

International Space Station (ISS) Environmental Control and Life Support (ECLS) System Overview of Events 2022

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Nov 20th, 2022 marks the 24th anniversary of the beginning of construction of the International Space Station (ISS). The ECLS system is constantly changing to meet the needs of current missions and future exploration. The ISS has become the laboratory that was always envisioned, allowing for an ever-growing class of exploration level technologies that will propel the stage forward as humanity advances beyond Low Earth Orbit (LEO). This paper will review the past year and look towards the future for each U.S. ECLS subsystem. The impacts, challenges, and successes related to the intermingling of incumbent and cutting-edge technologies are summarily discussed in this paper.

AC	= Assembly Complete	OA	= Orbital/ATK
ACS	= Atmosphere Control & Supply	OGA	= Oxygen Generation Assembly
AR	= Atmosphere Revitalization	OGS	= Oxygen Generation System
ASV	= Air Selector Valve	ORU	= Orbital Replaceable Unit
BPA	= Brine Processor Assembly	PDMS	= polydimethylsiloxane
CHIPS	= Charcoal HEPA Integrated Particle Scrubbers	PMD	= Pressure Management Device
CCAA	= Common Cabin Air Assembly	RPC	= Remote Power Controller
CWC	= Contingency Water Collection	RPCM	= Remote Power Control Module
CDRA	= Carbon Dioxide Removal Assembly	R&R	= Remove & Replace
CHX	= Condensing Heat Exchanger	RTA	= <i>Recharge Tank Assembly</i>
DAB	= Desiccant Adsorbent Bed	SDS	= Sample Delivery System
DCP	= <i>Damage Control Plan</i>	S/N	= Serial Number
D/L	= Down Link	SPRT	= System Problem Resolution Team
DTO	= Developmental Test Objective	SpX	= SpaceX
ECLS	= Environmental Control and Life Support	SSC	= Space Station Computer
EMU	= Extra vehicular Mobility Unit	THC	= Temperature & Humidity Control
EVA	= Extra Vehicular Activity	TT&E	= Test, Teardown & Evaluation
FDS	= Fire Detection and Suppression	UIA	= Umbilical Interface Assembly
GUI	= Graphical User Interface	UPA	= Urine Processor Assembly
HEPA	= High Efficiency Particle Air	USOS	= United States On-orbit Segment
IMV	= Inter-Module Ventilation	UWMS	= Universal Waste Management System
ISA	= Internal Sampling Adapter	WHC	= Waste & Hygiene Compartment
ISS	= International Space Station	WM	= Waste Management
ITCS	= Internal Thermal Control System	WPA	= Water Processor Assembly
JSL	= Joint Station LAN	WRS	= Water Recovery Subsystem
KSC	= Kennedy Space Center	WRM	= Water Recovery & Management
MCA	= Major Constituent Analyzer	WSS	= Water Storage System
NASA	= National Aeronautics and Space Administration	VES	= Vacuum Exhaust System
NORS	= Nitrogen/Oxygen Resupply System	VRS	= Vacuum Resource System
		VS	= Vacuum System
		VV	= Visiting Vehicle

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NOMENCLATURE

1. Introduction

The International Space Station (ISS) program achieved “Assembly Complete” (AC) in 2010, with the Environmental Control and Life Support (ECLS) system supporting ISS crews and visiting Shuttle and Soyuz crews since assembly began in 1998.

Through AC a total of 16 pressurized elements have been added to the ISS. Since then, ECLS activity has focused mainly on maintaining the ISS systems currently onboard while acquiring on-orbit operational knowledge in microgravity. Additional changes to the “AC” ISS configuration continue to occur, including preparations for the first Commercial Crew vehicle arrivals and support for exploration ECLSS technology testing.

A. ISS ECLS OVERVIEW

The ISS on-orbit ECLS system comprises 4 major subsystems: Atmosphere Control and Supply (ACS), Temperature and Humidity Control (THC), Fire Detection and Suppression (FDS), Atmosphere Revitalization (AR), Water Recovery and Management (WRM), and Vacuum System (VS). The following sections briefly summarize each subsystem and its function within the ISS pressurized elements.

1. Atmosphere Control and Supply (ACS)

The ACS subsystem provides cabin atmosphere pressure control, overpressure relief, pressure equalization, rapid depressurization detection and response, nitrogen and oxygen distribution, and nitrogen and oxygen high pressure tank recharge from NORS tanks delivered on unmanned logistics vehicles.

2. Temperature and Humidity Control (THC) & Fire Detection and Suppression (FDS)

The THC subsystem provides airborne heat removal, air temperature control and monitoring, intra-module and inter-module ventilation, humidity removal, and airborne particulate/bacteria removal. The FDS subsystem includes smoke detection, fire isolation, fire extinguishment, and fire recovery.

