49th International Conference on Environmental Systems
7-11 July 2019, Boston, Massachusetts ICES-2019-363

International Space Station as a Development Testbed for Advanced Environmental Control and Life Support Systems

Laura A. Shaw[1]
National Aeronautics and Space Administration, Houston, TX, 77058

Since the beginning of human spaceflight, mission durations have steadily increased. Current mission durations onboard the International Space Station are multiple months, but future exploration missions to cislunar space and beyond will require multiple year durations. In addition, missions to cislunar or deep space will encounter a much harsher environment than the current ISS low-earth orbit missions, with relation to radiation, isolation, and lack of timely available support from Earth. To meet the challenges of deep space, so-called "exploration missions" will require Environmental Control and Life Support systems with higher performance, lower mass and logistics requirements, and more endurance than are possible with current operational systems on board the International Space Station. As a currently operational human-occupied platform, the International Space Station presents a unique opportunity to act as a testbed for development of advanced next-generation Environmental Control and Life Support Systems, such that these systems may be tested, proven, and refined for eventual deployment on deep space human exploration missions. This paper will outline the history, progress to date, and future plans for efforts to design, select, build, test and fly Advanced Environmental Control and Life Support Systems on the ISS.

Nomenclature

AR	=	Air Revitalization
ARFTA	=	Advanced Recycle Filter Tank Assembly
BPA	=	Brine Processor Assembly
CCAA	=	Common Cabin Air Assembly
CDRA	=	Carbon Dioxide Removal Assembly
CHX	=	Condensing Heat Exchanger
CO_2	=	carbon dioxide
ECLS	=	environmental control and life support
ECLSS	=	environmental control and life support system
EVA	=	extravehicular activity
EXPRESS	=	Expedite the Processing of Experiments to ISS
(g)	=	gas phase
H2	=	hydrogen
H2O	=	water
HEPA	=	high efficience particulate air
ISS	=	International Space Station
(l)	=	liquid phase
MCC-H	=	Mission Control Center - Houston
MER	=	Mission Evaluation Room
NASA	=	National Aeronautics and Space Administration
NG-11	=	Northrup Grumman Flight 11 – a US commercial cargo vehicle flight number
OGA	=	Oxygen Generation Assembly
OGS	=	Oxygen Generation System
PWD	=	Potable Water Dispenser

[1] ISS Program Lead for Exploration ECLSS, NASA/Johnson Space Center, ISS Program Vehicle Office/OB, 2101 NASA Parkway, Houston, TX 77058.

TCCS	=	Trace Contaminant Control System
US Lab	=	United States Laboratory Module
USOS	=	United States On-orbit Segment
UWMS	=	Universal Waste Management System
UPA	=	Urine Processor Assembly
UTS	=	Urine Transfer System
UV	=	ultraviolet
VOC	=	volatile organic compound
WHC	=	Waste and Hygiene Compartment
WPA	=	Water Processor Assembly
WRS	=	Water Recovery System

I. Introduction

HUMAN exploration missions beyond low earth orbit will require effective and reliable environmental control and life support systems (ECLSS) to support human life during these long duration excursions far from the protection of Earth. The National Aeronautics and Space Administration (NASA) has initiated an effort to demonstrate an exploration-class ECLSS on the International Space Station (ISS). The purpose is to allow characterization of system performance, system reliability, and integration challenges in the relevant environment of ISS. ISS is unique in that it not only hosts a micro-gravity environment, which is essential for testing two or three-phase systems such as ECLSS, but it also hosts a closed atmosphere with crewmembers providing waste products while experiencing micro-gravity. This creates highly relevant conditions which properly challenge an ECLSS in a very similar manner as it would be challenged during long-duration human exploration missions beyond low earth orbit.

The ECLSS to be demonstrated on ISS will be a combination of upgraded existing systems as well as new technologies that will further close the loop and improve system reliability. The upgrades to existing systems will utilize the vast experience gained during ISS operations to date in order to update areas within the ECLSS that have shown the potential for performance and reliability improvements[1,2]. The new technologies that will be added have been matured through ground-based laboratory testing and been shown to perform well enough to necessitate an on-orbit demonstration to fully prove their viability for inclusion in a future exploration vehicle's ECLSS.

The demonstration on ISS will be configured to create an ECLSS that is as similar to a future vehicle's ECLSS as possible. This means that subsystems that directly integrate together to exchange process fluids will be physically co-located and integrated together via hoses and cables. Subsystems that will exhaust into or ingest the vehicle's cabin air will do so in the ISS configuration. The ISS demonstration configuration will not repackage the ECLSS subsystems to mimic a future vehicle's physical layout or secondary structure (e.g. rack or pallet). This is because the future vehicle's exact configuration is not known at this time and the ISS structure and layout limit significant reconfiguration. The ECLSS controllers will also not be redesigned to address mechanical and electrical parts obsolescence challenges, since these challenges would present themselves again when the detailed design for a future vehicle's ECLSS is initiated.

