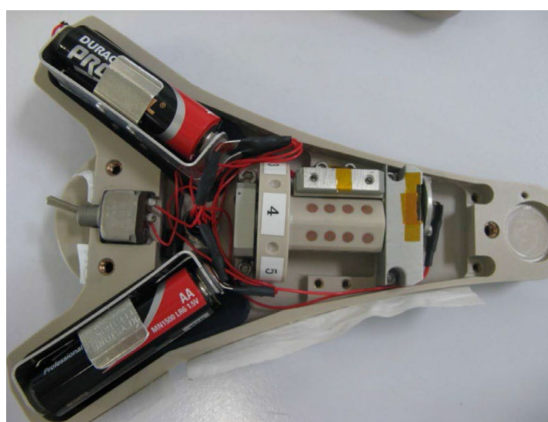


Figure 2. Diapason sampler (interior view).

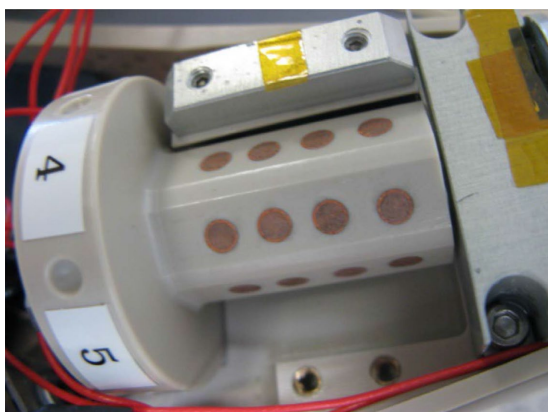


Figure 3. Diapason interior. Grids on the colder lamina.



Figure 4. NASA astronaut posing with DIAPASON in the U.S. Laboratory aboard the ISS.

3. Results

The Diapason was launched on May 28, 2013, from the Baikonur aerospace base aboard a Soyuz rocket that returned to Earth on November 10, 2013.

The Diapason was then sent to DTM laboratory, where the grids with the particle deposits were removed. Some of the grids were sent to NASA for Transmission Electron Microscope (TEM) particle analysis while others were analyzed at Department of Chemical and Geological Sciences -University of Modena and Reggio. **Figure 5** is a photograph of a single particle (12×75 nm); **Figure 6** shows the results of the TEM chemical analysis.

The particle spectrum includes one Cu peak due to the copper grid and one C peak prevalently due to the carbon film on the grid. The elements exhibited by this single specimen are Si, Ca and O, signifying it is a particle of calcium silicate.

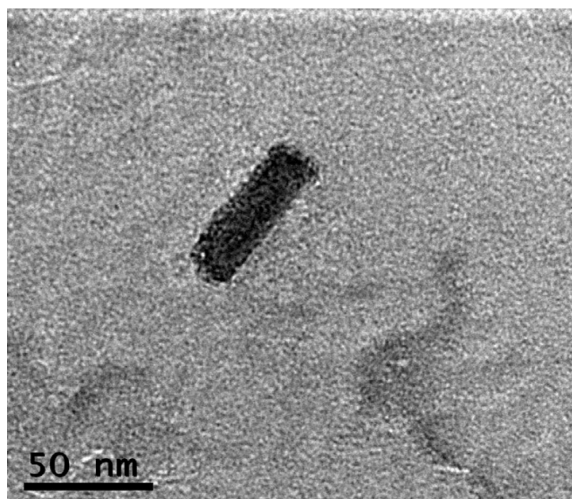


Figure 5. Particle no. 007 sampled on grid 4, Run 2.

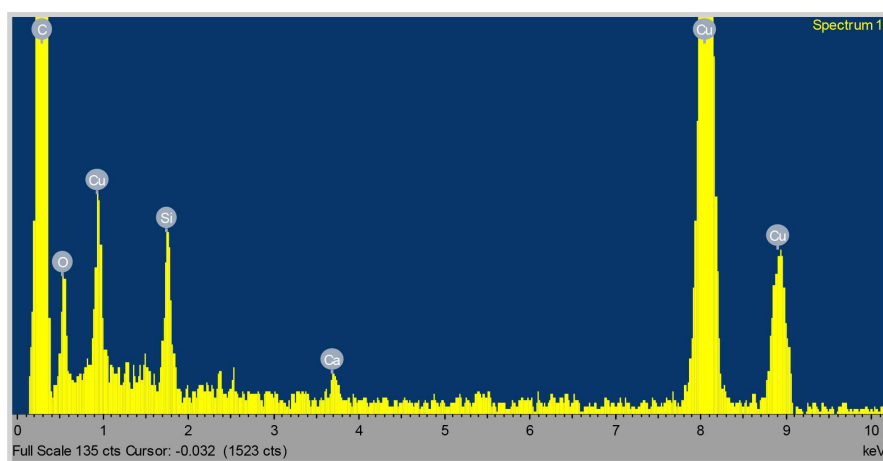


Figure 6. Spectrum of particle no. 007.