3. Atmosphere Revitalization (AR) & Vacuum System (VS)

The AR subsystem revitalizes the habitable atmosphere by removing carbon dioxide, potentially hazardous volatile trace contaminants generated by inadvertent spills, crew metabolic processes, and equipment off-gassing such that cabin contaminant levels are maintained within limits. Additionally, the ISS habitable environment is monitored for atmosphere major constituents O₂, N₂, and CO₂, as well as H₂, CH₄, and H₂O. In the United States On-orbit Segment (USOS), the Sample Distribution System (SDS) carries sample cabin air through lines from the various modules to the Major Constituent Analyzer mass spectrometer.

The VS supplies the U.S. Lab module payload rack locations with access to space vacuum. The VS consists of two separate subsystems: the Vacuum Exhaust System (VES) and the Vacuum Resource System (VRS). Connected to all thirteen payload rack locations, the VES can vent payload gases overboard. The VRS provides high-quality vacuum to nine of the thirteen payload rack locations for user access.

4. Water Recovery and Management (WRM) & Oxygen Generation Assembly (OGA)

The WRM subsystem supplies potable water, hygiene water, and water for payloads, as well as collecting humidity condensate. The WRM also provides excess wastewater venting; condensate storage; and potable and waste water distribution.

The WRM subsystem was expanded significantly prior to Shuttle retirement with the addition of the Regenerative ECLS Racks known as Water Recovery System (WRS) 1 and 2 and Oxygen Generation System (OGS), which include the Urine Processor Assembly (UPA), the Water Processor Assembly (WPA) and the Oxygen Generator Assembly

(OGA). WRM includes Waste Management (WM) which, for ISS, is the Waste & Hygiene Compartment (WHC), a U.S. On-orbit Segment (USOS) bathroom that collects solid waste and collects, treats and transports liquid waste to the Urine Processor Assembly (UPA) for water recovery.

2. SUMMARY DISCUSSION OF MAJOR SUBSYSTEM EVENTS IN UNITED STATES ON-ORBIT SEGMENT BY FUNCTION

A. Atmosphere Control and Supply

1. Nitrogen/Oxygen Recharge System (NORS) Recharge Tank Assembly (RTA) Composite Overwrap Pressure Vessel (COPV) Scratch Investigations

COPVs provide a low mass means for gas storage and transportation but are known to be susceptible to damage resulting from handling, tool drop impacts, or impacts from other objects (e.g. fork lift, shackles, etc). NORS RTAs consist of a COPV and Quick Disconnect (QD)-Valve Assembly. RTAs are pressurized with nitrogen (N₂) and oxygen (O₂) on the ground to about 6,000 psi for use in the ISS N₂ and O₂ pressure systems. RTAs are also pressurized with air to about 3,000 psi for use during an ISS ammonia emergency. The NORS RTA Pressure Vessel Damage Control Plan establishes a plan to mitigate damage to the NORS / Commercial Crew Vehicle (CCV) Emergency Breathing Air Assembly (CEBAA) RTA COPV throughout its life cycle. Part of the Damage Control Plan (DCP) is a ground inspection of the NORS RTA before servicing and upon return from ISS. The DCP describes damage that should and should not be documented in a Discrepancy Report/Non-Conformance.

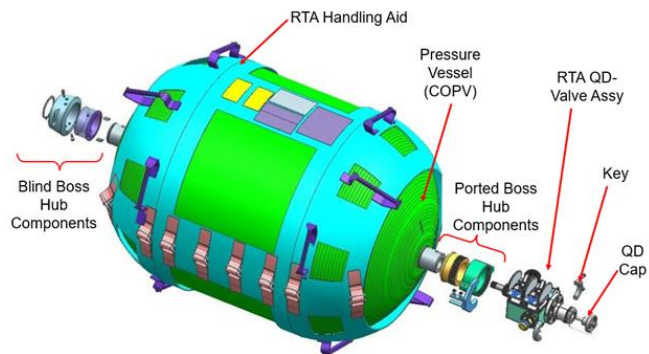


Figure 1. Nitrogen/Oxygen Recharge System Recharge Tank Assembly

Two separate tanks were noticed to have marks on the COPV portion of the NORS RTA during 2022. A Non-



Figure 2. COPV Scratches



Figure 3. COPV Scratch

Conformance was written on each tank to document and further inspect the damage. For both tanks, visual inspections found no impact cracks in the resin and no broken fibers on the COPV. Both Boeing and NASA Fracture Control/Pressure Vessel (FC/PV) experts agreed that the damage was superficial and there are no constraints to

continue to use both tanks. The marks on the RTAs have driven a reevaluation of ground handling procedures to ensure the RTAs are being handled properly at all time.



