

# International Space Station (ISS) Environmental Control and Life Support (ECLS) System Overview of Events: 2010 - 2014

Gregory J. Gentry<sup>1</sup>

*The Boeing Company, Houston, Texas*

John Cover<sup>2</sup>

*The National Aeronautics & Space Administration, Houston, Texas*

Nov 2, 2014 marked the completion of the 14<sup>th</sup> year of continuous human presence in space on board the International Space Station (ISS). After 42 expedition crews, over 115 assembly & utilization flights, over 180 combined Shuttle/Station, US & Russian 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 calendar years 2010 through 2014 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

ACS	= Atmosphere Control & Supply
AR	= Atmosphere Revitalization
CDRA	= Carbon Dioxide Removal Assembly
CHX	= Condensing Heat Exchanger
ECLS	= Environmental Control and Life Support
ECLSS	= Environmental Control and Life Support Systems
FDS	= Fire Detection and Suppression
HEPA	= High Efficiency Particle Air
HPGT	= High Pressure GasTank
HTCO	= High Temperature Catalytic Oxidation
ISS	= International Space Station
MPAM	= Multi-Platform Air Monitor
MPLM	= Multi-Purpose Logistics Module
OGA	= Oxygen Generation Assembly
ORU	= Orbital Replaceable Unit
TCCS	= Trace Contaminant Control System
THC	= Temperature & Humidity Control
UPA	= Urine Processor Assembly
USOS	= United States Operational Segment
UWMS	= Universal Waste Management System
WM	= Waste Management
WPA	= Water Processor Assembly
WRM	= Water Recovery & Management

---

<sup>1</sup> Associate Technical Fellow & ISS ECLS Technical Lead, Boeing 3700 Bay Area Boulevard, Houston TX 77058

<sup>2</sup> NASA ISS ECLS Deputy System Manager, Johnson Space Center, Houston TX 77058

## I. 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. 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 Multipurpose 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 Regeneratvie 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.

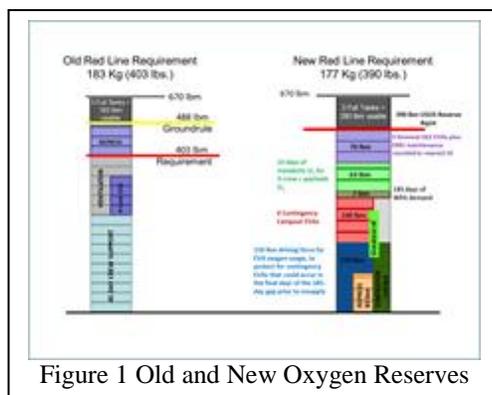
#### 6. Vacuum System (VS)

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.

## II. SUMMARY DISCUSSION OF MAJOR SUBSYSTEM EVENTS IN UNITED STATES ON-ORBIT SEGMENT OVER THE LAST FOUR YEARS BY FUNCTION

### A. Atmosphere Control and Supply

#### 1. High Pressure Gas Tanks (HPGTs)



As Ops and Engineering teams learn more about how to operate the ISS, some things evolve, and recently the amount of reserve oxygen was re-vamped to reflect this experience. Figure 1 shows old and new oxygen reserve amounts and their make-up.

A High Pressure Gas Tank (HPGT) ORU (see Figure 2) was delivered to ISS on STS-134 mounted to Express Logistics Carrier #3 (ELC-3) configured for and filled with oxygen. Once delivered the ELC-3 was parked on the starboard truss. As the last ground unit was designed for Shuttle transport, ISS program management decided to store the HPGT on ISS where it could be used on ISS rather than stranding it on the ground after Shuttle retirement. All five of the “HPGT parking spots” on the Airlock are full (three oxygen HPGTs and two nitrogen HPGTs) so a structural mounting location

had to be built on the ISS truss. Since it was never envisioned that a HPGT would reside on a truss, there isn’t any health monitoring of the ORU, which unfortunately leaves no method for verifying the HPGT integrity.



Given the recently updated oxygen reserve numbers the question of how to account for the truss mounted O<sub>2</sub> HPGT was raised. Conservatively, not being able to determine the state of the HPGT ORU gas pressure, flight support teams have been assuming it is empty. This was causing potentially unnecessary challenges with maintaining the required on-board oxygen reserve, so Program Management declared that it should be assumed the tank is full and assigned an action to the ECLS team to come up with options for monitoring the tank quantity on the truss.