The ECLSS demonstration on ISS has been partitioned into "strings" in order to group portions of the system together for ease of integration. The Air String and Water String are each described in subsequent sections of this paper. The Air String will be located in the United States Laboratory (US Lab) module of the ISS. The Water String will be located in the Node 3 module of the ISS. The two strings are integrated together via the common atmosphere that circulates throughout the ISS, particularly in the United States On-orbit Segment (USOS), as well as the potable and waste water busses that are routed throughout most of the USOS.

The environmental monitors that will be demonstrated on ISS will be deployed as installation volume, vehicle utilities (e.g. power, cooling, data), and their particular function dictate. For example, a device that autonomously monitors potable water quality would be co-located with the Water Processor Assembly in Node 3 in order to allow direct integration and demonstrate joint operations. A device that monitors trace contaminants in the atmosphere can be placed in one module of particular interest and potentially moved to a different module if deemed necessary.

The objective of this paper is to describe for interested stakeholders the scope of the Exploration ECLSS demonstration on ISS and the approach for integration of it into the ISS Vehicle. The author intends to provide an update to this paper in subsequent years as the ISS demonstration period continues and progress is made.

II. Air String

The Air String comprises the systems that revitalize the atmosphere and recover waste products from the atmosphere into usable products. The Air String that will be demonstrated on ISS is depicted schematically in Figure 1.

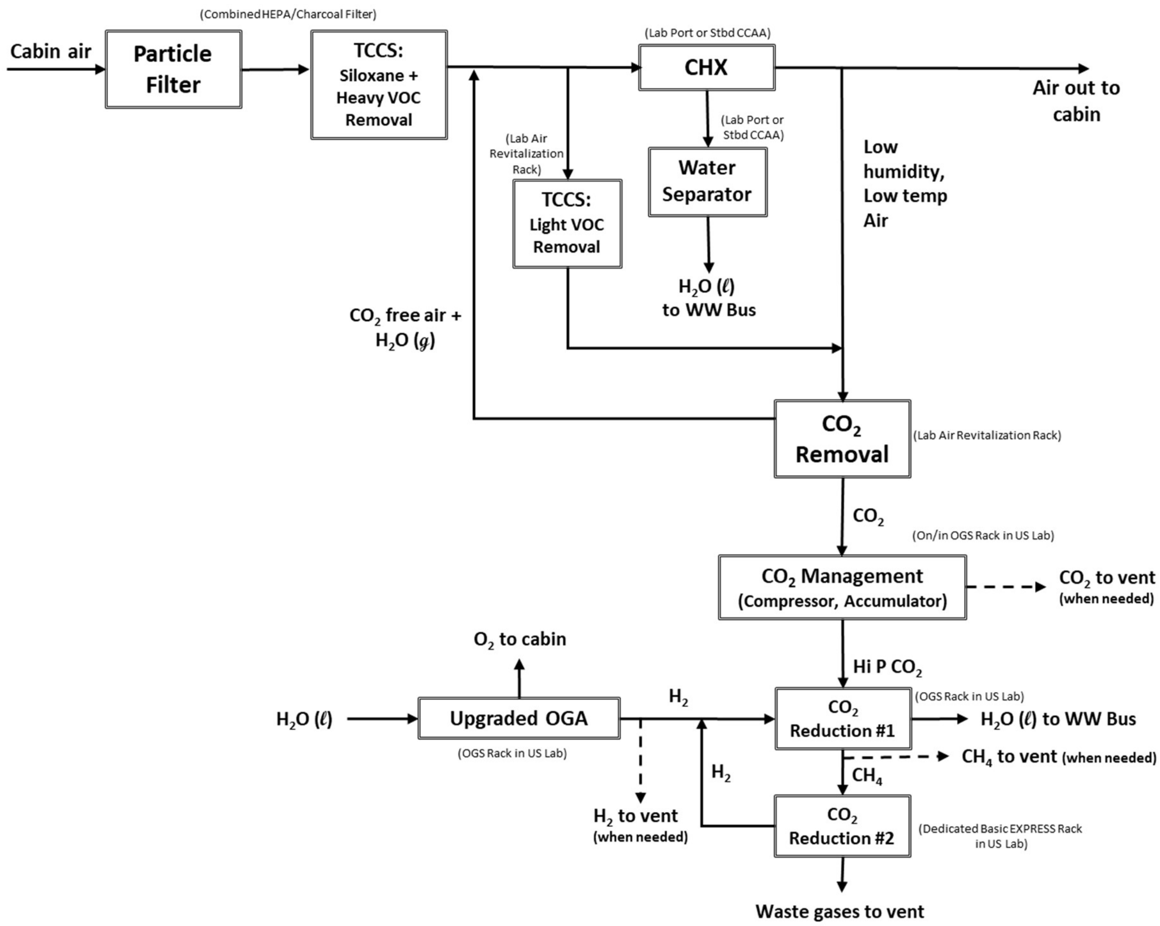

Figure 1. Air String Schematic.

