

Spacecraft Water Impurity Monitor, a System for Water Quality Analysis on Exploration Missions Beyond Low Earth Orbit

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Exploration missions beyond low-earth-orbit (LEO) will require advanced instrumentation to monitor water quality. Traveling beyond LEO means the transfer of water samples to an Earth-based laboratory for detailed analysis is not feasible. Detailed analysis of water composition during exploration is still necessary, because having the capability to determine the specific organic chemical causing a change in total organic carbon (TOC) or the specific metal or ionic species causing a change in conductivity has the potential to inform the crew health and system management decisions. On a new vehicle such as a lunar or Mars surface habitat or a Mars transit vehicle, finding “new” impurities not seen on ISS should be expected. The key is to identify the impurity so the correct action can be taken. On ISS we can measure TOC, conductivity, and other physical properties but do not have the capability for detailed analysis using vehicle instrumentation. This is acceptable because ISS can send samples down to Earth for further analysis and obtain the detailed composition. The Spacecraft Water Impurity Monitor (SWIM) will provide detailed water quality analysis for missions in which sample down mass is not available. SWIM is a system comprising organic and inorganic analysis modules. For organic chemicals, a gas chromatograph mass spectrometer (GCMS) detects and identifies organic impurities. For inorganic species, a capillary electrophoresis capacitively coupled contactless conductivity detection (CE-C4D) system as well as ion specific electrodes detect and identify metal ions and other inorganic salts / acids. The SWIM technology demonstration project has completed a System Requirements Review (SRR) to finalize detection requirements and is currently working to refine vehicle interface requirements for a future technology demonstration. The project also has begun preliminary flight design activities for the core analyzers in the instrument suite.

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Acronyms and Nomenclature

<i>C&DH</i>	=	command and data handling
<i>CE</i>	=	capillary electrophoresis
<i>CE-C4D</i>	=	capillary electrophoresis capacitively coupled contactless conductivity detection
<i>COTS</i>	=	commercial off the shelf
<i>DMSD</i>	=	dimethylsilanediol
<i>ECL</i>	=	Environmental Chemistry Laboratory
<i>ECLSS</i>	=	environmental control life support system
<i>EDL</i>	=	Entry, descent, landing
<i>EMU</i>	=	extravehicular mobility unit
<i>EPA</i>	=	Environmental Protection Agency
<i>EVA</i>	=	extravehicular activity
<i>FID</i>	=	flame ionization detector
<i>GC</i>	=	gas chromatography
<i>GCMS</i>	=	gas chromatography mass spectrometry
<i>I & T</i>	=	integration and test
<i>ISE</i>	=	ion selective electrode
<i>ISS</i>	=	International Space Station
<i>IWM</i>	=	inorganic water module
<i>JPL</i>	=	Jet Propulsion Laboratory
<i>JSC</i>	=	Johnson Space Center
<i>LC</i>	=	liquid chromatography
<i>LEO</i>	=	Low Earth Orbit
<i>MS</i>	=	mass spectrometer
<i>MTH</i>	=	Mars Transit Hab
<i>NASA</i>	=	National Aeronautics and Space Administration
<i>ORU</i>	=	orbital replacement unit
<i>OWM</i>	=	organic water module
<i>SRR</i>	=	system requirements review
<i>SWEG</i>	=	Spacecraft Water Exposure Guideline
<i>SWIM</i>	=	Spacecraft Water Impurity Monitor
<i>TCD</i>	=	thermal conductivity detector
<i>TIC</i>	=	total inorganic carbon
<i>TOC</i>	=	total organic carbon
<i>TOCA</i>	=	Total Organic Carbon Analyzer
<i>WRS</i>	=	Water Recovery System

I. Introduction

WATER quality monitoring for crewed missions is of critical importance [1]. On the International Space Station (ISS) water quality is monitored on the vehicle using many sensors, including conductivity sensors and the Total Organic Carbon Analyzer (TOCA). Samples are returned from the ISS to the NASA Johnson Space Center (JSC) Environmental Chemistry Laboratory (ECL) for detailed compositional analysis on a regular basis, because detailed compositional information about the water cannot be determined using the current suite of on-orbit hardware and analyzers. This program of on-orbit monitoring plus returned samples has been an effective and sufficient monitoring program. The ECL publishes water quality reports which are available publicly from NASA [2].