Adding a tank modification to provide an ability to monitor tank pressure while on the truss include the following options: 1) EVA crew pressure gauge installation that could be read during EVAs; 2) installation of a gauge visible to the robotic arm camera; and 3)

installation of a battery powered wireless sensor. As of this writing assessment of the various options is still in work with no specific plans yet for implementation.

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

The OGA, residing in the Oxygen Generation System (OGS) Rack (see Figure 3), has produced 3806 kg (8373 lbs.) of O<sub>2</sub> and 488 kg (1047 lbs.) of H<sub>2</sub> through 3/22/2015. With the rack plus spares weighing in at under 1,400 kg (3,000 lbs) water electrolysis has provided a large logistic advantage especially when the additional mass of tanks required to deliver oxygen to ISS is considered. Using the recently developed Nitrogen/Oxygen Resupply System



Figure 3 OGS Rack

(NORS) as a reference (NORS is about 0.7:1 weight of O<sub>2</sub> versus weight of tank), if OGA were not used the program would have had to launch 3806 kg (8373 lbs) (O<sub>2</sub>) + 5437 kg (11,961 lbs) (tank) totalling 9243 kg (20,335 lbs) of launch mass to maintain a habitable atmosphere compared with a cumulative launch mass of ~ 1,500 kg (~ 3,300 lbs.) for the OGS rack and spares.

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 moved into Node 3 accumulating ~38,000 hours of operational run time (through March 2015) with an *average* production rate of 2.4 kg /day (5.3 lbs/day) oxygen.

After the failure of the first OGA Hydrogen ORU (cell stack) in 2010, a mixed ion exchange resin bed to remove ionic contaminants including fluoride and shift pH closer to neutrality was added to the OGA recirculation loop. The first H<sub>2</sub> ORU failed after 250 days of operation.

The second H<sub>2</sub> ORU has now been operating for 3.5 years (32,552 hours as of 3/22/15) and, based on the new polarization scans implemented after the first failure to evaluate cell stack health, the ORU appears to be easily on its way to a full expected 5 year operating life, indicating the failure investigation conclusions and implemented recurrence controls were correct.

A perceived threat to OGA operation has been the occasional high Total Organic Carbon (TOC) in the Potable Water that the OGA (and crew) consume during operation. Ground testing was performed to challenge smaller cell sets with high TOC loads and evaluate the impacts, but due to technical complexities the testing could not fully characterize the risk to the on-orbit hardware. Now that the second installed unit has experienced several high TOC events and has continued to operate flawlessly, the conclusion has been reached that using the H<sub>2</sub> ORU as a real time exposure test with continued monitoring of system health has been the best option for evaluating the threat of high TOC to the OGA.

### 3. Nitrogen/Oxygen Recharge System (NORS)

To deal with the retirement of the Shuttle Orbiter fleet and the loss of gaseous oxygen and nitrogen resupply to the ISS HPGTs, the Nitrogen/Oxygen Recharge System (NORS) was developed. Figure 4 shows a NORS Resupply Tank Assembly (RTA) without its flight soft cover. The development of high pressure (41,369 kPa (6,000 PSI)) composite tanks, regulators and a modification kit for installation into the U.S. *Quest* Airlock to facilitate gas transfer to the HPGTs from inside the ISS has been challenging. NORS design and progress has been discussed in detail in several ICES papers at the 40<sup>th</sup>, 41<sup>st</sup>, 42<sup>nd</sup> & 43<sup>rd</sup> ICES conferences. Delivery of the Airlock Installation Kit



Figure 4 NORS RTA

(AIK) to ISS occurred on Orb-2 in July 2014, and is waiting to be installed in the *Quest* Airlock Equipment Lock. The flight RTAs deliveries to KSC have begun and first flight of a full NORS oxygen tank is imminent. The first attempted flight of a Nitrogen NORS tank was on the Cygnus CRS Orb-3 flight on October 28, 2014 but did not reach ISS due to loss of the vehicle following launch. One each O<sub>2</sub> & N<sub>2</sub> NORS tanks were planned for SpX-6, but due to the loss of Orb-3 vehicle and necessary manifest replanning they have been delayed to one O<sub>2</sub> tank on SpX-7 and one N<sub>2</sub> tank on SpX-8.

