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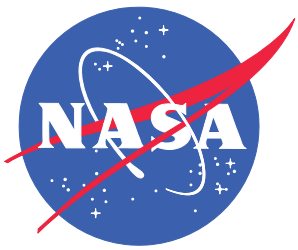

International Space Station (ISS) Orbital Replaceable Unit (ORU) Wet Storage Risk Assessment

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February 2014

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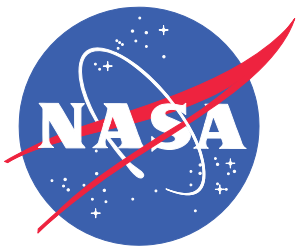

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International Space Station (ISS) Orbital Replaceable Unit (ORU) Wet Storage Risk Assessment

January 30, 2014

Report Approval and Revision History

Approved:	*Original Signature on File*	2/13/14
	NESC Director	Date

Version	Description of Revision	Office of Primary Responsibility	Effective Date
1.0	Initial Release	Mr. Michael Squire, NESC Associate Principal Engineer, LaRC	1/30/14
1.1	Updated Table of Contents *(Director's signature not required)*	Mr. Michael Squire, NESC Associate Principal Engineer, LaRC	1/30/14

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Technical Assessment Report

1.0 Notification and Authorization

Mr. Jay Leggett from the International Space Station (ISS) Program Chief Engineer's Office at Johnson Space Center requested the NASA Engineering and Safety Center (NESC) evaluate the risk of storing ISS orbital replacement units that have been serviced with deionized water for long periods of time (on the order of years) before being used on orbit.

Mr. Michael Squire, NESC Associate Principal Engineer at the Langley Research Center, was selected to lead this assessment.

The primary stakeholders are Mr. Jay Leggett from the ISS Program Chief Engineer's Office and Mr. Layne Carter, Marshall Space Flight Center Engineering Directorate Environmental Control Systems.

2.0 Signature Page

Submitted by:

Team Signature Page on File – 2/24/14

Mr. Michael D. Squire Date

Significant Contributors:

Mr. Henry A. Rotter Date

Dr. Jason Lee Date

Dr. Nigel Packham Date

Mr. Timothy K. Brady Date

Dr. Robert Kelly Date

Dr. C. Mark Ott Date

Signatories declare the findings, observations, and NESC recommendations compiled in the report are factually based from data extracted from program/project documents, contractor reports, and open literature, and/or generated from independently conducted tests, analyses, and inspections.

3.0 Team List

Name	Discipline	Organization
Core Team		
Michael Squire	NESC Lead	LaRC
Timothy Brady	Systems Engineering	JSC
Robert Kelly	Corrosion	University of Virginia
Jason Lee	Microbiologically Influenced Corrosion	Naval Research Laboratory/ SSC
Paul Mudgett	Biofilm	JSC
Mark Ott	Biofilm	JSC
Nigel Packham	Chemistry/Life Support Technical Discipline Deputy	JSC
Bob Piascik	NASA Technical Fellow for Materials	LaRC
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Roy Savage	MTSO Program Analyst	LaRC
Administrative Support		
Linda Burgess	Planning and Control Analyst	LaRC/AMA
Pamela Sparks	Project Coordinator	LaRC/AMA
Christina Williams	Technical Writer	LaRC/AMA

4.0 Executive Summary

The International Space Station (ISS) Program requested the NASA Engineering and Safety Center (NESC) to evaluate the risks posed by the practice of long-term wet storage of ISS Environmental Control and Life Support (ECLS) regeneration system orbital replacement units (ORUs). The ISS ECLS regeneration system removes water from urine and humidity condensate and converts it into potable water and oxygen. A total of 29 ORUs are in the ECLS system, each designed to be replaced by the ISS crew when necessary. Because spare ORUs are stored on ISS, each unit must be processed a long time (on the order of years) before it is installed and activated. Several of the ORUs are serviced (i.e., filled) with filtered deionized (DI) water prior to going into spares storage. Of these "wet" ORUs, some are disinfected using high-temperature disinfection or gamma irradiation to kill microorganisms that may reproduce and form a biofilm. Biofilms can grow to the point of impeding flow or causing other disruptions in system operation. When this occurs, it is called biofouling. Four of the wet ORUs are not disinfected but are serviced with DI water filtered for microorganisms. As a result, these non-disinfected ORUs may be at a higher risk for biofouling. A second concern for long-term wet storage of ORUs is the potential for corrosion. All wet ORUs, disinfected or not, may be susceptible to corrosion.

The NESC assembled a team to review the ISS ECLS regeneration system and evaluate the potential for biofouling and corrosion. The team worked with NASA and Boeing ISS Program representatives and the ORU vendor, Hamilton Sundstrand/Windsor Locks (HSWL), to understand the ECLS regeneration system operation and the individual ORUs. To look for evidence of biofouling or corrosion, water samples were taken from two spare non-disinfected ORUs and a ground servicing cart and were analyzed for microorganisms and chemical content. A historical review of biofouling and corrosion in the ISS Program, other space programs, and the United States (US) Navy was also conducted.

The two ORUs selected for sampling had not been disinfected, and each had stagnant water between 22 and 24 months prior to the sampling. A total of four samples were drawn from the two ORUs. The ORU samples showed very low levels of microbial contamination. One ORU sample had 1 bacterium colony forming unit (CFU) in a 10 milliliter (ml) sample, and the rest showed none. A sample from the water servicing ground support equipment (GSE) had 27 CFUs in a 20-ml sample. The results suggest that risk of biological growth and biofouling is low, and the procedures and equipment used by HSWL to maintain a clean system are effective for these two ORUs. The NESC team did not have the opportunity to sample more than two ORUs, so conclusions are based on this limited sample set. One of the NESC recommendations is to urge the ISS Program to sample more spare wet ORUs.

With respect to corrosion, the ORU sample results showed the presence of metal cations (e.g., iron, nickel, chromium, manganese, aluminum) consistent with passive dissolution that would be expected from the wetted materials in the system. For a nominal uniform corrosion rate for stainless steel in pure DI water, it would take several centuries to produce a breach in the system with a wall thickness of 0.016 inch. Low concentrations of corrosion-promoting chloride with

comparatively high concentrations of corrosion-inhibiting sulfate and phosphate provide confidence in the ORUs' abilities to withstand uniform corrosion. The greatest concern regarding this low-rate, passive corrosion would be metal ion electrodeposition on the hydrogen ORU electrolyzer cell stack. This deposition would cause a loss of electrolyzer performance/life; however, an Activated Carbon/Ion Exchange (ACTEX) bed has been added to the recirculation loop to mitigate this risk.

There is also a risk of localized corrosion (i.e., crevice corrosion) in physically occluded regions (e.g., fittings, under O-rings, etc.). Some of the materials used in the ORUs are susceptible to this mechanism in dilute chloride solutions. The likelihood of crevice corrosion is governed by temperature, degree of occlusion, a stagnant solution, and physical contact with a more noble material. A detailed examination of the internal ORU designs could give an understanding of the regions within the units that may be prone to this phenomenon. However, the NESC team was not granted access to this level of detail, so no specific determination of risk of crevice corrosion could be made in this assessment. A follow-up study to identify possible high-risk regions should be performed by those with access to the appropriate level of detail.

Microbiologically induced corrosion (MIC) is corrosion due to the presence and activities of microorganisms. Because low microbial concentrations were observed in the ground spare ORU samples, and only one species (*Ralstonia pickettii*) was detected, MIC is viewed as highly unlikely. However, as with the biofouling risk, conditions within the ORUs are such that the MIC risk is greater if microbial contamination takes place.

Some of the constituents found in the samples appear to have been introduced by a microbial check valve (MCV). The function of this valve is to add iodine to the water stream via an iodinated resin. Iodine, iodide (I^-, a decomposition product of iodine), potassium, and total organic carbon (TOC) were detected at elevated levels in the legs that contained or were in close proximity to the MCV. The NESC team recommends that legs with iodinated resins be flushed of these byproducts prior to use on orbit. Elevated levels of 2-propanol (i.e., isopropyl alcohol) and acetone detected in the samples may indicate insufficient drying time when 2-propanol was used to sterilize quick disconnect surfaces. Acetone can be a product of 2-propanol chemical or biological oxidation. Several minerals including calcium, magnesium, phosphate, potassium, and sodium were also detected, suggesting that residual cleaning agents used during ORU fabrication may have been present when the units were serviced. Further investigation is required to definitively identify the source of these analytes.

Review of water systems from the ISS, Apollo, and Space Shuttle Programs and the US Navy showed there is a history of biofouling in these systems. The materials and conditions in the ISS wet ORUs provide an environment that could lead to biofouling if the contamination controls are breached and microorganisms are introduced. The likelihood of microbial contamination was not estimated, but if it were to occur, biofouling is *possible* (*possible 3* as defined by the ISS risk matrix) based on an environment moderately accommodating for biological growth in the ORUs.

The likelihoods of microbial contamination and corrosion were assessed using the risk matrix on the ISS Program Risk Scorecard (see Appendix J). Based on the ground spare ORU sample

results, any microbial presence in a given ORU is *highly unlikely* (1 per the ISS risk matrix), assuming the same procedures used to limit contamination during servicing and sampling are followed. It follows that biofouling, MIC, and crew exposure are *highly unlikely* (1 per the scorecard) under this assumption. However, in the event of contamination taking place, the environment in the system is conducive to biological growth and biofouling and MIC are *possible* (3 per the scorecard); because the bacterial species observed in the samples are benign to humans, and more importantly, there are microbial controls to protect the crew (e.g., MCVs), the risk to crew health would be *unlikely* (2 per the scorecard). For the reasons described earlier, corrosion (not including MIC) is *highly unlikely* (1 per the scorecard).

5.0 Background

5.1 Problem Description and Plan

The ISS ECLS regeneration system removes water from urine and humidity condensate and converts it into potable water and oxygen. A total of 29 ORUs are in the ECLS regeneration system, each designed to be replaced by the crew. Limited opportunities for access to low Earth orbit requires that the spare ORUs must be stored on board the ISS, which necessitates that processing and preparation of each spare be completed a long time (i.e., years) before it is installed and activated. There is no requirement or specification that limits the storage duration or defines shelf life for each ORU except for those that contain resin beds (e.g., MCV). Several of the ORUs are serviced (i.e., filled) with DI water prior to going into storage. Of those ORUs, some are disinfected using either an autoclave or gamma irradiation to eliminate microorganisms that may reproduce and form an aggregate structure on the component surface called a biofilm. Biofilms can grow to the point of impeding flow or causing other disruptions in system operation (i.e., biofouling). ORUs serviced with filtered DI water, but not disinfected are at a higher risk for biofouling.

Another concern for wet ORUs is the potential for corrosion. All serviced ORUs, disinfected or not, are susceptible to corrosion (i.e., general and crevice) while stored. The dry-stored ORUs do not have a corrosion concern and were not considered for this assessment.

The conducted activities for this assessment included:

- Historical review of biofouling and corrosion in the ISS Program, other space programs, and the US Navy
- Limited review of ORU drawings and specifications
- Discussions with the ORU vendor
- Review of existing sample results
- Limited sampling of spare ORUs

An important step in determining the likelihood of biofouling or corrosion was to obtain samples from the ground spare ORUs. On board the ISS, water samples are periodically taken, but these samples are withdrawn from the potable water dispenser, which is downstream of an MCV. The MCV introduces a prescribed concentration of iodine into the water stream to kill microorganisms. Consequently, these data would not give a true indication of microbial levels for the system. Ideally, samples would have been taken from spare ORUs on board the ISS, but this was not feasible, so spare ORUs on the ground were evaluated for sampling. Working with the ORU vendor, HSWL, and Boeing, the NESC team chose two ORUs that were serviced but not been disinfected. Ideally, more than two ORUs would have been sampled. Because of the limited sample size, results were extrapolated to all of the wet ORUs, recognizing the possibility that further sampling may alter the conclusions drawn.

5.2 ISS ECLS Regeneration System Description

The ECLS regeneration system removes water from urine and humidity condensate and converts it into potable water and oxygen as shown in Figure 5.2-1. The ECLS regeneration system comprises the oxygen generation system (OGS) and the water recovery system (WRS). The OGS produces oxygen for breathing and payload use from potable water and consists of the oxygen generator assembly (OGA) and the carbon dioxide (CO_2) reduction system (CRS). The WRS consists of the water processor assembly (WPA) and the urine processor assembly (UPA). The UPA converts urine into urine distillate, which with humidity condensate and CRS product water, is processed by the WPA into potable water.

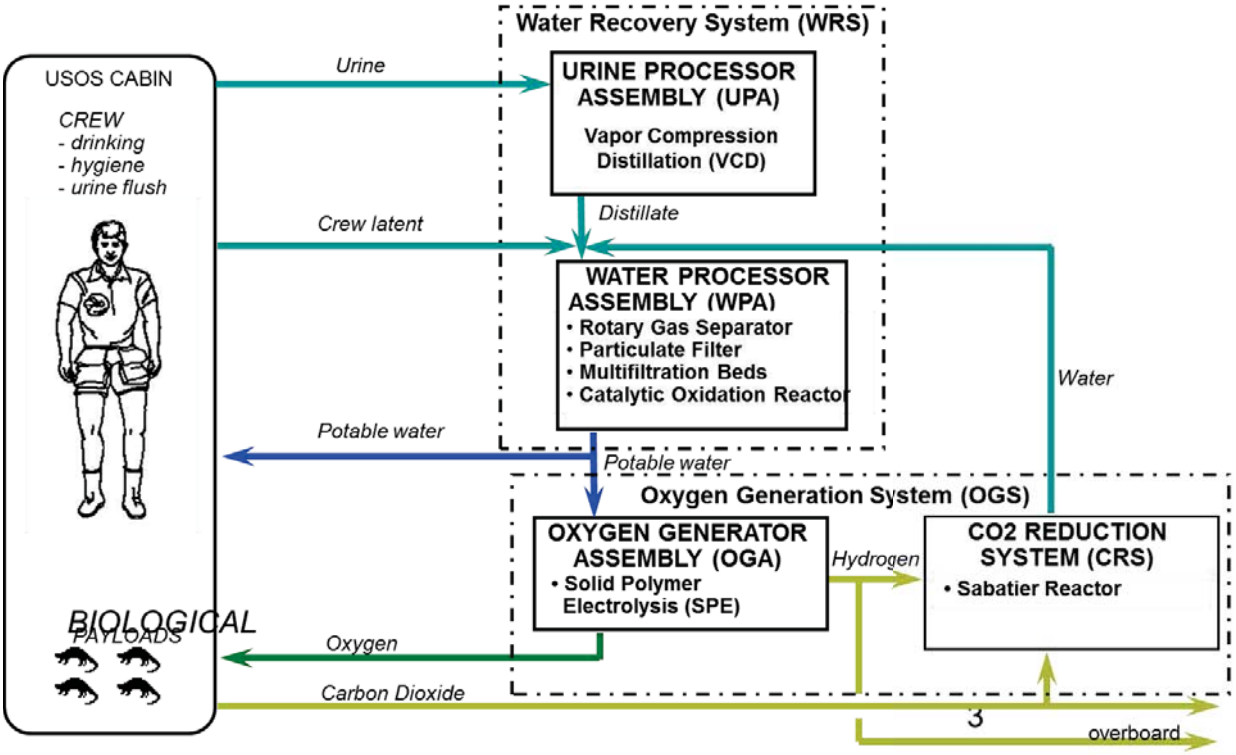

Figure 5.2-1. Flow Diagram of Overall ECLS Regeneration System

A listing of the ORUs in the OGA, WPA, and UPA is shown in Table 5.2-1, showing those that are stored wet and which ones undergo disinfection prior to storage. Descriptions of the OGA and WPA ORUs are given in Sections 5.2.1 and 5.2.2. Unless noted otherwise, history of ISS ORUs was shared with the NESC team by the ISS ECLS personnel.