A wealth of information has been acquired about the performance of the water recovery system (WRS) of ISS over its operational lifetime [3]. The processed water has toxic impurities below acceptable levels, and system managers are able to use trending data from TOCA and other sensors to help prescribe maintenance intervals for WRS components such as multifiltration beds. In addition to water quality monitoring, the program of onboard monitoring coupled with ground analysis makes possible the discovery of a new source of organic carbon in the water. Rising total organic carbon (TOC) levels could be correlated with a known source, which is important regardless of level of hazard caused by the chemical. This was the case in identifying dimethylsilanediol (DMSD) [4] as the source for increased TOC during a period of upward trending TOC values.

While much focus is placed on the safety and potability of the water consumed by the crew, clean water is necessary for correct hardware operation and performance in systems such as WRS, extravehicular activity (EVA) hardware, and electrolysis-based oxygen generation systems. The sublimator in the currently used extravehicular mobility unit (EMU) has shown historical sensitivity to organic compounds [5], and as suits get more advanced and systems are miniaturized, the potential for the hardware to have high sensitivity to impurities increases.

Part of the requirements of the monitoring program is related to the timing of water quality measurements. A certain frequency of sampling is required for the monitoring program that is determined by system managers, flight doctors, and toxicology. This measurement cadence is well established for ISS, but for any new vehicles or surface habitats the required frequency of detailed analysis has not yet been determined. It can be projected that monitoring frequencies between weekly and quarterly would be reasonable. On ISS, TOC determinations are made on a bi-weekly basis and samples are collected and transferred to the ECL on a roughly quarterly basis. Challenges for water monitoring on exploration missions arise when the vehicle is operating outside low earth orbit (LEO), for example the Mars Transit Hab (MTH) or a base on the surface of the Moon or surface of Mars. It is expected that a TOC analyzer will be included for the exploration environments, so the frequent monitoring of TOC can continue, but there will be limited (Moon) to no (Mars) capability to return water samples to the ECL in a sufficiently fast timeframe for compositional analysis or to determine the identity of an unknown compound causing rising TOC or conductivity. Sensing of physical properties such as pH and conductivity will still be required for the water system, but again due to the inability to return samples, no capability for analyzing dissolved metals and ions would be available from an ECL analysis. It would take months to transport water from an MTH or surface habitation module to the ECL, leading to as much as an 8- to 12-month cadence for detailed water analysis, likely not frequent enough to support water monitoring program requirements.

A new instrument suite that is capable of providing frequent and detailed compositional analysis of spacecraft water is required to support exploration programs and will need to be included in the hardware delivered to support the habitat or vehicle. Reliance only on returned samples for detailed analysis is not a viable option which would meet the monitoring requirements.

The Spacecraft Water Impurity Monitor (SWIM) is a suite of technologies that enables on-orbit or in-habitat determination of water composition and impurity information to a higher degree of detail than the ISS baseline. In order to analyze samples that are a complex mixture, a separation science based approach is applied. Separation science is described generally as a technique where a complex mixture is first separated into component parts so that the detector can analyze each component one at a time. Separation science specifically includes technologies such as gas chromatography (GC), capillary electrophoresis (CE), and liquid chromatography (LC), among many others. Following separation, detection of each component of the mixture is achieved using a suitable detector. Many detectors are available for GC, such as thermal conductivity detection (TCD), a flame ionization detector (FID), or a mass spectrometer (MS). CE detection methods include capacitively coupled contactless conductivity detection (C4D), among others. The application of separation science is included in the operational trace contaminant monitor for ISS, the Air Quality Monitor. Separation science is not a novel technique, instead it is the *preferred* technique for mixture analysis.

SWIM will be capable of identifying organic contaminants in water samples using gas chromatography mass spectrometry (GCMS) detection and will be capable of identifying inorganic contaminants using ion specific electrodes (ISE) and CE coupled with C4D detection (from here forward referred to as “CE-C4D.”) In this paper we report on progress made on the SWIM project and preparations toward a flight technology demonstration. A candidate mission profile for SWIM and derived lifetime requirements for the SWIM system will be discussed. The hardware architecture for SWIM will be shown, and updates on the required chemical target lists for organic and inorganic contaminants will be presented. A brief report on the progress of technology development for the subsystems will be given.

II. SWIM Mission Goal and Objectives

The SWIM project held a flight project System Requirements Review (SRR) in September 2025. SWIM is currently planned to be worked as a technology demonstration project. As part of preparing for the SRR, the project completed definition of the project’s primary goal and a set of objectives that support the achievement of the primary goal. The project goal and objectives are as follows:

Goal: Demonstrate a viable solution for water quality verification in down-mass-inhibited exploration missions.