Figure 4. COPV Scratch

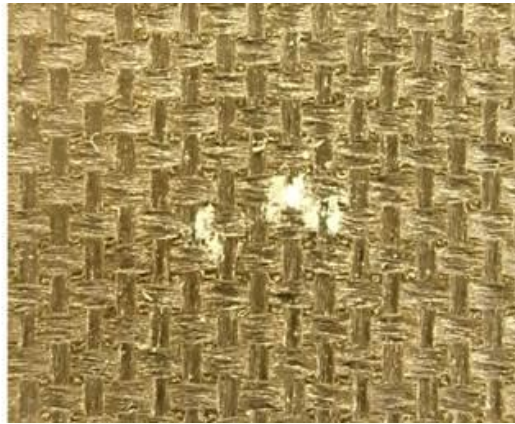


Figure 5. COPV Scratch

2. New Nitrogen/Oxygen Recharge System (NORS) Return Configuration

NORS Tanks have been launched and returned from ISS inside Vehicle Interface Assemblies (VIA), modified M-01 sized bags, starting with the Orbital-4 launch in 2016. The VIA includes the four (4) pieces of foam to protect the NORS Recharge Tank Assembly (RTA) and the VIA Bag. NORS RTAs have been difficult to return due to the size of the NORS VIA footprint, 21 x 35.3 x 32.2 inches. At the beginning of 2022 there were a total of ten (10) O₂ and N₂ NORS tanks on ISS, eight (8) of which were empty and waiting to be returned to ground.

Ground teams began to look at ways to return more tanks to alleviate on-orbit stowage issues. The VIA would not fit on Crew return flights so a smaller, more compact option was considered. The new design used a modified, bulging 4.0 CTB, 37.5 x 20.0 x 20.25 inches. This design has two (2) foam end caps and four (4) thin side foam pieces to help protect the tank. This 4.0 CTB configuration has been used to return one (1) NORS RTA on Axiom-1 (April 2022) and two (2) NORS RTAs on Boeing OFT-2 (May 2022). This configuration is going to be used for future NORS RTA returns on Crew vehicles starting with Crew-5. Currently there are six (6) O₂ and N₂ NORS RTAs on ISS.

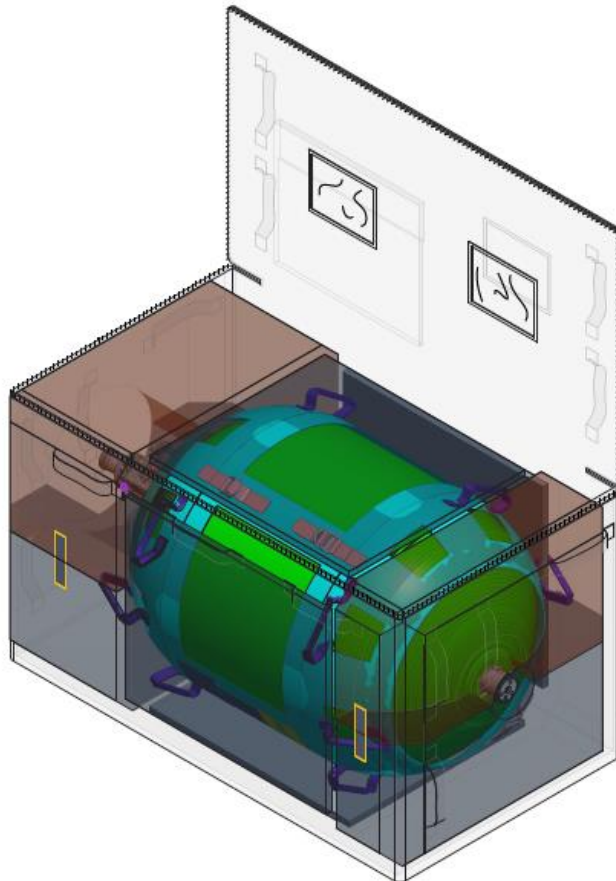


Figure 6. Modified Vehicle Interface
Assembly

B. Temperature and Humidity Control & Fire Detection and Suppression

1. Dual Common Cabin Air Assembly (CCAA) Test

Managing humidity and drying out the CCAAs across the USOS is becoming more challenging as larger amounts of crew are staying on Station for longer periods of time and more humidity-producing systems and payloads are being integrated into Station. As humidity has been increasing, the Node 3 CCAA has especially been struggling to dry out and stay dry at typical Low Temperature Loop (LTL) temperatures.

While Node 3, Airlock, and Node 2 each have one CCAA to manage temperature and humidity, Lab has two CCAAs. During nominal operations, only one of these Lab CCAAs operates to keep Lab comfortable for crew. However, it was unknown if running both CCAAs simultaneously in a “Dual CCAA” configuration for any extended period of time would be able to help manage humidity on Station enough to reduce the strain on the Node 3 hardware. This configuration had been tested once before in 2001, but no useful humidity control data came from that test. Therefore, a test was conducted from February 18th – March 7th, 2022 where the Lab CCAAs were run continuously in the Dual CCAA configuration, and various combinations of LTL flow and CCAA fan speeds were attempted to see if a specific configuration could help the Node 3 CCAA dry out more efficiently. Over this time, humidity in Node 3 was also impacted by several pieces of hardware outside of the control of this test. Humidity in Node 3 was reduced in comparison to typical humidity levels in Node 3 throughout much of the test by the Treadmill (T2) and the Brine Processor Assembly (BPA) being intermittently down, and humidity increased toward the end of the test by one of the Russian CKBs being intermittently down.

