

## International Space Station (ISS) Environmental Control and Life Support (ECLS) System Overview of Events: 2015-2016

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November 2, 2015 marked the completion of the 15<sup>th</sup> year of continuous human presence in space on board the International Space Station (ISS). After 44 expedition crews, over 115 assembly & utilization flights, over 180 combined Shuttle/Station, US & Russian Extra-Vehicular Activities (EVAs), the post-Assembly Complete ISS continues to fly and the engineering teams continue to learn from operating its systems, particularly the life support equipment. Problems with initial launch, assembly and activation of ISS elements have given way to more long term system operating trends. New issues have emerged, some with gestation periods measured in years. Major events and challenges for each U.S. ECLS subsystem occurring during the last year are summarily discussed in this paper, along with look aheads for what might be coming in the future for each U.S. ECLS subsystem.

### Nomenclature

<i>AC</i>	= Assembly Complete	<i>NORS</i>	= Nitrogen/Oxygen Resupply System
<i>ACS</i>	= Atmosphere Control & Supply	<i>OGA</i>	= Oxygen Generation Assembly
<i>AIK</i>	= Airlock Installation Kit	<i>OGS</i>	= Oxygen Generation System
<i>AR</i>	= Atmosphere Revitalization	<i>ORU</i>	= Orbital Replaceable Unit
<i>ARFTA</i>	= Advanced Resupply Filter Tank Assembly	<i>PDMS</i>	= polydimethylsiloxane
<i>ASV</i>	= Air Selector Valve	<i>PFE</i>	= Portable Fire Extinguisher
<i>BIT</i>	= Built-In Test	<i>PGT</i>	= Pirani Gauge Transducer
<i>CCAA</i>	= Common Cabin Air Assembly	<i>PIO</i>	= Provisioned Item Order
<i>CCT</i>	= Cold Cathode Transducer	<i>PMM</i>	= Permanent Multipurpose Module
<i>CWC</i>	= Contingency Water Collection	<i>PPT</i>	= <i>Positive</i> Pressure Transducer
<i>CDRA</i>	= Carbon Dioxide Removal Assembly	<i>RFTA</i>	= Resupply Filter Tank Assembly
<i>CHX</i>	= Condensing Heat Exchanger	<i>RTA</i>	= Resupply Tank Assembly
<i>DAB</i>	= Desiccant Adsorbent Bed	<i>R&amp;R</i>	= Remove & Replace
<i>DMCPS</i>	= Decamethylcyclpentasiloxane	<i>SBA</i>	= Sorbent Bed Assembly
<i>ECLS</i>	= Environmental Control and Life Support	<i>SpX</i>	= SpaceX
<i>ECLSS</i>	= Environmental Control and Life Support Systems	<i>STS</i>	= Space Transportation System
<i>EVA</i>	= Extra-Vehicular Activity	<i>TCCS</i>	= TraceContaminantControlSubassembl
<i>FOD</i>	= Foreign Object Damage	<i>THC</i>	= Temperature & Humidity Control
<i>FDS</i>	= Fire Detection and Suppression	<i>TOC</i>	= Total Organic Carbon
<i>FW</i>	= Firmware	<i>TT&amp;E</i>	= Test, Teardown & Evaluation
<i>HEPA</i>	= High Efficiency Particle Air	<i>TUBSS</i>	= Temporary Urine Bag Storage System
<i>HP</i>	= High Pressure	<i>UPA</i>	= Urine Processor Assembly
<i>HPGT</i>	= High Pressure Gas Tank	<i>USOS</i>	= United States Operational Segment
<i>HTCO</i>	= High Temperature Catalytic Oxidation	<i>UWMS</i>	= Universal Waste Management System
<i>HTV</i>	= H <sub>2</sub> Transfer Vehicle	<i>WM</i>	= Waste Management
<i>ISS</i>	= International Space Station	<i>WPA</i>	= Water Processor Assembly
<i>LiOH</i>	= Lithium Hydroxide	<i>WRS</i>	= Water Recovery Subsystem
<i>LP</i>	= Low Pressure	<i>WRM</i>	= Water Recovery & Management
<i>MCA</i>	= major Constituent Analyzer	<i>W&amp;HC</i>	= Waste & Hygiene Compartment
<i>MPLM</i>	= Multi-Purpose Logistics Module		
<i>MSFC</i>	= Marshall Space Flight Center		

### 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

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crews since assembly began in 1998. Shuttle retired in 2011 with completion of the last mission to the International Space Station, designated STS-137/ULF-7.

Through AC, new pressurized elements including Node 3 & the Permanent Multi-purpose Module (PMM) formerly known as the Multi-Purpose Logistics Module (MPLM) have been added to the ISS, making up a total of 16 pressurized elements. ECLS activity has focused on maintaining the ISS systems currently onboard while acquiring on-orbit operational knowledge in microgravity.

## **A. ISS ECLS OVERVIEW**

The ISS on-orbit ECLS system is comprised of 6 subsystems, including 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 Shuttle resources.

### **2. Temperature and Humidity Control (THC)**

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 U.S. Lab THC provides active cooling for Node 1 and the MPLM when docked to the ISS.

### **3. Fire Detection and Suppression (FDS)**

The FDS subsystem includes smoke detection, fire isolation, fire extinguishment, and fire recovery.

### **4. Atmosphere Revitalization (AR)**

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 contaminants levels are maintained within limits. Additionally, the ISS habitable environment is monitored for atmosphere major constituents O<sub>2</sub>, N<sub>2</sub>, and CO<sub>2</sub>, as well as H<sub>2</sub>, CH<sub>4</sub>, and H<sub>2</sub>O. 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.

