Technology Development and Demonstration

Dr. Dmitry Oleynikov remotely operates a surgical robot aboard the International Space Station using controls at the Virtual Incision offices in Lincoln, Nebraska. **Robotic Surgery Tech Demo** tests techniques for performing a simulated surgical procedure in microgravity using a miniature surgical robot that can be remotely controlled or teleoperated from Earth. Image courtesy of the University of Nebraska-Lincoln. NASA ID: jsc2024e041215.

Highlights in Technology Development and Demonstration

Future exploration — the return to the Moon and human exploration of Mars — presents many technological challenges. Studies on the space station can test a variety of technologies, systems, and materials that are needed for future exploration missions. Some technology development investigations have been so successful that the test hardware has been transitioned to operational status. Other results feed new technology development.

EXPLORATION

The NASA **Microgravity Investigation of Cement Solidification (MICS)** observed hydration reactions and microstructure formation in cement paste on the space station. As part of the human exploration roadmap, it is important to develop methods for civil engineering, construction, and manufacturing of industrial materials using the local environment. Due to the extensive costs associated with transporting materials to space, future missions require sustainable methods for constructing industrial materials and habitats to protect humans and equipment from extreme environments. Researchers use different types of regolith to learn more about hydration reactions and solidification in a low gravity environment.

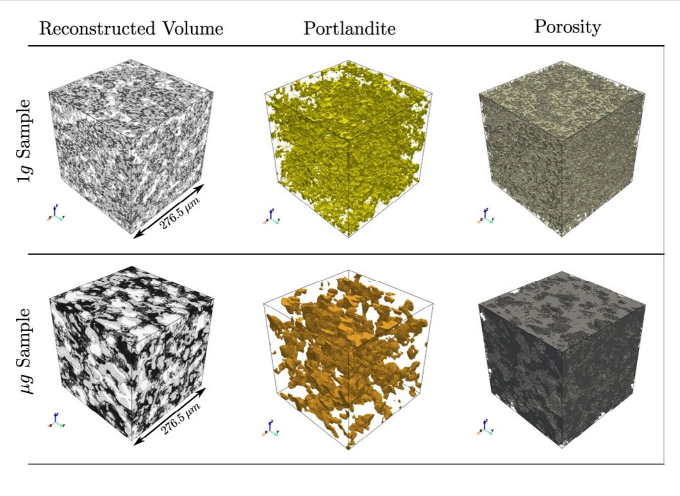

Figure 29. 3D reconstructed cement samples compared between Earth (1g) and microgravity. *Image adopted from Saseendran, npj Microgravity*.

Recently in the field of materials science, 2D to 3D reconstruction has become widely used to predict mechanical and physical properties. In a new *npj Microgravity* publication, artificial intelligence was used to create 3D models from microscope image scans of tri-calcium silicate cement samples formed on the space station.[27] The artificial intelligence model allows for prediction of mechanical and physical properties that can only be adequately captured in 3D. Additionally, the deep-learning model could be used to scale up 2D models for use in large scale concrete structures.

Researchers found that the hydrated space-returned samples had approximately 70% more porosity content than ground samples (Figure 29). It is important to identify porosity and trapped air potentials when planning for infrastructure on the Moon because these characteristics influence the strength of any concrete-like material.

Results from this investigation help to improve researchers' understanding of cement hardening, crystal growth and hydration kinetics, and pore distribution. Results from the MICS investigation may be used to improve concrete properties. Improved cement properties could also help enhance infrastructure practices on Earth through better structural integrity and reduced carbon dioxide emissions.

DISCOVERY

The **Experimental Studies Of The Possible Development Of Microscopic Deterioration Of ISS RS Module Structural Elements When Impacted By The Components Of The Station's External Atmosphere And Conditions Promoting The Life Of Microflora On Pressure Hull Surfaces Under MLI (Test)** investigation, conducted by Roscosmos and the Russian Academy of Sciences, used hardware on the external environment of the space station to determine the potential for biological life to persist in the vacuum of space.