After delivery of RTAs commenced, an issue with a lockout pin between the isolation valve and the vent valve designed to prevent both valves from a being opened at the same time was discovered.

Due to a tolerance stack-up issue when opening the vent valve the isolation valve was found to slightly open. As this was the complete opposite of the pins function, something had to be done. Subsequent study showed that the RTA design evolution enhanced safety in several areas after the pin was introduced, thus overcoming the need for the pin.

It was decided the pin could be removed completely to eliminate the vent valve opening risk. Since the only unit launched to date was lost on Orb-3, all other units were accessible on the ground. The pin removal modification has been completed for the next two RTAs scheduled to fly and subsequent flight units will be modified until the entire fleet of RTAs represent the latest configuration.

## **B. Temperature and Humidity Control**

### **1. Common Cabin Air Assembly (CCAA) Condensing Heat Exchangers (CHXs)**

CCAA CHXs have been reported to have issues with the hydrophillic coatings getting contaminated and becoming hydrophobic in flight. The source of the contamination has been determined to be Polydimethylsiloxanes (PDMS),



Figure 5 Node 3 CCAA Condensing HX

phthalate esters and fatty acids in the atmosphere given off by crew members and a myriad of products and materials on board ISS. Reporting on the PDMS problem has occurred in several ICES papers over the last few years from several aspects, including the periodic increase in WPA product water TOC.

Since the CHX ORUs are difficult, expensive and time-consuming to build, a dedicated effort to find a method to recover contaminated heat exchangers was initiated and successfully achieved. By “ashing” the CHX coating in an oven at high temperature, the coatings are rejuvenated allowing the CHX to successfully pass Acceptance Testing. Five contaminated CHXs have been through the rejuvenation process and the first rejuvenated CHX ORU has been flown and installed in the Node 3 CCAA, as shown in Figure 5, and is performing nominally.

This process of returning contaminated heat exchangers, rejuvenating them and re-flying them is expected to continue through the rest of the life of the ISS.

### **2. PDMS Scrubbers**

While the source of the PDMS contaminants cannot be eliminated on ISS a method of controlling the problem must be developed. To that end NASA has initiated efforts to develop concepts for system modifications and testing of candidate adsorbent media. The afore-mentioned Orb-3 vehicle loss affected several ECLS ORUs, including two WPA Multi-Filtration (MF) beds needed to keep the WPA operating. When the ISS program management asked what could be done to help with the equipment loss, the ECLS team offered up a way to reduce the impact of the



Figure 6 Final assembly of new Charcoal Filters at KSC

PDMS on the WPA and extend the MF bed life. While development of a “permanent long term” solution is being developed, a “temporary near term” solution was implemented and flown on SpX-6 in April 2015.

Cabin Air Catalyst Element Assemblies used for launch-to activation of Node 1 and the U.S Laboratory modules to scrub trace contaminants out of the cabin that build up between hatch closure on the ground and crew ingress in space were replaced with HEPA filters and returned to earth and have been stored at KSC for years. The ECLS team proposed re-purposing them by taking 4 units and filling them with the most promising (and accessible) scrubbing media in test at KSC. See Figure 6. This idea was approved by NASA and the four modified “charcoal filters” were installed in

Node 1 on May 12, 2015 in place of the currently installed HEPA filters. They expect to be installed and working for about a year. This should reduce the background PDMS level in the atmosphere, extend the WPA MF-bed life and delay the next high TOC event.

Because this is an considered an interim step, and does not directly protect the five installed CCAA CHXs, a permanent long term goal is to scrub the USOS atmosphere to eliminate or reduce exposure to the PDMS contaminants directly ahead of each installed CCAA CHX, located in the U.S. Lab, Airlock, Node 2 & Node 3.

