Status of the International Space Station Regenerative ECLSS Water Recovery and Oxygen Generation Systems

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ABSTRACT

NASA is developing three racks containing regenerative water recovery and oxygen generation systems (WRS and OGS) for deployment on the *International Space Station (ISS)*. The major assemblies included in these racks are the Water Processor Assembly (WPA), Urine Processor Assembly (UPA), Oxygen Generation Assembly (OGA), and the Power Supply Module (PSM) supporting the OGA. The WPA and OGA are provided by Hamilton Sundstrand Space Systems International (HSSSI), Inc., while the UPA and PSM are developed in-house by the Marshall Space Flight Center (MSFC). The assemblies have completed the manufacturing phase and are in various stages of testing and integration into the flight racks. This paper summarizes the status as of April 2005 and describes some of the technical challenges encountered and lessons learned over the past year.

INTRODUCTION

The U.S. regenerative Environmental Control and Life Support Systems (ECLSS) are being developed to enable the ISS to expand its crew size from three to six crewmembers. These regenerative systems include the Water Recovery System (WRS), comprised of the Urine Processor Assembly (UPA) and Water Processor Assembly (WPA). The Oxygen Generation System (OGS) includes the Oxygen Generation Assembly (OGA), the Power Supply Module (PSM) that supports the OGA, and scars to accommodate the later addition of a Sabatier Carbon Dioxide Reduction Assembly (CRA).

The layout of the various assemblies in the three Regenerative ECLSS racks is shown in Figure 1. The WPA is packaged entirely in WRS rack #1 and partially in WRS rack #2, linked by process water lines running between the two racks. The remaining portion of WRS rack #2 houses the UPA. The OGS rack, or rack #3, contains the OGA, PSM, and a scar for the CRA consisting of fluid and electrical interfaces and a carbon dioxide accumulator packaged in the bottom of the rack. Orbital Replacement Units (ORUs) designated with an "H" in Figure 1 are provided by Hamilton Sundstrand Space Systems International (HSSSI); while ORUs designated with an "M" are provided by NASA Marshall Space Flight Center (MSFC). HSSSI has integrated their WPA and OGA hardware into flight racks 1 and 3, and MSFC is integrating rack 2 and is completing rack 3 integration with the PSM and common hardware (avionics air assembly, smoke detector, rack power switch).

The Regenerative ECLSS racks were originally planned to be integrated and operated exclusively in the ISS Node 3 module. However, in order to take advantage of an opportunity for early on-orbit checkout, provisions are being made in the U.S. Laboratory module to integrate and operate the racks prior to the Node 3 launch. A summary of the U.S. Laboratory module modifications that are currently being developed to support Regenerative ECLSS functions is provided in reference 1.

The following sections provide a description of the WRS and OGS, give current status, and describe issues and lessons learned during the past year. For the prior years' status, see references 2-5.

WATER RECOVERY SYSTEM

WATER PROCESSOR ASSEMBLY OVERVIEW – A simplified schematic of the WPA is shown in Figure 2. Wastewater delivered to the WPA is temporarily stored in the wastewater ORU. Gas is removed from the wastewater by the Mostly Liquid Separator (MLS) (part

Oxygen Generation System Rack (Rack #3)

- Reserved volume for Sabatier CO2 Reduction System
- N₂ Purge ORU (H)
- Deionizer Bed (H)
- Pumps, Valves (H)
- Firmware Controllers (H)
- Power Supply Module (M)
- Electrolysis Cell Stack (H)
- Water Processor Delivery Pump (H)

Water Recovery System Rack #1

- Reactor Health Sensor ORU (H)
- Particulate Filter (H)
- Separator (H)
- Catalytic Reactor*(H)
- Storage Tanks (M)
- Distillation Assembly** (M)
- Product Water Tank (H)

Water Recovery System Rack #2

- Urine Processor Firmware Controller (M)
- Urine Processor Pumps (M)
- Water Processor Pump & Separator (H)
- Water Processor Waste Water Tank (H)
- Sensor ORU (H) (hidden)
- Multi-Filtration Beds (H/M)