### **5. Water Recovery and Management (WRM)**

The WRM subsystem supplies potable water, hygiene water, and water for payloads, as well as collects humidity condensate. The WRM also provides excess wastewater venting; condensate storage; and potable, waste, and fuel cell water distribution. The WRM subsystem was expanded significantly prior to Shuttle retirement with the addition of the Regenerative ECLS Racks known as WRS 1, WRS 2 & 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 (W&HC), a USOS bathroom that collects solid waste and collects, treats and transports liquid waste to the Urine Processor Assembly (UPA) for water recovery.

### **6. Vacuum System (VS)**

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.

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

### A. Atmosphere Control and Supply

#### 1. NORS AIK Installation and 1<sup>st</sup> gas transfer since Shuttle retirement

Five High Pressure Gas Tank (HPGT) ORUs are mounted to the *Quest* Airlock exterior (3 oxygen & 2 nitrogen).

To deal with the retirement of the Shuttle Orbiter fleet that resulted in the loss of its gaseous oxygen and nitrogen resupply to the ISS HPGTs, the high pressure (41,369 kPa (6,000 PSI)) Nitrogen/Oxygen Recharge System (NORS) was developed.

Delivery of the Airlock Installation Kit (AIK) to ISS occurred on Orb-2 in July 2014, and the device was installed in the *Quest* Airlock Equipment Lock on November 18, 2015 to enable gas recharge of the Airlock HPGTs via AIK installed Resupply Tanks Assemblies (RTAs). Two issues that occurred during AIK installation were: (1)

A small N<sub>2</sub> connection leak at a Gamah fitting due to difficult access to the connection and inability to R&R the Gamah seal, and (2) the Fluid Fitting Torque Device (FFTD) got stuck on the fitting that was leaking and could not be removed. The leak was determined to be low enough to not need repair (on the order of ~3 Kg (~ 6 lbs.) N<sub>2</sub>/year and the FFTD was abandoned in place. The crew may be asked to attempt retrieval later but a spare FFTD was launched on OA-6 in April 2016. (See Figure 1 for the AIK installed in the U.S. Airlock *Quest*.)

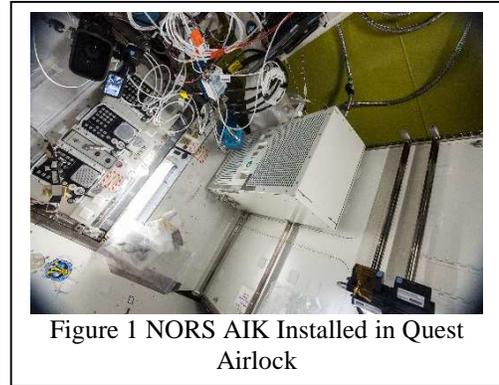


Figure 1 NORS AIK Installed in Quest Airlock

The first NORS oxygen and nitrogen RTAs were flown to ISS together on HTV-5 on August 19, 2015 loaded with 38.2 kg (84 lbs.) & 28.6 kg (63 lbs.) mass of stored gas respectively.

After delivery of the RTAs to ISS and installation of the AIK in the airlock, the crew installed the oxygen NORS tank onto the AIK on January 19, 2016 and accomplished the first gas transfer to a HPGT on ISS since Shuttle retirement.

Once the High Pressure (HP) oxygen tanks pressure was increased from 11,721 kPa (1700 psia) to 13,789 kPa (2000 psia) in a pressure equalization process that took approximately 6 hours, the configuration was changed to transfer gas to the Low Pressure (LP) oxygen tank, resulting in a pressure increase from 689 kPa (100 psia) to 2,757 kPa (400 psia). 21.95 kg (48.3 lbs.) of oxygen was transferred to the HP tanks and 11.55 kg (25.4 lbs.) of oxygen was transferred to the LP tank with 4.7 kg (10.3 lbs.) residual oxygen still in the NORS oxygen tank. (See Figure 2 for HP & LP HPGT pressure increases resulting from the first NORS oxygen transfers.)

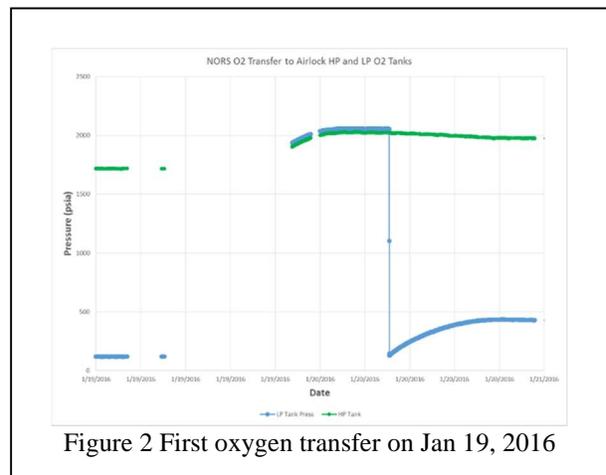


Figure 2 First oxygen transfer on Jan 19, 2016

When the nitrogen NORS tank is installed in the AIK the residual oxygen from the first RTA will be vented directly to the ISS cabin.

As of this writing the first nitrogen NORS tank installation into the AIK is still pending, however the target mass transfer and starting and ending HPGT tanks pressure are 17.8 kg (39.2 lbs.) and 10,687 kPa (1550 psia) to 12,590 kPa (1826 psia). The nitrogen RTA will stay in the AIK after the equalization with the nitrogen HPGTs and the residual

NORS tank nitrogen (10.8 kg (23.8 lbs.) and 12,590 kPa (1826 psia)) will be used to feed the nitrogen bus users until the pressure is below 827 kPa (120 psia), then the RTA will be removed from the AIK and the residual gas vented to the cabin.