### **C. Fire Detection and Suppression**

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

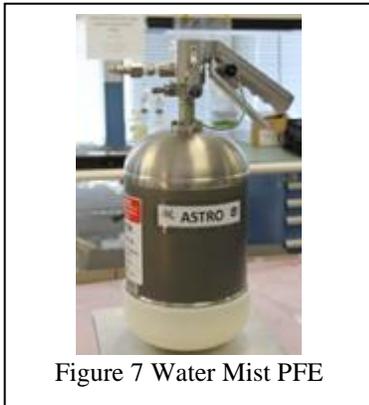


Figure 7 Water Mist PFE

The USOS Carbon Dioxide PFEs have flown on ISS since 1998 with no emergency discharges and only one unit replaced for leakage (beyond its 10 year expected life). Their on-orbit integrity has been so well established that a life extension effort was undertaken and has successfully extended the PFE life from 10 to 25 years. This has avoided the return and refurbishment of the 13 units on board.

Additionally NASA has developed the Water Mist (WM) PFEs (see Figure 7) for exploration use and intend to fly some to ISS for in-flight experience. This should begin in late 2015.

### **D. Atmosphere Revitalization**

#### **1. CDRA Beds Re-Design Progress, Desiccant Adsorbent Bed (DAB) ORU Evolution and Bed dP Increase**

The U.S. Lab CDRA was launched with “-1” DAB ORUs. Bed material containment failure that caused a re-design to the “-2” configuration which included precision machined bed canister inserts and baffle plates. This solved the containment issues but had an unintended consequence of trapping zeolite dust in the bed causing bed dP to increase substantially during CDRA operation. Consequently maintainable beds were desired but as an interim step to maintainable beds “-3” DAB ORUs were fielded with larger baffle plate screens to increase the life of an installed DAB ORU by 3 times.

The maintainable version of the DAB ORUs was the “-4” which provided mechanical features that allowed the crew to open up and clean out the adsorbent bed lid screen in flight when it got silted up. The “-4” DAB bed was packed with a new Zeolite material (known as RK-38) shown to be more robust to dusting under nominal operating conditions, so on-orbit crew cleaning was not expected to have to occur, or no more frequently than once every 3 years. It also provided new temperature sensors and heater sheets to solve other nagging problems with the bed design As it turns out this maintenance action has now happened four times (twice per Bed ORU) in one year of CDRA operation, which is significantly more frequent than envisioned. This has been attributed to possible water

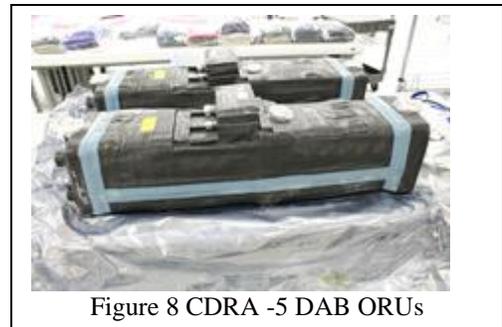


Figure 8 CDRA -5 DAB ORUs

carryover damaging the RK-38 and creating breakdown and subsequent rapid dusting of the material. With the priority of crew time on science, not maintenance, a “-5” version has been designed. It is essentially the “-4” mechanical design but with the original ASRT zeolite, which after more thorough testing proved to be more robust than the new zeolite under wetter than expected conditions, which appear to be more the norm in flight.

As of this writing two “-3” DAB ORUs are in the Lab CDRA and two “-4” Bed ORUs that were in Node 3 CDRA have just been replaced with two “-5” DAB ORUs on May 12, 2015 that flew up to ISS on SpX-6. The poorly performing “-4s” will be returned for conversion to “-5s” which will then launch and be installed in the Lab CDRA bringing the fleet of CDRA beds all up to the “-5” configuration. See Figure 8 for CDRA Dash 5 DAB ORUs delivered on SpX-6.

## 2. Node 3 CDRA Blower failure to start after Bed ORU R&R

During the re-start of the Node 3 CDRA after the Bed ORU R&R activity 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. Subsequent troubleshooting and ultimately an R&R of the Blower was performed. The crew visually inspected the blower and saw FOD inside the fan housing. The blower will be returned on SpX-6 along with the -4 Bed ORUs for refurbishment.

