Spacecraft Water Monitoring: Adapting to an Era of Emerging Scientific Challenges

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The International Space Station (ISS) obtains water from a variety of sources. Ground-supplied water is launched reliably to station on Russian Progress vehicles, via the European automated transfer vehicle, and by means of the Japanese H-II transfer vehicle. Another key source is potable water transferred from the shuttle; this high-quality water is generated as a by-product of the shuttle fuel cells. The ISS has the capability to use recycled humidity condensate and even urine reclamation to "recycle" water. The NASA publication "Spacecraft Water Exposure Guidelines" http://hefd.jsc.nasa.gov/toxeg.htm#sweg provides chemical-specific environmental challenges and health-based guidelines for the shuttle and the station. These limits are used to develop water-quality-monitoring technologies (Table 1).

The ISS is a closed-loop environment, so water quality controls are essential. Bladder/tank materials, added biocides, pollutants in source water, and unintended contributions from processors can negatively impact a spacecraft water supply that has no appropriate protections. Scientists discovered a variety of anomalies from water samples returned from the shuttle, Russian Space Station *Mir*, and ISS. Monitoring and anomaly mitigation from a remote environment is clearly a challenge. This report focuses on these challenges.

Water data are currently acquired through archive sampling or various real-time techniques. The ISS has 300-ml or 1-L bags for on-orbit collection. These bags are returned to the ground by Russian Soyuz or shuttle flights for testing, which allows for full microbial and chemical characterization. The weakness in this procedure is that it requires crew time, upmass for bags and adapters, and downmass for sample return, and it does not allow for in-flight decision-making.

ISS has a total organic carbon analyzer (TOCA) that works in conjunction with the water recovery systems on both the shuttle and the station. The TOCA provides information by taking compounds in the water, oxidizing them to carbon dioxide (CO_2), and reading the CO_2 level. It then provides screening indicators for water safety. The returned archive samples are analyzed to fully determine what compounds are associated with that organic carbon level.

Water-inoculated agar plates provide in-flight microbial analysis to determine the total bacterial count, and the archives allow for interpretation of microbes that are present. Water-inoculated agar plates provide in-flight microbial analysis to determine the total bacterial count, and the archives allow for interpretation of microbes that are present. The ISS also carries coliform bags that change colors in the presence of certain indicator organisms.

With the imminent retirement of the shuttle, downmass is more limited than upmass because of the reliance that will be placed on the Russian Soyuz capsule. As water can be relatively heavy to return, the new six-person crew is adding pressure for upmass and downmass to support systems on the ISS and to allow for troubleshooting. Ground control must be able to check out and provide data to all stakeholders on the function of these new systems. NASA therefore needs new hardware that is rugged, noncomplex, and less dependent on archives and resupply.

A number of potential technology needs exist at this time, including the need for a total alcohol detector since alcohol is a priority for environmental control. A front-end unit for water monitoring that is compatible with in-flight air monitoring systems (i.e., one piece of equipment that monitors both air and water) is also needed, as is a chemical-specific colorimetric test strip that would provide an indication of water contamination. To complicate this technology development, air-water interfaces in microgravity differ from those on Earth. For example, water bubbles in space do not escape the same way as they do on Earth. Simply put, small things can cause big complications, false results, and equipment failures.

A number of vital questions address the suitability of a technology to the unique conditions of Exploration missions. These are as follows:

Can the technology meet the required analytical detection limits?

Does the technology require resupply of consumables?

Does the technology use chemicals or reagents that can pose a crew health concern in a closed-loop spacecraft environment?

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Does the technology have the specificity to handle mixtures of pollutants without affecting the reliability of individual results?

Can the technology be adapted to the uniqueness of a microgravity environment?

Is the technology rugged enough to perform in a microgravity environment?

Does the technology minimize critical crew time/interactions?

Are weight and power needs within practical limits?

Colorimetric Solid-phase Extraction

Colorimetric solid-phase extraction (C-SPE) uses solid-phase extraction membranes impregnated with analyte-specific colorimetric reagents to rapidly and selectively measure low levels of key water quality indicators. The extractor, with water introduction, produces a color change in about 2 minutes.

A spectrometer then reads the color change and translates it into a concentration. C-SPE is used for iodine and silver, but can be adapted to other compounds as well.

The development of C-SPE is a success story because of a partnership that was formed among NASA, business, and academia. Iowa State University, Ames, scientists were developing a novel technology that could concentrate water analytes on a membrane and produce a measurable color change across a broad concentration range. Because they had to read that color change, they partnered with BYK-Gardner, Columbia, Md., who created the commercial technology used in "paint color matching." This commercially produced spectrophotometer was adapted to allow the translation of color change to analyte concentration. Through partnership with Iowa State University and BYK-Gardner, NASA thus developed a promising technology for space flight. Technical successes that arose from this three-way partnership include: small size, mass, and power needs; simplicity and adaptability; and in-flight data that can be used operationally.

ISS U.S. Laboratory condensate	Shuttle-generated fuel cell water	Ground-supplied Russian "Rodnik" water (Progress launched)
Benzyl achohol	Nickel[2]	Chloroform
Ethanol	Ethanol[1]	Manganese
Methanol	Iodine[1]	Silver[1]
Acetate	Free gas	
Formate	Cadmium[2]	
Proprionate	Lead	
Zinc[2]	Caprolactam[3]	
Nickel[2]		
Formaldehyde		
Ethylene glycol		
Propylene glycol		

[1] Related to biocide addition
[2] Generally resulting from releases from metallic heat-exchanger coatings, or dispenser parts
[3] Resulting from leaching for bladder material

Table.1. *Comparison of contaminants of concern for different potable waters.*

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