Objective 1: Demonstrate a system that performs in-flight monitoring of spacecraft water. This system will be capable of performing selective identification and quantification of a broad range of organic and inorganic contaminants.

Objective 2: Demonstrate in-flight monitoring of spacecraft water from various sources.

Objective 3: Provide detailed, low-latency water quality data to stakeholders, allowing for simulation of the decision environment associated with Earth-independent operations.

Objective 4: Produce a flight-proven system that is ready for infusion into Moon and Mars exploration programs.

Definition of goal and objectives for the technology demonstration project is the first step in a “top-down” requirements development approach. Each lower level requirement should tie back to the goal and objectives to ensure that the project achieves the desired result.

Objective 4 drives one focus area in requirements definition which will drive hardware development and hardware requirements. The project was directed by the Mars Campaign Office (MCO), the funding authority for SWIM, to consider a 1200-day Mars mission as a design reference. While this is useful guidance, it does not, by itself, contain sufficient detail to guide the design of SWIM. Considerations such as operational lifetime, storage lifetime, dormancy lifetime, and cycle life (number of analyses) all factor into how the system is designed, built, tested, and prepared for deployment. The longer time scales of exploration missions have the potential to drive hardware design from a component lifetime and maintenance perspective. As part of preparing for SRR we took the opportunity to carefully study what was known about candidate Mars mission profiles and architectures and use this information to derive candidate lifetime requirements for a SWIM system. These lifetime requirements were reviewed at SRR and accepted as baseline.

III. Mission Profile

The Mars Architecture Definition Document (ESDMD-001 Rev B) [6] and the SAC-21 mission profile documentation [7] were used to develop a hypothetical mission profile for an exploration SWIM. To satisfy Objective 4, as defined above, the SWIM technology demonstration should be designed to meet the needs of this mission profile. Based on the mission logistics concept described in ESDMD-001, it was concluded that any Mars mission will require the use of two SWIM units. One unit is the “Transit SWIM,” which stays with the Mars Transit Habitat (MTH) for the duration of the mission – the cruise phase to Mars, in orbit around Mars while the crew is on the surface, and the return cruise to Earth. The Transit SWIM is used to monitor water generated and/or stored within the MTH, which is consumed by the crew or systems aboard the MTH. The other unit is the “Surface SWIM.” It is predeployed to the Mars surface (along with other logistics) by an unmanned vehicle ahead of crew arrival and is used to monitor water generated and/or stored within the Habitat, which is then consumed by the crew or systems during the surface phase

IV. Lifetime Requirements

Evaluation of an exploration mission profile enabled definition of some key lifetime requirements for SWIM. Lifetime requirements are summarized in Table 1. The four lifetime requirements we have defined so far are Storage Life, Dormant Life, Operational Life, and Cycle Life (number of analyses). With a high-level mission profile defined for SWIM (see Figure 1), and the need established for two distinct SWIM units to accomplish the mission, detailed timelines were constructed for each use case: Transit SWIM and Surface SWIM. These timelines enabled the assignment of numerical quantities to each of the four lifetime requirements. The remainder of this section provides a description and rationale for each of these requirements, along with the numerical value rendered by analysis of the SWIM mission profile and detailed timelines of each use case. These requirements were presented at SRR and were accepted as baseline.

Storage Life: The SWIM Instrument shall be capable of being stored for a period of at least 730 days (2 years) with periodic maintenance permitted no more frequently than once every 180 days. Periodic maintenance shall be limited to powering on the instrument if necessary, performing any built-in tests, and replacement of orbital replacement units (ORU) that are limited lifetime items. Rationale: An Exploration SWIM (one deployed on a Mars exploration mission) must be ready to perform its mission after a period of unpowered pre-launch storage. This period exists due to an assumed delay between the completion of instrument integration and test (I&T) and the moment it is loaded on the launch vehicle. While the length of this delay varies by circumstance, it is common for spaceflight hardware to be stored for some amount of time prior to launch. In service of Tech Demo Objective 4, the Tech Demo SWIM will be designed to survive a period of unpowered storage prior to launch. The SWIM Life Analysis [8] examines the duration of each of the SWIM's mission phases, including pre-launch storage. This analysis leans heavily on information available in the Mars Architecture Definition Document (ESDMS-001 Rev B) and the SAC-21 mission profile. Pre-launch storage is one mission phase that is not addressed in either of these documents. The 730-day duration for this requirement is an assumption made by the SWIM project team.