A. Air String Hardware Complement

The Air String consists of the following functions:

- The condensing heat exchanger (CHX) and water separator that control humidity and temperature of the vehicle's atmosphere and collect the condensate for subsequent processing.
- The trace contaminant control system (TCCS) that removes chemical contaminants from the vehicle's atmosphere that are generated by crew, vehicle systems and surfaces, payloads, cargo, visiting vehicles, etc.
- The carbon dioxide (CO_2) removal system that scrubs crew metabolic CO_2 and payload-produced CO_2 from the atmosphere.
- The CO_2 reduction system that reacts CO_2 and hydrogen to create usable products such as water and methane.
- The oxygen generation system that ingests potable water and generates separated streams of gaseous oxygen for crew breathing and gaseous hydrogen for use in the CO_2 reduction system.

Each of the functions listed above will be represented in the Air String, either as an upgraded ISS system or as a new technology. The following are the expected systems that will fulfill the Air String functions. Areas where there are multiple potential candidates are described as such.

- CHX: NASA is pursuing several technologies as part of a down select process. A nanoporous membrane-based system has been demonstrated in ground testing. An advanced CHX coating formulation is being developed and ground tested. And a novel CHX surface concept has been proven and is undergoing detailed fabrication demonstration and testing on the ground. Following the completion of these efforts, NASA will select a candidate that will be built, launched, and will join the Air String as the CHX depicted in Figure 1.
- Water Separator post-CHX: A passive water separator device will be flown to ISS as a flight experiment to prove if its use of optimized geometry to harness capillary forces can effectively and repeatably separate a large volume and high velocity gas/liquid air stream. If this is proven successful, it will be traded against the current ISS Water Separator state-of-the-art and potentially flown as the Air String Water Separator in Figure 1. Or it may be operated as s supplement to the ISS Water Separator to improve the system's robustness.
- TCCS: Additional filtering will be added to the ISS at the inlet of the CHX to remove volatile siloxanes from the cabin atmosphere. These siloxanes have been shown to enter the condensate and negatively impact the life of components within the Water Processor Assembly. The upgraded filter design includes a portion for siloxane and heavy volatile organic compound (VOC) removal and a portion for high efficiency particulate air (HEPA) filtration as has always been present in the USOS. This filter combination is shown in Figure 2. Also, there is the potential to replumb the ISS TCCS to integrate it more heavily into the Air String for light VOC removal, which is also depicted in Figure 1.

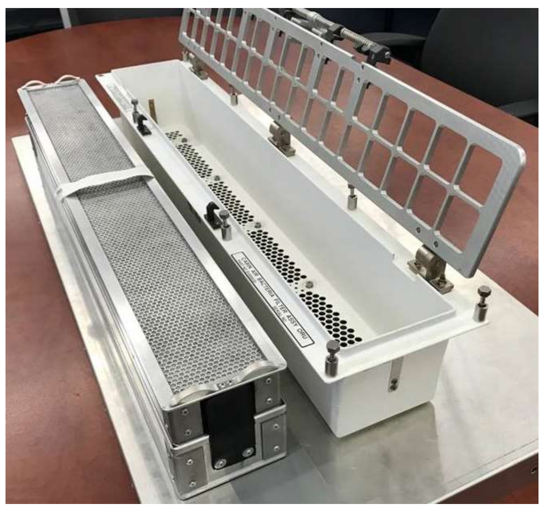

Figure 2. Siloxane and HEPA Filter Flight Hardware.

- CO_2 Removal System: NASA is pursuing three candidate CO_2 Removal technologies. Each will be built, launched, and operated on ISS for a minimum of one year. These will be located in Expedite the Processing of Experiments to ISS (EXPRESS) Racks or Basic EXPRESS Racks during this initial demonstration period. After each candidate has received at least one year of testing, NASA will select one candidate that will join the Air String as the CO_2 Removal System in Figure 1. The first CO_2 Removal candidate is Thermal Amine Scrubber, shown in Figure 3. It launched to ISS on Northrup Grumman flight 11 (NG-11) in the spring of 2019. As of this publishing, it has been installed and is beginning its on-orbit operational period. The subsequent two demonstrations will launch to ISS in approximately late 2020.

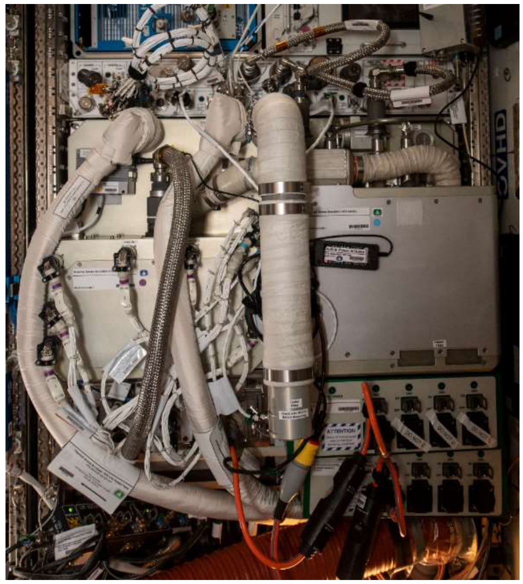

Figure 3. Thermal Amine Scrubber Flight Hardware Installed on ISS.