The empty NORS RTAs will be returned to earth on a subsequent SpaceX flight for re-fill and re-launch. NORS tanks can be re-used up to 10 times.

## 2. Oxygen Generator Assembly (OGA) status update

The OGS rack was launched on STS-121/ULF1.1 in July 2006 and initially installed in the U.S. Lab module for operation. After Node 3 arrived on STS-130/20A in 2010, the OGS rack (along with WRS 1 & 2 racks) was relocated to Node 3. The OGA has accumulated 40,344 hours of operational run time through Feb 14, 2016 with an *average* production rate of 2.74 kg /day (6.02 lbs./day) oxygen or a total of 4,563 kg (10,039 lbs.) of O<sub>2</sub> and 570 kg (1255 lbs.) of H<sub>2</sub>. (See Figure 3 for OGS rack.)

After the failure of the first OGA Hydrogen ORU (cell stack) in July 2010, a mixed ion exchange resin bed to remove ionic contaminants including fluoride and shifting the pH closer to neutrality was added to the OGA recirculation loop. The first H<sub>2</sub> ORU failed after 250 days of operation. As of Feb 14, 2016 the second H<sub>2</sub> ORU with the added mixed ion exchange resin bed has been operating for 4.5 years (34,832 hours) and the ORU has exceeded a 5 year installed life with good indication that the fleet of spares (1 on board ISS, 3 on the ground) will last to the currently projected end of the ISS program (2028). This also is a good sign the design and technology is suited for exploration class missions of 3+ years.



Figure 3 OGS Rack

## 3. OGA Hydrogen Sensor ORU update

The only life limited item left in the OGA design is the hydrogen sensor ORU. The hydrogen sensor ORU has 3 diodes in it and had an initial installed life of 150 days. (See Figure 4 for OGA H<sub>2</sub> Sensor ORU.) Based on recent extensive analysis of telemetry data to provide a basis for extending the installed life of the ORU, ISS Program Management approved extending the ORU installed life to 201 days in 2015.

In parallel, NASA MSFC has investigated methods of replacing the relatively short lived ORU for both ISS and exploration needs with new sensors that last longer and/or can be calibrated in place. In addition, NASA is looking at a potential hydrogen recombiner technology that could replace the sensors, if the ISS safety Panel agrees. Either path would be preferable for ISS and exploration needs.



Figure 4 OGA Hydrogen Sensor ORU

## 4. HPGT monitor update

The HPGT pressure monitoring device that was discussed in last year's paper (ICES-2015-155) has not been approved to go forward by NASA management so the oxygen ORU tank residing on the truss status is unknown, but still assumed to be full. However, there has been a change to the oxygen reserve management approach that has obviated the need to insure the truss HPGT is actually still full. So further pursuit of this capability is unlikely.

## B. Temperature and Humidity Control (THC)

### 1. Common Cabin Air Assembly (CCAA) Condensing Heat Exchangers (CHXs) Universal Hose Kit

CCAA CHXs have launched in the U.S. Laboratory *Destiny* module (2), the *Quest* Airlock (1), Node 2 *Harmony* (1) and Node 3 *Tranquility* (1) modules. (See Figure 5 for ISS CCAA CHX.)

The three U.S. installations have common structural, electrical and fluid connections where a single spare CHX ORU can be installed in any location.

The two Italian Nodes each have common structural and electrical connections to the U.S. design but have unique fluid connections, thus requiring pre-configuring the CHX on the ground for a specific installation location. While this didn't seem to be an issue during the design phase of the nodes, the subsequent CHX coating issues reported in last year's paper (ICES-2015-155) limit the logistics team's ability to pre-position a spare on board ISS.



Figure 5 CCAA CHX

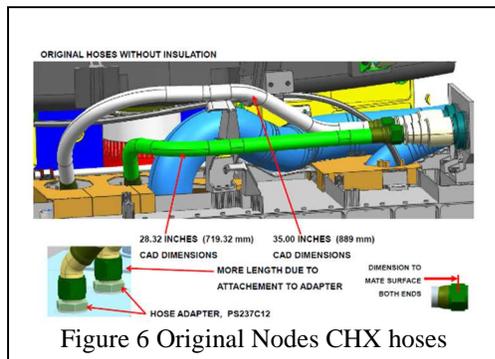


Figure 6 Original Nodes CHX hoses

As it works today the Node 2 & Node 3 CHX ORUs have to fly with hoses attached and plug into QDs several feet away from the CHX (each module having different length hoses), while the U.S. installation locations have hoses that route all the way to the CHX and mate to QDs directly on the ORU.

To respond to this new and challenging situation, a modification to both Node 2 and Node 3 CHX fluid connections was conceived and referred to as the *universal CHX* hoses modification. (See Figures 6 & 7 for before and after Nodes CHX coolant hose configurations.) These hoses are being manufactured by Alenia and will be flown to ISS in 2016. Once they are available, a common CHX spare ORU can be flown to become a universal CHX spare that can be installed in any of the five CHX locations. This will be accomplished by replacing the 'old' hoses with the new permanent Alenia designed hoses allowing for connection to a common CHX.