At the end of the test, it was evident that running both of the Lab CCAAs simultaneously over a duration of 18 days gave great temperature control in Lab, however, the Node 3 CCAA continued to have Wet Indications, despite the reduced humidity load. Therefore, the Dual CCAA set up was shown to not be an effective way of reducing humidity loads enough to help the Node 3 CCAA dry out and stay dry.

2. Lab Forward-Port Intermodule Ventilation (IMV) Fan Remove & Replace (R&R)

On February 5th, 2022, crew on-board the ISS reported hearing a loud squealing noise around the Node 2 Overhead P3 or P4 location. All of the Temperature & Humidity Control hardware in that area appeared to be running nominally from the available data, but, when the Lab Fwd Port IMV Fan was turned off, the squealing noise ceased, suggesting that something had happened to the fan. The initial assumption was that Foreign Object Debris (FOD) had become trapped in the air path and created the squealing via restricted airflow, so crew was instructed to clean the Node 2 Overhead Port IMV Diffusers first to see if that would solve the problem. After the cleaning, the noise persisted.

The next day, crew investigated the sound further, and reported that it was the loudest between the outlet of the Lab Fwd Port Silencer and the inlet of the Lab Fwd Port IMV Fan, seemingly more biased toward the Silencer. Crew then proceeded to do a cleaning of both the IMV Fan and the Silencer. The interior of the Silencer had a few areas of FOD buildup, but not enough to cause the squealing sound. The interior of the fan was about 25% blocked with FOD in areas that could not be readily cleaned. From this inspection, the decision was made to R&R the IMV Fan.

The squealing IMV Fan was removed successfully and the cause of the squealing will be investigated once the fan is returned to ground. However, when installing the new fan, crew was only able to fully replace 3 of the 4 fasteners used to attach the fan to structure, creating concern about the fan’s electrical grounding and any vibration or structural issues that may result due to the off-nominal configuration. Through analysis, it was determined that this 3-out-of-4 fastener configuration would still create a sufficient grounding between the structure and the IMV Fan as long as the three fully-installed fasteners were torqued to specification. It was also determined that the 3-out-of-4 fastener

configuration would not pose a structural or vibration issue, as this fan is designed to have a very high limit load, whereas the Station on-orbit loads are very small in comparison, and these fans are highly balanced and designed with vibration isolators implemented to reduce the impact of any potential vibrations.

C. Atmosphere Revitalization

1. Carbon Dioxide Removal Assembly (CDRA) Status

Performance for Lab and Node 3 CDRA's this year were nominal. NASA Technical Demonstrations are run preferentially in place of CDRA, according to availability. Thermal Amine System (TAS) failure has forced CDRA into active duty, where it has been nominally. Additionally, the Lab CDRA also has had the check valve reach its certified end of life without failure and is still going strong. It is unlikely any of the beds will need replacement in the near term.

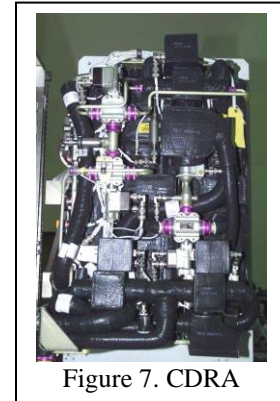


Figure 7. CDRA

2. Major Constituent Analyzer (MCA) Status

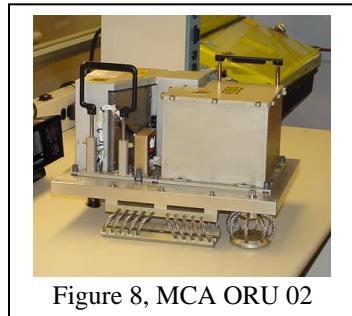


Figure 8. MCA ORU 02

The Lab MCA ORU 02 F0001 reached its end of life after receiving Error Code 36: 'Electrometer OP PBIT'. The ORU 02 was Removed and Replaced (R&R) with F0006. During a zero calibration in preparations for an EVA, the Lab MCA experienced Error Code 62: 'Both Filaments Failed'. The data showed that the filaments were receiving voltage and current which indicated that there was an issue in the control circuitry and it was not a failure of the filaments. The ORU 02 F0006 will be R&R'd with F0008 and further bench tested on the ground to better understand this anomaly.

Upon failure of the Lab MCA, Node 3 MCA was started. During startup, the Node 3 MCA transitioned to Startup, failed, and generated Error Code 1 "No Usable Pump." Both pumps in ORU 05 Q0001 had far exceeded their expected life. Following a R&R of ORU 05 with F0001, Error Code 1 was still received. Multiple troubleshooting attempts were made to get the MCA through Startup until a workaround procedure was developed. Then, during an EVA prebreathe, when the Airlock was depressurizing down to 527 mmHg (10.2 psia), Error Code 63: 'Plugged Line Pump Failure' was received. Node 3 MCA state remained in Operate and the Caution returned to normal about 20 seconds later. It continued to generate partial pressure values per the rapid sampling algorithm. Data review afterwards showed that the Sample Pump selection switched from pump #2 to pump #1 and the voltage went from being too high (hit 27 Volt max) to maintaining a steady 15 V. The cause of this fault is still under investigation.