Table 5.2-1. Microbial Control Processes on ECLS Regeneration System ORUs

OGA	Launch Condition	Microbial Treatment
Water ORU	wet	none
Inlet DI Bed ORU	wet	gamma irradiated
Molecular Hydrogen Gas (H_2) ORU	wet	none
Nitrogen Purge ORU	dry	launched dry
Oxygen Outlet ORU	dry	launched dry
H_2 Sensor ORU	dry	launched dry
Pump ORU	wet	heat treated (190 deg. F) for 12 hrs
Process Controller ORU	Internal Thermal Control System (ITCS) coolant	Ortho-phthaldehyde (OPA) included
Power Supply Module	ITCS coolant	OPA included
ACTEX Filter	wet	none
WPA		
Wastewater ORU	wet	none
Pump/Sep	wet	none
Separator Filter	dry	launched dry
Particulate Filter ORU	wet	heat treated (190 deg. F) 12 hrs
Sensor ORU	wet	heat treated (190 deg. F) 12 hrs
Multifiltration (MF) Bed ORU	wet	gamma irradiated
Cat Reactor ORU	wet	heat treated (190 deg. F) 12 hrs
Oxygen Filter ORU	dry	launched dry
Gas Separator ORU	dry	heat treated (190 deg. F) 12 hrs
Reactor Health Sensor (RHS) ORU	wet	heat treated (190 deg. F) 12 hrs
Ion-exchange (IX) Bed ORU	wet	gamma irradiated
Water Storage ORU	wet	heat treated (190 deg. F) 12 hrs
MCV ORU	wet	gamma irradiated
Water Deliver ORU	wet	heat treated (190 deg. F) 12 hrs

5.2.1 OGA

Using electrolysis, the OGA converts water from the WPA into oxygen, which is vented into the ISS atmosphere. The following paragraphs describe the ORUs in the OGA that are stored and launched wet. Figure 5.2-2 illustrates a simplified OGA schematic. This section describes the OGA ORUs.

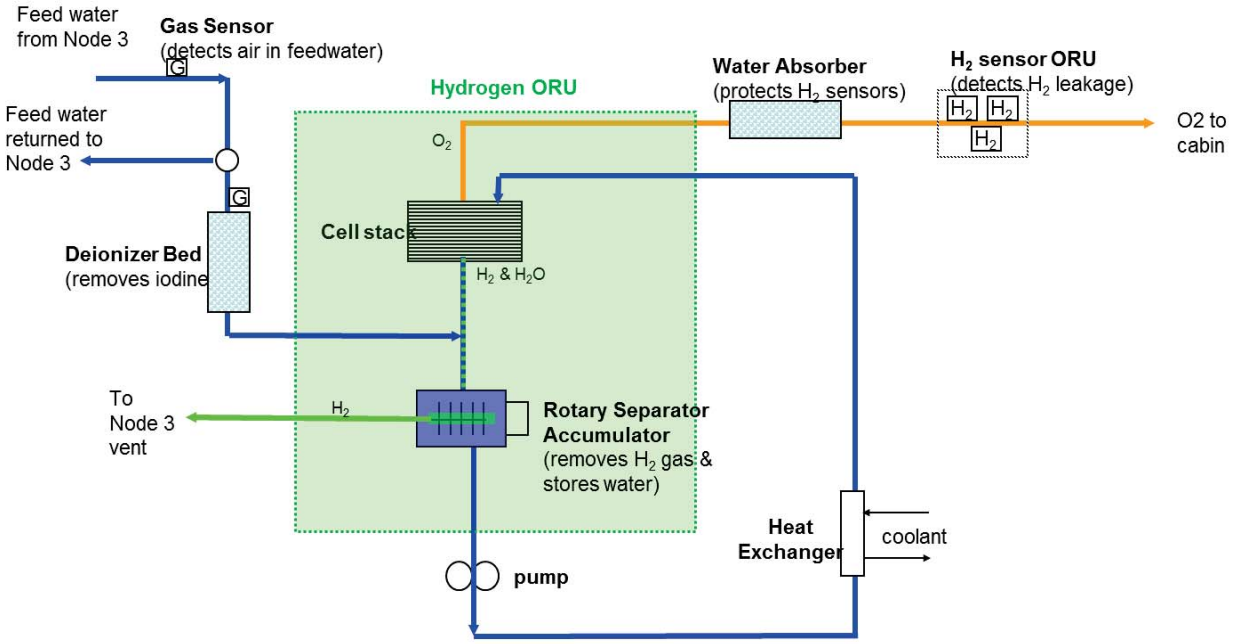

Figure 5.2-2. OGA Schematic

Hydrogen ORU

The hydrogen ORU uses solid polymer electrolysis (SPE) to generate oxygen. The SPE cell stack contains Nafion® proton exchange membrane (PEM) cells that electrochemically break water into oxygen and hydrogen. The hydrogen ORU is not disinfected because of potential damage the approved disinfection methods can cause to the cell membranes. Therefore, one of the primary concerns of the ISS ECLS team is the possibility of a biofilm forming on the cell stack. A biofilm on the membrane could degrade the performance of the hydrogen ORU. To mitigate the potential for biofouling, HSWL flushes the cell stacks every 6 months while on the ground with a DI water flush if the cell stacks are not integrated into the hydrogen ORU, or by electrolyzing the water if flushing a complete hydrogen ORU. This flushing protocol was in response to a British Navy biofouling incident related to the team by HSWL. The hydrogen ORU also contains a rotary separator accumulator to remove hydrogen from the water stream. The separator accumulator uses centrifugal force to remove hydrogen gas from the water coming exiting the cell stack.

The hydrogen ORU S/N 00001 experienced on-orbit corrosion issues from low acidity (pH) water in the recirculation loop. The cell stack Nafion® membranes deteriorate over time forming releasing fluoride, which forms hydrofluoric acid (HF) in the aqueous recirculation loop fluid,

which in turns lowers the pH of the water in the OGA. The acidic water corroded other parts of the system and released free cations. The free cations produced by the corrosion migrated to the cell stack and eventually contaminated the cell membranes to the point where performance degradation exceeded the allowable. A review of the system showed that the contamination had built up for approximately 1 year before the hydrogen ORU had to be deactivated, suggesting some tolerance for contaminants in the system. The ACTEX filter was added to the system to remove the HF and mitigate this problem.

Pump ORU
The pump ORU circulates water through the OGA and is located on the hydrogen ORU rotary separator accumulator outlet. The pump ORU is stored wet and thermally disinfected for 12 hours.

ACTEX Filter
A byproduct from normal operation of the Nafion® electrolyzer cells is HF, which lowers the pH of the OGA circulation loop over time. To counter this, the ACTEX filter was installed in the circulation loop. The ACTEX is an IX and activated charcoal cartridge that removes cations, anions, including fluoride ions. The ACTEX is a consumable as it is meant to be replaced after a period of time. Because of possible damage to the IX resin, the ACTEX is not disinfected even though it is stored wet.

Water ORU
The water ORU is a package of several subcomponents: two flow meters, a three-way valve, a solenoid valve, a dissolved gas sensor, and a MCV. The two Venturi flow meters are on the inlet to the hydrogen ORU/cell stack. The three-way valve is located at the inlet to the rotary separator accumulator in the hydrogen ORU. This valve accepts water coming from the WPA and rejects it back to the WPA if free gas is detected by the dissolved gas sensor. On the leg leading to the waste water bus is the MCV. The water ORU is stored wet, but it is not thermally disinfected because of possible damage to the MCV.

Inlet Deionizing Bed ORU
The inlet deionizing bed ORU removes iodine from the incoming water stream so that it does not contaminate the cell stack. This ORU is stored wet and is gamma irradiated.

Nitrogen Purge ORU, Oxygen Outlet ORU, and Hydrogen Sensor ORU
These three ORUs are stored dry and are dry during operation (i.e., not in the water stream).

Process Controller ORU and Power Supply Module
These ORUs, which provide control and power to the OGA, use internal thermal control system (ITCS) coolant (DI water with OPA disinfectant added). This kills microorganisms and keeps the coolant at a pH above 9 to limit corrosion.

5.2.2 WPA

The WPA accepts urine distillate from the UPA and water condensed from ambient atmosphere humidity and processes it into potable water. The potable water is routed to the crew or the

OGA to produce oxygen. A simplified schematic of the WPA is shown in Figure 5.2-3. This section describes the WPA ORUs.

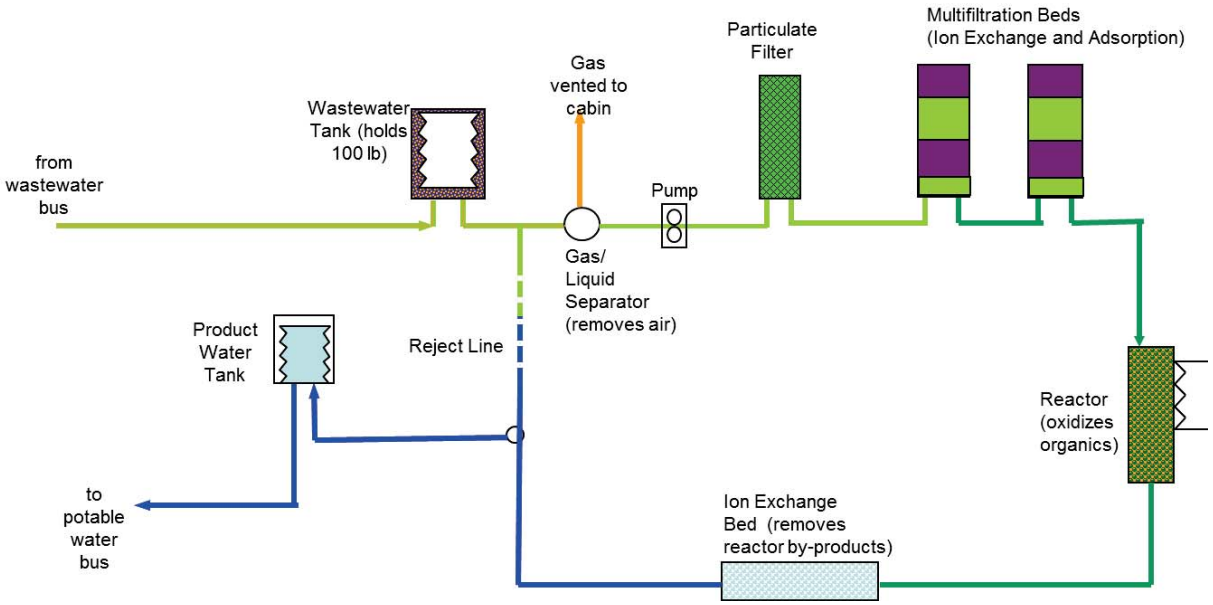

Figure 5.2-3. WPA Schematic

Wastewater ORU

Condensate from the wastewater bus flows into the wastewater ORU. This unit comprises the wastewater tank and associated valves and tubing. The tank contains a bellows and the water is stored on the outside of the bellows. The water becomes pressurized as the bellows is compressed by the spring force of the bellows. The liquid side of the wastewater ORU is stored with approximately 6 pounds of DI water. The bellows' convolute vanes that slide on the side of the tank pressure wall form liquid cavities that cannot be flushed or sampled directly. These cavities form ideal areas for biofilm growth and possible corrosion. This concern is minimized as the bellows material is Inconel® 718, which is A-rated for water. No disinfection takes place on the wastewater ORU. The gas side is stored with untreated air (i.e., air at the ambient conditions present when the ORU was sealed for flight at the vendor) and remains isolated until installed.

Pump/Separator

The condensate stored in the wastewater tank flows to the pump/separator ORU, which consists of a gas/liquid separator and a pump. The gas/liquid separator removes free gas from the liquid and vents the gas to the cabin. The pump moves the liquid through the filtration loop. This ORU is stored wet and receives no disinfection.

Particulate Filter ORU

The particulate filter ORU is located on the pump/separator outlet. The particulate filter is the first step of the primary treatment process. The filter consists of a series of 8 cylinders

manifolded together that provide a 0.5-micrometer (μm) mechanical filter. This ORU is stored wet and thermally disinfected for 12 hours.

Sensor ORU
The sensor ORU consists of a conductivity sensor and a pressure sensor. The unit is stored wet and thermally disinfected for 12 hours.

Multifiltration (MF) Beds
The MF beds contain packed media that removes solid contaminants from the water. The beds are stored wet and gamma irradiated.

Catalytic (cat) Reactor ORU
Downstream of the MF beds is the cat reactor ORU. This ORU oxidizes volatile organics in the liquid. The cat reactor ORU consists of the reactor, a heat exchanger, a preheater going into the reactor, and supporting sensors and valves. The cat reactor ORU is stored wet and thermally disinfected for 12 hours.

Reactor Health Sensor (RHS) ORU
Exiting the cat reactor, the water flows through the RHS ORU, which is stored wet and thermally disinfected for 12 hours.

Ion Exchange (IX) Bed ORU
After the RHS, the water flows through the IX bed ORU, which is filled with 1200 ml of an iodinated resin. The IX bed is stored wet and gamma radiated.

Water Storage ORU
From the IX bed ORU, the water flows to the water storage ORU. This ORU contains a three-way valve that sends the water to the product water tank/potable water system and on to the potable water system, or through the reject line and back to the pump/separator. During the process cycle, which takes place about three times per week, the water is circulated through the system through the reject line for approximately 1 hour. After 1 hour, if data from the conductivity sensors indicate acceptable water quality, then the three-way valve directs the water into the product water tank. The water storage ORU also contains the product water tank. This tank also contains a bellows except, unlike the wastewater tank, the water is on the inside of the bellows. The water side of the bellows operates at sub-ambient; at full extension (i.e., quantity of 100 percent), the pressure is approximately 0 pounds per square inch gauge (psig), and as it empties it ends up at approximately –1 psig. This tank is stored wet and thermally disinfected for 12 hours.

MCV ORU
Water routed through the reject line will pass through the MCV ORU. The MCV contains 450 ml of iodinated resin that releases iodine into the water to maintain a concentration of 1–4 mg/l. The MCV prevents microorganisms from entering the potable water system. It is stored wet and gamma disinfected.

Water Delivery ORU
Water from the water storage ORU is transferred to the water delivery ORU, which will then transfer the water to the potable water bus. The water delivery ORU consists of a gear pump that moves the water out of the water storage tank and into an accumulator, which also is part of the water delivery ORU. The accumulator is a bellows tank where the gas side is isolated and charged with a 5-percent helium/95-percent nitrogen mixture. When the gear pump fills the liquid side, the reduction in volume on the gas side increases the pressure. This pressure provides the motive force to move the water to the potable water bus. This ORU is stored wet with the accumulator fully retracted (i.e., quantity of 0 percent) and 0 psig. It is thermally disinfected for 12 hours.