## 3. Flight Doctors & Crew request for lower ppCO<sub>2</sub> in USOS

The DAB ORU design migration likely won't stop with “-5s”! Flight doctors and crew requests to operate ISS at lower ppCO<sub>2</sub> levels and eventual increase of the ISS crew from 6 to 7 in 2017 is all well below the CDRA ppCO<sub>2</sub> management and removal design point and thus taxes the CDRA capability to the point where two CDRA (intended to be fully redundant while meeting spec ppCO<sub>2</sub> levels and crew complement) have to run together in addition to the Russian Vozdukh to meet the new demands.

A “-6” CDRA bed concept is being considered where a new high performance polymer zeolite or other alternate sorbent media could be used to increase CDRA performance such that 4 U.S. crew can be supported at 3 mm Hg ppCO<sub>2</sub>. This would aid ISS meeting desired enhanced performance and also be a good proving ground for exploration systems that will no doubt have to meet more stringent requirements as our long-duration space flight experience increases. As of this writing it is only a concept, however the polymer zeolite is in development.

## 4. CDRA Air Selector Valve Issues



Figure 9 CDRA ASV

Along with CDRA DAB issues, the Air Selector Valves (ASVs) (See Figure 9) have shown a marked increase in failure rates at lower cycle counts. Four offending valves were returned in late 2013 and a failure investigation was conducted in 2014. The conclusion was discovery of several factors including a mis-match between the actuator torque output design point and the valve body allowable torque at assembly, causing the valve to be underpowered. Add to that a tolerance stack up condition that allowed excessive force to be applied to the ball seals resulting in buildup of contamination at the ball-to-seal interface that quickly exceeded the actuator torque capability required to rotate the ball valves.

A re-design of the valve body to a “-2” configuration should eliminate all the problems except contamination and the new valves should begin to be fielded in 2017.

## 5. MCA Operational Enhancements (Firmware Version 4.25)

The original Lab and Node 3 MCAs flew with firmware (FW) version 4.18 installed in the MCA Controller ORU (See Figure 10). 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.

Enhancements of firmware version 4.25 include:

- Adding the capability to measure water vapor (dewpoint) 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
- Providing improved accuracies for ISS partial pressure measurements in the telemetered data from the MCA.
- Retaining Built In Test (BIT) fault data until downloaded
  - 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 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

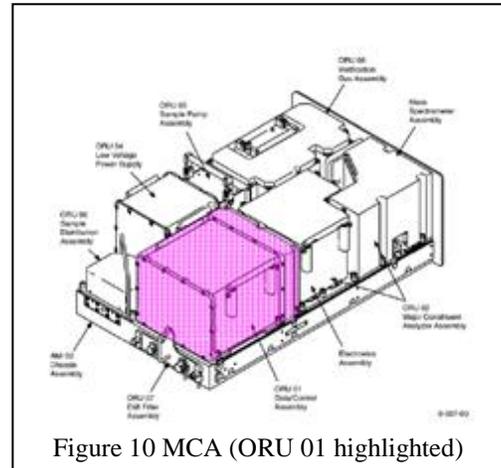


Figure 10 MCA (ORU 01 highlighted)

Since the MCA was not designed to have firmware uploaded through telemetry or on-orbit through a laptop connection, the Data & Control Assembly ORU (ORU 01) had to be returned, re-loaded and re-launched. This has happened for the Lab MCA with the new FW ORU being installed in December, 2014. Unfortunately a connection issue with a new mass spectrometer ORU (ORU 02) has delayed the initial on-orbit use and checkout of the new firmware. Hopefully crew time will be found to fix the problem and return the Lab MCA operation. Once that occurs the Node 3 MCA will will also receive a FW upgrade.

## 6. Multi-Platform Air Monitor (MPAM) Development

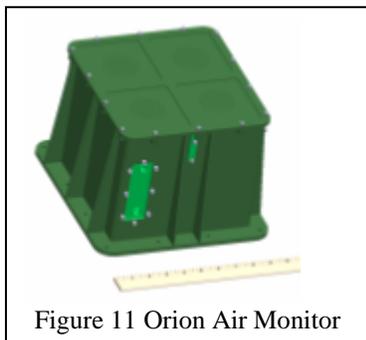


Figure 11 Orion Air Monitor

Not unlike the carbon dioxide removal system development with respect to exploration, the MCA, while currently comprised of 7 ORUs and takes up a full drawer in the AR rack, is not suitable for the challenge of supporting exploration vehicles going beyond low earth orbit. Case in point – Orion. Orion needs a similar capability to the MCA but in a much smaller package with lower power and weight. The Orion Program came to the ISS program and collaboration on a next-generation Multi-Platform Air Monitor (MPAM) concept was initiated. (See Figure 11.)