D. Water Recovery Management

1. WHC Rubber Seal on the PY-5 Connector

In May 2022, WHC maintenance was conducted. This included the concurrent R&R (Removal and Replacement) of the Dose Pump and Pretreat Tank. This also included replacement of the EK Hose. During the checkout procedure, which included a functional check, the WHC control panel Pretreat Bad Quality (PTBQ) light annunciated. Crew executed several manual doses, which is a standard documented countermeasure. However, the PTBQ light persisted.

In addition, Crew reported only the portion of the EK Hose on the Pretreat Tank side showed the color indicative of containing Pretreat, while the other half (on the Dose Pump side) remained clear. Nominally, this entire hose should contain Pretreat, a dark red / maroon fluid. Suspecting either an infant failure of the Dose Pump, which had already reached Shelf Life and Wetted Life certifications, or a misconfiguration of the Pretreat Tank connections, the next troubleshooting steps included R&R of each component serially to isolate the failure. The Pretreat Tank was R&R'd first, and crew was instructed to inspect and verify all connections. This Pretreat Tank was a new variant which does not fly with an EK hose attached and instead has a cap, which contains a center rubber seal on the Pretreat Tank side of the PY-5 handwheel connector. During the second attempt at activation, there was still no fluid movement seen in the EK hose. Next, the Dose Pump was R&R'd with a newer Dose Pump as well as a new EK hose, but this still resulted in no movement of pretreat through the EK hose. Ground teams decided to reinstall the original Dose Pump, which had started showing signs of failure (the original reason behind the R&R) but was still functional. The rationale being, since root cause was still not identified, to use the degraded Dose Pump for further troubleshooting to identify root cause. This was to avoid risking damage to the last pristine spare Dose Pump on orbit. Crew was asked to de-mate all connections and photo document to help identify the root cause. Finally, when Crew de-mated the PY-5 handwheel connector, a crew member noticed the seal had come off of the cap, and was stuck on the PY-5 handwheel connector side. This is an off nominal condition. This seal had prevented pretreat from flowing into the EK hose, thereby deadheading the second Dose Pump. This resulted in requiring installation of the last remaining USOS on-orbit Dose Pump to return WHC to nominal function.

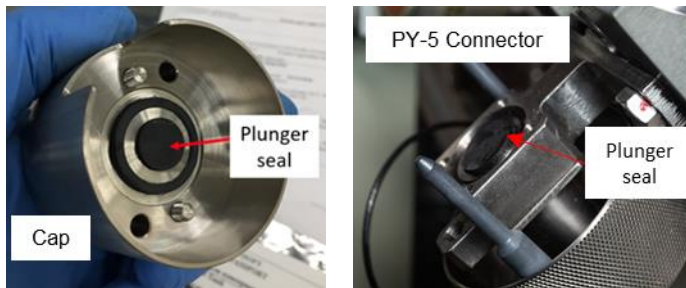


Figure 9. WHC Cap and Plunger Seal

WHC maintenance procedures have since been updated to instruct to Crew verify the seals remain in the caps and not stuck to the handwheel connector. It was also suggested, as a standard practice, to perform functional checks in between the removal and replacement of each hardware component. This is because neglecting the functional check can lead to indeterminate troubleshooting. Lastly, after discussion with Russian WHC counterparts, a new cap design was implemented to better secure the seal and prevent a

recurrence of this issue in the future.

2. Multifiltration Bed Operation Through Third Ionic Breakthrough

The Multifiltration Bed (MF Bed) has operated over a series of configuration changes over the lifetime of Water Processing Assembly (WPA), including a change from dual series bed operations to single bed in 2019, and change from the -1 legacy design to current -2 configuration in 2020. The new -2 design incorporates Ambersorb® 4652 in place of obsolete 580-26 charcoal media, and replacement of separate IRN-77 and IRA-67 media with all IRN-150 in Cylinder 9 to eliminate leachate issues and enable running beyond acetate breakthrough.

Effluent water samples were taken from previously installed MF Beds S/N 16 and 17 (dual beds in series), returned and analyzed after the first, second and third (for the first bed, S/N 16) ionic breakthroughs. Samples from the second ionic breakthrough contained compounds that challenge the catalyst in the

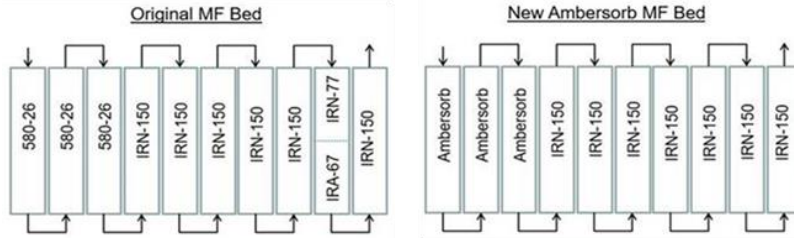


Figure 10. Original and Updated MF Bed Design

not at a level expected to harm the Reactor or present conductivity excursions too high for WPA reprocessing to handle. The Reactor installed at this time operated 4 months following the second breakthrough and returned to ground for testing, which confirmed exposure to these compounds did not result in performance degradation. It was thusly agreed in October 2021 to run the currently installed MF Bed S/N 7 past the second ionic breakthrough and plan for removal and replacement (R&R) after the third ionic break through.