Gas Separator ORU
The gas separator ORU removes free gas (chiefly oxygen) and some CO_2) exiting the cat reactor. It has a series of Teflon® lumen bundles with ~1100 lumens per bundle. It is stored dry and thermally disinfected for 12 hours.

Separator Filter and Oxygen Filter ORUs
These ORUs are stored dry and operate on the gas side of the system.

6.0 Data Collection and Analysis

6.1 History and Related Experience

The NESC team examined the history of ECLS water systems on the Apollo, Space Shuttle, and ISS Programs to identify biofouling or corrosion. Spares for the Apollo and Space Shuttle Programs were stored dry, so there are no data from those programs on long-term wet storage. Unless noted otherwise, historical data from the Apollo, Space Shuttle, and ISS Programs was provided by the NASA Technical Fellow for Life Support/Active Thermal. Long-term storage experience from environmental control systems aboard US naval vessels was also reviewed because of the similarity to some of the ISS ORUs.

6.1.1 Apollo

Command Module (CM)
No reports of biofouling in the Apollo CM water systems were documented during flight. Prelaunch and during flight, chlorine was injected daily into the water using sodium hypochlorite (NaOCl) at 5000 mg/l as a biocide. If biocide was not added daily, then bacterial growth would occur 24 hours after the chlorine addition. Microbial contamination problems were mostly limited to samples taken just prior to the last chlorine injection before flight.

CM corrosion was isolated to the heater inlet, the inlet to the drinking water gun, and a section of line between the chlorine injection point and the potable water tank. Subsequent investigation revealed pitting-type corrosion throughout the system occurring at surface imperfections in the 6061 aluminum. The corrosion was attributed to four factors:

1. The use of ultra-high purity water.

2. The chloride ions from the biocide penetrating the passive oxide layer on the aluminum.
3. Dissimilar metals, especially related to the nickel-copper brazing sites.
4. Internal surface imperfections.

A side-effect of the corrosion was that corrosion sites acted as chlorine sinks that reduced the microbial-killing effectiveness of the biocide. The solution to this issue was the injection of sodium nitrate as a corrosion inhibitor.

Lunar Module (LM)
Chlorine was incompatible with the LM sublimator so iodine at 0.5 mg/l was used as the biocide for the LM water system. Some corrosion, but not to the degree witnessed in the CM, was observed in the LM. Traces of nickel and cadmium were found in LM water samples. This was thought to be due to the interaction of iodine with the aluminum alloy. A slow iodine depletion was also observed in the LM water system and was thought to be the result of iodine diffusing through the semi-permeable silastic bladders used to pressurize the water tanks. Microbial samples taken after the introduction of iodine were always negative for microorganisms. All samples from the LM were taken prior to flight (the LM did not return after flight).

6.1.2 Space Shuttle

Supply Water System (SWS)
The SWS on the Space Shuttle Orbiter provided water for crew consumption and for the flash evaporator (FES), which was used for cooling the Freon® cooling loops. Iodine at 4–7 mg/l was added to the SWS water at servicing following a high biocide (20–30 mg/l) dwell and drain to disinfect the system. Typically, after servicing for flight, no microorganisms were seen in the water until the iodine concentration decreased to 1 mg/l or less. No biofouling was ever noted in the SWS.

Water samples were taken from a sampling port 5 days prior to launch (i.e., L–5 day), 1 day prior to launch (i.e., L–1 day), and approximately 3 hours (i.e., T–3 hour) prior to launch. Occasionally, the L–5 and the L–1 day samples results would fail due to the presence of microorganisms, requiring a flush of the tanks with elevated iodine levels (20–30 mg/l) prior to the T–3 hour sample. Typically, T–3 hour samples and post-flight samples did not contain microorganisms. If the T–3 hour sample had microorganisms, then a flush from Tank A through the galley, the path of which included an MCV to kill microorganisms, was performed in-flight prior to the crew's first consumption.

There were high nickel levels in the SWS chiller heat exchanger after long stagnant periods (on the order of months) between flights. The nickel leached from the nickel brazing areas in the heat exchanger. Water samples showed this could be controlled by a water flush prior to launch and was not an issue in flight with the daily flow of water through the heat exchanger. Analysis of a dissected heat exchanger showed some braze material removed but not enough to be considered an operational risk.

SWS tubing gold alloy-brazed connections were dissected from the orbiter *Columbia* and analyses showed that, based upon the small amount of material erosion between 1980 and 1998 (15+ years of wetted life, mostly stagnant), these connections would function through 2020 at a minimum.

Galley

The galley was not considered part of the SWS, but was a separate unit that was removed after each mission for processing. Unlike the SWS, the galley did not undergo a high-biocide treatment prior to servicing. It was simply serviced with 3–5 mg/l iodinated water. In addition, the galley was serviced sometimes over 5 months prior to installing in the Orbiter. After installation, water from the SWS was flushed through and sampled from the drinking port, often showing a high concentration of bacteria. This indicated that the galley was contaminated with bacteria, and the procedures used in servicing the galley were introducing microbial contamination. In addition, late in the Space Shuttle Program, the galley experienced some corrosion due to welding of dissimilar alloys and the use of 304 stainless steel. Design changes to use 304L stainless steel, which is more resistant to corrosion in welded structures, resolved the corrosion problems.

The galley hot-water tank had a long-term corrosion problem in the welded seams heat-affected zone. The resolution was cleaning the tanks after 15 years of usage and a re-passivation of the metal surfaces.

Water Coolant Loops (WCL)

The Orbiter had two WCLs, which were sampled periodically. These samples never revealed any bacteria. There were no reported problems with corrosion or biofouling in the WCLs because of the lack of oxygen in the system, the stainless steel construction, and the component cleaning regimen prior to installation. However, the "super-Q" deionizing GSE used for servicing the loops developed severe biofouling to the point of preventing flow after it was stored wet for approximately 1 year after servicing for STS-1. The solution was to replace the super-Q cartridges if they were unused for more than 1 month.

Waste Water System (WWS)

There were some microbial growth problems associated with the Orbiter WWS. The majority of obstruction problems were due to the accumulation of urine solid precipitates including calcium phosphate and urea. The filter located between the waste tank and the nozzle used for overboard dumps would become blocked 3–6 flights after cleaning of the urine solids. A low-acidic flush was used to remove the urea and a nitric acid flush was performed during major Orbiter maintenance periods to remove the calcium phosphate deposits in the tank. In the late 1990s, some of the WWS stainless steel tubing and flex hoses were removed and an inspection found no indications of any corrosion.

Extravehicular Mobility Unit (EMU)

Coolant water was supplied to the EMU from the Orbiter SWS. Early in the Space Shuttle Program, the water was loaded into the EMU with no added biocide. As a result, biofouling occurred in the EMU pumps, sublimator, and filters. The servicing procedure was changed to

"polish" the water after servicing, and an MCV was added to introduce iodine into the supply water. Another problem occurred when Neoprene, used as a bladder material, leached into the water over time and plugged the sublimator. This leaching was controlled by draining and refilling the water tank just prior to each extravehicular activity (EVA). The Neoprene bladder was eventually replaced with Fluorel™. However, the Fluorel™ absorbed iodine, so biocide could not be left in the system. The main source of bacteria on biofouled components was from condensate removed from the spacesuit air circulation and pumped into the water tank. Another source of bacteria was through the liquid cooling garment (LCG). The LCG contained nylon tubes that were in contact with the astronauts' skin to regulate their body temperature, but this also facilitated the transferal of microorganisms into the LCG water. There were only minor corrosion problems in the EMUs since they were disassembled and cleaned after each mission with an EVA.

6.1.3 Mir/Space Shuttle

When the Space Shuttle was flying missions to the Russian Mir space station, water would be transferred from the Orbiter to Mir. The Russians used silver ions as their biocide, but when combined with the iodine from the Shuttle Orbiter water, the biocidial effect was negated. The corrective action was the addition of an iodine-removing cartridge in the servicing line to the transfer bags for Mir. However, on the first flight of the cartridge, it was packed incorrectly and did not remove the iodine as planned. This resulted in failed bacterial samples of the water supply bags.

The condensate removal system on Mir had numerous biofouling blockage problems in the drain line from the condensing heat exchanger. This required line cleaning or replacement.

6.1.4 US Navy

Mr. Richard Hagar, from the US Naval Sea Systems Command (NAVSEA), provided information on the US Navy's experience with long-term storage and use of their ECLS systems, specifically the oxygen generating plant (OGP) used aboard submarines. Like the ISS hydrogen ORU, the OGP electrolysis unit contains a Nafion® PEM. The PEM conducts protons while providing a reactant barrier in an electrolysis reaction producing oxygen and H_2. Microbial or cation accretion on the membrane could reduce the active area of the membrane and lower the electrolyzer's performance. However, the Navy has never witnessed OGP performance degradation that could be attributed to biofouling. The spare cell stacks are stored wet at the vendor (HSWL) and, like the ISS ground spares, are flushed periodically.

Samples taken from active OGPs have tested positive for bacteria. Water and swab samples acquired from a Seawolf-class submarine "exhibited moderate levels of common water-borne bacteria that are known to form biofilms that could lead, under the right conditions, to biofouling" [ref. 1]. These samples were taken from both the primary and secondary electrolysis modules and the water influent to the OGP. The primary electrolysis module was active during the previous mission and had accumulated 5,292 total hours of operation. This module was stagnant for 28 days after its last shutdown prior to sampling. The secondary electrolysis module

was an onboard spare and was inactive (stagnant) for at least 25 months prior to sampling. Quantitative comparison between bacterial populations of the two modules is significant because the stagnant secondary module water contained bacterium counts (2.6×10^6 CFU/ml max.) 10 × greater than the highest from the primary module (1.8×10^5 CFU/ml max.). The high bacterial concentrations in samples from the secondary electrolysis module demonstrate the impact that stagnant conditions can potentially have on microbial contamination and growth.

Bacteria genus/species identified were not unexpected as they were also detected in the influent water (at lower levels). There are parallels between the bacterium types isolated from the ISS and the submarine's water systems. The bacterium *Ralstonia pickettii* was isolated from the submarine, and bacteria from similar genera have been detected in ISS samples (e.g., *Ralstonia* and *Cupriavidus*). These bacteria are biofilm formers even in low nutrient conditions. Another notable observation was the presence of the Gram-positive *Microbacterium* in the submarine swab samples. Gram-positive organisms are not as common in these water systems and may have been introduced externally (e.g., during sampling or servicing).

The chemical analyses of the secondary module revealed no constituents that were considered a threat to the PEM, but some may be detrimental from a corrosion standpoint. With 0.82 mg/l, the secondary module samples showed higher chloride levels than the primary module (<0.05 mg/l). Nitrate (0.80 versus <0.05 mg/l), sulfate (0.58 versus <0.05 mg/l), and conductivity (13.03 versus 7.26 microsiemens (μS)/cm maximum) were also higher in the secondary module. The probability of corrosion initiation for any given chloride concentration is a function of, among other factors such as time, temperature, etc., the alloy. Alloys with less chromium are more susceptible (e.g., 302 and 303 are more susceptible than 316). A biofilm in conjunction with higher chloride levels can result in an increased risk of local corrosion (pitting). A biofilm can increase the rate of the cathodic oxygen reduction reaction (ORR) and increase the corrosion potential (E_{corr}) of the system (i.e., ennoblement). For a given temperature and chloride/oxyanion ratio, E_{corr} ennoblement increases the likelihood for localized corrosion initiation. The increase in the rate of ORR can also support further propagation of localized corrosion once initiated. NAVSEA's primary concern for taking this sample set was the Nafion® membrane, so the report [ref. 1] did not discuss how other components of the OGP may be affected by the sample results.

The results from the US Navy study provided the following points relevant to this ISS assessment:

1. Microbial counts in the stagnant system were greater by an order of magnitude compared to the active system.
2. Chloride, sulfate, and nitrate levels were only evident in the stagnant system and not in the active system.
3. The active system contained significant microbial populations; electrolysis has limited effectiveness in disinfecting the water system.

4. Microorganisms in the water did not have a noticeable impact on the performance of the active electrolyzer. The impact of the microbes on the performance of the inactive unit is unknown.

6.1.5 ISS (Other than ECLS Regeneration System)

Internal Active Thermal Control System (IATCS)

The IATCS provides cooling for the US Laboratory and airlock modules using water as the coolant to transfer heat to the ammonia-cooled external active thermal control system (EATCS) using an ammonia/water heat exchanger. After the first year in service, pH levels in the IATCS coolant dropped from 9.3 to between 8.3 and 8.5 (the requirement is 9.5 ± 0.5). This decrease in pH coincided with an increase in nickel concentration and an increase in the microbial population. The decrease in pH was caused by CO_2 permeating into the water loop through the Teflon® flex hoses. The CO_2 created carbonic acid, which lowered the pH. The nickel was found to have originated in the boron nickel alloys (BNi-2 and BNi-3) brazes used in the heat exchanger and cold plates. Previous testing concluded that intermetallic-phase nickel present in BNi-2 and BNi-3 corrodes in pH conditions lower than 9.5. It was also possible that there was a contribution from galvanic corrosion due to silver deposition on the nickel braze surfaces. The silver would have come from silver phosphate added to the loop as an antimicrobial agent.

The microorganisms from the IATCS included *Ralstonia paucula* and were not considered to be dangerous for human exposure. However, the persistent risks due to the observed microbial contamination included continuing nickel precipitation and the presence of an established biofilm, which could possibly reduce flow, clog filters and pumps, or even affect the heat transfer properties in the heat exchanger by forming an insulating layer.

Testing was performed to evaluate the level of risk from MIC. Samples of BNi-2 and BNi-3 material, used in the ITCS heat exchanger, were exposed to ITCS water containing eight of the microorganisms identified in the ISS ITCS. The coupons were exposed for up to 180 days. The coupons did exhibit biofilms at the end of the test period (especially the samples exposed for 180 days), but no evidence of MIC was found (see reference 19 and Appendix A).

A related anomaly occurred when an IATCS pump seized. Examination revealed that the pump was clogged with a nickel oxide/biofilm gel. Samples from the gel revealed ammonia, which was a concern because this may have indicated cross-leakage within the ammonia/water heat exchanger. However, it was determined the ammonia was a waste product of the bacteria. The bacterial community later evolved to consume the ammonia rather than produce it. The source of the nickel was from braze material and the nickel-plate heat exchangers.

ISS EMU

The ISS EMU contains a coolant loop that circulates water through the liquid cooling and ventilation garment to cool the astronaut wearing it during an EVA. While operating, but still connected to the airlock, the EMU is normally mated to lines in the airlock that route the coolant through the service and performance checkout unit (SPCU) heat exchanger to reject heat from the EMU. Between EVAs, these two water cooling systems are stagnant and have experienced

problems that were addressed by a previous NESC assessment (see reference 20 and Appendix B). In May 2003, ISS EMU #13 lost cooling water flow during a two-crew don/doff evaluation. This EMU had been used successfully on previous EVAs. In 2004, EMU #5 failed with a loss of coolant flow during another don/doff evaluation. This unit had never been used for EVA but had undergone a functional check-out. Electrical current analyses showed the coolant pump rotors were not turning for either EMU. The gas trap from EMU #13 showed biofilm and nickel salt deposits on the downstream side of the separation filter. The inorganic precipitates were primarily nickel with some aluminum and silicone. The pump had seized with visible iron oxide, nickel salt, and biofilm deposits. The EMU #5 coolant pump had nickel salt and biofilm on the rotating surfaces with a trace of iron oxide. Several of the pump rotors were also observed to have increased in length by approximately 0.003 inches. This reduced the clearance for the rotor axial ends making them more sensitive to particulate and biofilm build-up. The lengthening was traced to debonding between an internal magnet and the impeller assembly.