Dormant Life: SWIM shall be capable of surviving a period of uninterrupted dormancy lasting at least 1760 days (nearly 5 years) while having access to keep-alive power. An Exploration SWIM (one deployed on a Mars exploration mission) must last the duration of the mission. In service of Tech Demo Objective 4, the Tech Demo SWIM will be designed to survive the worst-case period of uninterrupted dormancy that may be experienced by an Exploration SWIM. An Exploration SWIM would need to survive a period of uninterrupted dormancy lasting at least 1760 days. This period occurs in the "Surface SWIM" analysis case and is effectively the sum of the periods of dormancy incurred during the Earth-Mars transit phase and the Post- entry-descent-landing (EDL), pre- crew arrival phase of the mission. Some amount of power (referred to in the Lifetime analysis as "keep-alive power") is expected to be available to the SWIM during both of these mission phases. The project has also defined a requirement to prepare for dormancy: The SWIM integrated payload shall possess the necessary features for supporting preparation for dormancy, with maintenance required to be no more frequent than every 6 months. This requirement supports the dormancy requirement above by ensuring SWIM can be adequately prepared to survive long periods of dormancy.

Operational Life: The SWIM Integrated Payload shall be capable of operating for at least 1420 days (nearly 4 years), counted from the time of initial integration with the host vehicle. The Tech Demo SWIM will be designed to meet the expected operational life required of an Exploration SWIM, and as part of lifetime analysis we determined that an Exploration SWIM would need to operate for a total of at least 1600 days. This figure includes an assumed 180 days for integration and test prior to delivery. The remaining 1420 active days would be spent during the instrument's actual mission. Tech Demo SWIM will be designed to operate for 1420 days once integrated with the host vehicle.

Cycle Life (Number of Analyses): The SWIM Integrated Payload shall be capable of performing a minimum of 300 analyses in its operational life. A reasonable estimate for the total number of analyses an Exploration SWIM might be required to perform was obtained by analysis, and the worst case scenario arises from the "Transit SWIM" case. The Transit SWIM Split Crew analysis case assumes a nominal once-weekly analysis cadence. "Split Crew" refers to the scenario where SWIM supports water analysis for two different crews present at very different times in the overall mission. The exception to this nominal once-weekly case is an "anomaly resolution" period that lasts 31 days, during which the SWIM performs two analyses daily. The total number of analyses for the Split Crew + Anomaly Resolution case, assuming the prescribed analysis schedule, is 271. For this requirement, this number is rounded up to 300 analyses, which provides some margin.

Table 1. Summary of lifetime requirements for SWIM.

	Requirement	Notes
Storage Life	Store for 730 days.	Maintenance permitted at 6-month or longer intervals. Maintenance includes power-on, perform built-in-test (BIT), and replacement of ORUs.
Dormant Life	1760 days after start of mission, with keep-alive power.	
Operational Life	Operate for 1600 days.	Includes 1420 days of mission ops plus 180 days of integration & test.
Cycle Life	300 analyses over operational lifetime.	Supports mission duration.

V. SWIM Hardware Architecture

The basic architecture of SWIM comprises sampling water and supplying that water to the inorganic water module (IWM) and organic water module (OWM) of SWIM, as shown by the routing of the blue lines in Figure 2. For OWM, a GCMS determination of organic impurities is performed. For IWM, a CE-C4D determination of metals and ions is performed with specific ISEs used to monitor some species. Physical properties monitoring of the water will be included with IWM, and quantities such as conductivity can be monitored by the system either on a semi-continuous basis, or during routine sample analysis.

SWIM is a stand-alone water analysis system and will require power and data interfaces to the environment in which it operates, whether that be a vehicle or a habitat. Shown in the block diagram is a configuration that could sample both a water bus and also accept samples of water from other sources. Independent of the exact schematic of the water sampling system, the OWM and IWM modules of SWIM analyze the same water sample from a single input source. For both OWM and IWM, electronics to power and control the subsystems is required along with the separation and detection hardware. SWIM system level power and data handling will be included in the system design.