(H) = Hamilton Sundstrand provided hardware
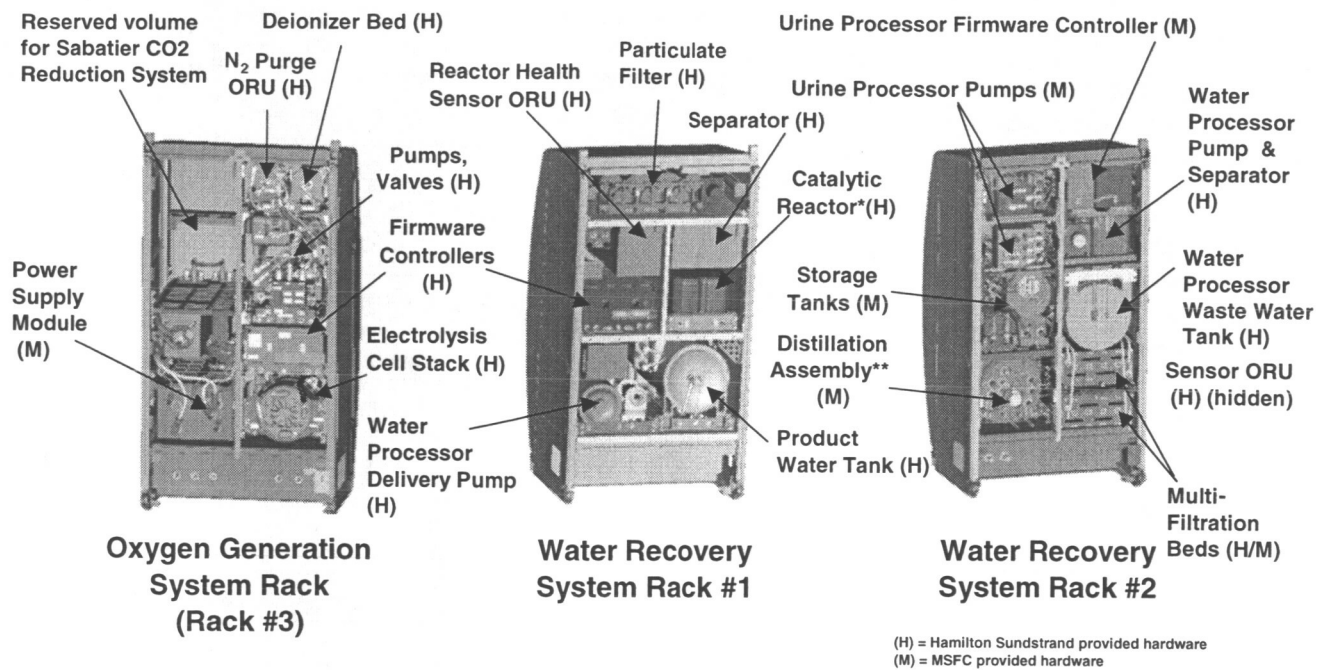(M) = MSFC provided hardware

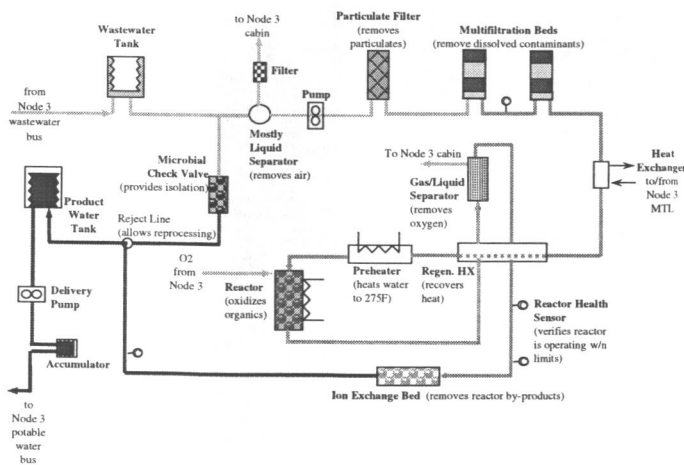Figure 1. Regenerative ECLSS Rack Configurations

Figure 2. WPA Simplified Schematic

are removed from entrained air before returning the air to the cabin. Next, the water is pumped through the particulate filter ORU followed by two multifiltration beds where non-volatile organic and inorganic contaminants are removed. Once breakthrough of the first bed is detected, the second bed is relocated into the first bed position, and a new second bed is installed. The sensor ORU located between the two MF beds helps to determine when the first is saturated based on conductivity. Following filtration, the process water stream enters the catalytic reactor ORU, where low molecular weight organics not removed by the filtration

process are oxidized in the presence of oxygen, elevated temperature, and a catalyst. A regenerative heat exchanger recovers heat from the catalytic reactor effluent water to make this process more efficient. The gas/liquid separator ORU removes excess oxygen and gaseous oxidation by-products from the process water and returns it to the cabin. The reactor health sensor ORU monitors the conductivity of the reactor effluent as an indication of whether the organic load coming into the reactor is within the reactor's oxidative capacity. Finally, the ion exchange bed ORU removes dissolved products of oxidation and adds iodine for residual microbial control before the water is stored in the product water tank prior to delivery to the station potable water bus. The water delivery ORU contains a pump and small accumulator tank to deliver potable water on demand to users. The WPA is controlled by a firmware controller. The WPA operates in batch mode, consuming an average of 343W when processing and 163W in standby.

WATER PROCESSOR ASSEMBLY (WPA) CURRENT STATUS AND INTEGRATION CHALLENGES – Over the course of the last year, integrated functional performance testing of the WPA was completed. A photograph of the WPA flight hardware after the completion of integrated testing is shown in Figure 3. In addition, performance qualification testing of the WPA's expendable filtration beds was completed using human-generated wastewater.
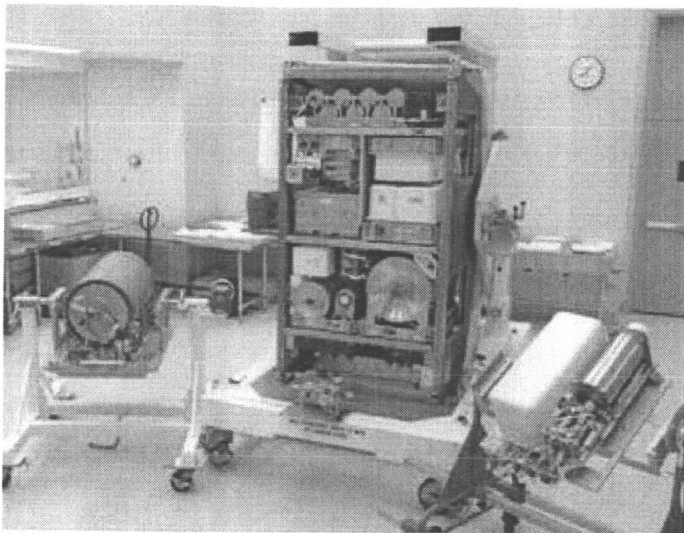
Figure 3. Water Processor Assembly