ISS, driven by obsolescence issues with MCA electronics making sparring for 2028 a challenge, and Orion, looking for ways to cost-share component development, are working together to develop the MPAM for use on both programs. The idea is that ISS will develop the MPAM and retro-fit an MPAM in one of two MCA on-orbit locations adapted to work with the existing Sample Distribution System (SDS) and AR rack structural, power and C&DH interfaces, while Orion will be able to buy a flight MPAM directly and install it in an Orion capsule for atmospheric monitoring.

## E. Water Recovery Management

Overall the USOS WPA has processed 22,350 kg (49,170 lbs.) of water on ISS. The UPA has provided 8,817 kg (19,399 lbs.) of distillate, and the rest has been 13,532 kg (29,771 lbs.) combined condensate + CWC transfers, and includes approximately 490 kg (1077 lbs.) of Sabatier product water through 3/22/2015.

Considering the combined launch weight of the WRS 1 & 2 racks (See Figure 12) and all needed spares come to approximately 3,000 kg (6,600 lbs.) that proves the investment in regenerative water processing systems.

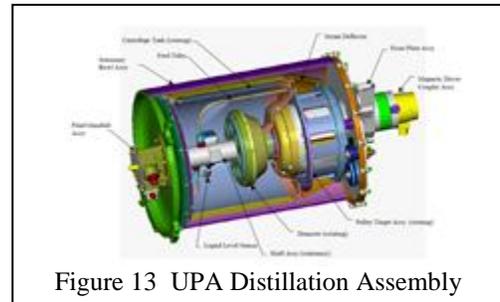
### 1. Urine Processor Assembly (UPA)

With the UPA providing 8,817 kg (19,399 lbs.) of distillate, it has certainly been proven to be a valuable system, but not without problems, as summarized below.



#### a. Distillation Assembly

The Distillation Assembly (DA) ORU had early problems with its DA bearings that needed to be re-designed. The redesigned bearings resolved the DA rotation issue. This was followed by encountering a higher calcium concentration residing in the on-orbit pretreated urine supply relative to ground test assumptions. The higher calcium level resulted in precipitation of calcium in the UPA DA causing its fluid passages to get blocked. Investigation revealed that a new pretreat formulation had to be developed that could more effectively handle the calcium load without precipitating solids. Prior to this problem, UPA recovery of water from the pretreated urine was approximately 85%, but due to the precipitation risk recovery had to be reduced to 75%. It is expected that the new pre-treat formulation, targeted for implementation in late 2015, will allow for recovery rates to return to ~ 85%. See Figure 13 for image of the UPA DA.



#### b. Fluids Control Pump Assembly

The most significant issue for the FCPA has been associated with the harmonic drive, where misalignment, inadequate lubrication, and a snap ring groove issue have led to premature pump failures.

#### c. Pressure Control Pump Assembly

While also susceptible to the same premature failure issues as the FCPA due to design similarity, the PCPA has not experienced any on-orbit failures due to the harmonic drive. The failure mode for both failed PCPAs to date has been rupture of the peristaltic tubing.

#### d. Processing Russian Urine

Until the Russian Segment has plans to fly its own urine processor, the U.S. water team has expressed interest in processing Russian urine using the UPA. However, the calcium concentration in Russian segment urine has shown the potential to be higher than US segment urine, thus increasing the risk of precipitating solids during the UPA distillation process. Therefore the maximum UPA water recovery rates while processing Russian urine has been set at 70% rather than the 75% used for US urine. If the Russian toilet is converted to use the new pre-treat formula planned for implementation on the US segment then the allowable water recovery from Russian urine can be re-evaluated and increased.