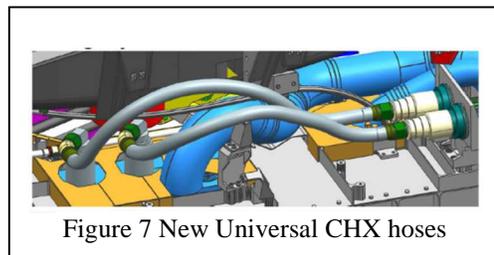


Figure 7 New Universal CHX hoses

### 2. Polydimethylsiloxane (PDMS) Scrubbers update

While the source of the PDMS contaminants on ISS cannot be eliminated, a method of controlling the problem has been developed. Concepts for system modifications and testing of candidate adsorbent media have been performed and a "permanent long term" solution has been chosen. A "temporary near term" solution was implemented and flown on SpX-6 in April 2015, as reported last year (Reference: ICES-2015-155).

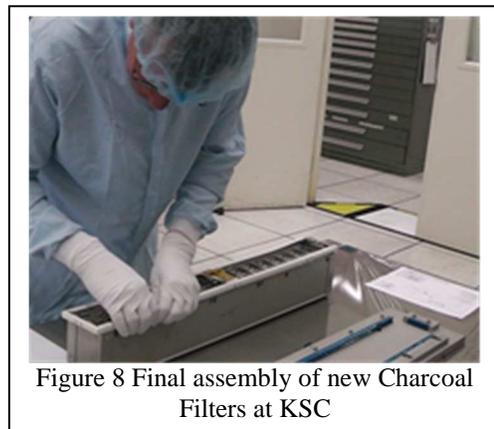


Figure 8 Final assembly of new Charcoal Filters at KSC

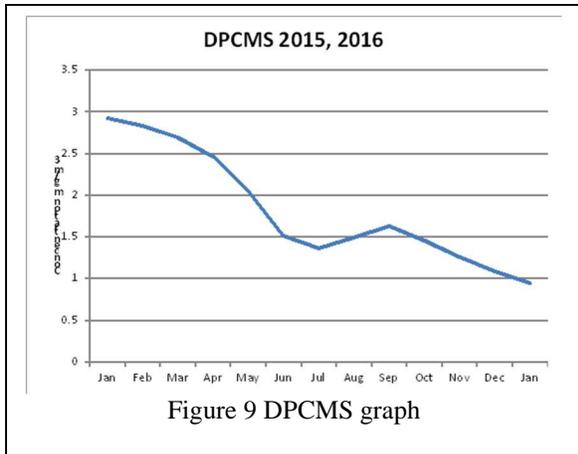


Figure 9 DPCMS graph

The four modified “charcoal filters” were installed in Node 1 on May 12, 2015 in place of the currently installed HEPA filters. (See Figure 8 for Charcoal filter assembly at KSC.) They have been installed and working for about a year and as expected have reduced the background PDMS level in the atmosphere with the goal of extending the WPA MF-bed life and delaying the next high TOC event (Reference: ICES-2015-155).

Looking at the Decamethylcyclpentasiloxane (DMCPS) trend the first 4 months of 2015 (before charcoal filter installation), the average was 2.72 mg/m<sup>3</sup>, while the next 9 months with the charcoal filters installed was 1.42 mg/m<sup>3</sup>, equating to about a 50% reduction in background levels over the installed time period. How this affects WPA MF bed life or rate of CHX coating contamination is still being studied.

(See Figure 9 for DPCMS scrubbing performance of the first set of charcoal filters through January 2016.)

Because the modified Charcoal filters are considered an interim step that doesn’t directly protect the five installed CCAA CHXs, a long term goal is to scrub the USOS atmosphere to eliminate or reduce exposure to the PDMS contaminants by installing combined Charcoal/HEPAs (CHEPAs) directly ahead of each installed CCAA CHX, located in the U.S. Lab, Airlock, Node 2 & Node 3.

Anticipating depletion of the first set of filters in Node 1 before the permanent design solution can be manufactured and flown, a second set of four filters were built in late 2015 and flown on OA-6 in March 2016. When the signs are that the first set of charcoal filters have hit breakthrough (DPCMS begins to return to pre-charcoal filter installed levels) the second set of charcoal filters will be installed. Since there were only 10 original charcoal filters built for launch-to-activation control of trace contaminants in U.S. elements and are now available for modification to the new configuration, engineering has requested the first expended set of four charcoal filters be returned on a SpaceX flight to allow re-packing and flying them again if needed to bridge the gap to the final design solution. Returning these filters will also allow for detailed chemical assay of collected contaminants to confirm ISS atmospheric constituent species and loading.

**C. Fire Detection and Suppression**

**1. Portable Fire Extinguishers (PFEs) update**



Figure 10 ISS CO2 PFE

The USOS Carbon Dioxide PFEs have flown on ISS since 1998 with no emergency discharges and only one unit replaced for leakage (it had exceeded its 10 year expected life). (See Figure 10 for ISS CO<sub>2</sub> PFE.) Their on-orbit integrity has been so well established that a life extension effort was undertaken and has successfully extended the CO<sub>2</sub> PFE life from 10 to 25 years. This has avoided the expensive return, refurbishment and re-launch of the 13 units on board.

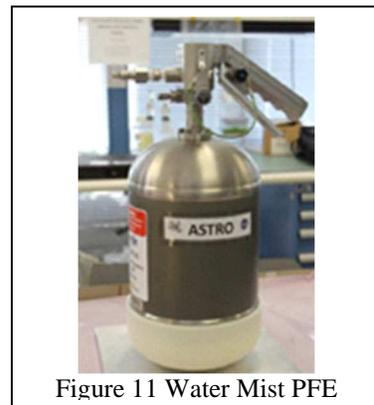


Figure 11 Water Mist PFE

Additionally, NASA has developed the Water Mist (WM) PFEs for ISS and Orion use. (See

Figure 11 for WM PFE.) The first two Water Mist PFEs flew to ISS on OA-4 on December 6, 2015 to be deployed in the Columbus and JEM modules, with 4 more PFEs flying on OA-6 on March 22, 2015. To make room for the WM PFEs 4 CO<sub>2</sub> PFEs will be decommissioned and returned later this year.