In a new study published in *Scientific Reports*, researchers selected three different types of microorganisms previously found on the exterior of the space station (bacteria, fungi, and archaea) and evaluated their survivability in the harsh environment of space.[28]

To assess survivability, researchers deposited the three microorganisms onto cotton wool and wrapped the cotton around a metal rod. The metal rod and cotton were exposed directly to the space environment with no material interference. In other exterior facilities, special barriers such as metal casings, membranes, filters, and glasses, may mitigate the full range of space physical factors on microorganisms. The experiment hardware was installed on the exterior of space station via a spacewalk, where it remained for segments of 12 and 24 months.

Researchers found that bacteria, fungi, and archaea can survive the harsh conditions of space for at least two years (Figure 30). Compared to ground controls, archaea showed slow growth and fungi showed increased resistance to radiation and a reduced reaction to stress factors such as disinfectants. A cyst-like form was also observed in the archaea species, which displayed the presence of a novel multilayer thickened cell membrane.

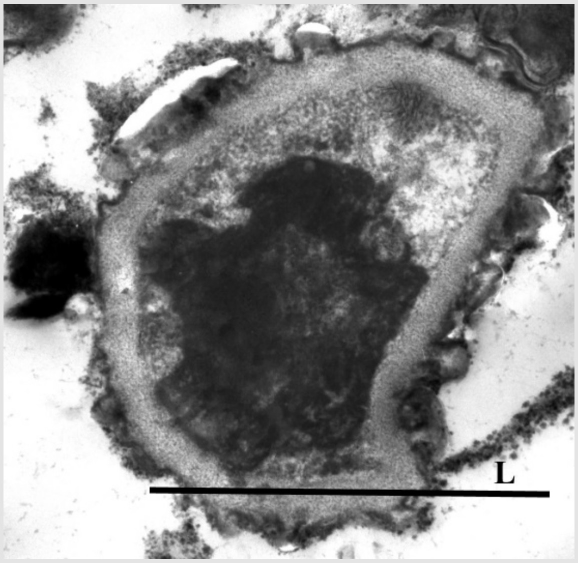

Figure 30. Scanning electron microscope image of Methanosarcina mazei S-6T cell (archaea) from the isolate obtained after the 24-months exposure. *Image adopted from Deshevaya, Scientific Reports*.

Researchers hypothesize that enhanced survival of these microorganisms is due to partial freezing and dehydration in space. It is also possible that the outer fibers of cotton wool provided mild shielding from the Sun's ultraviolet radiation, and the microorganisms located on the inner fibers of cotton wool were partially protected from ultraviolet radiation effects, increasing their survival odds.

These results take researchers a step closer to understanding how the seeds of life can be propagated through space. Understanding the survivability of microorganisms during space travel could help prevent the return of harmful microbes to Earth and limit biological contamination of spacecraft or other planetary bodies.

EXPLORATION

The ESA investigation **Fiber-optic Active Dosimeter (Lumina)** uses an embedded dosimeter in a high-speed fiber optic to measure, in real-time, radiation levels on station by darkening the fiber optic after exposure to ionizing energy photons. Higher radiation doses lead to more signal loss at the end of the fiber, allowing researchers to use this information to monitor radiation changes.

Signal loss is additionally examined using different optical fibers (infrared and visible light) to better understand fiber behavior after extended periods of time in space. Accurate measurement of ionizing radiation on station could help crew members respond to radiation flares, allowing them to implement a plan of action prior to a hazardous incident.

Lumina arrived on station in 2021 and operated for more than 699 days before the first analysis was conducted (Figure 31). In a new study published in *IEEE Transactions on Nuclear Science*, researchers reported that the Lumina instrument detected slight increases in radiation levels related to solar particle events or solar flares.[29]

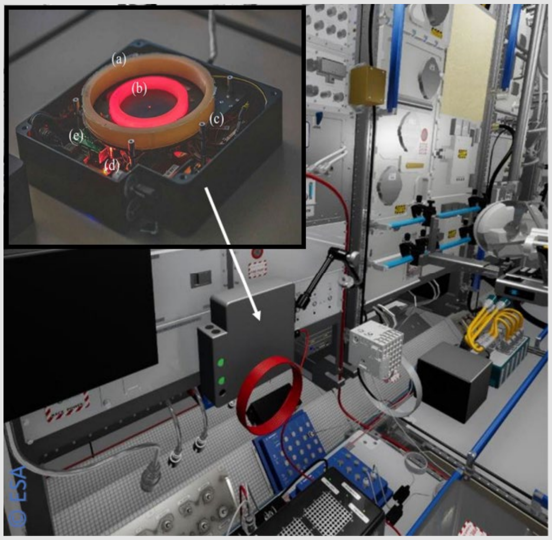

Figure 31. Digital mockup of the Columbus module on station. Inset shows fiber coils and boards inside the investigation. *Image adopted from Roche, IEEE Transactions on Nuclear Science*.