#### e. RFTA vs ARFTA

As originally designed, the 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 brine. Once processing was complete the RFTA would be 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 U.S. had no means of brine disposal (short of venting overboard from Shuttle) the design made sense. However, once the Shuttle retired it became a challenge to continue operating this way, so the *Advanced* RFTA (or ARFTA) was built. (See Figure 14.) It is a bellows tank design that can be filled with pretreated urine on board, just like the RFTA, but then when processing is complete it can be removed from the UPA and by applying a back pressure to the bellows the brine can be dumped to a Progress Rodnik tank (with Russian permission), EDV (Russian fluid container) or into a 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 with good operational success to-date.

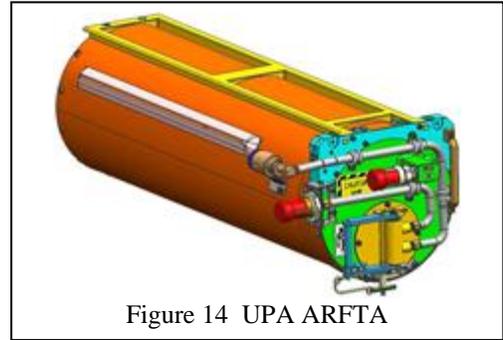


Figure 14 UPA ARFTA

## 2. Water Processor Assembly (WPA)

Overall the WPA has been a tremendous workhorse for recycling water for ISS crews and reducing upmass, as the water recovery numbers 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. However it has had a few problems as identified below.

### a. Biofouling

The WPA suffered an early component failure in the Pump/Separator ORU due to a combination of stagnant conditions during UPA failures and a lack of any implemented active control of biomass growth in the waste water collection and transportation system section of the WPA. With all the challenges of effectively implementing active fungal and bacterial controls, the next best thing was to add a filter between the waste tank and the pump/sep ORU, referred to as the External Filter Assembly, and implement operational constraints to minimize stroking of the waste tank bellows to reduce sluffing of biomass into the downstream system components.

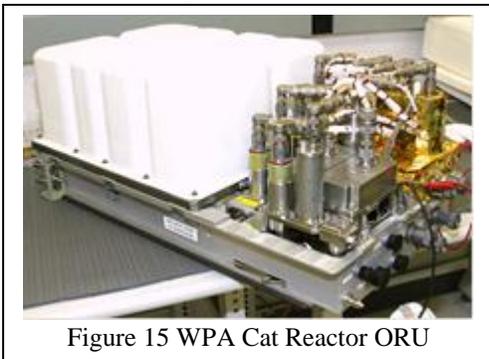


Figure 15 WPA Cat Reactor ORU

### b. Catalytic Reactor ORU leakage

The WPA Cat Reactor ORU S/N 0001 first suffered a water leak on-orbit on March 10, 2010. It appeared a seal in the ORU “hot section” was at fault. While the ORU life is expected to be 5 years and seal life is the limiting factor driving the ORU life, it might not be surprising that a seal leak occurred, except the ORU had only been installed for 16 months prior to the failure. The ORU was replaced with on-board spare Cat Reactor S/N 0002 and returned to ground for investigation.

The investigation determined that many of the seals in the reactor hot section were, in fact, severely heat strained and no longer compliant enough to perform their sealing function. Cat Reactor ORU S/N 0003 was flown with “improved” soft seals and installed in March 2012, after Cat Reactor S/N 0002 failed in a similar fashion to S/N 0001 after 23 months of installed life. Unfortunately Cat Reactor S/N 0003 also suffered early seal failure, and now the ISS Program wants a solution that is more dependable. The WPA engineering team investigated ways to eliminate soft seals from the cat reactor hot section and has developed a method to reduce the reactor temperature when the WPA is in standby in the hopes of extending the Cat Reactor installed life. A re-design eliminating soft seals in the hot section of the ORU was proposed but not implemented due to cost. See Figure 15 WPA Cat Reactor.

### c. High TOC and MF-bed life

As discussed under the T&HC section, PDMS in the ISS atmosphere is a problem. (ref 43<sup>rd</sup> ICES paper: Investigation of DMSD Trend in the ISS Water Processor Assembly.) With almost annual high TOC events in the potable water, the ISS program has embarked on a temporary measure to knock down the background PDMS levels while developing a long-term solution. In parallel, the WPA MF-bed ORUs are being investigated for more efficient PDMS removal along with a charcoal obsolescence issue, possibly culminating in a bed packing recipe upgrade.