A significant amount of effort has been spent over the last year developing and implementing design modifications necessary to correct an internal condensation problem within the Gas/Liquid Separator (GLS) ORU reported last year (5). Performance test data indicated that water vapor was condensing within the gas-side of the GLS's sweep gas system. The potential for condensed liquid to block airflow through the relatively narrow valve manifold passages and thus, over time, shutdown the GLS's gas removal function necessitated measures to reduce the likelihood of condensation and to enhance the tolerance to condensation if it should so occur. Redesign features that have been incorporated into the GLS include:

- improved sealing of the GLS thermal enclosure
- warming of air flows through the enclosure (required for oxygen leakage hazard control) and through the membrane bundles
- introduction of dilution air to reduce the dewpoint of exhaust gas from the membrane modules
- increase air flowrate through the membrane modules
- improved thermal isolation of the GLS and plumbing
- zoned heater configuration
- enlarging small diameter passageways to reduce liquid blockage risk
- optimize plumbing layout to eliminate water traps in 1-g testing

A comparison of the GLS configuration before and after the redesign activity is shown in Figure 4. At the time of this writing, the GLS was undergoing ORU-level performance testing. Data to date indicates the presence of internal convection and thermal gradients within the GLS assembly. Data also indicates greater than predicted conductive heat losses through the GLS structural attach points. Circuit changes to boost the heat input into the modules to compensate for thermal losses are being incorporated. Parametric tests to
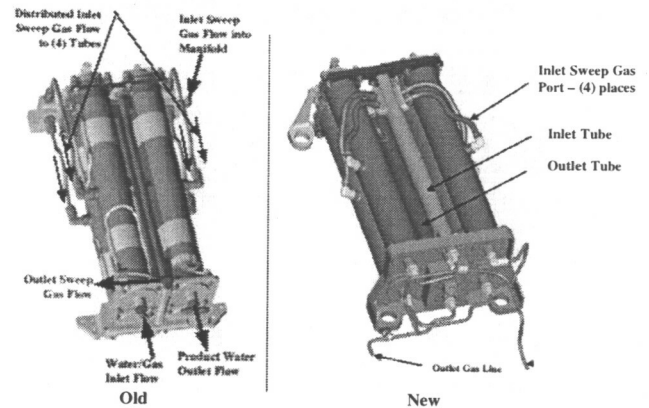

Figure 4. WPA Gas/Liquid Separator Redesign

identify the optimum control thermocouple locations and relative input water and air temperatures are also continuing. Vertical (normal and inverted) and horizontal tests are being conducted to characterize the internal convection effects in order to assess expected performance in microgravity.

In addition to the modifications to the GLS itself, supporting modifications have been implemented to the WPA Controller and Catalytic Reactor ORUs as part of the integrated effort to resolve the GLS condensation issue. Controller modifications were incorporated to accommodate the addition of heaters to the GLS. As part the redesign, two solenoid valves were eliminated from the GLS ORU; the deletion of these effectors allowed two valve driver circuits within the Controller to be converted to heater driver circuits with a minimum amount of effort. The regenerative heat exchanger within the Catalytic Reactor ORU was replaced with a new unit that provided slightly cooler two-phase input fluid to the GLS as part of the approach to lower the overall operating temperature of the assembly.

During the integrated performance test of the WPA, a high organic challenge of the Catalytic Reactor ORU was conducted in order to verify the response of the Reactor Health Sensor (RHS). The RHS design concept originally incorporated a slip stream of GLS effluent water that was routed through solid phase pH adjuster beds and monitored for high conductivity that would be indicative of high organic input loads to the reactor that could exceed its oxidation capacity. The pH adjustment was implemented in order to drive the equilibrium of inorganic oxidation by-products towards carbonate and bicarbonate species to maximize conductivity response. Routing the slip stream from downstream of the GLS was necessary to avoid the two-phase fluid conditions in the reactor effluent itself that would pose a risk to gas-binding the small diameter flow passages of the RHS that were necessary to minimize the flow through, and maximize the life of, the RHS's pH adjuster beds. During integrated testing, the RHS did not display the expected conductivity response when the reactor was being over-challenged with organics. Investigation indicated that the dissolved inorganic oxidation by-

products were being lost, presumably as carbon dioxide, through the membranes of the GLS upstream of the sidestream tap leading to the RHS. The result was that although the reactor's conductivity was elevated as expected during high organic input loads, the inorganic reaction by-products were removed from the process stream before the RHS conductivity sensors could detect them. Fortunately, the reactor effluent contained sufficient concentrations of ionic inorganic anions (acetate in particular) that direct conductivity measurement without pH adjustment was found to provide adequate responsiveness for monitoring reactor performance. The RHS design concept was therefore greatly simplified by incorporating conductivity sensors (suitable for two phase fluid conditions) directly in the reactor effluent. The two pH adjuster beds and associated selector valves were eliminated from the WPA design. This issue demonstrated the importance of integrated component effects on the performance of chemical processing technologies.

