NASA STTR 2020 Phase I Solicitation

T6.06 Spacecraft Water Sustainability through Nanotechnology

Lead Center: JSC

Participating Center(s): ARC, GRC, JPL, KSC, MSFC

Technology Area: TA6 Human Health, Life Support and Habitation Systems

Scope Title

Nanotechnology Innovations for Spacecraft Water Management Applications

Scope Description

Water recovery from wastewater sources is key to long duration human exploration missions. Without substantial water recovery, life support system launch weights are prohibitively large. Regenerative systems are utilized on the International Space Station (ISS) to recycle water from humidity condensate and urine. The Water Processor Assembly (WPA) accepts distillate from the Urine Processor Assembly (UPA) and humidity condensate from condensing heat exchanges. The WPA contains multi-filtration beds to remove inorganic and non-volatile organic contaminants, followed by a catalytic oxidation reactor where low molecular weight organics not removed by the adsorption process are oxidized in the presence of oxygen, elevated temperature, and a catalyst. To stabilize urine and protect components from biofouling and precipitation, a toxic pretreatment formula is added to collected urine. Simple measurements of water composition are made during flight, including conductivity, total organic carbon and iodine concentration. For determination of ionic or organic species in water and wastewater, samples must be returned to earth.

This subtopic solicits for technologies to fill specific gaps in NASA’s water management systems for human spaceflight. Proposals must address needs in one of the three target areas specified. These areas of scope are aligned with the three specific thrusts described within the white paper of the Nanotechnology Signature Initiative (NSI) "Water Sustainability through Nanotechnology". Please see references for additional information, including water quality requirements and guidelines.

<u>Increasing Water Availability Using Nanotechnology: Removal of Problematic Contaminants from Processed Wastewater</u>

Two problematic organic compounds are recalcitrant to WPA processing on the ISS. Dimethylsilanediol (DMSD) is a silicon-containing degradation byproduct from siloxane based compounds. DMSD can violate ISS potable water quality standards over time, requiring premature multifiltration (MF) bed replacement. Dimethyl sulfone (DMSO2) is a sulfur-containing metabolic byproduct that has historically been consistently present in ISS potable water delivered to the Oxygen Generation Assembly (OGA) for electrolysis to O_2 and H_2. DMSO2 accumulates in the OGA water recirculation loop and is thus present in the OGA hydrogen product stream. When fed to the Sabatier reactor this contaminated H_2 has been shown to poison the Sabatier catalyst over time from sulfur exposure. The presence of DMSO2 is negatively impacting exploration design requirements and Concepts of Operation

(CONOPS) for the Advanced-OGA and the Sabatier subsystems, including periodic automated flushing and trace contaminant getter devices. The development of a technology or method for physicochemical removal of these contaminants, compatible with the ISS WRS/WPA, will benefit both current manned and future exploration missions. Although technical solutions are sought that involve novel utilization of nanotechnology, proposals using more conventional or alternative approaches will also be considered.

Improving the Efficiency of Water Delivery and Use with Nanotechnology: Management and Monitoring of Silver Biocide in Potable Water

NASA is considering using silver as the active biocide in potable water systems for use in future spacecraft. NASA is seeking technologies for delivery, maintenance and monitoring silver in potable water.