In April 2022, the MF Bed reached the third ionic breakthrough and was R&R'd, after the first breakthrough in April 2021 at approximately 9000 lbs. of throughput and second breakthrough in October 2021 at approximately 16,000 lbs. This marked the first time a single bed had been allowed to operate past the second breakthrough, allowing an additional approximately 11,000 lbs. of throughput and 6 months of operational run time before reaching required R&R levels of conductivity. Total Organic Carbon (TOC) levels remained in family and no other indications of Reactor catalyst degradation have been observed. The new MF Bed S/N 11 (installed April 2022) is planned to run in the same configuration and through the third breakthrough.

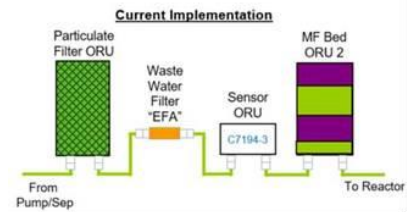
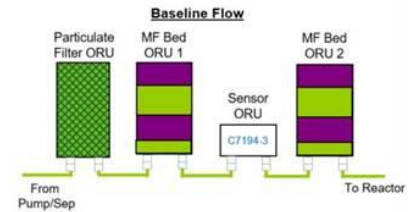


Figure 11. Original and Updated MF Bed Configuration

3. Catalytic Reactor Off-Nominal Failure Signature

The typical failure mode for Catalytic Reactors is leaking of the Hot Item Assembly elastomeric seals, which are subject to wear from oxidation and thermal cycling during WPA processing. Reactor High Pressure sensor P_7112_3 is used to monitor the start and progression of a potential seal leak. In nominal operations, a single repressurization follows a process cycle due to thermal cooldown following the previous process cycle. A second repressurization is possible with extended time in standby due to nominal Reactor seal leakage, or due to either an internal (through a pressure regulator or check valve) or a small external leak. Three or more repressurizations is not common in nominal processing operations, and indicative of degraded elastomeric seals in the Cat Reactor no longer holding pressure.

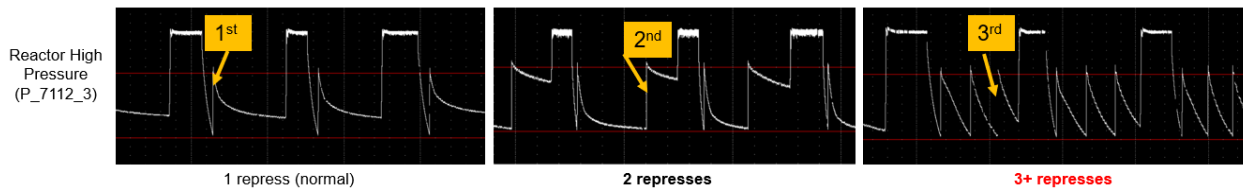


Figure 12. Water Processor Assmbeley Repressurization Cycles

Catalytic Reactor S/N 5 demonstrated signs of significant leakage (three or more repressurizations) and was R&R'd in June 2022, after an expected number of cycles based on historical averages of prior Reactors operating at the same temperature and pressure. Typically, in the current operating configuration, the second repressurization starts at approximately 300-400 process cycles. S/N 5, however, first started showing this second repressurization sooner than expected, at around 150 cycles. Because this second repressurization was seen sooner than average but the Reactor still reached average life before gross leak occurred, it is suspected that there was a premature internal leak in either the

inlet check valve [0165-1], inlet isolation valve [1126-1], or pressure regulator [1115]. S/N 5 returned on SpX-26 and will be investigated to assess valve performance and identify root cause of failure

4. Oxygen Generation Assembly (OGA):

The ISS Oxygen Generation Assembly (OGA) has been operating for over 15 years and is currently installed in Lab. As of December 31, 2022, the ISS OGA has produced a total of 25,911 lbm of oxygen and 3,239 lbm of hydrogen since initial activation in 2007. The OGS rack was moved from Node 3 to Lab in September 2022 to enable co-location and integration of exploration demonstration air string systems including future (2025) upgrades planned for an Advanced OGA (AOGA) that will be more reliable and maintainable while requiring less sparring. AOGA will be demonstrated on ISS for at least 3 years.

Several OGA issues have evolved in the past year associated with pump lockups, recirculation loop pressure, hydrogen sensor output voltage off-scale high, and nitrogen purge valve leakage.

a. Spare Pump Lockups

In March 2021 crew attempted to replace a legacy design positive displacement gear Pump ORU to begin getting run time on an updated pump of similar design that included new wear couple materials, increased bearing thrust surface, journal bearing length change and additional hydrostatic bearing feeds to improve operating and cycle life. Both prepositioned on-orbit new design Pump ORU spares failed to spin-up upon initial activations. Crew reinstalled old design Pump ORU SN1 to successfully regain OGA operation.