A performance qualification test of the WPA's expendable multifiltration beds, particulate filter, ion exchange bed, and microbial check valve was conducted at the Marshall Space Flight Center. The test served to verify the chemical performance of the test articles under high fidelity wastewater challenge conditions over their expected useful operational lifetimes. During the test, human test subjects contributed to the generation of high fidelity wastewater that was supplemented as needed based on previous analyses of *ISS* humidity condensate samples. The testing was conducted with an average of 20-30 test subject participants per day in order to maximize the amount of wastewater throughput that was available for processing each day, thereby providing accelerated performance data compared to expected on-orbit wastewater quantities for six crew. The overall test duration was 137 days, of which the 1st 112 days were dedicated to evaluating overall water purification performance and expendable life under expected wastewater conditions. During the 112 days of performance testing, the WPA expendable qualification test articles processed a total of 14,480 lb of wastewater. The first multifiltration bed processed 7280 lb of wastewater (equivalent to 158 on-orbit days) before becoming expended while the second bed processed 6800 lb of wastewater while in the 1st position. Product water met the 0.5 mg/l total organic carbon maximum allowable concentration. With the exception of one sample collected on the second day of testing, product water met the 1 CFU/100ml microbiological maximum allowable concentration. A detailed review of the WPA expendables qualification test is provided in reference (6).

URINE PROCESSOR ASSEMBLY OVERVIEW – A simplified schematic of the UPA is shown in Figure 5. Urine is delivered to the UPA either from the Node 3 Waste and Hygiene Compartment (currently scarred only) or it can be supplied via manual transfer from the Russian EDV. The urine is temporarily stored in the

Wastewater Storage Tank Assembly (WSTA). The Fluids Control and Pump Assembly (FCPA) is a four-tube peristaltic pump that moves urine into the Distillation Assembly (DA), concentrated waste from the DA into the Recycle Filter Tank Assembly (RFTA), and product water to the interface with the WPA. The DA is the heart of the UPA, and consists of a rotating centrifuge where the waste urine stream is evaporated at low pressure and condensed on the opposite side of the surface thus conserving latent energy. A rotary lobe compressor provides the driving force for the evaporation and compression of water vapor. Waste brine resulting from the distillation process is stored in the RFTA. The Pressure Control and Pump Assembly (PCPA) is another four-tube peristaltic pump, which provides for the removal of non-condensable gases and non-condensed water vapor from the DA. These gases are pumped to the Separator Plumbing Assembly (SPA), which recovers and returns water from the purge gases to the product water stream. A Firmware Controller Assembly (FCA) provides the command control, excitation, monitoring, and data downlink for UPA sensors and effectors.
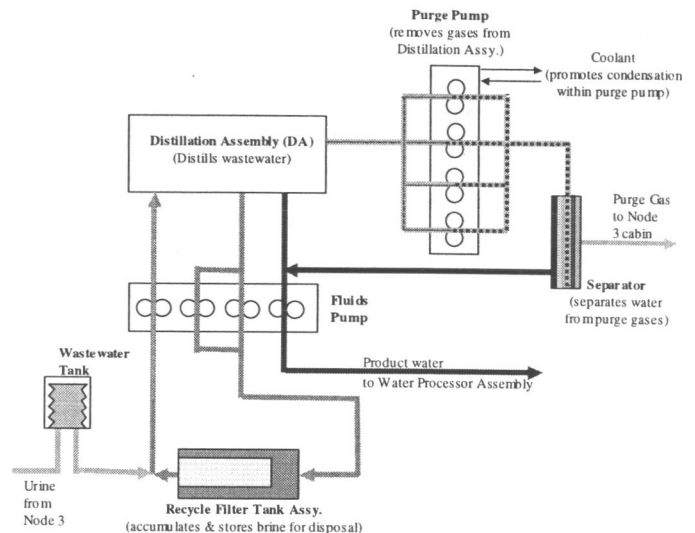

Figure 5. Urine Processor Assembly Schematic

The UPA is designed to process a nominal load of 8.4 kg/day (18.6 lbs/day) of wastewater consisting of urine, flush water, and a small amount of waste from Environmental Health System water samples. At a maximum load, the UPA can process 13.6 kg (30 lbs) of wastewater over an 18-hour period per day. Like the WPA, it operates in a batch mode, consuming 424 W when processing, and 108 W during standby (current projections). Product water from the UPA must meet specification quality requirements for conductivity, pH, ammonia, particles, and total organic carbon. It must recover a minimum of 85% of the water content in the specified wastewater stream.

The UPA is packaged into 7 ORUs, which take up slightly more than half of the WRS Rack #2. The RFTA

is the only expendable ORU, designed for a 30-day changeout.