The SPCU heat exchanger was removed and examined. Iron oxide deposits were found on the heat exchanger and there was crevice corrosion in the heat affected zone of a weld repair. The SPCU heat exchanger was determined to be source of the corrosion products found in the pumps and other components. Several factors were identified as contributing to the debris found in the systems:

- The single braze compound BNi-3 for the first SPCU heat exchanger was not compatible with the stainless steel of the heat exchanger. Double braze heat cycles or a long single heat cycle are needed to eliminate the intermetallics from the braze layer to increase corrosion resistance.
- The Teflon® flex hoses allowed CO_2 to permeate from the cabin atmosphere into the loop. The CO_2 in the water lowered the pH, which encouraged bacterial growth and accelerated the corrosion rate.
- The ISS EMU system certification did not adequately address long periods of down time. This down time was not an issue during the Space Shuttle Program where the Orbiter EMUs were only wet for ~1–2 months at a time, and the loops were flushed and polished while on the ground.

6.2 Ground Spare Samples

6.2.1 ORU Sampling Process

HSWL sampled two ground spare ORUs that had not been disinfected. The ORUs sampled were water ORU serial number 3 and OGA pump ORU serial number 5. These ORUs were referred to as Component 1 and Component 3 respectively in the sampling procedures and analysis reports. HSWL generated the sampling procedures and obtained the samples at their Windsor Locks, CT facility. The samples were shipped overnight for analysis by the Johnson Space Center Water and Food Analysis Laboratory (WAFAL). Samples of a wider variety of ORUs could not be obtained for this assessment, but the NESC suggests that the ISS Program take more samples to broaden the knowledge base of the state of the wet ORUs.

Sample kits were provided by the WAFAL. These kits contained everything necessary to collect the samples including multiple Teflon® sample bottles filled with high purity DI water from the lab (a common laboratory practice to avoid inward permeation of contaminants through the Teflon® container – this water was emptied before the actual sample was taken). Each bottle was labeled with the sample identifier. Freezer packs were provided for the return journey. A chain of custody form was included for HSWL personnel to complete upon sample collection. One of the sample bottles, labeled as "trip blank," was included. This bottle was to be shipped and returned without opening. This is a standard practice to ensure that nothing occurred during shipment in either direction. Two kits were prepared, one for each sampling session, and shipped overnight to HSWL prior to each sample session.

Component 3 (pump ORU) was sampled on April 29, 2013. A simplified schematic for Component 3 is shown in Figure 6.2-1.

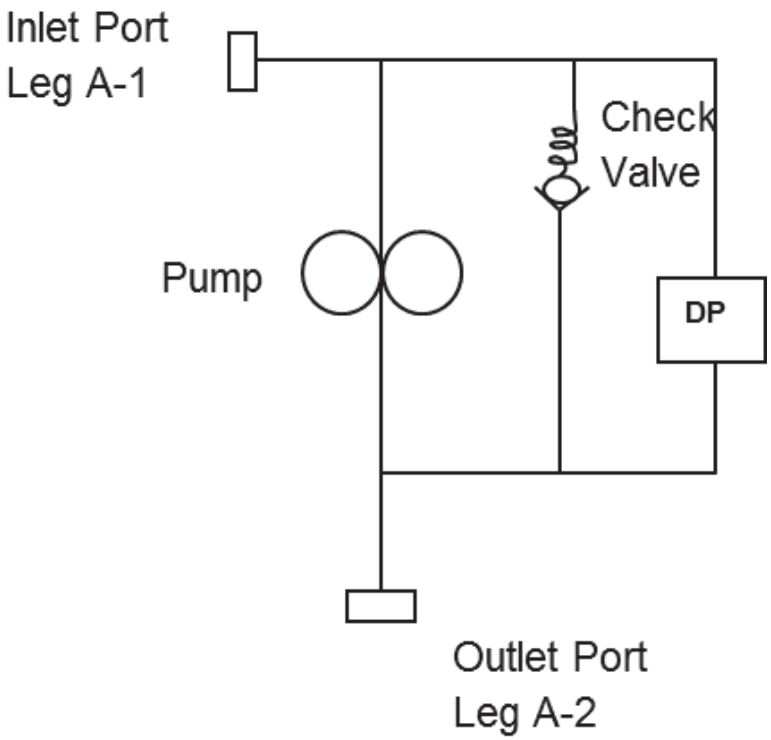

Figure 6.2-1. Component 3 Schematic

The major elements of Component 3 are a pump, a check valve, and a delta pressure sensor. There are quick disconnects (QDs) on the inlet and outlet of the ORU. The ORU was pressurized with gaseous nitrogen at the inlet port to Leg A-1 and the sample was collected at the outlet port Leg A-2, where each leg represents the tubing on either side of the pump, check valve, and delta pressure sensor. The process was then repeated in reverse, using the same sample container, to capture any residual water. Total volume collected from Component 3 was 46 ml.

Three samples were collected. The first, labeled "Legs A-1 and A-2," represented the water that stored in the ORU for nearly 2 years. The second, labeled "QD Sampling Setup," was a check sample to ensure that the QDs were not contaminated chemically or microbially. The final sample labeled, "Water Cart (WC5)," was a sample of the high purity water system used by HSWL (see schematic in Figure 6.2-2).

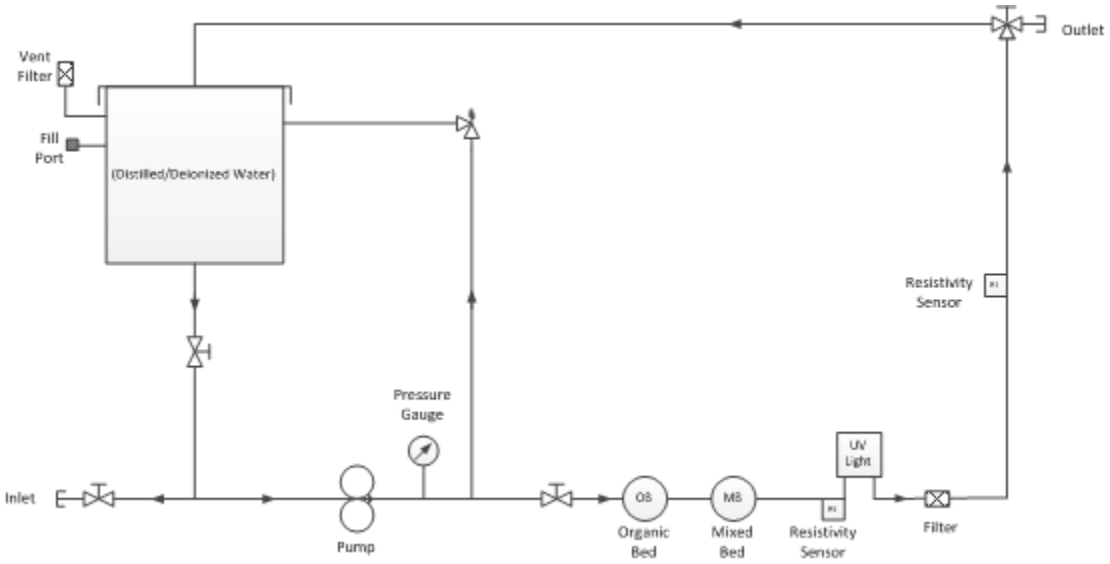

Figure 6.2-2. HSWL Water Cart Schematic

Component 1 (water ORU) was sampled on May 23, 2013. A schematic of Component 1 is shown in Figure 6.2-3. Component 1 comprises several separate subcomponents and 5 distinct legs defined for the purpose of sampling. Leg B interfaces to both Leg C and Leg D via a three-way valve, and the pressure source to sample from the Leg C and Leg D outlets was mated to Leg B. For this reason, the samples obtained are referenced as Leg B-C and Leg B-D. The water from Leg B-D was captured first, then the three-way valve was repositioned and the Leg B-C sample was taken in a new sample container. Leg E was captured separately, also in its own sample container. Leg A is stored dry, so no sample was taken. Figure 6.2-3 highlights the MCV in Leg C, which is discussed in Sections 6.2.2 and 6.2.3.

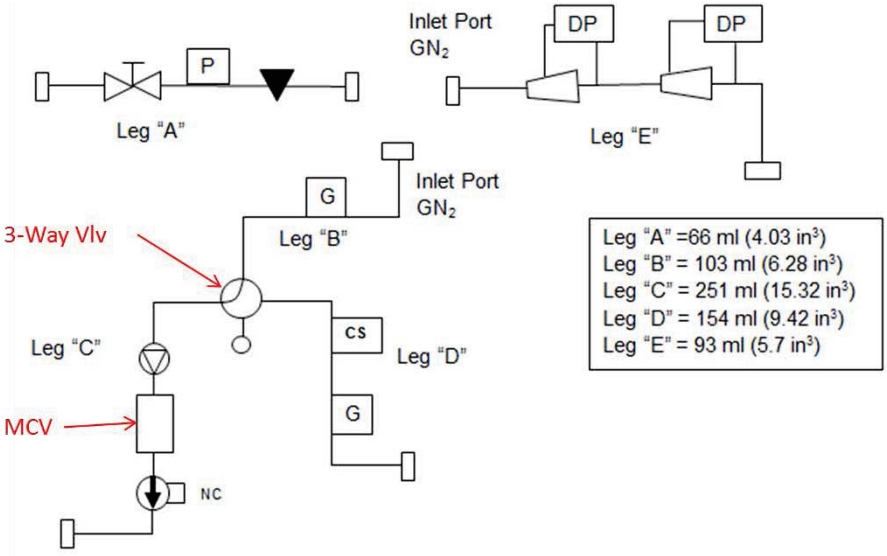

Figure 6.2-3. Component 1 Schematic with Leg Volumes

Four samples plus the trip blank were collected. Three of the samples represent water that had been stored in the component for nearly 2 years in each of three legs. These three were labeled "Component 1 Leg B-D," "Component 1 Leg B-C," and "Component 1 Leg E," which contained 125, 115, and 55 ml of water, respectively. The fourth sample was from the high purity HSWL system, labeled "Water Cart 5," and contained 250 ml of water. The 115 ml sample from Component 1 Leg B-C had a yellow color and was received in the 250 ml bottle with headspace. The headspace is not a recommended practice if quantitative analysis is required for volatile compounds.

After the samples were collected, they were returned to the shipping container with the chain of custody form, packed with the frozen ice packs, sealed, and returned overnight to the JSC WAFAL. Once the samples were received at the WAFAL, the chain of custody form was completed and the samples allocated to the WAFAL and the JSC Microbiology Laboratory.

6.2.2 Sample Analysis

6.2.2.1 Discussion of Analytical Results

The JSC WAFAL and the Microbiology Laboratory are accredited facilities and utilize techniques that are used throughout laboratories around the world. The Microbiology Laboratory analyzed for total counts for bacteria and fungi using a standard 48-hour incubation period for bacterial isolates and a 5-day incubation period for fungal isolates. The initial WAFAL analyses depended on the volume of sample available. Available analytical tools were TOC; Leuco crystal violet assay for iodine and iodide; inductively coupled plasma-mass spectrometry for iodine, trace metals, and minerals; and ion chromatography for anions.

Results of the initial analyses are attached in the Appendices. Appendices D and E present the microbiological results from Components 1 and 3, respectively. Appendices F and G present the

chemical analyses performed on the various sub-elements of Components 1 and 3, respectively. Note that in all cases, the data were reviewed by two individuals from the respective laboratories before being approved for release to the NESC team. In addition to being shared with the NESC team, the data set was shared with HSWL, Boeing, and Marshall Space Flight Center (MSFC) ECLS personnel.

Microbiology

With the exception of two of the entire sample set, the levels of bacteria and fungi were reported as less than the reporting limit (1.0 CFU per ml of sample). No fungi were detected above the reporting limit in any of the samples received. For the two samples that bacteria were identified above the reporting limit, the identification was made as *Ralstonia pickettii*. Both positive samples came from the Component 1 sampling session: Component 1 Leg B-D had a bacterial count of 1.0 CFU/10 ml, and Water Cart 5 had a bacterial count of 27 CFU/20 ml. *Ralstonia pickettii* is a common water isolate found in water systems on Earth and in water samples returned from ISS. It poses no threat to human health (i.e., is non-pathogenic). Additionally, the levels detected are very close to the lower reporting limit. It is possible that other microorganisms could have populated the components in the form of stable biofilms. However, the likelihood is low since some bacteria would have been expected to have been flushed out during sampling and detected after the 48-hour incubation period.

Chemistry

The following samples were unremarkable in their chemistry:

- Trip blank sample for Component 1 - Expected since this was high purity water from the WAFAL.
- Samples from HSWL Water Cart 5 during Component 1 and Component 3 sampling - Expected since this was high purity water from the HSWL laboratory.
- Sample from Component 1 Leg E, except for a low concentration of nickel and the presence of minerals (discussed below).

The sample from Component 1 Leg B-D exhibited TOC high levels (33.9 mg/l), iron (0.213 mg/l), manganese (0.295 mg/l), and nickel (1.56 mg /L). This sample also exhibited iodide (10.4 mg/l), which was unexpected since this leg was not in the path with the MCV[1]. Also unexpected was the presence of all analyzed minerals: calcium, magnesium, phosphate, potassium, and sodium in various concentrations. HSWL suggested that the presence of such minerals could possibly be a result of agents used to clean the tubing.

After discovering that the WAFAL had archived some of the Component 1 Leg B-D sample, it was decided to perform further analysis by direct injection gas chromatography/mass spectrometry (GC/MS), and purge and trap GC/MS in an effort to identify the organic species present. The analysis by TOC only provides data on the overall amount of organic material present. The use of GC/MS allows for the identification of thousands of compounds. The only

[1] Iodine breaks down into iodine with time, so some of the iodine is the result of the iodine added to the system by the MCV.

two compounds detected above their lower detection limit using direct injection GC/MS were acetone (7.57 mg/l) and 2-propanol (35.4 mg/l) (2-propanol is also known as isopropanol or IPA). No organic species were detected above their detection limits using the purge and trap GC/MS method. Acetone and 2-propanol made up approximately 77 percent of the TOC measured in the sample. The noted headspace presents the potential, and as noted previously, since the samples were returned with headspace, it is quite possible the actual concentrations in the Leg B-D sample could have been higher. Results of this analysis can be seen in Appendix H.