Water samples are supplied to the system and could be sourced from a connection to the potable water bus similar to what is done for MiniTOCA [9] or could be provided using sample bags, which is standard practice for operating TOCA and MiniTOCA. An interesting source of water for analysis on ISS or any vehicle with a regenerative environmental control life support system (ECLSS) would be humidity condensate. The condensing heat exchanger is part of the water recovery system, and in the process of condensing humidity in the cabin also condenses organics

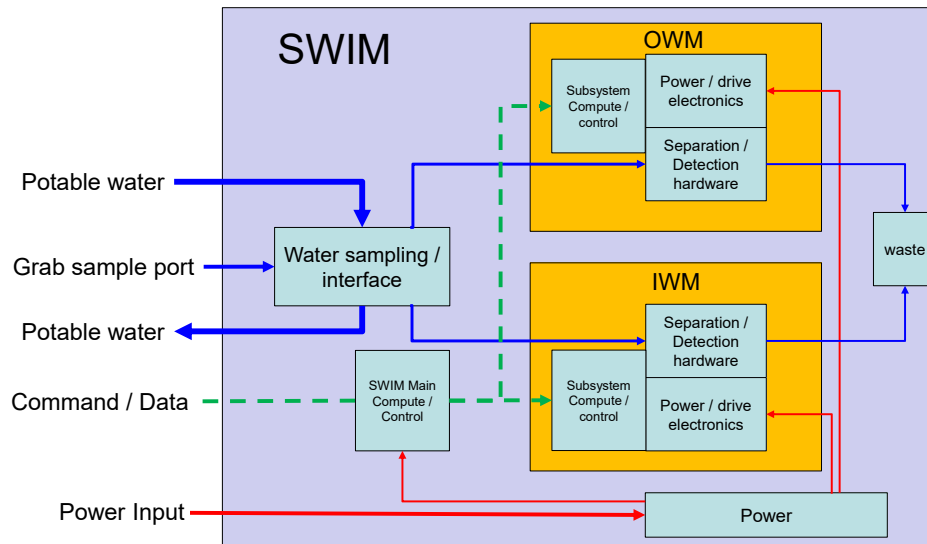


Figure 2. Block diagram of the SWIM system. Water could be sampled from multiple locations such as the potable water bus, or other locations using grab sample bags. The water sample is routed to OWM and IWM for chemical analysis. The OWM and IWM hardware will require command / data / control electronics for the analytical hardware that is used. Some waste water is expected to be produced.

that may be present in the air. The schematic shows the water sample traveling to OWM and IWM sampling points before being routed to a waste container. OWM and IWM will sample the same water sample, but report results according to their different analytical capabilities.

A more detailed diagram showing some of the OWM and IWM subsystems is shown in Figure 3. OWM is a GCMS system. The injection, separation, and detection sections of OWM are shown in block diagram form. Project-developed pneumatic controls supply GC carrier gas to the injector, which injects the water sample onto the separation column. The GC will need a source of carrier gas. After column separation, detection by FID, TCD, and mass spectrometry can occur. The detection section of OWM requires low voltage, high voltage, and radio frequency electronics. OWM electronics will interface back to the SWIM main control electronics as is shown conceptually in Figure 2.

The IWM section comprises a block of physical properties monitors and ion selective electrodes, followed by the CE-C4D section. The pH, conductivity, and ISEs can be thought of as “online” detectors. The separation science portion of IWM occurs in the CE separation section. A high voltage supply biases the end of two separation capillaries using opposite polarity biases, shown as the circled “plus” and “minus” on the diagram. Positively charged and negatively charged ionic species are detected at the end of the respective CE capillaries with separate C4D detectors. The capillary shown between the two detectors is to complete the electrical biasing circuit using the working fluid as the conducting medium. IWM requires some reagents, for example the CE background electrolyte, and will generate some waste.