## D. Atmosphere Revitalization

### 1. CDRA bed re-design progress, and bed $\Delta P$ increase update

As of April 2016 the “-5s” in Node 3 CDRA have accumulated approx. 11 months of run time and the  $\Delta P$  signature is flat and without need for crew maintenance, indicating the “-5” bed ORU configuration is performing as expected. The rapid dusting “-4s” have been returned for conversion to “-5s” which, as of this writing, is nearly complete. They will launch on HTV-6 in October 2016 and be installed in the Lab CDRA, bringing the fleet of CDRA beds on orbit all up to the “-5” configuration.

Leaving the -3 bed ORUs on ISS as CDRA bed ORU spares when the second set of -5s are delivered and installed or returning them on a subsequent SpaceX flight is still under discussion with NASA.

### 2. Node 3 CDRA Blower failure update

During the re-start of the Node 3 CDRA after the Bed ORU R&R activity in May 2015 the blower (part of the Blower/Pre-cooler ORU that provides the motive force for the process air to move through the CDRA beds) failed to start. (See Figure 12 for CDRA blower.) Subsequent troubleshooting and ultimately an R&R of the blower was performed. The crew visually inspected the removed blower and reported seeing FOD inside the fan housing. The blower was returned on SpX-6 and a TT&E conducted at Honeywell Torrance, CA in December 2015. Blower manual torque measurement was above the specification limit, however the blower did start up when commanded. Despite this the blower was disassembled for detailed bearing inspection. Upon more detailed inspection, accumulated zeolite dust was observed in the bearing flow passages and the thrust bearings were substantially worn. There was also evidence of motor over speed seen on the motor shaft. Over speed was suspected of happening when ASV 103 failed during commanded transition back in 2012, thus exposing the blower to a lack of airflow and starving the air bearings. There was no “smoking gun” to say why the blower failed to start on ISS after the maintenance event, however transient FOD could not be ruled out. The blower will be rebuilt and returned to ISS as a second spare.



Figure 12 CDRA Blower

### 3. Newly discovered heater sheet migration in “-3” heater cores

During the Blower TT&E at Honeywell in December 2015 the engineering team had the opportunity to inspect the returned “-3” bed ORU heater cores. Engineering interest was in confirming the root cause of the heater shorts that occurred in-flight (predicted to be FOD related (Reference ICES-2015-155). Based on the first bed ORU with an electrical short on-orbit that was inspected on the ground the root cause of the short was inconclusive, so redesign of everything thought to be a possible contributor was implemented. When the team disassembled the -3 bed ORU heater cores they found that some of the heater sheets sandwiched between aluminum parting sheets making up the core assembly had “migrated” along the long axis of the core toward the check valve to the degree that several tie rods had made contact with heater traces causing the in-flight electrical short. (See Figure 13 for heater core with extruded heater sheet.) As this was a different failure mode than previously seen it puts into question the -4 configuration redesign that was thought to be the solution to the heater sheet shorting problem. The opportunity to also inspect the returned -4 heater cores showed evidence of similar “migration” but to a lesser extent, likely due to

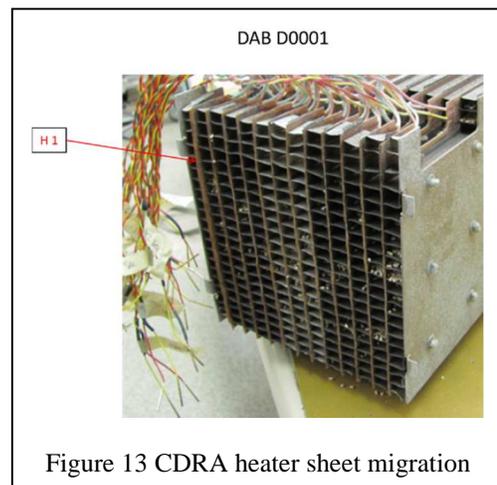


Figure 13 CDRA heater sheet migration

the thicker Kapton sheets used in the “-4” redesign. As of this writing, a preliminary fault tree has been developed and review is on-going.

#### 4. Flight Doctors & Crew Request for Lower ppCO<sub>2</sub> in USOS update

Flight doctors and crew requests to operate ISS at or below 3 mm Hg ppCO<sub>2</sub> levels for the 1-year crew (and no doubt beyond) and the planned increase of the ISS crew from 6 to 7 in 2018 when Commercial Crew vehicles begin to ferry astronauts to ISS is well below the CDRA ppCO<sub>2</sub> management and CO<sub>2</sub> removal design point of 5.3 mm Hg. This taxes the CDRA capability to the point where periodically two CDRA (intended to be fully redundant while meeting spec ppCO<sub>2</sub> levels and crew complement) have to be run together in addition to the Russian Vozdukh operation, and occasionally turning on the amine swing bed payload experiment to meet the demands if a second CDRA is not available.