URINE PROCESSOR ASSEMBLY CURRENT STATUS AND CHALLENGES – Over the last year, all the UPA ORUs underwent stand-alone functional and environmental performance tests. These tests uncovered several technical issues that are discussed below and which have been resolved. By April 2005, integrated UPA functional and performance testing in a benchtop configuration was underway. A photograph of the UPA integrated benchtop test configuration is shown in Figure 6.
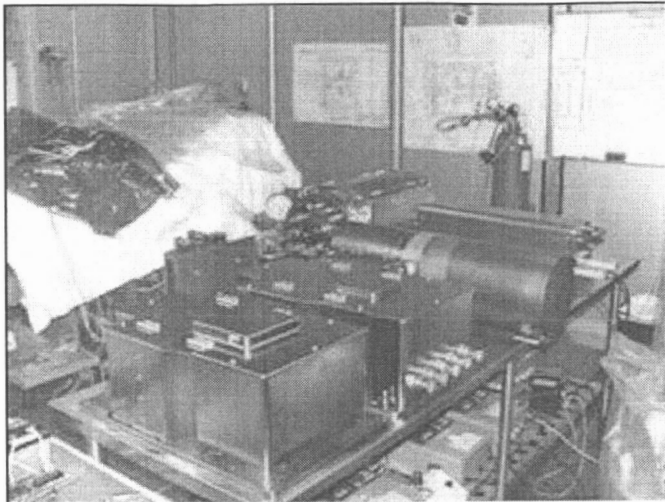

Figure 6. UPA Benchtop Test Configuration

Leakage problems with manifold mounted ball valves installed within the FCPA were again encountered after change out of the seat materials reported previously (5). The balls, originally fabricated by the government based on a commercial design that was unavailable in the requisite material needed for pretreated urine compatibility, were being used in tandem with commercially-procured seats. However, the achieved tolerances between the balls and seats that were necessary to ensure pristine sealing surfaces after repeated valve cycling were inadequate and leakage occurred with continued valve usage. Fortunately, by the time this cycle life issue appeared, compatible balls made of Hastelloy became commercially available with valve seat materials as matched sets. The availability of matched sets of balls and seat components resolved the valve cycle leakage problem.

During extended run time of the DA necessary to collect vibration emissions data, motor current rises were seen that had not been evident during any of the functional testing done to that point. The root cause of the anomalous transient behavior was an inadequate amount of backlash between the DA's stainless steel drive and Vespel driven gears. Although the dimensions of the individual stainless and Vespel gears were marginally within dimensional tolerances, the resulting backlash between teeth in the assembled gear pair was inadequate to tolerate the amount of material expansion

caused by elevated temperatures occurring during extended DA operation. The relatively short duration functional checkout tests conducted to verify DA operability after vibration and thermal cycles tests were too short to get the gears to their full operating temperatures and therefore this dimensional sensitivity went undetected until the extended runtime of the vibration emissions test. Once uncovered, the backlash required to compensate for thermal expansion was determined, the gears were reworked and backlash was dimensionally verified as an assembled pair, and the DA was reassembled and retested. Extended runtime since then has shown stable DA motor currents.

The Power Module (PM) portion of the UPA's Firmware Controller Assembly (FCA) experienced a functional failure during a powered vibration test. A transformer within the PM that had been mounted and remounted during PM assembly experienced a failed lead. Close inspection of the transformer after the failure detected tooling marks in the vicinity of the break, suggesting that a defect introduced onto the lead during the remounting operation led to ultimate failure of the lead during vibe. The failed transformer was replaced and the PM completed its functional acceptance testing.

At the time of this writing, an intermittent FCA reboot anomaly remains unexplained. The infrequent unexplained reboots have yet to occur while the FCA has been instrumented specifically to look for data that might suggest a root cause.

Also at the time of this writing, leakage has been discovered during UPA benchtop performance testing across the FCPA's peristaltic pump. Insufficient occlusion of the pump's internal Norprene tubes appears to be the cause. Investigation is continuing in order to confirm whether the lack of occlusion is due to fatigue aging of the Norprene tubes with usage or whether any mechanical misalignments or tolerance stackups may be contributing factors.

OXYGEN GENERATION SYSTEM

OXYGEN GENERATION ASSEMBLY OVERVIEW - A simplified schematic of the OGA is shown in Figure 7. Feed water from the potable water bus enters the assembly through the Water ORU and flows through an Inlet Deionizing Bed, which serves as an iodine remover as well as a coalescer for any gas bubbles that may be present in the feed water. If gas bubbles are detected by the gas sensor downstream of the DI bed, the feed water is rejected to the waste water bus. This serves to prevent any oxygen that may be present in the feed water from mixing with generated hydrogen. Water is electrolyzed into oxygen and hydrogen in the Hydrogen ORU, which contains the electrolysis cell stack. Oxygen produced by the cell stack passes through the Oxygen Outlet ORU containing a water absorber, which protects the downstream hydrogen sensors from liquid moisture. The Hydrogen Sensor ORU monitors the product oxygen for the presence of hydrogen, which would indicate a

problem with the cell stack and signal the controller to shut down the OGA. The Rotary Separator Accumulator (RSA) within the H_2 ORU separates the product gaseous hydrogen from the water which is re-circulated by the Pump ORU. The Nitrogen Purge ORU serves to purge system lines upon shutdown with nitrogen, and the Process Controller ORU is responsible for OGA System command/control and communication with the ISS Multiplexer/Demultiplexer (MDM).
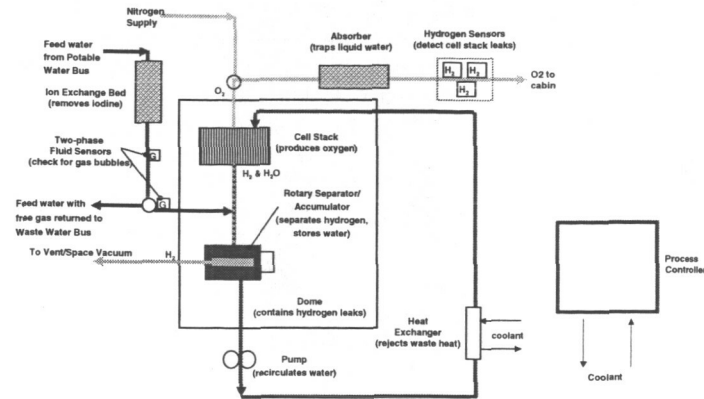