- NASA seeks technologies to deliver and replenish silver ions in potable water, to maintain a concentration at a chosen set point within a range of 200 to 400 ug/L. The system should be capable of operating in-line, to deliver silver at a flow rate of 0.1 to 0.15 L/min potable water. Furthermore, the device should be able to operate at ambient temperature, pH ranges between 4.5 - 9.0, and system pressures up to 30 psig (200 kPa). Moreover, the device should also be small, robust, lightweight, and have minimal power and consumable mass requirements. Additionally, candidate technologies should be microgravity compatible and have no adverse effects on the potability of the drinking water system. The technology should also be capable of providing continuous, stable and autonomous operation, and be fully functional following periods of long-term system dormancy – up to 1 year.
- Silver ions may drop out of solution, depositing on fluid lines and tank surfaces, resulting in loss of silver concentration, impacting its efficacy as a residual disinfectant in potable water. Alternative methods are sought to minimize loss of silver ions in spacecraft potable water plumbing systems.
- NASA is interested in sensing technologies for the in-line measurement of ionic silver in spacecraft potable water systems. Overall, the sensing technology should offer small, robust, lightweight, low-power, compatible design solutions capable of stable, continuous, and autonomous measurements of silver for extended periods of time. Sensors of particular interest would provide: continuous in-line measurement of ionic silver at concentrations between 0 and, at least, 1000 parts per billion (ppb); a minimum detection limit of 10 ppb or less; measurement accuracy of at least 2.5% full scale (1000 ppb); stable measurements in flows up to 0.5 L/min and pipe diameters up to ¾ inch; high sampling frequency, e.g., up to 1 measurement per minute; stable calibration, greater than 3 years preferred; minimal and/or no maintenance requirements; operation at ambient temperature, system pressures up to 30 psig (200 kPa), and a solution pH between 4.5 - 9.0; and finally, a volumetric footprint less than 2000 cubic centimeters. The sensing technology should have little to no impact on the overall volume and concentration of silver being maintained within the spacecraft water system.

Enabling Next-Generation Water Monitoring Systems with Nanotechnology

NASA is seeking miniature analytical systems to measure mineral and organic constituents in potable water and wastewater. NASA is interested in sensor suites capable of simultaneous measurement of inorganic and organic species. Spacecraft applications exist for monitoring species within wastewater (potential waste streams: urine, humidity condensate, Sabatier product water, waste hygiene, and waste laundry water), regenerated potable water and in support of on-board science. Multi-species analyte measurement capability is of interest that would be competitive to standard water monitoring instruments such as ion-chromatography, inductively coupled plasma spectroscopy, and high performance liquid chromatography. Components that enable the miniaturization of these monitoring systems, such as microfluidics and small scale detectors, will be considered. Technologies should be targeted to have >3 year service life and >50% size reduction compared to current state of the art. Ideally, monitoring systems should require no hazardous reagents, have long-term calibration stability, and require very little crew time to operate and maintain.

References

NASA is a collaborating agency with the NTSC Committee on Technology Subcommittee on Nanoscale Science, Engineering and Technology's Nanotechnology Signature Initiative (NSI): "Water Sustainability through Nanotechnology" (Water NSI). For a white paper on the NSI, see https://www.nano.gov/node/1580

A high-level overview of NASA's spacecraft water management was presented at a webinar sponsored by the

Water NSI: "Water Sustainability through Nanotechnology: A Federal Perspective, Oct. 19, 2016" https://www.nano.gov/publicwebinars

A general overview of the state of the art of spacecraft water monitoring and technology needs was presented at a webinar sponsored by the Water NSI: "Water Sustainability through Nanotechnology: Enabling Next-Generation Water Monitoring Systems, Jan. 18, 2017" located at https://www.nano.gov/publicwebinars

For a list of targeted contaminants and constituents for water monitoring, see "Spacecraft Water Exposure Guidelines for Selected Waterborne Contaminants" located at https://www.nasa.gov/feature/exposure-guidelines-smacs-swegs

Advanced Exploration Systems Program, Life Support Systems Project https://www.nasa.gov/content/life-support-systems

National Aeronautics and Space Administration, NASA Technology Roadmaps, TA 6: Human Health, Life Support, and Habitation Systems (National Aeronautics and Space Administration, Draft, May 2015, www.nasa.gov/sites/default/files/atoms/files/2015_nasa_technology_roadmaps_ta_6_human_health_life_support_habitation.pdf).

Layne Carter, Jill Williamson, Daniel Gazda, Chris Brown, Ryan Schaezler, Frank Thomas, Jesse Bazley, Sunday Molina “Status of ISS Water Management and Recovery” 49th International Conference on Environmental Systems, ICES-2019-36 https://ttu-ir.tdl.org/bitstream/handle/2346/84720/ICES-2019-36.pdf

Dean L. Muirhead, Layne Carter “Dimethylsilanediol (DMSD) Source Assessment and Mitigation on ISS: Estimated Contributions from Personal Hygiene Products Containing Volatile Methyl Siloxanes (VMS)” 48th International Conference on Environmental Systems, ICES-2018-123. https://ttu-ir.tdl.org/bitstream/handle/2346/74112/ICES_2018_123.pdf

