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Biofilm and human spaceflight

On Earth, biofilms are ubiquitous and represent the predominant mode of growth by microorganisms in their natural environments including those of biomedical and industrial importance [1,2]. While microbial contamination has been reported on the Mir (1986–2001) and earlier spacecraft, notably Skylab (1973–1979) [3], the first experimental evidence of biofilm formation during spaceflight was reported with *Burkholderia cepacia* flown on STS-81 in 1997 [4] and *Pseudomonas aeruginosa* during a 1998 experiment on STS-95 [5]. Biofilm formation has since been confirmed in a number of other spaceflight and microgravity analog studies (reviewed in Ref. [6]). Due to the potential risk of damage to key spacecraft materials and instrumentation, biofilms represent a risk that must be addressed for future human space missions beyond low Earth orbit [7]. In this special issue of *Biofilm*, several notable publications are presented that all enhance the understanding and the importance of biofilms in space.

Two manuscripts in the special issue provide a review of biofilms in space. Velez Justiniano *et al.* [8] describe both the positive and negative impacts of biofilm that need to be considered for long term space travel. In their paper, they present a schematic and detailed description of where biofilm may grow and therefore where astronauts may contact biofilm. Each section ends with a list of knowledge gaps and research needs at the time the paper was written. This theme is continued by Marra *et al.* [9] as they explore how biofilm may propagate in space habitats and what this means for astronaut health. Are biofilms in space more pathogenic and possess a larger threat than on Earth?

While research on biofilms in space dates to the late 1990s and early 2000s, it was during a workshop in 2019 that a team of researchers began discussing the importance of biofilm in the water recovery system on the International Space Station (ISS) [7]. This system processes water recovered from the humidity condensate system and the urine processor assembly. Biofilm growth may lead to equipment malfunction, thus it is critical to explore strategies to control and mitigate biofilm formation in this system during operation and dormancy. Nguyen *et al.* [10] identified the relative abundance of microorganisms in samples collected from used hoses on the ISS, characterized the microbial colonies, as well as captured images that documented that biofilm was the culprit. Diaz *et al.* [11] focused on one of the species recovered from the water processor assembly, *Burkholderia contaminans*, which they cultivated in a low shear modeled microgravity reactor to study how *B. contaminans* responded to the presence and absence of different essential nutrients. Mettler *et al.* [12] continued the exploration into the importance of growth media from the lens of planetary protection and the ability of brines on Mars to support the growth of terrestrial microbes. Demir *et al.* [14] investigated the use of an antimicrobial surface coating, N-halamine, to control biofilm growth in the water systems necessary for long term space travel. Finally, Espinosa Ortiz *et al.* [13] investigated using biofilm as a water treatment solution, rather than considering biofilm as a problem for long term space travel.

There is still a lot that we do not know about biofilm in space - we do not even know if the research done on Earth (for example using reactors to simulate microgravity), is translatable for how biofilm exists in space and if the biofilm has similar characteristics including virulence. Decisions based on risk-benefit calculations may need entirely new input parameters and initiatives for how biofilm impacts planetary protection will also be required. Regardless, we know that as a result of human spaceflight, we (and biofilms) will boldly go where no one has gone before.

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