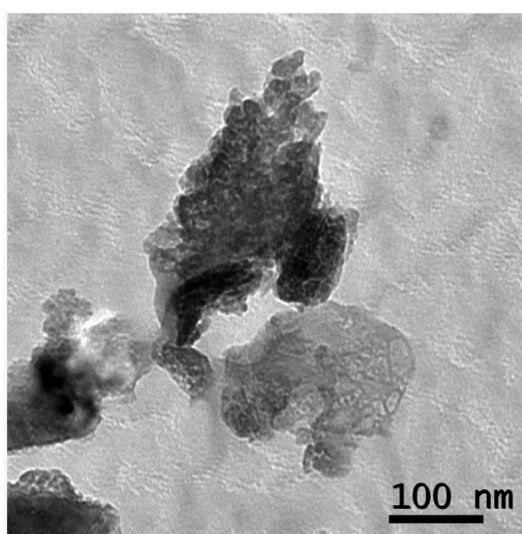


Figure 7. Aggregate no. 005 sampled on grid 1, Run 1.

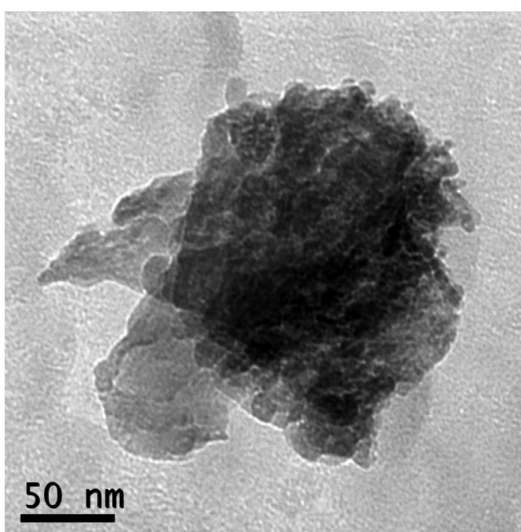


Figure 8. Aggregate no. 013 sampled on grid 1, Run 1.

Figure 7 and **Figure 8** show two-aggregates. **Figure 9** shows the TEM chemical analysis of the entire particle shown in **Figure 7** and **Figure 10** the chemical analysis of the blank, *i.e.*, the grid at a point close to the particle. To obtain the chemical analysis of the particle alone, the blank (**Figure 10**) should be subtracted from the complete analysis (**Figure 9**).

Subtracting the blank spectrum from the full spectrum indicated the presence of the following elements: Al, Mg, P, S, Ca, Ti, Cr, and Fe, with Al, Fe and Ca the prevalent elements in the aggregate. The carbon peak is due both to carbonaceous material and the carbon film on the grid surfaces. The aggregate shown in **Figure 8** shows a similar composition of elements.

Many of the aggregates examined were made up of multiple elements (prevalently Ca, Al, Si, K, Na, S, Ti, Ni, O) and exhibited uncommon morphologies. **Figure 11** shows an evident example of particle agglomeration, and **Figure 12** shows the chemical composition.