Figure 7. OGA Simplified Schematic

The OGA is designed to generate oxygen at a maximum nominal rate of 5.4 kg/day (12 lb/day) when operated on day/night orbital cycles, and also at a selectable rate between 2.3 and 9.2 kg/day (5.1 and 20.4 lb/day) when operated continuously. At the nominal rate, the OGA can support oxygen needs for 4 crew, biological specimens, and atmosphere leakage, while at the maximum rate it can support 7 crew, biological specimens, and atmosphere leakage. The assembly consumes 3573 W when processing, and 382 W during standby. The product oxygen meets quality specifications for temperature, free water, dewpoint, and hydrogen content.

The OGA is packaged into 8 ORUs, residing in the OGS Rack #3. These ORU's have a combined weight of 786 pounds. The Hydrogen Sensor ORU requires a regular 90-day changeout for recalibration.

OXYGEN GENERATION ASSEMBLY CURRENT STATUS AND CHALLENGES - Table 2 gives the current status of OGA assemblies through manufacturing and test. Currently, 7 of the ORUs are complete through protoflight testing. The Hydrogen ORU was partially disassembled to correct a design issue dealing with the cell stack resistive washers. The OGA was initially assembled and tested from January to May 2004. However, several problems (relief valves, design pressure, resistive washers) required the disassembly and modification of hardware items in the Hydrogen ORU. Figure 8 shows photos of some of the OGA ORUs. The photograph of the Hydrogen (H_2) ORU

is with the dome removed to illustrate the complexity of the ORU.

Table 2. Oxygen Generation Assembly/Test Status

Assembly	Manufacturing Status	Testing Status
Water ORU	Complete	Complete
Inlet Deionizing Bed	Complete	Complete
Hydrogen ORU	Cell Stack resistor modification in process.	Complete During System Test
Oxygen Outlet ORU	Complete	Complete
Hydrogen Sensor ORU	Complete	Complete
Nitrogen Purge ORU	Complete	Complete
Pump ORU	Complete	Complete
Process Controller	Complete	Complete
System	Complete	ECD June 05

The OGA recirculating pump has a specified operating life of 1200 on/off cycles and 21,700 hours of continuous operation. During pump testing the pump experienced degraded performance. Troubleshooting revealed wear between the zirconia gears and an alumina oxide coating on the pump housing. The pump was redesigned to minimize the axial thrust load onto the pump's driven gear. An additional change to replace the alumina oxide coating with a zirconia wear plate was unsuccessful. The investigation has not determined if the problem is a wear couple or geometry issue, however, the degradation/wear of the alumina surface seems to diminish with operating time. A continuous operation "break-in period" will be performed on all spare pumps during pump and subsequent ORU testing. A "temporary" Pump ORU that performed successfully during OGA system level testing in January through May 04 was upgraded and re-designated as the flight configuration. A pump of the same configuration is being assembled and will be subjected to a series of qualification tests. The results of these tests will be used to determine the cycle life and continuous operation life of the Pump.

Figure 8. Oxygen Generation Assembly Flight Hardware

The OGA uses a number of pressure sensors in the system. The most sensitive is a 0.6 psia sensor used in the hydrogen dome to determine if sufficient vacuum is being maintained for safety control. Downward measurement drift was observed in these sensors during vendor testing. This sensor was specified to have an operational life of 10 years, however, based on data collected to date, this drift will effectively reduce the life to 4 years. An extensive investigation identified outgassing in the vacuum reference chamber from the Inconel 625 used in the sensor as the most likely cause of the drift. The vendor has recently manufactured two development pressure sensor gauge sub-assemblies using SS321 for the housing and A286 for the diaphragm. Stability test data is being evaluated to verify that the drift phenomenon does not exist with these alternate materials. If successful, the flight units will be re-manufactured using these alternate materials.

The Hydrogen Sensor ORU consists of three independent hydrogen sensors housed in an in-line flow manifold and an enclosure that contains the power and sensor processor circuit boards. Through testing of development and flight hardware, issues were identified with accuracy, response time, and a shift in performance (due to exposure to water). Changes were made to the sensor element screening process, hydrogen sensor calibration process, temperature compensation process, and test rig to address the accuracy and response time issues. Two flight units completed acceptance testing which validated these changes. The sensor elements can be exposed to water as a result of condensation after loss of power. Physical damage to the sensor element die can occur from electrolysis if liquid water is on the sensor element die when power is applied. Options preventing the element from being exposed to water and for drying out the sensor after exposure to water are being evaluated. Also, NASA Glenn Research Center and Case Western Reserve University are evaluating product improvements to the die to address this condition. In addition, testing with a qualification unit and a development unit is being performed to evaluate the calibration cycle of the sensor, which is currently estimated to be 90 days. A more detailed description of the Hydrogen Sensor is provided in reference 7.