These increases were primarily observed near Earth's poles and sometimes over the South Atlantic Region. Additionally, the fiber optic designed for visible light spectrum measurements appeared more sensitive and better able to detect changes in radiation.

Results from this proof-of-concept study demonstrate that the technology employed in Lumina can effectively track radiation and assist the crew in mitigating the risks associated with high energy emissions.

Crew members on station have been breathing the same air for years. Inhaling small particles suspended in the air, known as bioaerosols, can cause allergies as well as nose and eye irritation, so an air revitalization system is necessary to clean the air. The NASA investigation **Aerosol Sampling Experiment (Aerosol Samplers)** uses powerful microscopes to examine airborne particles returned from station. A better understanding of the sizes, shapes, composition, and origin of the particles onboard can inform the design of particulate monitors and spacecraft fire detectors for crew health, safety, and comfort.

DISCOVERY

To learn how elevated moisture on station, typically found in hygiene, exercise, food, and plant habitat areas, affects microbial growth, researchers collected dust samples from vacuum bags from residential homes on Earth and on station. Characterization of bacterial and fungal communities residing in the dust were performed while dust was exposed to varying moisture conditions.

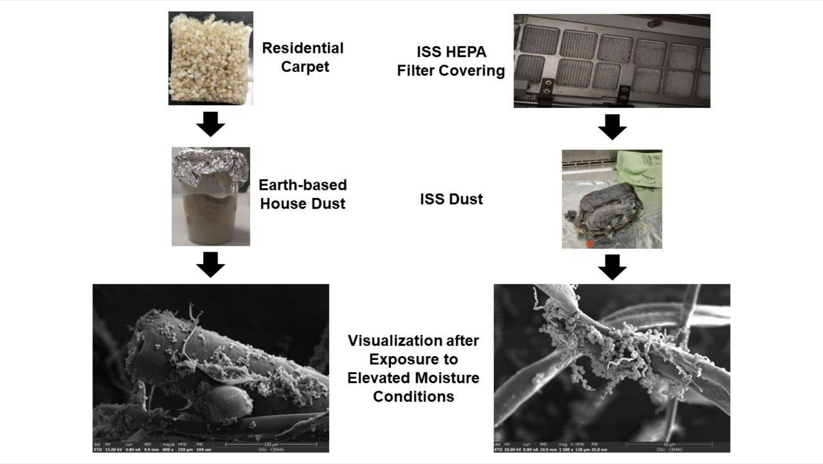

Figure 32. Fungal communities on Earth and station. *Image provided by the Aerosol Samplers research team*.

The results published in *Scientific Reports* revealed that fungal communities in Earth samples were much more diverse than station samples with Aspergillus being most abundant on station while on Earth Epicoccum dominated.[30] This finding applied to both high and low moisture conditions (Figure 32). Analyses also demonstrated a higher bacterial diversity on Earth than on station, with an abundant family of Paenibacillaceae on station, and Staphylococcaceae and Bacillaceae on Earth. Between fungi and bacteria, fungi appeared to be more sensitive to increased moisture both on the station and on Earth.

As human activity increases in space for both low Earth orbit and beyond, it becomes increasingly important for life support engineers, toxicologists, and biologists to fully understand the risk to health from the accumulation of microorganisms in a confined space. These findings enable future spacecraft designers to create healthy indoor microbiomes that support crew health, spacecraft integrity, and planetary protection.

If you are interested in learning more about microbial contamination on station, how to execute microbial experiments in space, and research sponsors, read our **Researcher's Guide to: Microbial Research**. *This guide also includes a comprehensive review of microbial research describing the genetic characteristics and interactions of microbes with plants and humans.*

References

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