There is a potential explanation for the presence of 2-propanol and acetone. When mating QDs, it is common practice to disinfect the QD surfaces using disinfectant wipes containing 2-propanol. The sampling procedure reviewed by the NESC team called for a 10-minute waiting period before mating to allow for any remaining 2-propanol to evaporate. If an insufficient time was allowed to pass, then residual 2-propanol could have been trapped in the mated QDs and entrained into the two legs during the original filling of the ORU. Leg B-C also had a high TOC and most probably had a 2-propanol component in the carbon balance, but because of the smaller sample size available, not enough remained after analysis for archiving. Considering the low dead volume in these two legs, it would not take much 2-propanol to reach the observed concentration; furthermore, oxidation of 2-propanol results in the formation of acetone. Chemical oxidation requires a strong oxidizer such as hydrogen peroxide. Hydrogen peroxide was used to wipe the QDs prior to connection to the HSWL water cart for the sampling performed during this assessment. Some bacteria are known to oxidize 2-propanol to acetone. In the end, a definitive answer on the origin of the acetone cannot be given from the data provided. The JSC toxicology laboratory determined that the Spacecraft Water Exposure Guideline for 2-propanol is 118 mg/L/day for a 1-day exposure and 65 mg/L/d for a 10-day exposure (see Appendix K). These levels are well above the 35 mg/L concentration reported in the Leg B-C sample, and any 2-propanol would be diluted when the ORU is connected to the system, reducing the exposure concentration. Therefore, the levels of 2-propanol witnessed in Leg B-C do not pose a risk if ingested by a crew member.

Component 1 Leg B-C analytes of interest were: elevated TOC (69.7 mg/l); high iodide (1400 mg/l); elevated levels of chromium, iron, nickel, and zinc at a variety of concentrations; and all of the analyzed minerals (calcium, magnesium, phosphate, sodium, and potassium). With the exception of potassium, all of the other minerals were at roughly the same concentrations as Leg B-D.

Leg C in Component 1 contains an MCV (see Figure 6.2-3). The purpose of the MCV is to add iodine to the water as it flows through the MCV cartridge, which contains a resin impregnated with iodine (the process by which iodine is loaded onto the resin is proprietary to the manufacturer, Umpqua Research Company (URC), Umpqua, OR). The Component 1 Leg B-C sample potassium concentration was significantly elevated (445 mg/l). If the concentrations of iodide and potassium are compared from the stoichiometric (i.e., molar basis) standpoint, then it is a close match for potassium iodide (KI). This result led the NESC team to question if KI was used during the manufacture and preparation of the MCV. The team asked HSWL to inquire from URC, who supplies the MCV to HSWL for integration into the flight water systems,

whether KI was used during the MCV preparation. URC confirmed that potassium was used in the process but, citing proprietary concerns, would not identify the counter ion. However, from the analysis performed by the WAFAL, it is probable that it was there as KI.

The WAFAL had on the shelf a non-flight MCV, which had been stored wet for at least 2 years. Samples from this MCV were taken to compare to the Component 1 chemistry analysis. Upon sampling and analysis, iodide and potassium were identified at 291 and 5.31 mg/l, respectively. Although the stoichiometric balance is not as close as in Leg B-C, it is still suggestive of the presence of KI. Results from this analysis are given in Appendix I.

In terms of TOC, the same argument for Leg B-D could be invoked (2-propanol from disinfectant wipes). The higher concentration could also be ascribed to the normal breakdown of the backbone of the polymeric resin in the MCV, which is commonly used in IX beds. Looking at additional data (combustion products), it appears that the resin backbone is polystyrene divinylbenzene. However, due to the lack of sample volume, this identification could not be confirmed.

F-9. MCVs with iodinated resin produce potassium and increasing concentrations of iodide as a result of iodine decomposition during long-term wet storage.

F-11. Calcium, magnesium, phosphate, potassium, and sodium are used in cleaning compounds during hardware preparation, and this may explain the presence of these minerals in the sample analyses.

6.2.3 Sample Analysis Conclusions and Recommendations

From the microbiological standpoint, considering that these ORU's had not been disinfected, the procedures used to maintain a disinfected environment were largely very effective. Component 1 legs B-C and B-D samples from the chemical standpoint have a marginal concern of evidence of corrosion (iron, nickel, zinc, chromium).

Elevated TOC levels in Component 1 Leg B-C and Leg B-D could be accounted for by improper use of the disinfectant wipes (2-propanol) and, in the case of Leg B-C, breakdown of the MCV resin material. The presence of acetone in the Leg B-D sample cannot be accounted for definitively, but can be the byproduct of 2-propanol bacterial oxidation. The presence of a variety of minerals could be accounted for by the incomplete removal of cleaning fluids during hardware preparation. HSWL conjectured the cleaning materials used could account for the presence of minerals. The high levels of potassium and iodide ions in both Legs B-C and B-D can be accounted for by the reported use of a potassium salt during MCV preparation and the natural decay of iodine to iodide over time. Other ORUs, like the ACTEX, that have resin may also produce TOC that could build up during storage. This TOC could then be introduced to other components upon installation. Sampling of spare ACTEX ORUs may provide evidence of TOC production during storage.

F-10. Presence of 2-propanol and acetone in the sampled ORU water cannot be explained assuming adherence to documented procedures as presented to the NESC team, and could possibly serve as nutrients for certain bacteria.

6.3 Assessment of Corrosion and Biofouling

The two failure mechanisms of importance in long-term storage of ISS wet ORUs are corrosion and biofouling. Corrosion can lead to leakage or formation of precipitates within the working fluid. Biofouling has been shown to decrease efficiency in heat exchangers, slow or block fluid flow, decompose distributed fluids (e.g., hydrocarbons), degrade drinking water quality, and increase the likelihood of corrosion.

6.3.1 Corrosion

Corrosion can be defined as the interaction of a material with its environment leading to degradation of the material capabilities and/or function. It follows that to assess the risk of corrosion for any engineered structure, information regarding both the material and the environment, including chemistry, temperature, and microflora, to which it is exposed, is required. The limitations of the information available for this review prevented such assessments from being made with a high degree of confidence, particularly with regards to an individual ORU. For each type of ORU, a list of wetted materials was provided with a general description of the nominal chemistry of the working fluids. Information regarding connections between wetted materials was not given due to proprietary concerns. Such geometric information is critical in fully assessing the risk of galvanic and crevice corrosion.

6.3.1.1 Materials Assessment

The ORUs are constructed using a broad range of materials. Lists of wetted materials provided by HSWL identify materials that are wetted in at least one of the ORUs under consideration. The materials of most interest for this analysis are the metallic alloys. Those alloys that could be susceptible to corrosion damage in nominal or contaminated working fluids are listed for each ORU in which they are present in Table 6.3-1.

Table 6.3-1. Materials of Construction for ORUs of Interest that are Susceptible to Corrosion in Contaminated Working Fluids

	SS302	SS303	SS304	SS305	SS316	SS18-8	Ni201	17-7PH	17-4PH	15-5PH
OGA H_2	x				x	x				
OGA Water	x	x			x	x				
OGA Pump										
WPA Pump/Sep	x	x			x	x		x		x
WPA Sensor			x		x		X	x		x
WPA Waste Water	x	x	x	x	x	x	x		x	x

Materials used in an ambient temperature water solution range from borderline corrosion resistant stainless steels (e.g., 18-8, SS302, SS303) to highly corrosion resistant materials such as titanium and nickel-base alloys. The materials of greatest concern are the borderline stainless steels. The materials listed in Table 6.3-1 would be expected to have sufficient corrosion resistance in the nominal working fluids of the ORUs (i.e., DI water) for long-term storage and use. For example, a reasonable uniform corrosion rate for stainless steel in potable water might be 10^{-7} A/cm^2, meaning that it would take almost 400 years for a wall of 0.016 inches (400 μm) to be breached[2].

Unfortunately, low levels of contamination by chloride ions make these materials susceptible to localized corrosion such as pitting and crevice corrosion. The level of contamination depends on the alloy, the solution temperature, and the composition of the working fluid, but levels on the order of 10–20 mg/l would be potentially deleterious, especially above room temperature [ref. 2]. There are numerous potential sources of such contamination, with the most likely coming from human handling of the ORU during installation and replacement.

Localized corrosion occurs when discrete areas of an otherwise corrosion resistant material undergo high-rate dissolution. It is generally categorized by the geometry created or involved. The two most likely important localized corrosion modes in the ORUs are pitting and crevice corrosion.

Pitting occurs when local sites on a surface that is fully exposed to the bulk environment are attacked and grow flaws into the surface due to dissolution. Often, these flaws are nearly hemispherical, but alloy microstructure and environmental conditions can conspire to make them

[2] Using Faraday's Law, the time to dissolve through 0.016 inches of steel can be estimated given the density of steel (8.03 g/cm^3), the equivalent weight (25.12 g/equivalent), Faraday's constant (96,485 C/equivalent), and an assumed dissolution rate (10^{-7} A/cm^2) according to 0.016 in × 2.54 cm/in × 8 g/cm^3 × 3 equiv/55 g × 96500 C/equiv × cm^2-s/10^{-7} C.

have a wide range of aspect ratios. In many cases, these pits initiate at metallurgical flaws such as inclusions that intersect the surface, but in some instances, the spatial distribution of pits appears stochastic.

Crevice corrosion occurs on a surface that is in some way occluded, for example, by the presence of a gasket or another metal in intimate contact, as in a QD connector. The geometry of the occluded site, including the types of materials in contact, has a significant effect on the likelihood and severity of the damage. Both types of localized corrosion can propagate at rates sufficient to cause leaks rapidly after initiation of corrosion. For a given material, the initiation time is determined in large part by the composition and condition of the working fluid. Higher temperatures and chloride concentrations drive initiation times lower, whereas flow and the presence of non-aggressive anions (such as sulfate) increase initiation times.

F-6. Some wetted materials (those identified in Table 6.3-1) used in the ORUs have a borderline resistance to corrosion and may be susceptible to localized corrosion in the presence of sufficient concentrations of chloride ions.

6.3.1.2 Geometry Considerations

All localized corrosion of stainless steel occurs when the environmental and geometrical conditions allow for dissolution products of the material to accumulate in a small volume. Given a sufficient impediment to diffusive dispersion, metal cations (e.g., Fe^{2+}, Cr^{3+}, and Ni^{2+}) will react with water (hydrolyze), creating locally acidic conditions according to a reaction such as Equation 6.3-1:

$$Cr^{3+} + 3H_2O = Cr(OH)_3 + 3H^+ \qquad \textit{(Eq. 6.3-1)}$$

The creation of an increased local concentration of cations (e.g., metal ions and hydrogen ions) creates an electrical potential/driving force for anions to migrate into the local site to maintain charge neutrality. Chloride ions are some of the most mobile ions, and if present as the dominant anion, will concentrate in the occluded site. Thus, the restricted diffusion at an incipient localized corrosion site leads to the creation of a local solution that is hydrogen chloride. Stainless steels lose high corrosion resistance in acidic chloride solutions, so the material in the occluded site starts to dissolve rapidly, further exacerbating the aggressive solution. Local solution compositions can have pH values as low as 0 and chloride ion concentrations as high as 9 mol/l, even if the bulk solution is neutral with a chloride concentration in the tens of mg/l range [ref. 3].

The degree of occlusion of the potential corrosion site is a key factor. The more occluded (e.g., the tighter the crevice), the more likely corrosion is to occur. In engineered systems as complicated as the ORUs, there are many possible crevices due to the number of wetted components that are mechanically connected. The list of geometries conducive to crevice corrosion include the QDs, at gaskets, valves, threaded fasteners, etc. One example from an ISS ORU is shown in Figure 6.3-1.

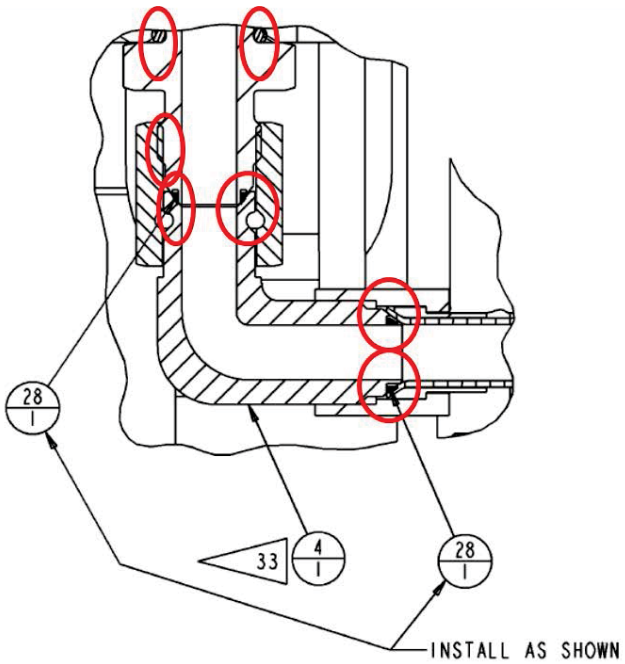

Figure 6.3-1. Example of Occluded Regions from the ISS ORUs
Note: Red ovals and circles highlight areas of possible crevice corrosion.

An additional accelerating complication is the likelihood that some of these susceptible materials are part of a crevice with another material that is more electrochemically noble (e.g., graphite, silver, Inconel® 625, Ti-6Al-4V, or plated chromium). These materials can dramatically increase the rate and probability of crevice corrosion of the susceptible material [ref. 3]. The extent of this potential problem cannot be evaluated, because although the list of wetted materials for each ORU was provided, no information concerning what materials are connected was made available. HSWL was not willing to share that information with the NESC team due to proprietary concerns, so the extent of the potential for crevice corrosion could not be fully assessed and thus only general conclusions can be made with respect to crevice corrosion risk.

6.3.1.3 Corrosion Risk Discussion

Active corrosion in wet ORUs appears small based on limited sample analyses (i.e., two units) described in Section 6.2 (i.e., very low concentrations of metals that could originate from metallic materials of construction). Thus, the likelihood of substantial corrosion of boldly exposed[3] surfaces is highly unlikely. The alloys listed as wetted materials in the ORUs considered are generally compatible with long-term storage of DI water in the absence of extenuating circumstances (i.e., geometry, microbes, chloride contamination). Analyses of samples are consistent with high purity water (low concentration of aggressive species (chloride)

[3] "Boldly exposed" refers to surfaces that are in direct contact with the bulk environment. It describes surfaces that are not occluded.

with higher concentrations of inhibiting species (sulfate, phosphate)). Low-rate (passive) dissolution has undoubtedly occurred, as demonstrated by the detection of metal cations (e.g., iron, nickel, chromium, manganese, aluminum, etc.) in the samples analyzed. Such passive dissolution would be expected. At this rate, it would be many years to perforation (See Section 6.3.1.1 for a quantitative example).

It would seem that the primary risk associated with the low rate, passive corrosion of the stainless steel components during storage is their potential effects on the hydrogen ORU cell stack. A number of these metals can be electrodeposited under the conditions present at the cathode in the cell stack. Such electrodeposition would most likely occur at the catalytic sites designed to be active for hydrogen generation, leading to a loss of efficiency of the cell stack and possible early failure if enough of the reaction sites are neutralized. It has been documented that metal ions also degrade Nafion® membranes [refs. 9 and 10].

There exists some likelihood of localized corrosion in physically occluded regions (e.g., crevices at fittings, crevices under O-rings, etc.). Some of the wetted materials of construction (see Table 6.3-1) are susceptible to such attack in dilute chloride solution (e.g., 304 stainless steel in 50 mg/l NaCl [ref. 2]). Note 303 stainless steel is substantially less resistant to localized corrosion than 304 stainless steel. This likelihood increases with increased temperature, degree of occlusion, stagnant solution, and physical contact with more noble materials (e.g., graphite, titanium) [ref. 3]. The inability to have access to information regarding the detailed geometry of the ORUs makes assessment of the likelihood of crevice corrosion speculative, but similar components do have many such physically occluded regions. The most likely consequence of such corrosion would be the development of leaks at the affected fittings, which would increase in severity with time. Sample results for this assessment were for < 2 years of storage. Localized corrosion occurs after an induction period the length of which depends on the material, the occlusion of the site, and the chemical environment (e.g., chloride concentration, temperature, flow).