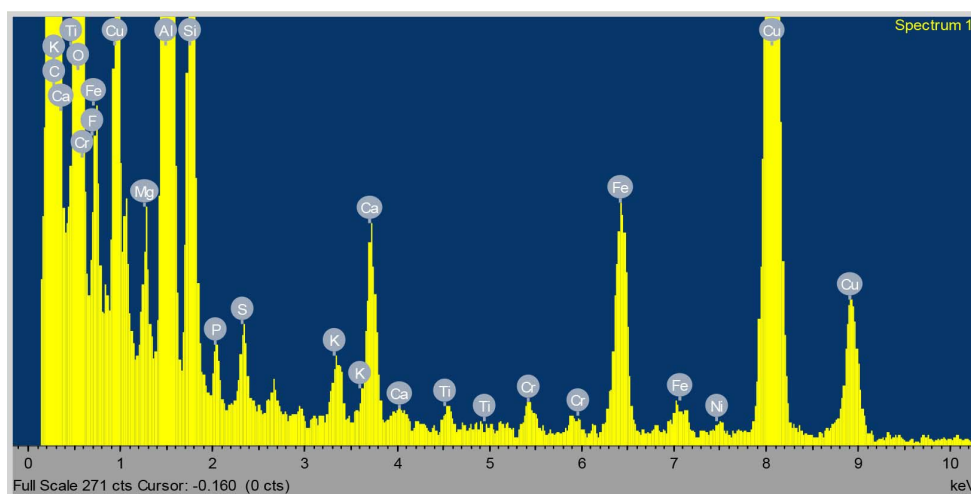


Figure 9. Spectrum of aggregate no. 005.

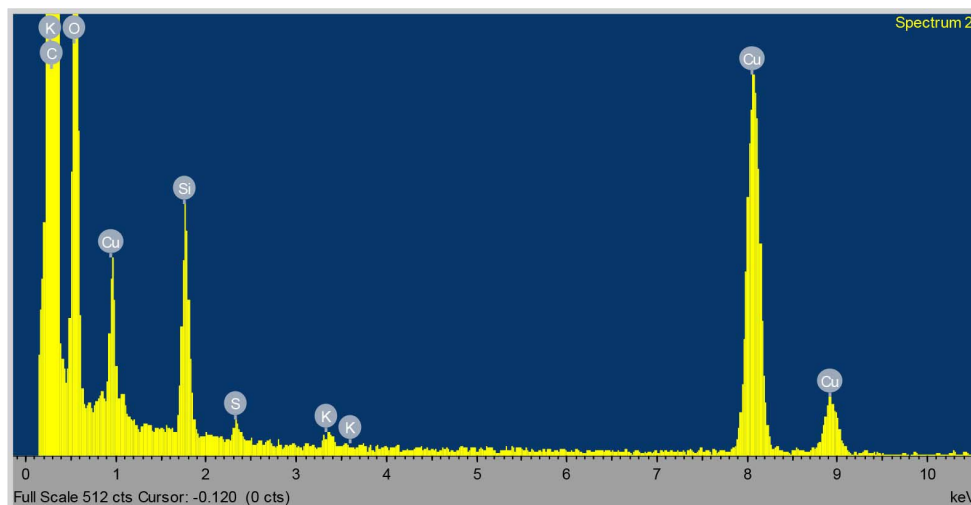


Figure 10. Blank for aggregate no. 005.

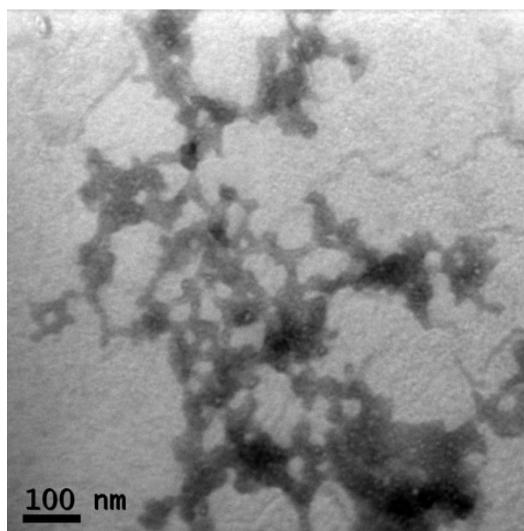


Figure 11. Aggregate no. 05 grid 4, Run 2.

4. Comparison with Published Measurements

Only a few commercial devices exist that measure concentration and/or size distribution of aerosol in terrestrial laboratories or during field campaigns. These are: the Condensation Particle Counter (CPC) measures particles as small as 5 nm; the Differential Mobility Particle Sizer (DMPS), which couples a CPC and a Differential Mobility Analyzer (DMA); and a Low-pressure Cascade Impactor measuring real-time size distribution and aerosol concentrations of 6 nm - 10 μm , etc.