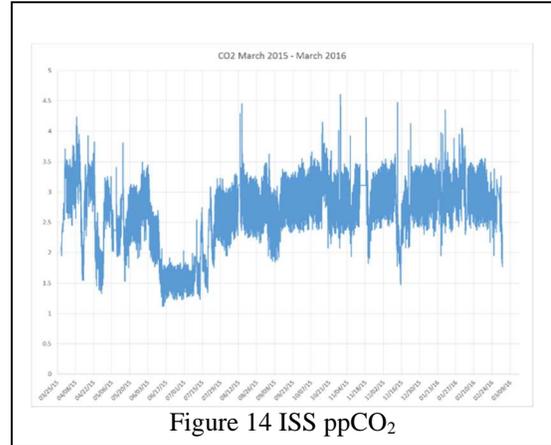


Figure 14 ISS ppCO<sub>2</sub>

A “-6” CDRA bed concept discussed last year (Reference ICES-2015-155) based on a new high performance polymer Zeolite failed to realize the potential as a replacement media when it was determined it needed much higher regeneration temperatures than CDRA can produce or handle and it had a much higher pressure drop than existing media.

As of this writing and to the author’s knowledge no promising new technology has surfaced to meet the demands in time for 4 USOS crew in 2018, so the Logistics team is stepping up orders to manage the spares pipeline assuming a second CDRA will have to run more often, in addition to the first CDRA and the Russian Vozdukh running, when 4 U.S. crew arrive.

However, with the 1-year crew mission now completed, the average ppCO<sub>2</sub> over the 12 month period that they were on orbit was maintained at an average of 2.7 mm Hg. (See Figure 14 for one-year crew ppCO<sub>2</sub> trend.)

#### 5. CDRA Air Selector Valve Issues update

Air Selector Valve (ASV) failure rates continue to be a maintenance and logistics challenge. (See Figure 15 for CDRA ASV.) Driven by zeolite dust migration into the valves, the torque required to drive the valves increases due to increased friction with the ball seals and ball shaft bearings to the point the actuator can no longer drive the ball and the valve stalls out.



Figure 15 CDRA ASV

A re-design of the valve body to a “-2” configuration to be more tolerant of dust and provide more actuator torque margin is in work. An Interim Design Review of the new design was held in December 2015 with development testing and authorization to proceed with development of the flight hardware design. Mod kits to convert the -1 valves to -2s are expected to be available in late 2016. The new valves should begin to be fielded in mid-2017. Meanwhile, five additional “-1” spare ASVs were ordered under a Provision Item Order (PIO) from NASA and will be delivered between May and August 2016 to help with the ASV logistics supply pipeline to keep both CDRA running to meet crew and flight doctor’s requests.

#### 6. TCCS flow ΔP

By design, the expected end of life of the Trace Contaminant Control Subassembly (TCCS) Sorbent Bed Assembly (SBA) is due to chemical saturation of the sorbent media (LiOH) based on calculated acid gas generation in the cat reactor. Based on operational experience on ISS, the TCCS SBA has a second end of life feature relating to water carryover into the LiOH bed media causing the front end to become deliquescent (Reference 2006-01-2056). This slowly plugs the flow passages and, over time, eventually drives the TCCS blower to full speed at which point the flow through the entire TCCS begins to decrease. This occurred in the Lab TCCS in 2006 and the now again with the Node 3 TCCS in 2015. The SBA and Charcoal bed were R&R'd in November 2015. The Node 3 TCCS SBA will be returned for repacking and re-launch as a spare for future use on ISS. Data from two units now indicates the delta-P issue will routinely occur well ahead of the chemical capacity limit of the SBA, making it the end-of-life driver for the ORU.



Figure 16 ISS TCCS

Also, when the Node 3 TCCS was activated in February 2016 (first activation following the R&R while Lab TCCS was operating in the interim period) the air flow rate was not normal. The TCCS blower, designed to operate with flow meter feedback to control blower speed, was operating at maximum speed and the flow meter was still sensing a low flow through the system despite the R&R of the plugged SBA. The TCCS is still performing its function at the lower flow rate but the flow anomaly is currently under investigation. (See Figure 16 ISS TCCS.)

## 7. MCA Operational Enhancements (Firmware Version 4.25) update

The original Lab and Node 3 MCAs flew with Firmware (FW) version 4.18 installed in the MCA ORU 01 Data & Control Assembly (firmware controller). (See Figure 17 ISS MCA with ORU 01 highlighted.) Since 2001 this FW provided the basic functionality for the MCA, however over time many “tweaks” to the firmware were identified for operational improvements. Eventually the list of software improvements became so long the program agreed to an upgrade. This became known as FW version 4.25.

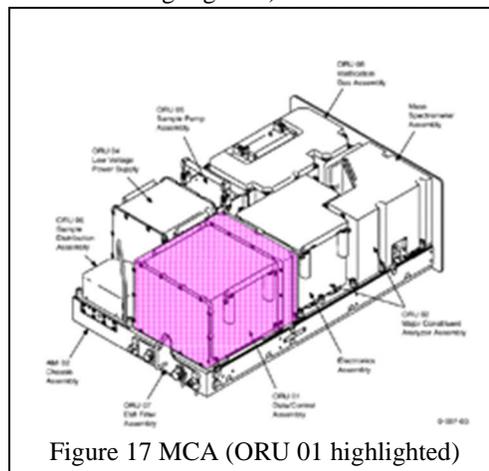


Figure 17 MCA (ORU 01 highlighted)

Enhancements of firmware version 4.25 include:

- Adding the capability to measure water vapor (dew point) in the ISS atmosphere
- Significantly improving the life of MCA calibration gas supply
  - It is estimated the new firmware will increase Verification Gas Assembly (VGA) life from 2.9 to between 4.1 and 4.8 years, depending on the number of calibrations performed over time
- Providing improved accuracies for ISS partial pressure measurements in the telemetered data from the MCA (previously a ground calculation)
- Retaining Built In Test (BIT) fault data until downloaded to aid in troubleshooting faults
  - Version 4.18 firmware holds BIT fault data for 2 minutes, then data is overwritten
- Providing the capability to adjust ion pump current threshold value for MCA shutdown and filtering of transient ion pump current spikes
  - This will have the effect of extending the life of the mass spectrometer (ORU 02)
- “Zero calibrations” (calibrations to determine background levels of gases) occasionally need to be repeated due to transient N<sub>2</sub> partial pressure spikes. Firmware version 4.25 filters N<sub>2</sub> partial pressure spikes to eliminate this problem and allow zero cals to continue to be successful as the ORU ages

Since the MCA was not designed to have FW uploaded through telemetry or on-orbit through a laptop connection, ORU 01 had to be returned, re-loaded and re-launched. The Lab MCA has been through this upgrade. ORU 01 with the new FW was installed in the Lab Atmosphere Revitalization rack in December, 2014. Unfortunately an electrical connection issue between the ORU 02 (installed at the same time the new ORU 01 was installed) and the MCA chassis has delayed the initial on-orbit use and checkout of the new firmware in the Lab MCA. Crew time has not been available to fix the problem and recover the Lab MCA operation.

On April 3, 2016 Node 3 MCA ORU 01 failed and was replaced with an on-orbit spare ORU 01 on April 7, 2016 that had the 4.25 firmware load. Checkout of the new firmware is currently in work.

### E. Water Recovery Management

As of Feb 14, 2016 the USOS WPA has processed 25,765 kg (56,684 lbs.) of water on ISS. The UPA has provided 11,026 kg (24,258 lbs.) of distillate, and the rest has been 14,738 kg (32,425 lbs.) combined condensate + CWC transfers, and includes approximately 608 kg (1,338 lbs.) of Sabatier product water.

Considering the combined launch weight of the WRS 1 & 2 racks (See Figure 18) and identified spares come to approximately a total weight of 3,000 kg (6,600 lbs.). The WPA has processed almost nine times its hardware weight in water proving that the investment in regenerative water processing systems for ISS has been worthwhile. (See Figure 18 ISS WRS1 & WRS 2 Racks.)



WRS 1 WRS 2  
Figure 18 WRS 1 & 2 Racks

#### 1. ARFTA Mod kit

As originally designed, the Urine Processor Assembly (UPA) Recycle Filter Tank Assembly (RFTA) was a one-time use on-board design. It was a non-bellows tank that had a vacuum applied pre-launch. When on-board ISS it would be filled with pretreated urine and used in the UPA until it had concentrated urine brine. Once processing was complete the RFTA was brought back to the ground for brine disposal and re-application of a vacuum for re-flight. Since the UPA was designed during the Shuttle era and the ISS had no means of brine disposal other than Russian Progress vehicles, the design made sense. However, once the Shuttle retired, it became a challenge to continue operating with this design, so the *Advanced*



Figure 19 UPA ARFTA

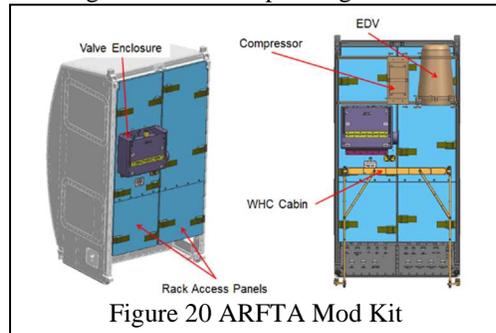


Figure 20 ARFTA Mod Kit

RFTA (or ARFTA) was built (reference AIAA 2010-6249). (See

Figure 19 ISS ARFTA.) It is a bellows tank design that can be filled with pretreated urine on board, just like the RFTA, but when processing is complete it can be removed from the UPA and emptied by applying a back pressure to the bellows to allow the brine to be transferred to a Progress Rodnik tank (with Russian permission), EDV (Russian fluid container) or into a U.S. Temporary Urine Brine Storage System (TUBSS) bag for disposal on an unmanned logistics vehicle. Six ARFTAs have been built with 3 units (2 in regular use,

1 spare) sent to the ISS in 2011 with good operational success to-date.

However, due to the crew time intensive nature of removing the ARFTA from the rack and replacing it after the pre-treated urine has been offloaded, a mod kit was designed and built to allow the crew to offload the ARFTA while the ARFTA stays in the rack. This mod kit was installed on January 25, 2016 and has successfully demonstrated its viability in reducing crew time as intended. (See Figure 20 ARFTA Mod Kit on WRS2 Rack face.)

#### 2. Water Processor Assembly (WPA) status update

The WPA continues to perform its function of recycling water for ISS crews and reducing up mass, as the water recovery numbers mentioned above indicate. With process cycles averaging approximately 3/week and processing an average of 18 kg/water per cycle (40 lbs.), the WPA is a hard working part of the ECLS system.

**a. Catalytic Reactor ORU leakage**

In the last few months of 2015, the installed Catalytic Reactor (CR) ORU showed signs of seal failure, despite the efforts to reduce the standby temperature in the hope of prolonging the ORUs seal service life (Reference ICES-2015-73). The ORU was R&R'd on 2/23/16 and WPA operation returned to normal. As a result of the last returned CR ORU seal evaluation, it has been decided that the radial seals in the “-1” configuration performed better than the seals in the “-2” configuration, so a hybrid configuration having the “-1” radial seals and “-2” boss fitting seals will be employed on CR ORUs launched in the future. (See Figure 21 WPA Cat Reactor ORU.)