6.3.2 Biofouling

Biofouling is the contamination of a system by biological components, including microorganisms, plants, animals, and/or the resulting by-products of biological activities. Dimensionally, biofouling is often separated into macro-scale (e.g., barnacles) and micro-scale (e.g., bacteria). In regards to ISS ORU components, biofouling caused by microorganisms is of chief concern. Microorganisms are spatially located in contaminated systems at surfaces (sessile) or in the bulk electrolyte (planktonic).

Biofouling requires biological components and a medium capable of biological sustainment. Microorganisms require water, nutrients, and electron acceptors. Liquid water is needed for all forms of life and the availability of water influences the distribution and growth of microorganisms. Chemical and biological analyses of waters from the two sampled ORUs indicate the presence of organics, metal cations, and bacteria (see Section 6.2).

The term biofilm embraces an enormous range of microbial associations generally found at phase boundaries [ref. 4]. Biofilms form on all engineering materials exposed in biologically

active environments including extreme environments such as ultrapure waters [refs. 5, 6]. Immediately after attachment, microorganisms initiate production of slimy adhesive extracellular polymeric substances, which assist in bridging microbial cells with the substratum. Biofilm accumulation at surfaces is an autocatalytic process. Initial colonization increases surface irregularity and promotes further biofilm formation. Biofilms provide protective environments for microorganisms and in most cases allow different types of microorganisms to flourish within different strata of the biofilm [ref. 7]. Microorganisms within the biofilm act symbiotically to produce conditions more favorable for the growth of each species. Dense biofilms can form as a result of high shear stress or starvation [ref. 8]. Evidence of biofilm was not noted in the water sampled from the two ORUs. However, neither component was disassembled for examination.

Water with suitable forms of carbon, nitrogen, phosphorus, and sulfur supports microbial growth. Microorganisms can use a variety of electron acceptors for respiration including oxygen, sulfate, nitrate, nitrite, CO_2, Fe^{3+}, Mn^{4+}, and Cr^{6+}. Energy derived from organic carbon drives heterotrophic microbial growth within biofilms. Heterotrophs cannot fix carbon directly but require organic carbon molecules from their surroundings. Generally, increasing the TOC increases the substrate or carbon source available to the biofilm. Carbon is not always the growth-limiting nutrient for microorganisms. Phosphorus and nitrogen may be limiting in some aquatic systems.

Chemical analysis of the working fluids indicates low levels (< 1 mg/l) of phosphorous, calcium, magnesium, sodium, and potassium while TOC concentrations were between 50 and 100 mg/l. Nitrogen was below the detection limit for all water samples. Chemical analyses from the HSWL Water Cart 5 and WAFAL triple blank control samples were below detection limits for all contaminants. From the working fluid of Component 1 Leg B-D, direct injection GC/MS identified 2-propanol (35.4 mg/l) and acetone (7.5 mg/l) (see Section 6.2.2). Regardless of the origin of the 2-propanol and acetone, their presence provides one of the requirements for sustainment of microbial constituents.

Component 1 Leg B-D had a bacterial count of 1.0 CFU/10 ml, and Water Cart 5 had a bacterial count of 27 CFU/20 ml (Section 6.2.2). Component 1 Leg C had an MCV that was the suspected source of iodine and iodide. Leg B was open to Leg C by way of a three-way valve (see Figure 6.2-3) and would have been expected to be free of microorganisms due to the iodine. Leg D was isolated from the MCV and would be more likely to have a positive indication of microorganisms and biofouling. The Leg B-D sample was collected first, by pushing water from Leg B through Leg D and collecting water from both legs together. The results suggest that the water without access to the MCV/iodine was able to maintain the microbial components, but proliferation did not occur. It should be noted that the low measured CFUs in Leg B-D could also have been due to the influence of iodine from Leg B, where the time between sampling and analysis was 48 hours. Iodine from Leg B, when mixed with microbially contaminated water from Leg D, could have reduced the microbial numbers and resulted in a false low CFU number. However, iodine concentration in Leg B-D was below detection limit (0.05 mg/l). Iodine was detected in measurable amount (4.8 mg/l) in Leg B-C, the sample taken after Leg B-D.

6.3.3 MIC

Biofouling and MIC are not synonymous; MIC is a potential consequence of biofouling. The term MIC is used to designate corrosion due to the presence and activities of microorganisms. As shown in Figure 6.3-2, MIC requires: 1) microorganisms to be present, 2) an electrolyte capable of sustaining microorganisms, and 3) a material susceptible to corrosion exposed to the electrolyte. MIC has been reported for all engineering metals and alloys with the exception of predominantly titanium and high chromium/nickel alloys [ref. 11 and 14]. Microorganisms can accelerate rates of partial reactions in corrosion processes or shift the mechanism for corrosion. Microorganisms do not produce unique types of corrosion. They produce localized attack including pitting, dealloying, enhanced erosion corrosion, enhanced galvanic corrosion, stress corrosion cracking, and hydrogen embrittlement. MIC occurs in environments where corrosion would not be predicted (e.g., low chloride waters), and the rates can be exceptionally high.

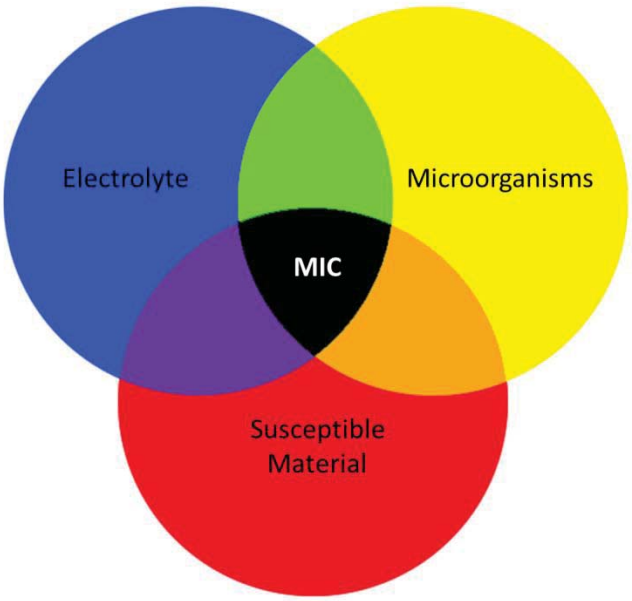

Figure 6.3-2. Requirements for MIC

Biofouling can increase the likelihood of corrosion through numerous microbiologically-mediated processes including sulfide derivatization, acid production, biomineralization/metal deposition, and ennoblement. These processes are listed in increasing likelihood of occurrence in the wetted ORUs.

Sulfide derivatization occurs when biotically produced sulfides react with the protective metal oxide producing a less tenacious and less protective metal sulfide [ref. 12]. Sulfide derivatization requires sulfate reducing bacteria (SRB) and sulfate. Not surprising considering the water source (water cart), SRB were not detected and sulfate concentrations were low (max 0.8 mg/l) for all of the analyzed samples.

Heterotrophic bacteria that secrete organic acids during fermentation of organic substrates are referred to as acid-producing bacteria. The kinds and amounts of acids produced depend on the type of microorganisms and the available substrate molecules. Organic acids may force a shift in the tendency for corrosion to occur. The impact of acidic metabolites is intensified when they are trapped at the biofilm/metal interface. In addition, acidification causes the pitting potential (E_{pit}) to become more negative, thereby increasing the likelihood of pitting. Like sulfide production, acid production is often organism-specific. *Ralstonia pickettii* is not known to produce copious amounts of acids and therefore, MIC due to acid production is not expected.

Biomineralization can be carried out by a variety of organisms including bacteria, yeast, and fungi [ref. 13]. Localized corrosion of 300 series stainless steels has been related to the biomineralized metal deposits [refs. 15, 16, 17, and 18]. The most common microbiologically mediated metal deposits include manganese and iron oxides. Manganese deposits are efficient cathodes and can result in increased likelihood of pitting and crevice corrosion due to ennoblement. Deposits containing microbes and oxidized species create oxygen concentration cells that effectively exclude oxygen from the area immediately under the deposit and initiate a series of events that are individually or collectively corrosive. In an oxygenated environment, the area immediately under individual deposits becomes deprived of oxygen. This area becomes a relatively small anode compared to the large surrounding oxygenated cathode. The largest pH decrease is found in alloys containing chromium. For this reason, under-deposit attack is particularly aggressive on 300 series stainless steels. In addition, chloride from the electrolyte will migrate to the anode to neutralize charge buildup, forming corrosive metal chlorides. Under these circumstances, corrosion involves the conventional features of localized corrosion (i.e., crevice and pitting corrosion): differential aeration, a large cathode/anode surface area, and the development of acidity and metallic chlorides within an occluded volume. Samples from the HSWL water cart indicated a lack of measurable manganese and iron. However, these elements were detected in samples taken from Component 1 Legs B-C and B-D. Increased metal concentrations are most likely due to passive dissolution of the wetted alloys (see Section 6.3.1.2). *Ralstonia pickettii* is not a metal depositing bacteria and the low concentrations of dissolved iron and manganese (< 1 mg/l) found in the working fluids would preclude proliferation of metal depositing microorganisms even if they were introduced into these systems. Elevated levels of dissolved iron would have indicated active corrosion had already occurred, making microbially mediated deposition doubtful.

Ennoblement is the increase of the corrosion potential (E_{corr}) due to biofilm formation on a metal surface [ref. 12]. Ennoblement has been observed in distilled, fresh, estuarine, and marine waters with various metals and alloys including all of the wetted metals listed in Table 6.3-1. Microbial colonization of passive metals can shift E_{corr} in the noble direction and produce accompanying increases in current density and polarization slope at mild cathodic overpotentials (i.e., the metal/biofilm provides a better source of cathodic current than the metal alone). Due to charge conservation, anodic and cathodic currents must be equal at E_{corr}. Therefore, the higher the available cathodic current, the more likely any initiated site of localized corrosion (anode) can be supported and allowed to propagate. Of all the microbiologically mediated processes,

ennoblement is the most likely to occur in wetted ORUs. Ennoblement does not affect the intrinsic electrochemical parameters of an electrolyte/metal system. Critical potentials for describing susceptibility to localized corrosion including pitting, repassivation, or crevice potentials are unaltered. Ennoblement increases the driving force (i.e., electrochemical potential) that results in higher probability of corrosion initiation. For example, the phenomenon is particularly important for alloys that have pitting potential (E_{pit}) a few hundred millivolts more noble than E_{corr} (e.g., 300 series stainless steels). As the difference between E_{corr} and E_{pit} (or crevice corrosion potential, $E_{crevice}$) becomes less, the probability for corrosion initiation is increased. Therefore, materials inside of ORUs that are susceptible to pitting/crevice corrosion become even more "borderline" in the presence of biofouling.

Ralstonia pickettii has not been examined for its potential ability to cause ennoblement, but it is unlikely that the single species alone at its measured concentrations (1 CFU/ml) could produce a sufficient biofilm to cause ennoblement. Therefore, as long as the sterilization protocols are followed, or the presence of an MCV is maintained, MIC is not expected to be an issue in long-term wet ORU storage. This statement can be explained by examination of Figure 6.3-2 where removing any one of the overlapping circles (electrolyte, susceptible material, microorganisms) removes the possibility of MIC. However, if additional species and numbers of microbes are unintentionally added to the working fluids, biofouling becomes more likely as does MIC. Therefore, sterile protocols for introduction of working fluids and their periodic sampling should be strictly maintained.

6.4 Risk Assessment

The NESC team assessed the risk to ISS due to biological growth/biofouling and corrosion separately. The ISS 5 × 5 risk matrix was chosen to express the assessed risk qualitatively (see Appendix J for a description of the ISS risk matrix). The matrix shows the *likelihood* of an event occurring versus the *consequences* of that event, and the NESC team estimated each per the matrix format. However, the technical analyses and conclusions drawn for this assessment focused primarily on the likelihood of occurrence, and the team acknowledges that the ISS Program has better insight into the consequences than the NESC team. This risk assessment was based on factors described in the previous sections, but the sample results from the two non-disinfected ORUs were the primary basis of the findings. Conclusions were extrapolated to all of the ORUs based on sampling from two ORUs. For this reason, all of the risk assessments portray minimum risks due to lingering uncertainty. One of the recommendations made is for the ISS Program to continue to sample spares when possible.

F-1. A limitation to this assessment is that the team was restricted to a small sample set (four samples) taken from two ORUs and was limited access to ORU design configuration information. This resulted in higher uncertainty associated with the risk assessments.

6.4.1 Biological Growth/Biofouling

The biological growth hazard targets crew health and the ECLS regeneration system components for biofouling and MIC. Based on the ground spare ORU sample results that show very low microbial concentrations, any microbiological presence in a given ORU is highly unlikely if the same procedures used to limit contamination during servicing and sampling each ORU are followed. However, conditions in ORUs may be conducive to microbial growth if, due to human error (e.g., failure to properly follow established QD cleaning procedures) or some other mechanism, microorganisms are introduced into the system.

The servicing and sampling procedures either reviewed by the team or described to the team in cases where the actual procedures were inaccessible (due to proprietary restrictions) were found to be robust and protect the integrity of the ORUs in preventing contamination. The sample results showing microbial CFUs were very low in the two ORUs sampled gives confidence that the procedural controls in place are effective. However, the sample results also revealed 2-propanol and other TOCs that could serve as nutrients for microorganisms. A probable source of 2-propanol was identified as residual 2-propanol wiped on QDs for sterilization prior to servicing or sampling that was not allowed to dry completely before exposure to the water in the ORU. Other TOCs may be from the breakdown of iodinated resins used in MCVs that are in some of the ORUs (e.g., the water ORU). The observation of organic compounds presents an additional concern that if an ORU with an iodinated resin is installed and not flushed prior to exposure to the system, TOCs, and other contaminants resulting from MCV resin breakdown will be transferred into the system. The OGA also has materials that could serve as nutrients to microorganisms, including polymeric materials and the Nafion® membrane in the hydrogen ORU cell stack.

The risk for human exposure to harmful bacteria is directly related to the overall risk of biological contamination plus the probability of the presence of harmful species. In the samples reviewed, none of the microorganisms detected present a health hazard to humans. Also, there are MCVs in both the OGA and the WPA, and additional measures to kill any bacteria, before water is retrieved for crew consumption. The placement on the risk matrix for crew exposure to harmful microorganisms is 1/2 (likelihood/consequence) assuming current procedures are followed, and a 2/2 on the assumption that there has been a contamination (see Figure 6.4-1). The consequence is assumed to be crew illness due to bacterial exposure.

F-7. Crew member exposure to harmful microorganisms is highly unlikely (1 on the ISS risk scorecard) if the contamination control in the servicing and sampling procedures used in preparation of the two ORUs sampled continue to be followed. If microorganisms are introduced into the OGA or WPA, then crew member exposure to harmful microorganisms is unlikely (2 on the ISS risk scorecard).