- CO_2 Reduction System: The Sabatier Reactor Assembly (SRA) that was operating on ISS will be upgraded and returned to the ISS for continued operation. The unit was returned to the ground for evaluation in 2017. The results of that evaluation will be used to redesign the system for improved system performance and reliability. This unit will join the Air String as the CO_2 Reduction #1 system in Figure 1. NASA may also develop an additional technology that will join the Air String as the CO_2 Reduction #2 system in Figure 1. It would ingest the methane created as a product of the Sabatier reaction and decompose it into hydrogen that can be utilized to improve the efficiency of the Sabatier reaction for creating water. The waste products generated will be vented overboard.
- Oxygen Generation System: The Oxygen Generation Assembly (OGA) that is currently on the ISS will be upgraded based on the operational experience gained since its activation. The OGA upgrades will consist of improvements to correct design weaknesses noted during operation, a redesign that will enable smaller components to be replaced, as well as improvements to reduce spares usage rates and potentially reduce overall vehicle risk. For example, the cell stack that contains the electrolyzing membranes is currently, along with other components, within a sealed box that cannot be opened in-flight. To replace any one failed component within this box, the entire box must be replaced. The upgraded OGA will enable replacement of the major subassemblies contained within the box. This approach will greatly reduce the mass and volume of the total OGA spares complement.

B. ISS Integration Approach

The subsystems within the Air String are required to be integrated together in order to perform their functions. Products from one system flow directly into another system to enable further processing as depicted in Figure 1. Some of these products, such as gaseous hydrogen from the OGA, are hazardous and their quantity needs to be reduced as much as possible to reduce overall ISS vehicle risk. It is also important to reduce the number of components or length of hoses containing these hazardous materials that are exposed to the ISS cabin and the ISS crew in the event that a leak occurs.

To enable the required degree of subsystem integration and reduce vehicle risk as much as possible, the components of the Air String will be co-located in the US Laboratory module. This module contains twenty-four rack locations within six full rack bays. It is the location of the majority of the US payloads, and its large size and reconfigurability affords the opportunity to outfit the module to accommodate the Air String. The ISS ECLSS currently contains a pre-upgraded air string in Node 3. However, because of the addition of the CO_2 Reduction #2 system, the Air String cannot be accommodated unless the Air String is established in the US Lab, which will require relocating the OGS Rack to the US Lab.

The Air String subsystems described in the section above will be located as follows:

- CHX and Water Separator will be installed in one of the two Common Cabin Air Assembly (CCAA) racks located in the US Lab.
- TCCS combined siloxane and HEPA filters will be installed in the locations of the current HEPA filters throughout the USOS.
- TCCS system upgrades, if deemed necessary, will be located in the existing location of the TCCS in the US Lab Air Revitalization (AR) Rack. Plumbing to route TCCS flow as depicted in Figure 1, if deemed necessary, will be within the US Lab AR Rack, the US Lab CCAA Rack containing the Air String CHX and Water Separator, and between the two racks.
- CO_2 Removal System will be installed in the US Lab AR Rack in-place of the US Lab Carbon Dioxide Removal Assembly (CDRA). The US Lab CDRA will be removed and stowed onboard ISS in the event it is needed in the future. The CO2 Removal candidate that is rated as the second best in the NASA selection will remain in its EXPRESS Rack or Basic EXPRESS Rack in the US Lab to continue to gather operational experience and to assist with ISS CO_2 removal needs.
- CO_2 Reduction #1 (the Sabatier Reactor Assembly) will be installed in its prior location inside the Oxygen Generation System (OGS) Rack. CO_2 Reduction #2 will be allocated a portion or entirety of a Basic EXPRESS Rack in a rack bay near the OGS Rack so as to reduce the hose length to route hazardous gases such as hydrogen and methane between the racks. A CO_2 Management System will be installed or upgraded to compress and accumulate the CO_2 that is provided from the CO_2 Removal System to the CO_2 Reduction System
- OGA upgrades will be located in the OGS Rack. This rack will be relocated from Node 3 to its previous location in the US Lab.

C. Challenges

Outfitting the US Lab to accommodate the Air String has numerous challenges to overcome. Currently, the US Lab contains a rack in each rack bay. In order to execute the Air String as shown in Figure 1, described in the section above, and depicted in the US Lab topology layout of Figure 4, existing racks will have to be relocated to other modules or positions within the US Lab. For example, to place the OGS Rack in its previous location at LAB1P1 which affords it the proper utilities including interfaces for potable water, waste water, adequate power, active liquid cooling, and overboard venting, the European Space Agency's Life Support Rack must vacate this location. It is likely that the Life Support Rack will be relocated to the Node 3 module which will require design and build of hoses and cables, performance of detailed system analyses, and revisions to ISS vehicle software. This type of effort will also be required to move payload racks to accommodate the CO_2 Reduction #2 rack in LAB1S1 near the OGS Rack in the US Lab.