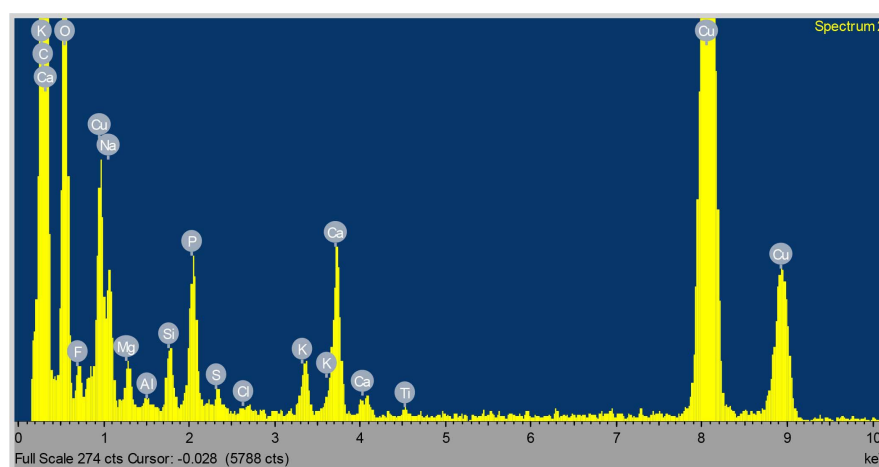


Figure 12. Spectrum of aggregate no. 05 grid 4, Run 2.

These devices may not be used inside the ISS, however, for several reasons, such as their power consumption and the pollution they generate in a closed ambient. Aerosol sampling inside ISS requires a different measuring device. Identifying particle materials (particle composition, concentrations, and size) and emission sources on the ISS is important to understand whether these aerosols have a significant impact on astronaut health.

Perry and Coston [9] analysed samples collected from cleaners on the ISS with scanning electron microscopy using energy dispersive X-ray spectrometry (SEM/EDX). The chemical composition of the particles collected during Expedition 30 - 31 (30 Dec. 2011-Jul. 2012) indicated carbon, silicon, aluminium, sodium, chlorine, and potassium as the predominant elements, with carbon and silicon being the most prevalent. We note that the particles examined are in the coarse fraction.

Subsequent to the measurements with Diapason, Meyer [10] [11] used passive samplers (surfaces exposed to air) and a commercial personal thermophoretic sampler to collect NPs from 10 nm to 250 nm directly on a transmission electron microscope grid. On return to Earth, the samples were examined under the electron microscope, which provided an overview of the airborne particulate matter in multiple locations aboard the ISS.

EDX analysis evidenced large clothing fibre as well as biological particles. Particles lower than 10 μm were identified as stainless steel. Other particles contained Al, Cl, Zr, Si, Mg, Na, Cl, K, C, Ti and O. The possible sources of the titanium dioxide particles on the ISS could be food, personal care products, clothing, paper, plastics, and paints.

Air quality inside the ISS was measured during 2016 and 2018 [12] [13] with a real time Airborne Particulate Monitor (APM) that combines two aerosol instruments in one box. A virtual impactor diverts the minor flow of coarse particles (from 2 to approximately 20 micrometres) whose concentrations are then measured by a miniaturized water-based condensation particle counter (CPC); the major flow of small particles (from 5 nm to 3 micrometres) is measured with an optical particle counter.

Despite the small number of particles examined with the Diapason, it is possible to make qualitative assessments by data comparison with the above-mentioned measurements taken subsequently on board the ISS. The elemental particle/aggregate composition observed during these subsequent campaigns is prevalently in agreement with the Diapason results. Moreover, to the best of our knowledge, our Diapason readings were the first to use a thermophoresis-based method on the ISS. The aggregation of millimetre and submillimetre particles made up of several types of material was measured during ISS—Expedition 30 (2011-2012). Importantly, it was found that sub-millimetre particles aggregate rapidly to form clusters while round, smooth particles aggregate weakly or not at all [14].

Meyer [11] also examined the aggregation of particles sampled with a passive aerosol sampler on the ISS, concluding that the mechanism of formation of many aggregates is probably through the agglomeration by electrostatic forces of primary particles, with diameters in the range below one micron up to tens of micrometers.

5. Conclusions

We used a new thermophoretic sampler on the ISS to capture particles on 3 mm-diameter copper grids covered with a thin film of pure carbon. Four grids were sent to NASA laboratories for analysis, and others were examined at the Depart-

ment of Chemical—University of Modena and Reggio Emilia.

The elements most frequently observed in the NPs examined were Ca, Al, Si, K, Na, S, Ti, and Ni.

The uniform deposition of aerosol (from 2 nm to about 2 μm) observed on TEM grids and observation of similar particle chemical composition readings to those reported in previously published papers [10] [11] would strongly suggest that the Diapason works very satisfactorily even in microgravity conditions.