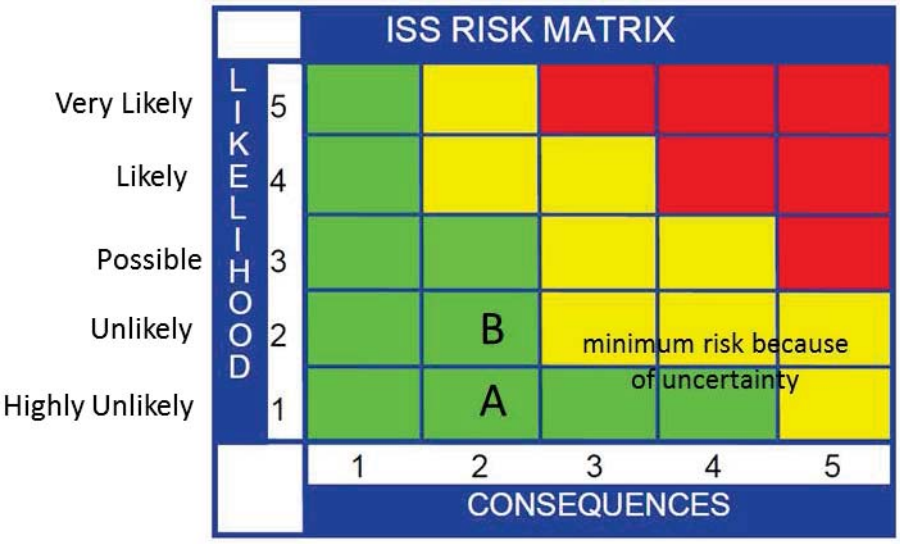

Figure 6.4-1. Minimum Risk Matrix for Crew Member Exposure to Harmful Microorganisms

A = Nominal processing and procedures are followed, B = Microbial introduction into system occurs

Biofouling has a history on ISS and other spacecraft, so occurrence would not be unique. However, the conditions described in Section 6.2 detailing previous biofouling instances do not apply to the current ISS ECLS regeneration subsystem configuration and use. An exception may be the biofouling witnessed on the US Navy's spare OGP, which was found to have a substantial biofilm after unknown storage conditions and influent water. This incident prompted HSWL to initiate periodic flushing for the spare ISS hydrogen ORU cell stacks while stored on the ground. Navy operational experience revealed no biofouling incidents that resulted in performance degradation on active systems. The samples taken from a recently active system and an inactive spare showed inactivity can result in substantially higher microbial counts. The observation of some biological activity in the recently active OGP highlights limitations of the disinfection ability of electrolysis.

As in the case of crew exposure to harmful microorganisms, the risk for biofouling was assessed both for when the normal procedures are followed and in the event of contamination. The worst case consequence was assumed to be biofouling in the hydrogen ORU cell stack to the point of losing the use of the OGA. It was then assumed that if this occurred, a full crew complement of six could not be accommodated, resulting in a "significant impact to" or "loss of some mission objectives"[4] (ref. Appendix J). This equates to a 3 or 4 on the risk matrix. If procedures are executed nominally, then a biofouling event on the hydrogen ORU is highly unlikely (i.e., 1 on the ISS risk matrix). However, if biological contaminants were to be introduced into the OGA or WPA, then the environment may be conducive to growth and possible biofilm formation. In this case, the likelihood rises to possible (i.e., 3 on the ISS risk matrix) (see Figure 6.4-2).

[4] Quotation marks denote wording on the ISS risk matrix.

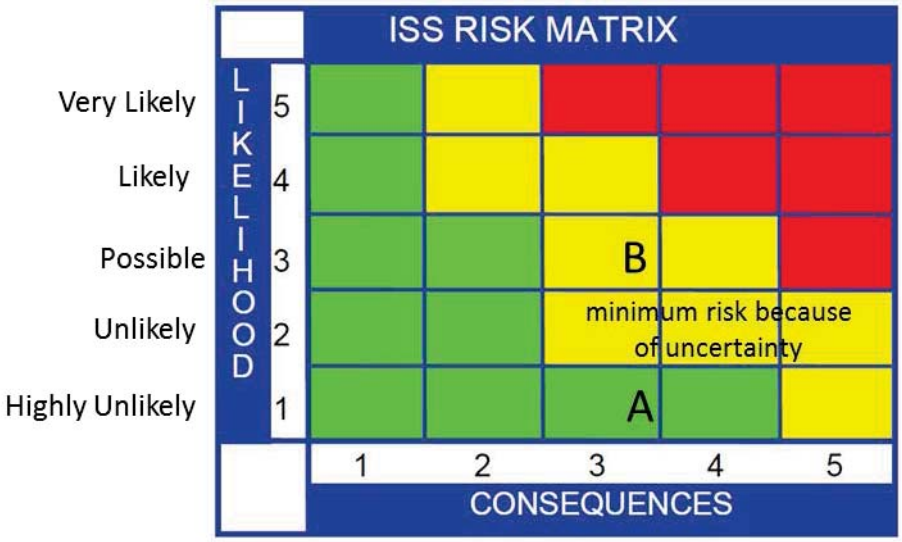

Figure 6.4-2. Minimum Risk Matrix for Biofouling

A = Nominal processing and procedures are followed, B = Microbial introduction into system occurs

F-2. Biofouling in the OGA or WPA is highly unlikely (1 on the ISS risk scorecard) if the contamination control in the servicing and sampling procedures used in preparation of the two ORUs sampled continue to be followed.

F-3. If microorganisms are introduced into the OGA or WPA, then it is possible (3 on the ISS risk scorecard) for biofouling to occur to the point of degrading the performance of the hydrogen ORU.

6.4.2 Corrosion

The risk of corrosion, including MIC, from long-term wet storage was also assessed. From material lists provided to the NESC team, some of the wetted materials used in the ECLS regeneration system were identified as susceptible to corrosion under some conditions (see Section 6.3). Typically, a primary concern for corrosion in a fluid system would be material degradation to the point of causing a leak. However, based on the ground spare sample results showing low concentrations of metal ions, corrosion activity appears to be low in the two ORUs sampled. In addition, chloride concentrations were relatively low and corrosion-inhibiting sulfate and phosphate were comparatively high, suggesting it unlikely for uniform corrosion to be taking place at a rate that would be untenable. Crevice corrosion is a possibility, and metal ions produced could possibly be masked by dilution when sampled (see Section 6.3.1). Corrosion products may also pose a threat to the hydrogen ORU Nafion® membrane by blocking reaction sites and decreasing performance. The consequence is a 3 or 4 risk on the matrix as it is for biological growth (see Figure 6.4-3) with a likelihood value of 1 (highly unlikely).

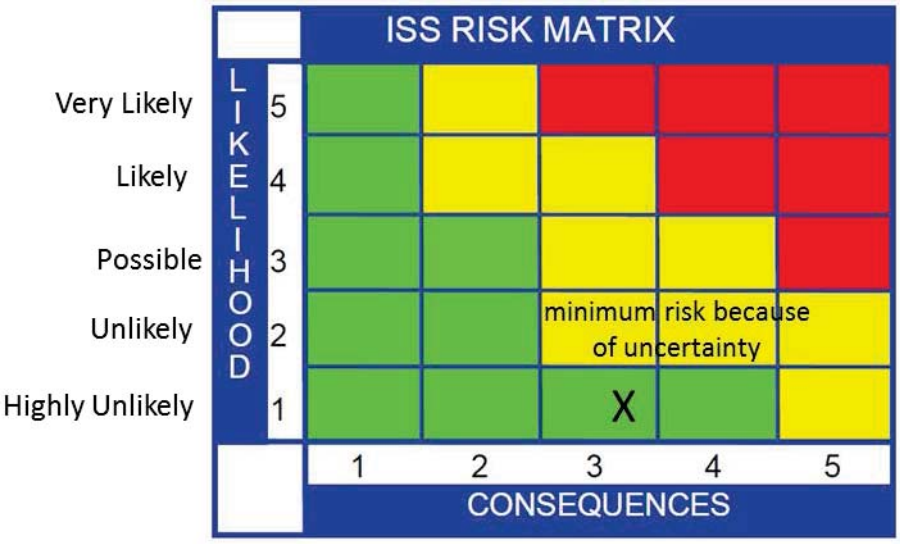

Figure 6.4-3. Minimum Risk Matrix for Corrosion

The risk for MIC, as described in Section 6.2.4, correlates with the risk for biofilm growth and biofouling. Two of the three requirements for MIC, electrolytes and susceptible materials, are present, but the samples from the two ORUs indicate microorganisms are not. Because conditions within the ORUs may be conducive to bacterial growth, and the other factors necessary for MIC are present, the risk for MIC assuming a microbiological presence is 3/3 on the ISS risk matrix. If there is no microbial introduction, then the risk is a 1/3 (see Figure 6.4-4).

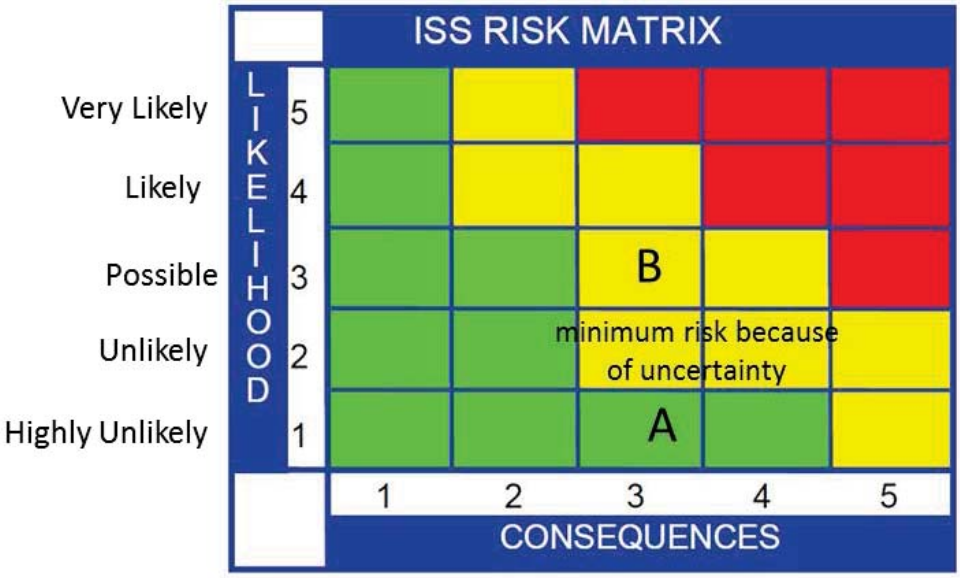

Figure 6.4-4. Minimum Risk Matrix for MIC

A = Nominal processing and procedures are followed, B = Microbial introduction into system occurs

F-4. The primary concern for corrosion in the OGA is the possibility that metal ions released as corrosion products will affect the performance of the hydrogen ORU cell stack as opposed to perforation or leakage.

F-5. Corrosion is a time-dependent damage mechanism and is highly unlikely (1 on the ISS risk scorecard) based on low levels of metal ions associated with corrosion in the two ORUs sampled.

F-8. MIC is highly unlikely (1 on the ISS risk scorecard) if the contamination control in the servicing and sampling procedures used in preparation of the two ORUs sampled continue to be followed. If microorganisms are introduced into the OGA or WPA, then it is possible (3 on the ISS risk scorecard) for MIC to occur.

6.4.3 Overall Assessment

Overall, the risk posed by long-term wet ORU storage is driven by the risk that microorganisms are introduced into the system after the last disinfection process (if there is one). Risk is minimal if it is assumed that no contamination will take place, but although the procedures in place have proven, at least for the two ORUs sampled, that biological contamination controls are sound, human error and equipment failure may undermine those controls. Therefore, the overall risk assessment must attempt to determine the likelihood of a failure in contamination control, and that is judged to be unlikely. If the consequence is assumed to be significant impact to mission objectives, then the position on the risk matrix is 2/3 as shown in Figure 6.4-5.

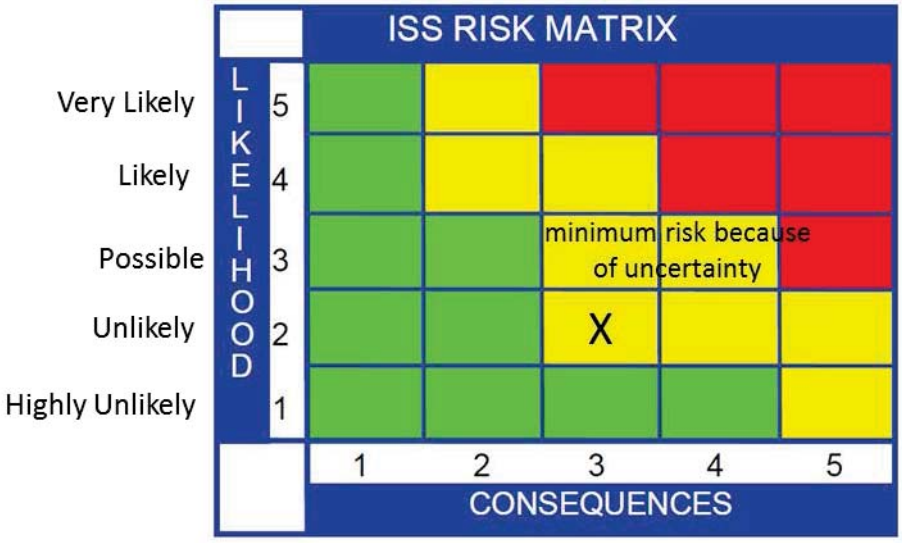

Figure 6.4-5. Minimum Risk Matrix for Long-term Wet ORU Storage (overall)

6.5 Long-term Wet Storage Risk Mitigation

The procedures and protocols followed by the ISS Program to minimize ORU contamination culminate in a low risk for biofouling and corrosion. However, the risk still remains that bacteria will be introduced into the OGA or WPA, and if that occurs, conditions within the loops may

promote bacterial growth leading to biofouling. Although the sampling undertaken in this assessment of two spare ORUs provides some level of confidence in the state of the systems and effectiveness of the procedural controls in place, more samples would have been preferable to provide a broader indication of the state of spared ORUs. The NESC recommends that the ISS Program continue sampling ground spare ORUs. Sampling of disinfected ORUs would also indicate the effectiveness of the disinfection techniques.

Onboard the ISS, the NESC team recognizes that flushing operations would be problematic. Because of the relatively low risk posture as described in Section 6.4, periodic flushing of in-flight spares is not recommended. However, because metal ions, TOCs, and other constituents accumulate in ORUs, especially those with an MCV, the NESC recommends flushing the ORU leg with an MCV prior to allowing the water that had been resident in the stagnant ORU into the system. Another recommendation is to reassess logistics planning due to the availability of visiting vehicles to deliver spares to ISS. This reassessment may allow more spares to be kept on the ground where they could be kept dry or flushed periodically.

As described in Section 6.3, crevice corrosion occurs on occluded surfaces and is influenced by the geometry of the surface and the materials in contact with each other. These design details were not made available to the NESC team due to proprietary concerns, so specific judgments as to the risk for crevice corrosion are somewhat speculative. However, the team feels that this is an important investigation for the ISS Program to consider.

7.0 Findings and NESC Recommendations

7.1 Findings

The following findings were identified:

F-1. A limitation to this assessment is that the team was restricted to a small sample set (four samples) taken from two ORUs and was limited access to ORU design configuration information. This resulted in higher uncertainty associated with the risk assessments.