After two ground spare Pump ORUs, S/N 2 (5.8 years in stowage) and S/N 6 (newly built), were both spin checked and expedited for launch to ISS in April 2021, the old design pump S/N 1 was replaced with a new design Pump ORU S/N 6 and OGA was successfully reactivated in May 2021.

Test Teardown and Evaluations (TT&E) and failure investigation performed on two failed pumps, S/Ns 3 and 5, determined that nickel phosphate and oxide precipitation deposited on the pump's gears and housing, causing gear lockup after 10 years of stagnant stowage. The deposits originated from degradation and corrosion of the water filled spare ORU's inlet and outlet Quick Disconnects' (QD) internal electroless nickel coating. Recurrence control is to use new QDs for all future refurbished Pump ORU QDs that do not have internal electroless nickel coatings to mitigate any precipitation induced pump lockups in the future. Refurbished Pump ORUs S/Ns 3 and 5 are planned to be completed and launched in early 2024.

In April 2022 crew collected and returned for analysis a 20 ml water sample from spare Pump ORU S/N 2. In May 2022 spare Pump ORU S/N 2 was also powered outside of the OGS rack and was successfully rotated while performing a 10 L water flush. The 10 L flush effluent was returned for chemical and particulate analysis. The 20 mL sample and 10 L powered flush effluent analysis did not show any significant particulates of interest (Ni or P containing). Analysis of the dissolved chemicals was used to evaluate current status of S/N 2 and to assess the possibility of minimizing precipitate formation over time using a periodic flush for future preventative maintenance until early 2024 when newly refurbished spares arrive. Analysis results indicate power flushing spare pumps likely have limited value (not clearing precipitate). The best method to keep spares viable is to install them into the OGA. The team is awaiting a NASA program decision on multiple options including installation of S/N 2 or risk acceptance for leaving S/N 6 installed until newly refurbished spare Pump ORUs arrive in early 2024.

b. Recirculation Loop Pressure

Water recirculation loop pressure is maintained by a hydrogen Back Pressure Regulator (BPR) located in the Hydrogen Dome ORU downstream of the Rotary Separator Accumulator (RSA) within the hydrogen vent line. Since early 2020 (S/N 3 H2 Dome ORU installed), there were several OGA fast shutdowns due to triggering a low pressure fault limit within the recirculation loop after transitioning into Standby. In 2020, ETHOS commanded an OGA software override to implement one minute standby holds to evacuate the dome every 100 minutes while in process (was 5 minutes) to reduce time in standby and enable OGA reactivation.

In 2021, the recirculation loop and oxygen outlet low pressure shutdown limits were lowered to avoid nuisance shutdowns while not violating any hazard controls nor flight rules which enabled continued OGA operations with the suspected BPR performance issues. A similar change in the regulated recirculation loop pressure signature in standby has also been observed with the currently installed S/N 4 H2 Dome ORU (installed in Oct 2021 to present due to S/N 3 H2 ORU cell stack failure).

After S/N 3 H2 Dome ORU was returned to ground in Jan 2022, the suspect BPR was removed for TT&E and failure investigation. Both the suspect and a nominally performing BPRs were CT-scanned and performance tested. A stepwise teardown of S/N 3 H2 ORU's BPR (S/N 006) was completed in April 2022. Corrosion residue was found in the tightly toleranced poppet / guide seat area of S/N 006 BPR. The team has made changes to BPR manufacturing processes to ensure proper passivation of metallic and is currently assessing other potential recurrence controls.

c. Hydrogen Sensor Output Voltage

In June 2022, the installed Hydrogen (H2) Sensor ORU S/N 1004 voltage output in one of three hydrogen sensor semiconductor die spiked off-scale high (-1 sensor) and was inhibited as allowed by flight rule to enable continued OGA system operation.

The H2 Sensor ORU is utilized as a hazard control to detect unsafe amounts of hydrogen within the OGA oxygen outlet stream. Only two of three sensor dies are required to be operational to consider the ORU as a hazard control. The ORU has a calibration life of 201 days of being powered then it is replaced with a spare and returned to ground for refurbishment.

In August of 2022, OGA went to fast shutdown due to a power feed loss. Upon reactivation of OGA, the S/N 1004 H2 Sensor ORU's -1 sensor voltage output was no longer spiked off-scale high and back in family with the other two sensors. Teams determined that likely cause was -1 sensor recovery from clearing a latched fault within the ORU's sensor board memory register after power reset. Team continued to monitor installed S/N 1004 H2 sensor die outputs until end of calibration life. S/N 1004 ORU was replaced in October 2022 and returned for refurbishment or removal from fleet.

d. Nitrogen Purge Valve Leakage

The OGA's Nitrogen Purge ORU provides the capability to purge the OGA's oxygen outlet line and anode oxygen side of the electrolysis cell stack with nitrogen after OGA shutdown. The ORU's internal volume includes orifices and solenoid valves to store pressurized nitrogen volume and control purge flow rates. Solenoid valves are used to control the nitrogen flow from ISS to ORU and a three-way valve directs the ORU's pressurized volume of nitrogen either to the oxygen outlet or to the cell stack anode.