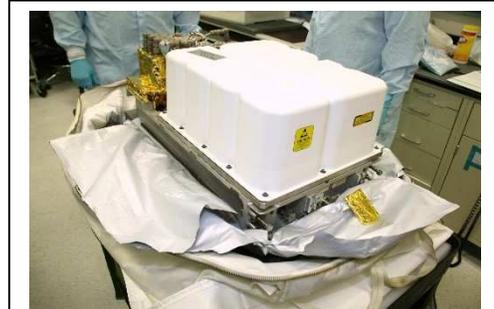


Figure 21 WPA Cat Reactor ORU

**b. High TOC and MF-bed ORU life**

As discussed under THC Section B, PDMS in the ISS atmosphere is a problem because it hydrolyzes into DMSD and gets through the WPA raising the TOC level of the product water. This happens once per installed set of MF bed ORUs and drives MF Bed ORU change out. With these almost annual high TOC events affecting the potable water, the ISS program has embarked on a temporary measure to reduce background PDMS levels (reference section B.2 of this paper) while in parallel developing a long-term solution. The WPA MF-bed ORUs are being investigated for upgrade to a more efficient PDMS removal media selection along with also addressing a charcoal obsolescence issue, possibly culminating in a bed ORU packing recipe upgrade.



Figure 22 WPA MF Bed ORU

This MF Bed ORU upgrade will provide better bed ORU performance under conditions of the PDMS challenge, however, MF Bed ORUs do not have the resin volume/capacity to resolve the PDMS problem on their own, hence, as mentioned earlier, an atmosphere scrubber approach is also under study. It is anticipated that the combination of the improved MF bed ORUs along with an atmosphere scrubber concept will significantly reduce, if not eliminate, the annual high potable water TOC events experienced to date on ISS. This is an excellent lesson learned for exploration since this issue was unknown during ISS design and took years of vehicle operation to surface and become a problem.

NASA MSFC has been testing a new media called Ambersorb™ 4652 to replace the currently used 580-26 charcoal and to provide some benefit to the PDMS scrubbing problem. When the testing is complete (est. late 2016), the MF bed ORU drawings can be updated to include Ambersorb™ 4652 as an alternate material for use in subsequent MF bed ORU packings. (See Figure 22 MF Bed ORU.)

**F. Waste Management update**

The USOS Waste & Hygiene Compartment (W&HC), flown to ISS on STS-126/ULF-2 in November 2008, was initially installed in the U.S. Laboratory module *Destiny*, then on June 24, 2010 the W&HC was transferred to the Node 3 *Harmony*, where it resides today. (See Figure 23 ISS W&HC rack.) The W&HC has experienced myriad nuisance problems and has required numerous scheduled component change-outs based on exposure to pre-treated urine, including pumps and hoses. However, the last year has been fairly routine in operation due to the great attention provided by the W&HC ground team and on-orbit crew members performing the maintenance activities.



Figure 23 ISS W&HC

On the near horizon is implementation of the new alternate pre-treat for use in the W&HC. Approved by NASA in February 2016 and already flown to ISS, the new chemistry changes the pre-treat from sulfuric acid to phosphoric acid to reduce crew urine calcium precipitation causing early UPA shutdowns when operating above 75% brine concentrations. The new pretreat will allow increasing brine water recovery from 75% to 90% thus significantly improving UPA water recovery performance. The calcium precipitation problem was a surprise finding not experienced during extensive ground testing and has taken quite some time to determine a solution. A new sensor set point has to be installed with the new pre-treat to correctly read the new acid content (sensor reading is based on conductivity of the flush water) to monitor for correct dosing.

### G. Vacuum System

The U.S. Laboratory *Destiny* vacuum system operates with a suite of 3 types of vacuum sensors. These sensors provide a tiered approach to pressure monitoring with the Positive Pressure Transducers (PPTs) operating from 0.38 to 40 psia, the Pirani Gauge Transducers (PGTs) operating between 1E-5 to 1E-1 Torr in low pressure range and 1E-1 to 20 Torr in the high pressure range and the Cold Cathode Transducers (CCTs) operating between 1E-7 to 1E-3 Torr. Offgassing of the components since initial activation in February 2001 have resulted in PGTs drifting upward, which did not allow the CCTs to be activated when the Vacuum System was activated. Ever since then the Lab vacuum system has operated with only two of three vacuum system pressure sensors working. As it turned out no payload users at the time needed the CCTs so no effort had been made to establish their operation. Fast forward 14 years to 2015 when the flight control team requested to operate the CCTs. The PGT drift rate had long since leveled off at a point compatible with CCT ops and the offgassing of system materials also abated over time, so by merely applying an offset to the PGT readings the software was able to activate the CCTs . (See Figure 24 Lab Vacuum System CCT.)



The bias was entered on September 10, 2015 and the CCTs were activated. The Vacuum Exhaust System CCT was stable and reading as expected. The Vacuum Resource System developed erratic readings but was attributed to a transient thermal event and has since stabilized.

### 3. Conclusions/Forward work

This paper documents ECLS system events encountered mostly between January and December 2015. Significant progress has been made in resolving ISS on-orbit problems to achieve full ECLS system operational status. After almost 17 years on-orbit, the ISS ECLS system has established an outstanding continuum of data and operation, working from a level of experience supporting over 45 Expedition crews, as well as providing support to Shuttle and Soyuz taxi crews.

Opportunities exist to begin flying astronauts to ISS in U.S. commercial crew vehicles in 2018 and NASA has been discussing augmenting the existing ISS ECLS with components and technologies anticipated for exploration, utilizing ISS as a flying testbed for those systems, all of which will provide great content for future ISS ECLS status papers!

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