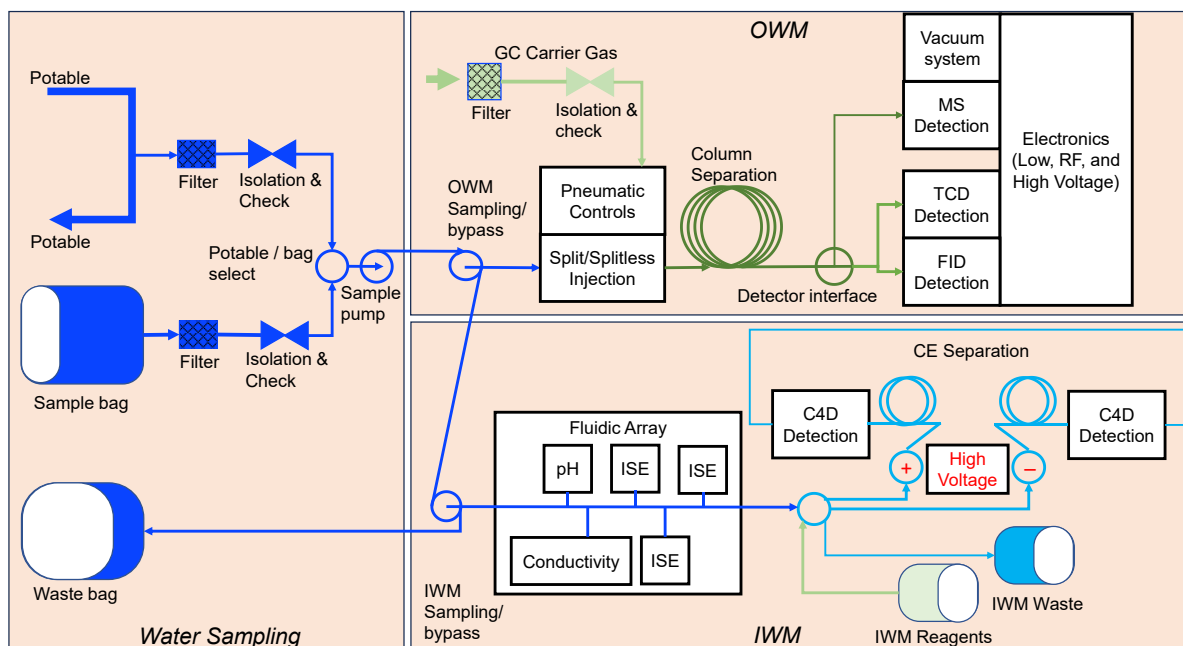


Figure 3. SWIM system schematic showing water sampling, OWM, and IWM sections of the system.

VI. Chemical Target Lists

SWIM subsystems OWM [10] and IWM [11] have previously presented lists of chemicals and species of interest for detection. These compounds, ions, or metals all have relevance to potable water quality or water quality for the safe and correct operation of spacecraft systems. The project SRR resulted in defining the baseline for the required chemical targets for SWIM, shown in Table 2 below.

The required compounds to measure are sourced from requirements documents for ISS as well as from stakeholder inputs. Requirements documents to consider include SSP 41000, System Specification for the International Space Station, SSP 50260 International Space Station Medical Operations Requirements Document (MORD), and JSC-63414 Spacecraft Water Exposure Guidelines (SWEG) [12].

The majority of the chemicals on the organics detection list are listed in the SWEG document. Ethanol, isopropanol, methyl sulfone, trimethylsilanol, benzyl alcohol and o-phthalaldehyde were added as a result of stakeholder inputs to the project. Those organics are of special interest to stakeholders because they are historically

observed on ISS in humidity condensate or present a useful system diagnostic or consequence. Ethanol and isopropanol, for example, are commonly used for cleaning of spacecraft parts and may be present at higher concentration in atmospheres of visiting vehicles or due to other ISS operations. With regenerative ECLSS, there is the possibility of those two chemicals breaking through the water processing and being present in the water. Some of the chemicals on the list also appear in water quality requirements for ISS Russian segment water. Formaldehyde is listed as an organic detection goal because GCMS without sample preparation is atypical for determination of formaldehyde in water. The derivatization normally used to detect formaldehyde with GCMS is not included with SWIM.

The choice of GCMS for organics detection matches the state of the art and standard practices for water analysis. Environmental Protection Agency (EPA) methods 524, 624, 8260, and 8270 are GC- and GCMS based methods for complex organic mixtures and many OWM chemical targets are listed in these methods. The ECL utilizes GCMS as part of their analysis sequence on returned water samples. We expect that given the wide range of chemical functionalities included in the OWM target list that designing SWIM to detect the listed range will lend itself to future characterization of unknowns, if they occur. GCMS for organics has space flight heritage, a recent relevant example being Spacecraft Atmosphere Monitor (S.A.M.) [13] which is currently an ongoing technology demonstration project on ISS. The provider of the mass spectrometer for SAM is also the provider of the mass spectrometer for SWIM.