In December 2021, frequent depressurization and repressurization cycles were trended within the installed N2 Purge ORU's pressurized volume. The team determined that the ORU's three-way valve had developed an internal leakage path to oxygen outlet into cabin. The ORU had been operational since 2007 and was beyond its design life of ten years.

In Feb 2022, unsuccessful troubleshooting steps were performed that included cycling of the S/N 1 ORU's three-way valve several times to attempt removal of potential particulate contamination on the valve seat. Nitrogen Purge ORU S/N 1 was replaced with S/N 2, which continues to operate nominally. The failed S/N 1 ORU was returned in August 2022 for an abbreviated TT&E planned in 2023 to confirm the three-way valve internal leakage and if valve seat particulates or seat wear was the root cause of nitrogen leakage failure.

5. Advanced Oxygen Generation Assembly (AOGA):

The Advanced O2 Generation Assembly (AOGA) program is a partial redesign of the ISS OGA to support future long duration exploration missions to the moon and beyond. As part of the redesign effort, NASA program has a stated goal of reducing total weight and volume of the assembly and its spares through enhancing design maintainability. Program also wants to operate AOGA on ISS for three years minimum beginning in 2025.

AOGA is an upgrade to the OGA since system incorporates a new design cell stack (same maximum oxygen 20.4 lbm/day production rate as OGA), increases cell stack life by minimizing membrane thinning, allows for additional system maintenance, and incorporates dormancy nitrogen purge and deionized water flush of the recirculation loop to allow the system to be shut down for up to one year and as a preventative maintenance feature to periodically reduce build-up of concentrating contaminants.

For ISS demonstration, the AOGA is controlled by the existing OGA Process Controller with its original software and firmware. Commanded software overrides will be utilized for unique AOGA system operation parameters and fault limits. The AOGA will be reusing most of the hardware that is in the OGA system but will be replacing the OGA Hydrogen Dome ORU (includes a fracture containment dome that is not removeable on-orbit rendering the cell stack, Rotary Separator/Accumulator (RSA), valves, pressure and temperature sensors non-maintainable) with the AOGA maintainable Oxygen Hydrogen Domes Assembly (OHDA) to enable significant reductions in spares mass and volume.

The OHDA contains two smaller domes (cell stack and RSA) that are removable on-orbit for replacement of failed components with spares. The new AOGA pressure sensors are now located external to the domes. The OGA RSA Differential Pressure (DP) sensors will be reused and remain located within the OHDA's RSA Dome Assembly.

The OGA recirculation loop ACTEX will be replaced within the OGS rack with the AOGA ReMediation Advanced DeIonization and Limited Life Optimization (ARMADILLO) Ion Exchange Bed which has lower pressure drop, depth filter, meets AOGA MDP, has redundant seals and is designed for a three year operational life given it contains about five times the volume of mixed ion exchange resin. ARMADILLO CDR is planned in February 2023.

A H2 Sensor Tech Demo (H2ST) containing three commercial hydrogen sensors is currently mounted onto the front of the OGS rack and will remain installed on OGS after AOGA is installed to gain at least three years of operation time. The H2ST is connected to OGA's oxygen outlet port and monitors the OGA's product oxygen for hydrogen and is located in series with the upstream legacy OGA H2 Sensor ORU, allowing comparisons of new sensor performance. The H2ST's new commercial hydrogen sensors are checked for drift every 90 days using a pressurized container of 1% in air calibration gas.

The H2ST sensors do not need to be returned to ground for recalibration (OGA H2 Sensor ORU is life limited to 201 powered-on days and must be recalibrated on ground), are not sensitive to nitrogen, water moisture, nor exhibit any significant upwards drift of voltage output, unlike the current H2 Sensor ORU.

As of February 2023, the AOGA has completed CDR and gained Phase 2 Safety Review Panel approvals of both AOGS Integrated Hazard Reports and Maintenance Hazard Analyses.

E. Conclusions/Forward Work

This paper documents ECLS system events encountered mostly between January and December 2022 with a few events dating back to previous years not documented in systems status papers. Twenty-four years strong, and the ISS National Laboratory still stands as one of the greatest, if not the greatest, international engineering achievement. The future is rapidly approaching, with Artemis I's inaugural launch of the Orion Capsule and NASA's newest heavy launch vehicle, the Space Launch System Rocket (SLS). The moon is now within reach, and the follow-on Artemis missions will bring humans back the first footsteps on the moon since the end of the Appolo program over 50 years ago. Those missions will build NASA's next great station, the Gateway, paving the way for mars.

In the commercial sector, multiple commercial entities are aiming to commercialize Low Earth Orbit (LEO). Commercial Elements will attach to the ISS, while multiple providers vie to provide free-flying solutions under the Commercial LEO Destinations Contracts.

The ISS National Lab serves as the nation's testbed, feeding the innovation that all of these exciting programs offer for the future. It serves as the platform and test bed for all the advanced technologies needed for the years ahead. The future is bright, and the ISS is that shining light leading the way to the future in space exploration.

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