Chad Morrison, Christopher McPhail, Mike Callahan, Stuart Pensinger “Concepts for a Total Organic Carbon Analyzer for Exploration Missions” 49th International Conference on Environmental Systems, ICES-2018-254 https://ttu-ir.tdl.org/bitstream/handle/2346/84465/ICES-2019-254.pdf

Molly S. Anderson, Ariel V. Macatangay, Melissa K. McKinley, Miriam J. Sargusingh, Laura A. Shaw, Jay L. Perry, Walter F. Schneider, Nikzad Toomarian, Robyn L. Gatens " NASA Environmental Control and Life Support Technology Development and Maturation for Exploration: 2018 to 2019 Overview", 49th International Conference on Environmental Systems, ICES-2019-297 https://ttu-ir.tdl.org/bitstream/handle/2346/84496/ICES-2019-297.pdf

Donald Layne Carter, David Tabb, Molly Anderson "Water Recovery System Architecture and Operational Concepts to Accommodate Dormancy", 47th International Conference on Environmental Systems, Paper ICES-2017-43 https://ttu-ir.tdl.org/ttu-ir/bitstream/handle/2346/72884/ICES_2017_43.pdf

Li, Wenyan, Calle, Luz, Hanford, Anthony, Stambaugh, Imelda and Callahan, Michael "Investigation of Silver Biocide as a Disinfection Technology for Spacecraft – An Early Literature Review", 48th International Conference on Environmental Systems, Paper ICES-2018-82

Expected TRL or TRL range at completion of the project for Phase I: 3

Expected TRL or TRL range at completion of the project for Phase II: 4 to 5

Desired Deliverables of Phase II:

Research, Analysis, Prototype, Hardware

Desired Deliverables Description

Phase I Deliverables - Reports demonstrating proof of concept, including test data from proof of concept studies, and concepts and designs for Phase II. Phase I tasks should answer critical questions focused on reducing development risk prior to entering Phase II.

Phase II Deliverables - Delivery of technologically mature hardware, including components and subsystems that demonstrate performance over the range of expected spacecraft conditions. Hardware should be evaluated through parametric testing prior to shipment. Reports should include design drawings, safety evaluation, test data and analysis. Prototypes must be full scale unless physical verification in 1-g is not possible. Robustness must be demonstrated with long term operation and with periods of intermittent dormancy. System should incorporate safety margins and design features to provide safe operation upon delivery to a NASA facility.

State of the Art and Critical Gaps

NASA has unique water needs in space that have analogous applications on Earth. NASA's wastewater collection differs from systems used on Earth in that it is highly concentrated with respect to urine, uses minimal flush water, is separated from solid wastes, and contains highly acidic and toxic pretreatment chemicals. NASA is interested in recovery of potable water from waste water, low toxicity residual disinfection, antifouling treatments for plumbing lines and tanks, "microbial check valves" that prevent microbial cross-contamination where water treatment and potable water systems share connections, and miniaturized sensors and monitoring systems for contaminants in potable water and waste water. NASA's goal is zero-discharge water treatment, targeting 100% water recycling and reuse. Spacecraft traveling away from Earth require the capability of a fully functional water analysis laboratory, including identification and quantification of known and unknown inorganic ions, organics, and microbes, as well as pH, conductivity, total organic carbon and other typical measurements. Spacecraft Water Exposure Guidelines (SWEGs) have been published for selected contaminants. Nanotechnology may offer solutions in all of these application areas.

Relevance / Science Traceability

This technology could be proven on the ISS and would be useful to long duration human exploration missions, including Gateway, Lunar surface, and Mars, including surface and transit. It is essential and enabling for water to be recycled to reduce launch costs associated with life support consumables. This subtopic is directed at needs identified by the Life Support Systems Capability Leadership Team (CLT) in areas of water recovery and environmental monitoring, functional areas of Environmental Control and Life Support Systems (ECLSS).

This subtopic is directed at meeting NASA's commitments as a collaborating agency in the National Nanotechnology Signature Initiative: "Water Sustainability through Nanotechnology". This initiative was established under the NTSC Committee on Technology, Subcommittee on Nanoscale Science, Engineering and Technology.