For IWM, carbonate and bicarbonate are of interest to the SWIM project and are listed as inorganic detection goals. Motivation for detection includes that they comprise the total inorganic carbon (TIC) component of the water, as well as bicarbonate being a filtration bed breakthrough product. Knowledge of TIC can be important for understanding TOC measurements. TOC analyzers such as TOCA and MiniTOCA are designed to measure total organic carbon in the presence of TIC. MiniTOCA does not report the TIC value directly. Determining the value of TIC present when a TOC measurement is made allows better understanding of the detected TOC value and total carbon accounting for the water sample.

A key feature of SWIM is determination of unknowns or new chemicals that appear in the water that is analyzed. The technology is capable of this because the separation science approaches used are generalized for chemicals that would be present. We expect that if other organics or inorganics are present in water samples, SWIM will be capable of identifying those as well. Examples include any variety of alcohols or ketones present in a water sample. After GC

Table 2. List of chemicals of interest for SWIM. Those marked in asterisks are detection goals.

Organics	CAS Registry	Inorganics	Detected as
Acetone	67-64-1	potassium	K ⁺
methyl ethyl ketone	78-93-3	calcium	Ca ²⁺
methanol	67-56-1	magnesium	Mg ²⁺
isopropyl alcohol	67-63-0	chloride	Cl ⁻
ethanol	64-17-5	nitrate	NO ₃ ⁻
dichloromethane	75-09-2	sulfate	SO ₃ ²⁻
trimethylsilanol	1066-40-6	ammonium	NH ₄ ⁺
benzene	71-43-2	barium	Ba ²⁺
chloroform	67-66-3	manganese	Mn ²⁺
propylene glycol	57-55-6	nickel	Ni ²⁺
ethylene glycol	107-21-1	silver	Ag ⁺
benzyl alcohol	100-51-6	zinc	Zn ²⁺
phenol	108-95-2	chromium	Cr ³⁺
dimethylsilanediol (DMSD)	1066-42-8	cadmium	Cd ²⁺
caprolactam	105-60-2	lead	Pb ²⁺
methyl sulfone	67-71-0	iron	Fe ³⁺
o-phthalaldehyde	57-55-7	copper	Cu ²⁺
di-n-butyl-phthalate	107-21-2	formate	HCO ₂ ⁻
2-mercaptobenzothiazole	100-51-7	iodide	I ⁻
n-phenyl-beta-naphthylamine	108-95-3	carbonate*	CO ₃ ²⁻
di(2-ethylhexyl) phthalate	1066-42-9	bicarbonate*	HCO ₃ ⁻
formaldehyde*	50-00-0		

separation of the mixture, mass spectrometry will be able to uniquely identify which alcohol or ketone is present. The same situation occurs with inorganic analysis. Ions such as sodium, bromide, or phosphate are in-family with the species normally measured by IWM using CE-C4D and are not actively excluded from detection by SWIM. If those species are present, they would also be detected. For the GCMS and CE-C4D functionalities of SWIM, there is not a specific detector or collector per chemical. The detectors are non-specific, which is why they were chosen. It is possible to use a non-specific detector when the mixture is pre-separated.

VII. Forward Work and Project Plans

The OWM and IWM subsystems continue subsystem technology maturation efforts. Following the baselining of chemical target lists at SRR, the OWM team has focused on feasibility studies for separation of mixtures of target list chemicals using breadboard GCMS hardware. The design team is finalizing candidate designs for packaging gas chromatography columns in a way to meet volumetric requirements (size) as well as perform temperature programming and survive launch loads (thermal performance and ruggedization). The IWM team has demonstrated performance of a metals preconcentrator, which will result in IWM exceeding requirements for sensitivity in metals analysis. Overall, the IWM and OWM teams have been working together to evaluate the overall SWIM instrument architecture and layout.

To support radiation tolerance and design flexibility, SWIM plans to have a philosophy of minimizing COTS devices that have processors or embedded computing in favor of lower level implementation of these functions. This philosophy will be applied to the technology demonstration project where possible, which will set the hardware design in the right direction for future implementations. The motivations for this low-level implementation approach include future flexibility in electronics parts selection and ability to tailor future designs to be radiation tolerant. An example of this on OWM is the pressure and flow control hardware for controlling the carrier gas in the GC section of SWIM. COTS mass flow controllers and pressure controllers are widely available and widely used for GC and other applications. Each of these has a microcontroller running vendor-supplied firmware which provides the physical control over the sensors and valve packaged in the flow controller or meter. Even in LEO applications, COTS hardware presents challenges in the areas of obsolescence and supply chain. SWIM has built and tested simple, robust pressure control for the GC from component parts. Control loop and processing comes from a microcontroller we selected that has a known radiation hardened version. Pressure sensors are driven and read out by project-developed electronics circuits. For IWM, development of miniaturized multiport valves and actuators for those valves has taken place. Already as part of the initial concept development for some of the IWM components, the designs were implemented “flight forward” in terms of radiation tolerance because they were originally developed for planetary missions to Mars or outer planets where the radiation environment is more severe than in LEO.