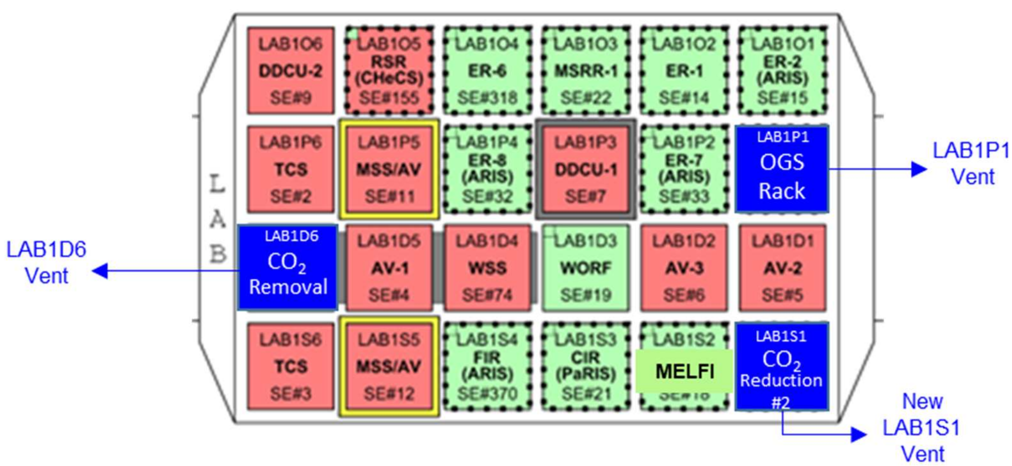

Figure 4. US Laboratory Topology in Era of Air String. *The runner-up CO2 Removal candidate will be located in one of the EXPRESS Racks in the US Lab (e.g. ER-2 in LAB1O1)*

Additionally, the utilities required to support the Air String in the US Lab are a major aspect of the integration process into ISS due to the heavy usage of liquid cooling and power by these systems. The active liquid cooling (moderate temperature and low temperature) is a limited resource in the US Lab because numerous systems and payloads utilize these resources on a continuous or intermittent basis. Detailed assessments to date indicate changes to the US Lab Internal Thermal Control System will likely be necessary to enable operation of the Air String in the US Lab while simultaneously continuing to support science payload operations. The exact nature of these changes is to be determined.

Power availability is similarly a limited resource that must be judiciously utilized to enable support of the Air String and simultaneously continue operation of science payloads. ISS power will be supplemented in the future with solar array enhancements. However, the ISS power demand also has the potential to increase as other modifications are made to the vehicle to help foster commercialization of low earth orbit, other critical exploration demonstrations are integrated into the ISS vehicle, etc. Power availability for the CO_2 Reduction #2 system is of particular concern since this is an addition to the ECLSS and may require significant power to operate. This aspect will need to be addressed as the integration plans for this system demonstration mature.

Overboard venting in the US Lab is the third resource that is limited and this utility significantly drives the location of the subsystems described above. The LAB1P1 location contains an overboard vent that was converted from a water to a gas vent (specficially hydrogen and methane) in 2006 in order to accommodate the OGS Rack in this location during that timeframe. CO_2 Reduction #2 will need an overboard vent that is capable of venting its waste products at appropriate pressures and rates to accommodate efficient and safe system operation. Due to this need, this system cannot share the LAB1P1 vent with the OGS Rack. Consequently, to support CO_2 Reduction System #2 on ISS and co-locate it with the Air String to enable operation, an effort has been initiated to create a dedicated vent at LAB1S1. Similar to the LAB1P1 vent, the effort will involve converting an existing overboard water vent to a gas vent. This effort will require design and build of hardware as well as two Extravehicular Activities (EVAs) to install it. Once it is installed, this vent will be available for use by the CO_2 Removal candidates during their minimum of one year demonstration periods prior to CO_2 Reduction #2 arrival.

D. Schedule

The target date to establish the full Air String in the US Lab is the beginning of 2023. There are many aspects of the effort that do not yet have solidified project schedules, so it is not possible to predict the actual timeframe. The integrated Air String development and integration schedule will be finalized when the scope of the entire effort has been defined and the associated project schedules are baselined.

III. Water String

The Water String comprises the systems that collect human waste and the systems that process the liquid waste along with other waste waters to potable water for crew consumption and hygiene, oxygen generation, spacesuit cooling, and payload use. The Water String that will be demonstrated on ISS is depicted schematically in Figure 5. It should be noted that the CHX and Water Separator as well as OGA and Sabatier are shown on both the Air String and Water String schematics. These indicate key areas where the two strings interact via the potable and waste water buses that are routed throughout most of the USOS.