During the first half of 2004, HSSSI completed the assembly and test of the OGA ORU's, installation/integration of these ORU's into the OGA flight rack, and integration of the OGA with the HSSSI test rig. Once completed, HSSSI performed over 1000 hours of system operation in electrolysis. System testing included verifying the performance of the OGA during continuous operation and day/night cycle operation. HSSSI verified that the quality of the product oxygen and hydrogen meets the specified requirements. System testing also provided the opportunity to evaluate the OGA software. Changes were defined and implemented, as required, based on system dynamics. Electromagnetic Interference (EMI) testing identified a problem with the interface between the OGA Controller and the MSFC Power Supply Module (PSM). This problem was corrected by changing the "value" of some transorbs in the OGA Controller. HSSSI also modified the configuration of the OGA to temporarily route product hydrogen into the oxygen outlet line upstream of the Hydrogen Sensors. This demonstrated the function of the sensors, as installed in the Oxygen Outlet ORU, to monitor the product oxygen and shutdown the OGA when the hydrogen concentration exceeded one percent.

During system level testing in May 2004, the nitrogen pressure was observed to decay upon completion of a purge through relief valves in the Hydrogen ORU. The cause of the leak was an inadequate bond on the valve seat's nonmetallic poppet. HSSSI worked with the

vendor to define and implement improvements to the bonding process. During the investigation, HSSSI also observed contamination adjacent to the valve seat. To mitigate the potential for a contamination induced failure, a lower micron rating filter was installed on the inlet to the relief valve.

During the review of documentation in support of the OGA Functional Configuration Audit (FCA), it was determined that design pressures for several OGA assemblies were understated due to an increase in the volume/quantity of hydrogen "on-board" the OGA at any given time. This "finding" required HSSSI to reassess the predicted single and double fault conditions to re-identify the new worst case failure scenarios that could result in the maximum explosion pressure. The resultant explosion pressures are used to derive the proof, leak and burst pressures for the affected hardware. The increase in the volume of hydrogen drove an increase in the design pressure for the Hydrogen ORU, which then required HSSSI to redesign the hydrogen dome tie rods to accommodate the higher pressure. Software changes were also defined and implemented to change the operation of the OGA to minimize the severity of potential hazards. These changes reduce the hydrogen volume, explosion initiation pressures, and prevent combustible mixtures from forming in the OGA during normal operation and faulted conditions. Throughout this process, HSSSI consulted with NASA White Sands Test Facility and a NASA Johnson Space Center Structures group to develop/refine the method for applying the standard factors for calculating proof and burst pressures to the explosion pressures.

Voltage taps are located on each of the twenty-eight cells of the cell stack in the Hydrogen ORU for the purpose of monitoring the health of each cell. Resistive elements in the shape of a washer were installed between the individual cell terminating separator sheets at each voltage tap. The function of the resistive washer is to limit the current in the wiring/circuit between the voltage tap and the voltage monitoring circuit in the Controller in the event of a short to ground in this wiring/circuit. During system testing in February 2005 the OGA shut down when a cell voltage measurement exceeded the upper limit shutdown of 3.0 volts. The subsequent investigation isolated the cause of the apparent over-voltage to resistive washers that had failed open. Due to this and a previous failure (reference 5), HSSSI decided to replace the resistive washers with hermetically sealed resistors wired in-line in a harness inside the Hydrogen ORU. This redesign required the development of a procedure to solder nickel-plated wire (solder, flux, temperature) and selection of a resistor value so as not to impact the Controller voltage monitor circuit. This modification to the cell stack current limiting resistors is currently in process.

HSSSI is in process of reassembling the Hydrogen ORU with the new in-line resistor harness. Once completed the OGA will be put back on test to evaluate the new software changes that resulted from the design pressure

issue and complete EMI CS01 and power quality testing. In parallel with this effort, HSSSI and MSFC will continue with the Functional Configuration Audit. Upon completion of HSSSI testing and the audit, the OGA will be shipped to MSFC for integration with the MSFC PSM and additional testing.

POWER SUPPLY MODULE OVERVIEW – A photograph of the PSM is shown in Figure 9. The PSM provides 10-55 amps current to the OGA cell stack during Process mode and 1.0+/-0.2 amps during Standby mode, with a minimum efficiency of 91% in Process mode. The PSM is designed for 60,000 process/standby cycles, and a 10-year life.
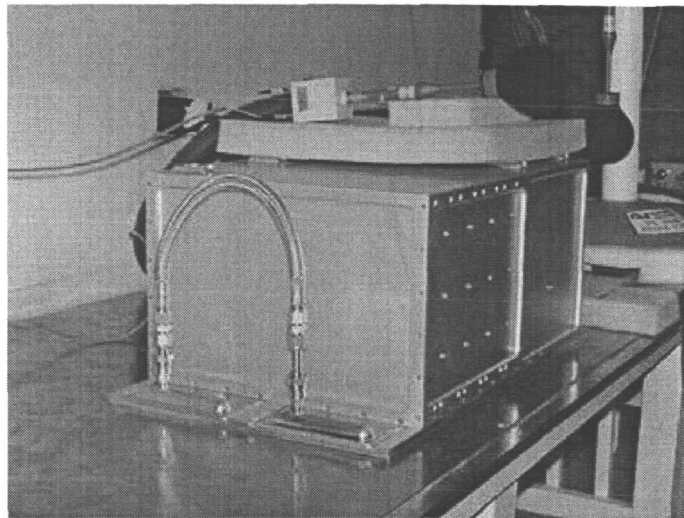

Figure 9. Power Supply Module Flight Hardware

POWER SUPPLY MODULE CURRENT STATUS AND CHALLENGES – Manufacturing and assembly of the PSM has been completed and the box successfully passed toxicity, EMI, power quality, and acoustics testing. However, component failures during powered vibration testing necessitated that the box be partially disassembled and that some structural enhancements be added to the box to minimize baseplate and board dynamic deflections that likely contributed to the component failures. At the time of this writing, the structural enhancements have been completed, the failed components have been replaced, and the box is ready for functional regression testing. The PSM is expected to be ready for integration into the OGS rack in May 2005.