Thanks to its very small size (maximum length 160 mm, maximum width 120 mm, height 45 mm), very low weight (225 g), the device can be moved easily to different positions inside the ISS, allowing aerosol sampling at different points. This is important since the aerosol concentration and chemical composition depend on the particular activities carried out in the different areas of the ISS. The samples collected by Diapason in conditions where air flow rates and volumes sampled are known, can then be examined under the electron microscope to assess the size distribution, concentration and chemical composition of aerosol from a few nanometers to 2 μm .

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

- [1] Chu, B., Kerminen, V., Bianchi, F., Yan, C., Petäjä, T. and Kulmala, M. (2019) Atmospheric New Particle Formation in China. *Atmospheric Chemistry and Physics*, **19**, 115-138. <https://doi.org/10.5194/acp-19-115-2019>
- [2] Moreno-Ríos, A.L., Tejada-Benítez, L.P. and Bustillo-Lecompte, C.F. (2022) Sources, Characteristics, Toxicity, and Control of Ultrafine Particles: An Overview. *Geoscience Frontiers*, **13**, Article ID: 101147. <https://doi.org/10.1016/j.gsf.2021.101147>
- [3] Sonwani, S., Madaan, S., Arora, J., Suryanarayan, S., Rangra, D., Mongia, N., *et al.* (2021) Inhalation Exposure to Atmospheric Nanoparticles and Its Associated Impacts on Human Health: A Review. *Frontiers in Sustainable Cities*, **3**, Article 690444. <https://doi.org/10.3389/frsc.2021.690444>
- [4] Kelly, F.J. and Fussell, J.C. (2012) Size, Source and Chemical Composition as Determinants of Toxicity Attributable to Ambient Particulate Matter. *Atmospheric Environment*, **60**, 504-526. <https://doi.org/10.1016/j.atmosenv.2012.06.039>
- [5] Macko, M., Antoš, J., Božek, F., Konečný, J., Huzlík, J., Hegrová, J., *et al.* (2022) Development of New Health Risk Assessment of Nanoparticles: EPA Health Risk Assessment Revised. *Nanomaterials*, **13**, Article 20.

<https://doi.org/10.3390/nano13010020>

- [6] Santachiara, G., Prodi, F. and Belosi, F. (2012) A Review of Thermo- and Diffusion-Phoresis in the Atmospheric Aerosol Scavenging Process. Part 1: Drop Scavenging. *Atmospheric and Climate Sciences*, **2**, 148-158. <https://doi.org/10.4236/acs.2012.22016>
- [7] Bakshi, S., He, Z.L. and Harris, W.G. (2014) Natural Nanoparticles: Implications for Environment and Human Health. *Critical Reviews in Environmental Science and Technology*, **45**, 861-904. <https://doi.org/10.1080/10643389.2014.921975>
- [8] Prisk, G.K. (2000) Invited Review: Microgravity and the Lung. *Journal of Applied Physiology*, **89**, 385-396. <https://doi.org/10.1152/jappl.2000.89.1.385>
- [9] Perry, J.L. and Coston, J.E. (2014) Analysis of Particulate and Fiber Debris Samples Returned from the International Space Station. *The 44th International Conference on Environmental Systems*, Tucson, 13-17 July 2014, 1-12.
- [10] Meyer, M.E. (2018) Results of the Aerosol Sampling Experiment on the International Space Station. *48th International Conference on Environmental Systems, ICES-2018-100*, New Mexico, 8-12 July 2018, 1-12.
- [11] Meyer, M.E. (2019) Further Characterization of Aerosols Sampled on the International Space Station. *49th International Conference on Environmental Systems, ICES-2019-246*, AIAA, Boston, 7-11 July 2019, 1-11.
- [12] Meyer, M.E. (2020) Airborne Particulate Monitor: A Real-Time Reference-Quality Aerosol Instrument Payload for ISS Air Pollution Quantification. *50th International Conference on Environmental Systems, ICES-2020-65*, Lisbon, 12-16 July 2020, 1-9.
- [13] Meyer, M.E. (2022) Lessons Learned from the Airborne Particulate Monitor ISS Payload. *51st International Conference on Environmental Systems, ICES-2022-311*, St. Paul, 10-14 July 2022, 1-13.
- [14] Love, S.G., Pettit, D.R. and Messenger, S.R. (2014) Particle Aggregation in Microgravity: Informal Experiments on the International Space Station. *Meteoritics & Planetary Science*, **49**, 732-739. <https://doi.org/10.1111/maps.12286>