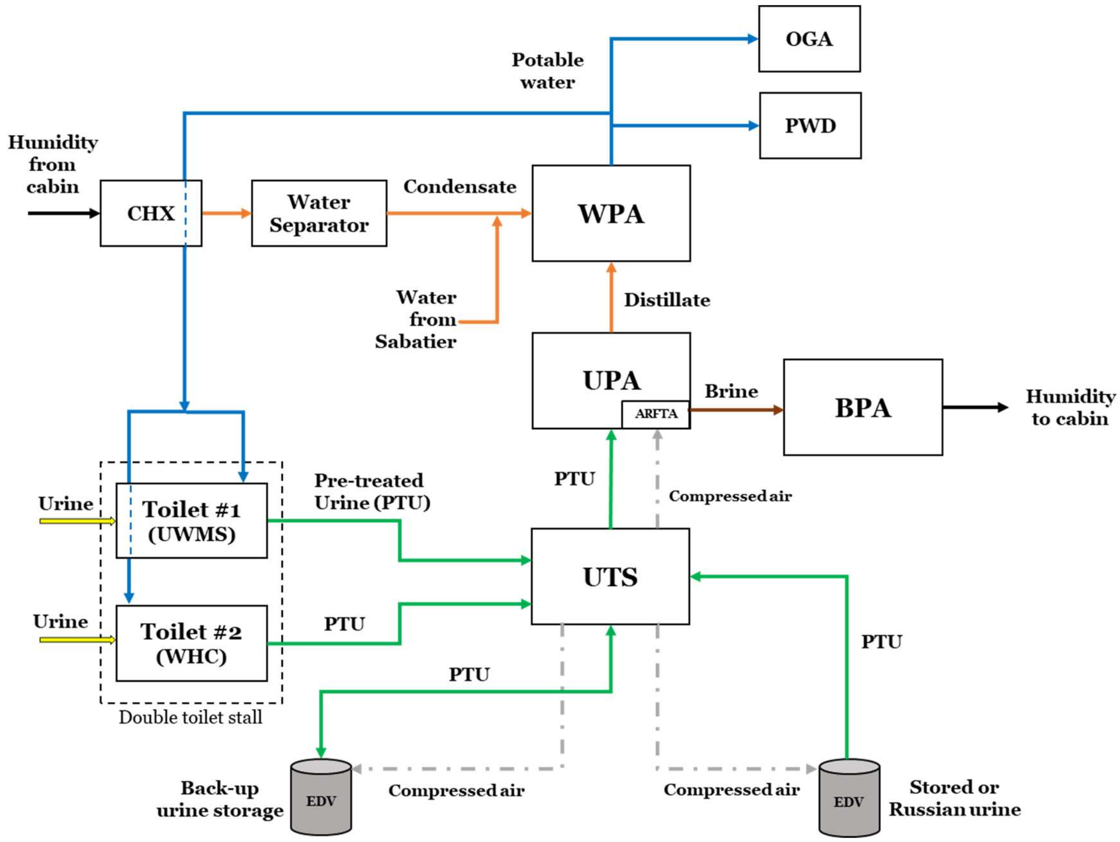

Figure 5. Water String Schematic.

E. Water String Hardware Complement

The Water String consists of the following functions:

- The human metabolic waste collection system that will collect human solid waste for disposal and will collect and stabilize the liquid human waste for processing.
- The urine processing system that recovers usable water from liquid human waste.
- The water processing system that processes and polishes waste water including processed urine, condensate, and Sabatier-produced water into potable water of the quality necessary for crew consumption and hygiene as well as oxygen generation, spacesuit cooling, and payload use.
- The brine processing system that recovers usable water from the brine generated by the urine processing system.
- The potable water dispensing system that meters and distributes potable water from the potable water bus to the crew for consumption and filling of hygiene water bags.

Each of the functions listed above will be represented in the Water String, either as an upgraded ISS system or as a new technology. The following are the systems that will fulfill the Water String functions.

- Human Metabolic Waste Collection (Toilet): A micro-gravity compatible toilet is under development by NASA that is intended to reduce mass and volume as well as consumables usage rates as compared to the existing ISS toilet state-of-the-art. This Toilet, also known as the Universal Waste Management System (UWMS), will join the USOS toilet complement along with the existing Waste and Hygiene Compartment (WHC) toilet that is currently located within Node 3. Both toilets will feed their collected urine to the Urine Processor Assembly. The newly designed Toilet is intended to become the primary toilet in the USOS so that it can be demonstrated for an extended duration with multiple crew complements. The new Toilet is depicted as Toilet #1 in Figure 5.

- Urine Processing System: The Urine Processor Assembly (UPA) that is currently on the ISS will be upgraded based on the operational experience gained since its activation. The UPA upgrades will consist of improvements to correct design weaknesses noted during operation, a redesign that incorporates an alternate pump type that is smaller and more efficient, redesigns that will enable smaller components to be replaced, as well as enhancements to improve system reliability.
- Water Processing System: The Water Processor Assembly (WPA) that is currently on the ISS will be upgraded based on the operational experience gained since its activation. The WPA upgrades will consist of improvements to reduce water leak potential and sensor drifts that has been observed during operations, demonstration of a reduced size packed bed that more closely matches an exploration mission's needs, and redesign or operational changes that better control biofilm growth in the waste water side of the system.
- Brine Processing System: A new technology has been proven in ground-based laboratory testing that is capable of dewatering UPA-produced brine so that more of the total system water can be recovered for crew/system use. The water that is liberated passes through a semi-permeable membrane that is optimized to contain urine-borne VOCs. The liberated water vapor is passed into the cabin air and collected by the CHX for processing by the WPA. This technology is being developed into a flight demonstration called the Brine Processor Assembly (BPA) that will join the Water String as depicted in Figure 5.
- Potable Water Dispensing System: An upgraded Exploration Potable Water Dispenser (PWD) will be developed that will utilize lessons learned from the operation of the existing PWD on ISS. The Exploration PWD will have all stagnant portions of the system removed to prevent microbial growth. It will also be capable of hosting demonstrations of a flow-through ultraviolet (UV) disinfection technology and silver biocide dispensing if they are deemed viable and necessary.