INTEGRATED RACK MANUFACTURING AND ASSEMBLY – Significant progress has been made on all three Regenerative ECLSS racks this past year. WRS rack #1 is fully integrated has been shipped from Hamilton Sundstrand to MSFC with the exception of the WPA GLS and controller which were retained for modifications to resolve the GLS condensation issue.. The integration of shelves, hoses, and cables into WRS rack #2 has been completed. The OGA was integrated into the OGS rack by Hamilton Sundstrand. Integration

of additional OGS rack resident hardware such as the carbon dioxide tank farm (part of the OGS scar for carbon dioxide reduction), avionics air assembly, smoke detector, and rack power switch were completed by MSFC in parallel with activities to correct OGA issues.

Fabrication of the faceplates for all three racks has been completed at MSFC. Photographs of the recent configurations of each of the three racks are shown in Figure 10.
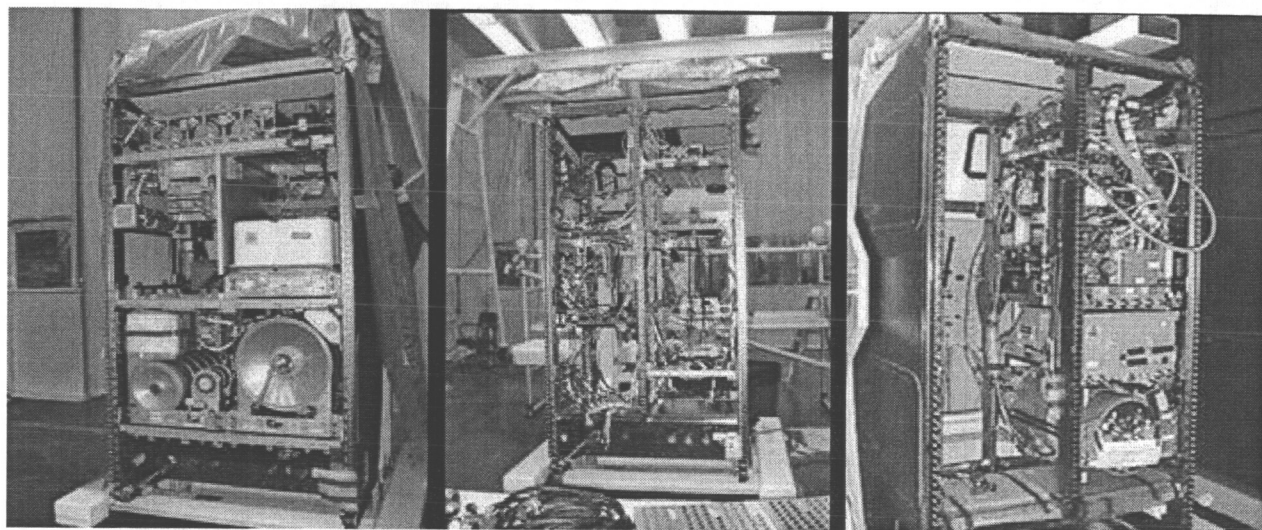

Figure 10. Water Recovery Racks #1 and #2 and Oxygen Generation System Rack

REFERENCES

1. Link, D.E., "Integration of Regenerative ECLSS Functions into the International Space Station U.S. Laboratory Element", SAE 2005-01-2780, 35th International Conference on Environmental Systems, Rome Italy, July 2005.

2. Reuter, J.L., and Reysa, R.P., "International Space Station Environmental Control and Life Support System Status: 2000-2001", SAE 2001-01-2386; 31st International Conference on Environmental Systems; Orlando, Florida, July 2001.

3. Williams, D.E., Lewis, J., Carrasquillo, R.L., Reysa, R., and Gentry, G., "International Space Station Environmental Control and Life Support System Status: 2001-2002", SAE 2002-01-2494; 32nd International Conference on Environmental Systems; San Antonio, Texas, July 2002.

4. Carrasquillo, R.L., "'Status of the Node 3 Regenerative ECLSS Water Recovery and Oxygen Generation Systems", SAE 2003-01-2590; 33rd International Conference on Environmental Systems; Vancouver, B.C., July 2003.

5. Carrasquillo, R.L., Cloud, D., and Kundrotas, R., "Status of the Node 3 Regenerative ECLSS Water Recovery and Oxygen Generation Systems," SAE 2004-01-2385, 34th International Conference on Environmental Systems, tbd, July 2004.

6. Carter, D.L., D. Tabb, J.D. Tatara, and R. Mason, "Performance Qualification Test of the ISS Water Processor Assembly (WPA) Expendables", SAE 2005-01-xxx, International Conference on Environmental Systems, Rome, July 2005.

7. M'Sadoques, G., Makel, D., "Flight Hydrogen Sensor for Use in the ISS Oxygen Generator Assembly," SAE 2005-01-xxxx, 35th International Conference on Environmental Systems, Rome, July 2005.