This upgrade will provide better bed ORU performance under conditions of the PDMS challenge. Bed ORUs do not have the capacity to resolve the PDMS problem on their own, hence the atmosphere scrubber approach is also under study. It is anticipated that the combination of new and 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 was an unknown during ISS design and took years of vehicle operation to come to light as a problem.



### F. Waste Management

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. Lab module, then on June 24, 2010 the W&HC was transferred to Node 3, where it resides today. (See Figure 16.) It has experienced a myriad of nuisance problems, including Pre-Treat Bad Quality Light (PTBQLs) annunciations, dose pump failures, water separator failures, etc.. The design, based heavily on the Russian commode system, has required numerous component change outs based on exposure to pre-treated urine, including pumps and hoses. Recent investigation has determined a relationship between “full fills” of the flush water tank and PTBQLs, with

correlation of the resulting pressure affecting the dose pump performance. The team developed a method to “burp” the residual pressure created during a flush tank fill into a bag, effectively eliminating PTBQLs.

### G. Vacuum System

For the reporting period of this paper the vacuum system on-board ISS has been nominal.

## III. Conclusions/Forward work

This paper outlines ECLS system events encountered between January 2010 and December 2014. Significant progress has been made in resolving ISS on-orbit problems to achieve full ECLS system operational status. After almost 16 years on-orbit, the ISS ECLS system has established an outstanding continuity of data and operation, working from a level of experience supporting over 43 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 by 2017 and NASA intends to augment the existing ISS ECLS with components and technologies anticipated for exploration utilizing ISS as a flying testbed for those systems, all of which will no doubt provide content for future ISS ECLS status papers!

## References

1. International Space Station (ISS) Environmental Control and Life Support (ECLS) System Equipment Failures, Causes, and Solutions, February 2001 - February 2002, Gregory J. Gentry, Richard P. Reysa, John F. Lewis, SAE Paper 2002-01-2495, 32<sup>nd</sup> International Conference on Environmental Systems, July 15-18, 2002, San Antonio, Texas.
2. International Space Station (ISS) Environmental Control and Life Support (ECLS) System Overview of

Events: February 2002 – 2004, Gregory J. Gentry, Richard P. Reysa, Dave E. Williams, SAE Paper 2004-01-2383, 34<sup>th</sup> International Conference on Environmental Systems, July 19-22, 2004, Colorado Springs, Colorado.

3. International Space Station (ISS) Environmental Control and Life Support (ECLS) System Overview of Events: February 2004 – 2005, Gregory J. Gentry, Richard P. Reysa, David E. Williams, SAE Paper 2005-01-2778, 35<sup>th</sup> International Conference on Environmental Systems, July 12-15, 2005, Rome, Italy.
4. International Space Station (ISS) Environmental Control and Life Support (ECLS) System Overview of Events: February 2005 – 2006, Gregory J. Gentry, Richard P. Reysa, David E. Williams, SAE Paper 2006-01-2056, 36<sup>th</sup> International Conference on Environmental Systems, July xx-xx, 2006, Norfolk, VA.
5. International Space Station (ISS) Environmental Control and Life Support (ECLS) System Overview of Events: February 2006 – 2007, Gregory J. Gentry, Richard P. Reysa, David E. Williams, SAE Paper 2007-01-3099, 37<sup>th</sup> International Conference on Environmental Systems, July 9-12, 2007, Chicago, IL.
6. International Space Station (ISS) Environmental Control and Life Support (ECLS) System Overview of Events: February 2007 – 2008, Gregory J. Gentry, Richard P. Reysa, David E. Williams, AIAA Paper 2008-01-2132, 38<sup>th</sup> International Conference on Environmental Systems, June 30-July 3, 2008, San Francisco, CA.
7. Investigation into the High-Voltage Shutdown of the Oxygen Generation System Aboard the International Space Station, Joyce Carpenter, paper AIAA 2012-3613, 42<sup>th</sup> International Conference on Environmental Systems, July 15-July 19, 2012, San Diego, CA.
8. Development of the International Space Station Nitrogen Oxygen Recharge System, Brandon Dick, Paper AIAA 2013-3499, 43<sup>rd</sup> International Conference on Environmental Systems, July 14 –July 18, 2013, Vail, CO.