F. ISS Integration Approach

The Water String will be created in the Node 3 module where the Water Recovery System (WRS), containing the WPA and UPA, and the WHC currently reside. Similar to the Air String, the subsystems of the Water String will be co-located and physically integrated to enable process fluids to pass between them as depicted in Figure 5. The exception is the Exploration PWD that is likely to be located in the US Lab in an EXPRESS Rack, as described below.

The Water String subsystems described in the section above will be located as follows:

- The newly designed Toilet will be located next to the WHC, inside a new double toilet stall that was created to provide a private space for crew use for both the Toilet and the WHC independently. The Toilet Stall has been delivered and deployed on ISS, as shown in Figure 7. The Toilet and WHC will be physically plumbed to deliver their collected urine directly to the UPA via the Urine Transfer System that is described below.
- The UPA will be upgraded inside its current WRS#2 Rack.
- The WPA will be upgraded inside its current WRS#1 and WRS#2 Racks.
- The BPA will be mounted in the Node 3 Overhead Midbay, with an interfacing hose allowing direct transfer of brine from the UPA to the BPA. The water liberated by the BPA will enter the Node 3 cabin and be removed by the USOS humidity control system.
- The Exploration PWD will be located in an EXPRESS Rack in the US Lab. It will receive potable water from the Water String via the USOS potable water bus that distributes potable water from Node 3 to the US Lab.

An isometric layout of the Water String in the Node 3 module is shown in Figure 6.

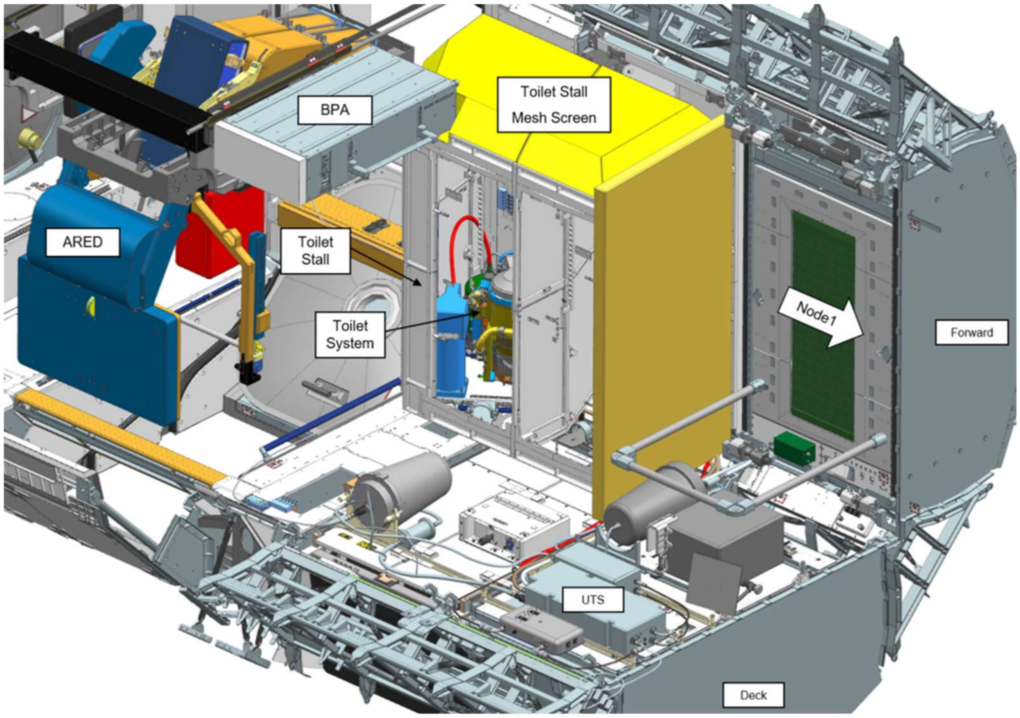

Figure 6. Water String Hardware Locations in Node 3. ***Looking towards Node 3 forward port, with all aft and overhead rack bays invisible***

G. Challenges

Physical space on ISS is at a premium given the amount of systems, payloads, spares, consumables, etc that are operating and/or stored on the ISS. Because of this limitation, determining the best location to house the Toilet and its associated privacy compartment was a significant challenge that has been overcome. In order to enable unimpeded operation of the new Toilet to characterize its performance and reliability, a dedicated privacy compartment for it was needed. The double toilet stall shown in Figure 7 is the result of that effort. This hardware will support the WHC in the right compartment and the Toilet in the left compartment.