An initial requirements set for SWIM was baselined as part of the SRR. Preliminary design activities have begun, and architecture studies will be completed to further define the instrument schematic. For IWM, we will need to determine how best to implement the measurement sequence for inorganic species. Referencing Figure 3, the exact plumbing routing for pH, conductivity sensors, and ISEs is forward work because if SWIM has a direct connection to the potable water bus, it may be desirable for higher frequency or “constant” monitoring of physical properties such as conductivity. There are complexity consequences due to this type of architecture. It could be that SWIM must be built so that some sections are powered constantly, and other sections powered on only as required. Other decisions to make are regarding OWM detectors. While GCMS will be required, the exact use cases and interface for the FID and TCD detectors will need to be further defined. It is possible one of those detectors will be included in SWIM differently than is shown in Figure 3. On the subject of required chemicals to detect, more feasibility studies will be performed for the detection goal chemicals. Capability for detection of dissolved formaldehyde without sample prep or derivatization will be determined. A study on detection of carbonate and bicarbonate with IWM technologies is planned.

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References

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- [1] Limero, T. F., and Wallace, W. T., "What Air and Water Quality Monitoring Is Needed to Protect Crew Health on Spacecraft?," *New Space*, Vol. 5, No. 2, 2017, pp. 67-78.
 - [2] Reports for water and air quality are reported in periodically published reports, "Toxicology Analysis of Spacecraft Air," <https://www.nasa.gov/directorates/esdmd/hhp/toxicology-analysis-of-spacecraft-air/>
 - [3] Williamson, J.; Wilson, J.P.; Robinson, K.; Luong, H. "Status of ISS Water Management and Recovery." 52nd International Conference on Environmental Systems, Calgary, Alberta, Canada, 2023.
 - [4] Rutz, J.A.; et al. "Discovery and Identification of Dimethylsilanediol as a Contaminant in ISS Potable Water." 41st International Conference on Environmental Systems, Portland, Oregon, 2011.
 - [5] Wickham, A.R.; Wickham, D.T.; Campbell, C.; Humbert, M.P. "EMU Ventilation Loop Simulation and Assessment of Contamination of the EMU Sublimator Hydrophilic Coating." 52nd International Conference on Environmental Systems, Calgary, Alberta, Canada, 2023.
 - [6] "NASA's Moon to Mars Architecture." Document number ESDMD-001, Revision C, National Aeronautics and Space Administration, 2025.
 - [7] "Reference Surface Activities for Crewed Mars Mission Systems and Utilization." Document number HEOMD-415, Version 1, National Aeronautics and Space Administration, 2022.
 - [8] Pensinger, Stuart. "Spacecraft Water Impurity Monitor (SWIM) Life Analysis." Project Memorandum, NASA JSC, 2025.
 - [9] Morrison, Chad; Smith, Melanie; et al. "Development of the Miniature Total Organic Carbon Analyzer." 53rd International Conference on Environmental Systems, Louisville, Kentucky, 2024.
 - [10] Neidholdt, E.L.; Pensinger, Stuart; et al. "Developmental Hardware Testing Results and Forward Plans for the Spacecraft Water Impurity Monitor (SWIM) Organic Water Module (OWM)." 53rd International Conference on Environmental Systems, Louisville, Kentucky, 2024.
 - [11] Noell, Aaron; Oborny, Nathan; et al. "Developmental Hardware Testing Results and Forward Plans for the Spacecraft Water Impurity Monitor (SWIM) Inorganic Water Module (IWM)." 53rd International Conference on Environmental Systems, Louisville, Kentucky, 2024.
 - [12] "Spacecraft Water Exposure Guidelines," JSC Document 63414. <https://www.nasa.gov/wp-content/uploads/2024/02/jsc-63414-swegs-rev-a.pdf>
 - [13] Madzunkov, Stojan; Malone, Charles P.; et al. "Progress report on the deployment of the second Spacecraft Atmosphere Monitor Technology Demonstration Instrument." 53rd International Conference on Environmental Systems, Louisville, Kentucky, 2024.