Figure 7. Toilet Stall Deployed on ISS.

Also, the presence of two toilets in the USOS operating simultaneously created a unique challenge of managing the urine flow from both of these systems into the UPA. To overcome this challenge, an automated system is in development to detect urine flow from either toilet and direct only that system's flow to the UPA. If the second toilet is also sending urine at the same moment, its urine will be sent to a backup urine storage tank. The automated system is the Urine Transfer System (UTS) and it, along with the backup urine storage tank, is depicted in Figure 5. Also shown in this figure is the UTS's ability to transfer urine into the UPA from an external tank via a built-in air compressor.

H. Schedule

The planned schedule for the Water String is to have the Toilet, UTS, BPA, and some of the UPA and WPA upgrades on ISS and integrated together in late 2020. Additional upgrades to UPA and WPA, as well as delivery of the Exploration PWD, will occur later in 2021 and beyond.

IV. General ISS Integration

The effort to integrate the ECLSS demonstrations on ISS is a high priority within the ISS Program and NASA. The ISS was created in order to test both science payloads as well as advanced technologies that will be needed for future human space exploration. As such, ISS Program resources and processes on the ground and on-orbit are being put to bear to enable this effort.

I. Operations and Certification Approach

The standalone demonstrations such as the CO_2 Removal candidates, the BPA, the Toilet, and the Exploration PWD are being developed as non-critical system technology demonstrations that will be certified with little to no reliability requirements to facilitate quicker and less costly certification efforts. The intent, however, is that these systems perform the intended functions and all are required to operate safely. The system upgrades will be operated as part of the existing critical system; however, most of the subassemblies that are upgraded will be considered as demonstration units and not certified as part of the critical system configuration until they have been proven to function. As such, the ISS Program will continue to maintain the nominal spares fleet for the critical systems to ensure uninterrupted operations of these systems on ISS.

Another objective of demonstrating an upgraded ECLSS on ISS is to operate the entire system in an integrated fashion in the same manner as the ISS ECLSS is operated. This will allow characterization of the real-time operations aspects of the system upgrades and new technologies. To facilitate this approach, the ISS ECLS System Team is the responsible engineering organization for supporting real-time operations and hardware sustaining efforts. Mission Control Center – Houston (MCC-H) will be responsible for installing, operating, and monitoring, as well as training the crew for installation and maintenance, for each of the demonstrations. Also, as with the ISS vehicle systems nominally, MCC-H flight controllers and the Mission Evaluation Room (MER) will develop and execute strategies for troubleshooting any noted issues for each of the demonstrations.

J. Command and Telemetry Approach

The demonstration of ECLSS on ISS necessitated a new system for command and telemetry that enables an effective yet straightforward approach to real-time telemetry downlink, archive of this telemetry data, and commanding via MCC-H. The current command and telemetry pathway for payloads requires a dedicated Ethernet connection for each payload, which is not practical for the real-time, long-term operation of an ECLSS with multiple subsystems operating simultaneously. The new command and telemetry approach, known as the Arcturus capability, uses the onboard Ethernet system to allow regular monitoring of system performance and analysis of performance trends over an extended duration. It also facilitates quicker turnaround of demonstration software updates in the event optimization or improvements are deemed warranted. Commanding via MCC-H enables the system-like operations approach that was described in the section above.

Systems that are being upgraded in their existing racks will continue to be operated and monitored via their current command and telemetry pathway. This approach minimizes the overall changes needed and ensure continued operation of the critical ECLS systems.

V. Conclusion

The opportunity afforded by the presence of the ISS as a testbed for ECLSS advancements is being utilized to the fullest extent. A fully integrated and upgraded ECLSS is in development and will be tested on ISS for an extended duration to characterize the system's performance and reliability. There are many challenges to overcome to outfit such a complex system in the existing ISS vehicle, but many of these challenges have already been addressed. The effort will be on-going for many years, and the progress of this effort will be the subject of future papers.

Acknowledgments

The author would like to thank John Garr, Alesha Ridley, Michael Salopek, Brienne Shkedi, Katherine Toon, and Dana Weigel from the ISS Program Vehicle Office for their immense efforts to formulate and execute the scope of work identified in this paper. This effort is funded by the Human Exploration and Operations Mission Directorate at NASA Headquarters and championed by ECLS System Capability Leadership Team lead Robyn Gatens.

References

[1] Carter, D.L, J. Williamson, C. Brown, J. Bazley, D. Gazda, R. Schaezler, F. Thomas, "Status of ISS Water Management and Recovery", Paper # 2018-088, presented at the 48th International Conference on Environmental Systems, Albuquerque, New Mexico, July 2018

[2] Reysa, R. P.; Lumpkin, J.; Sherif, D. E.; Kay, R.; Williams, D. E. "International Space Station Carbon Dioxide Removal Assembly (ISS CDRA) Desiccant/Absorbent Beds Redesign", International Conference On Environmental Systems, Chicago, IL, SAE: Chicago, IL, 2007