F-2. Biofouling in the OGA or WPA is highly unlikely (1 on the ISS risk scorecard) if the contamination control in the servicing and sampling procedures used in preparation of the two ORUs sampled continue to be followed.

F-3. If microorganisms are introduced into the OGA or WPA, then it is possible (3 on the ISS risk scorecard) for biofouling to occur to the point of degrading the performance of the hydrogen ORU.

F-4. The primary concern for corrosion in the OGA is the possibility that metal ions released as corrosion products will affect the performance of the hydrogen ORU cell stack as opposed to perforation or leakage.

F-5. Corrosion is a time-dependent damage mechanism and is highly unlikely (1 on the ISS risk scorecard) based on low levels of metal ions associated with corrosion in the two ORUs sampled.

F-6. Some wetted materials (those identified in Table 6.3-1) used in the ORUs have a borderline resistance to corrosion and may be susceptible to localized corrosion in the presence of sufficient concentrations of chloride ions.

F-7 Crew member exposure to harmful microorganisms is highly unlikely (1 on the ISS risk scorecard) if the contamination control in the servicing and sampling procedures used in preparation of the two ORUs sampled continue to be followed. If microorganisms are introduced into the OGA or WPA, then crew member exposure to harmful microorganisms is unlikely (2 on the ISS risk scorecard).

F-8 MIC is highly unlikely (1 on the ISS risk scorecard) if the contamination control in the servicing and sampling procedures used in preparation of the two ORUs sampled continue to be followed. If microorganisms are introduced into the OGA or WPA, then it is possible (3 on the ISS risk scorecard) for MIC to occur.

F-9. MCVs with iodinated resin produce potassium and increasing concentrations of iodide as a result of iodine decomposition during long term wet storage.

F-10. Presence of 2-propanol and acetone in the sampled ORU water cannot be explained assuming adherence to documented procedures as presented to the NESC team, and could possibly serve as nutrients for certain bacteria.

F-11. Calcium, magnesium, phosphate, potassium, and sodium are used in cleaning compounds during hardware preparation, and this may explain the presence of these minerals in the sample analyses.

7.2 NESC Recommendations

The following NESC recommendations were identified and directed towards the ISS Program:

R-1. Prior to on-orbit installation, flush ORUs with resin beds to minimize TOC, potassium, and iodide/iodine. ***(F-9)***

- The water in the ORU MCV can be flushed through the waste water leg after installation.

R-2. Develop a sparing plan to minimize long-term storage of serviced ORUs. Utilize the available visiting vehicles to minimize on-orbit storage time of serviced ORUs. ***(F-1, F-3, F-4, F-6, F-8)***

R-3. Perform periodic sampling of ground-spared ORUs for chemistry and microorganism speciation. ***(F-1, F-3, F-8)***

R-4. Reinforce sterilization protocols in procedures for crew when removing and replacing ORUs on orbit. ***(F-1, F-2, F-3, F-8)***

R-5. The HSWL procedures used during disinfection of mating surfaces with wipes should stress the observance of the waiting/drying period prior to mating of QDs to flight units. ***(F-10)***

R-6. Ensure ORU cleaning procedures are adequate to remove detectable levels of residual cleaning agents. ***(F-11)***

R-7. Perform a review of ORU materials and internal geometry to evaluate potential for crevice corrosion. ***(F-1, F-4, F-5, F-6)***

8.0 Alternate Viewpoint

There were no alternate viewpoints identified during the course of this assessment by the NESC team or the NRB quorum.

9.0 Other Deliverables

No unique hardware, software, or data packages, outside those contained in this report, were disseminated to other parties outside this assessment.

10.0 Lessons Learned

No applicable lessons learned were identified for entry into the NASA Lessons Learned Information System (LLIS) as a result of this assessment.

11.0 Recommendations for NASA Standards and Specifications

No recommendations for NASA standards and specifications were identified as a result of this assessment.

12.0 Definition of Terms

Corrective Actions	Changes to design processes, work instructions, workmanship practices, training, inspections, tests, procedures, specifications, drawings, tools, equipment, facilities, resources, or material that result in preventing, minimizing, or limiting the potential for recurrence of a problem.
Finding	A relevant factual conclusion and/or issue that is within the assessment scope and that the team has rigorously based on data from their independent analyses, tests, inspections, and/or reviews of technical documentation.
Lessons Learned	Knowledge, understanding, or conclusive insight gained by experience that may benefit other current or future NASA programs and projects. The experience may be positive, as in a successful test or mission, or negative, as in a mishap or failure.
Observation	A noteworthy fact, issue, and/or risk, which may not be directly within the assessment scope, but could generate a separate issue or concern if not addressed. Alternatively, an observation can be a positive

	acknowledgement of a Center/Program/Project/Organization's operational structure, tools, and/or support provided.
Problem	The subject of the independent technical assessment.
Proximate Cause	The event(s) that occurred, including any condition(s) that existed immediately before the undesired outcome, directly resulted in its occurrence and, if eliminated or modified, would have prevented the undesired outcome.
Recommendation	A proposed measurable stakeholder action directly supported by specific Finding(s) and/or Observation(s) that will correct or mitigate an identified issue or risk.
Root Cause	One of multiple factors (events, conditions, or organizational factors) that contributed to or created the proximate cause and subsequent undesired outcome and, if eliminated or modified, would have prevented the undesired outcome. Typically, multiple root causes contribute to an undesired outcome.
Supporting Narrative	A paragraph, or section, in an NESC final report that provides the detailed explanation of a succinctly worded finding or observation. For example, the logical deduction that led to a finding or observation; descriptions of assumptions, exceptions, clarifications, and boundary conditions. Avoid squeezing all of this information into a finding or observation

13.0 Acronyms List

ACTEX	Activated Carbon/Ion Exchange
Al	Aluminum
BNi	Boron Nickel Alloy
cat	Catalytic
CFU	Colony Forming Unit
CM	Command Module
CO_2	Carbon Dioxide
CRS	Carbon Dioxide Reduction System
DI	Deionized
EATCS	External Active Thermal Control System
ECLS	Environmental Control and Life Support
EMU	Extravehicular Mobility Unit
EVA	Extravehicular Activity
FES	Flash Evaporator
GC/MS	Gas Chromatography/Mass Spectrometry
GSE	Ground Support Equipment
H_2	molecular hydrogen gas

H_2O	Water
HF	hydrofluoric acid
HSWL	Hamilton Sundstrand Windsor Locks (CT)
IATCS	Internal Active Thermal Control System
ISS	International Space Station
ITCS	Internal Thermal Control System
IX	Ion Exchange
JSC	Johnson Space Center
KI	potassium iodide
LaRC	Langley Research Center
LCG	Liquid Cooling Garment
LM	Lunar Module
MCV	Microbial Check Valve
MF	Multifiltration
mg/l	milligrams per liter
MIC	Microbiologically Induced Corrosion
ml	milliliter
MSFC	Marshall Space Flight Center
NaOC1	sodium hypochorite
NAVSEA	Naval Sea Systems Command
NESC	NASA Engineering and Safety Center
NRB	NESC Review Board
O_2	Oxygen
OGA	Oxygen Generator Assembly
OGP	Oxygen Generating Plant
OGS	Oxygen Generation System
OPA	ortho-phthaldehyde
ORR	Oxygen Reduction Reaction
ORU	Orbital Replaceable Unit
PEM	Proton Exchange Membrane
pH	Acidity
psig	Pounds per Square Inch Gauge
QD	Quick Disconnects
RHS	Reactor Health Sensor
SPCU	Service and Performance Checkout Unit
SPE	Solid Polymer Electrolysis
SRB	Sulfate Reducing Bacteria
SWS	Supply Water System
TOC	Total Organic Carbon
UPA	Urine Processor Assembly
URC	Umpqua Research Company
US	United States

USOS	US Orbital Segment
VCD	Vapor Compression Distillation
WAFAL	Water and Food Analysis Laboratory
WCL	Water Coolant Loops
WPA	Water Processor Assembly
WRS	Water Recovery System
WWS	Waste Water System
µm	micrometer
µS	microsiemens

14.0 References

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15.0 Appendices

Appendix A. Executive Summary from NESC Report RP-05-71: *Technical Consultation of the International Space Station Internal Active Thermal Control System Cooling Water Chemistry*

Appendix B. Executive Summary from NESC Report RP-05-121: *Recovery Plan for Extravehicular Mobility Unit and International Space Station Airlock Coolant Loop Review for Return-to-flight Technical Assessment Report*

Appendix C. Apollo and Space Shuttle Water Systems Description

Appendix D. Component 1 Samples Microbiology Report

Appendix E. Component 3 Samples Microbiology Report

Appendix F. Component 1 Samples Chemical Analysis Report

Appendix G. Component 3 Samples Chemical Analysis Report

Appendix H. Component 1 Leg B-D Sample Follow-up Chemical Analysis Report

Appendix I. Stagnant Class III MCV Sample Chemistry Report

Appendix J. ISS Risk Matrix

Appendix K. Spacecraft Water Exposure Guideline for Isopropyl Alcohol

Appendix A. Executive Summary from NESC Report RP-05-71: Technical Consultation of the International Space Station Internal Active Thermal Control System Cooling Water Chemistry

NASA Engineering and Safety Center (NESC) Technical Consultation Position Paper	Document #: RP-05-71	Version: 1.0
Title: Technical Consultation of the International Space Station (ISS) Internal Active Thermal Control System (IATCS) Cooling Water Chemistry		Page #: 5 of 318

1.0 Executive Summary

The on-orbit ISS IATCS consists of a Low Temperature Loop (LTL) and a Moderate Temperature Loop (MTL), which provides coolant to the U.S. Laboratory and airlock modules (Figure 1-1). The nominal circuit volumes and supply temperatures for the LTL are 63 liters (L) and 3.3 to 6.1° Celsius (C), and for the MTL, 200 L and 16.1 to 18.3° C. The LTL and MTL normally operate independently in a dual loop mode, but can be cross-connected (single loop mode) so that a single Pump Package Assembly (PPA) circulates both loops. The water-based IATCS collects heat from sources within the pressurized elements and transfers heat to the External Active Thermal Control Systems (EATCS) via the ammonia-to-water Interface Heat Exchangers (IFHXs) mounted externally to the U.S. Laboratory endcone (Figure 1-2). Future pressurized modules (Node 2, Columbus, etc.) will have independent IATCSs, but the potential exists for fluid from one IATCS to mix with fluid from another IATCS during switching of equipment racks on-orbit.

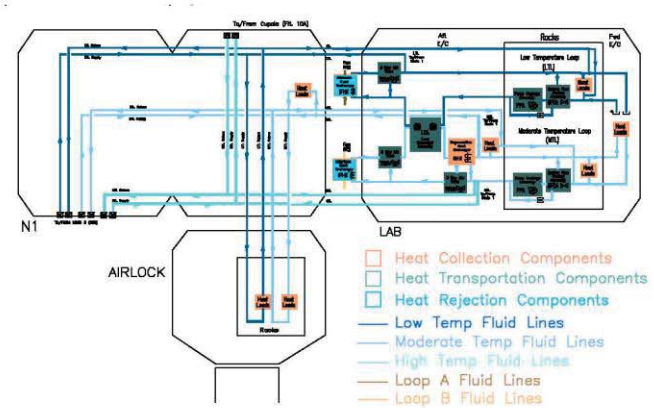

Figure 1-1. U.S. Laboratory, Node 1, and Airlock General IATCS Schematic

NESC Request No. 04-018-E

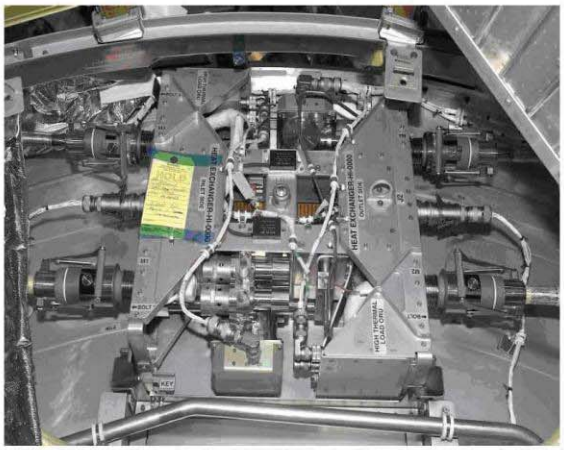

Figure 1-2. Heat Transfers to the EATCS via the Ammonia-to-Water -IFHXs

Since early 2002, the IATCS coolant chemistry has deviated from "as circulated" specification limits identified in SSP 30573, Revision B, ISS Program Fluid Procurement and Use Control Specification (shown in Table 1-1). The chemistry deviation was the result of the normal ISS on-board control range of the partial pressure (2-6 mmHg) of carbon dioxide (CO_2), combined with the use of Teflon flexible hoses for the IATCS coolant. Diffusion of CO_2 from the cabin atmosphere through the flexible hoses and into the coolant loop increased carbonic acid levels in the coolant fluid and lowered the coolant pH (Figure 1-3).

Table 1-1. IATCS Coolant Chemistry Specification Limits

Chlorides	1.0 ppm maximum
Dissolved Oxygen	6.0 ppm minimum
Total Organic Carbon (TOC)	5 ppm maximum
Di or Tri Sodium Phosphate	200 – 250 ppm
Sodium Borate	800 – 1200 ppm
Silver Sulfate	0.1 – 0.3 ppm
pH	9.5 ± 0.5

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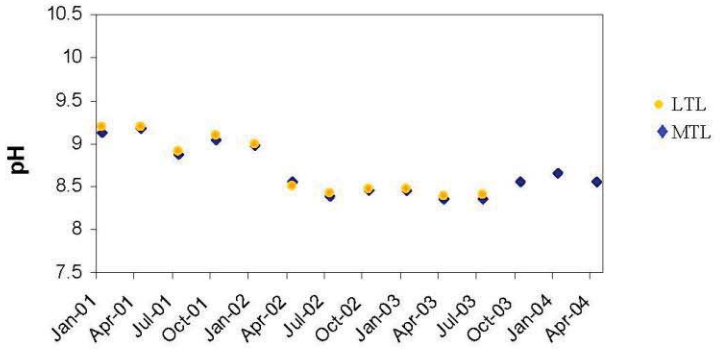

Figure 1-3. pH Decrease caused by Diffusion of Cabin CO_2 into IATCS Coolant (permeated through the IATCS Teflon flexible hoses)

As the pH decreased, the microbe population increased, and the dissolved nickel content increased (shown in Figures 1-4a and 1-4b), as determined from returned ISS IATCS water samples. Subsequently, the phosphate concentration decreased as the nickel phosphate saturation limit was exceeded (shown in Figure 1-4c). Furthermore, nickel precipitates (primarily nickel phosphate) were observed in IATCS filters. A green color was noted on gas traps, which may or may not be due to precipitates. Nickel dissolution and the formation of nickel precipitates were not observed in the ground-based development and certification testing, where IATCS-specified fluid chemistry (especially the pH) remained stable for at least 2 years. Concerns were raised that continued precipitation in the IATCS fluid could lead to other fouling-related issues associated with several system components. Further investigation into the effects of pH reduction increased the area of concern to include increased microbial levels and biofilm development. These latter conditions could lead to galvanic and/or microbial corrosion and reductions in cold plate/HX efficiencies.

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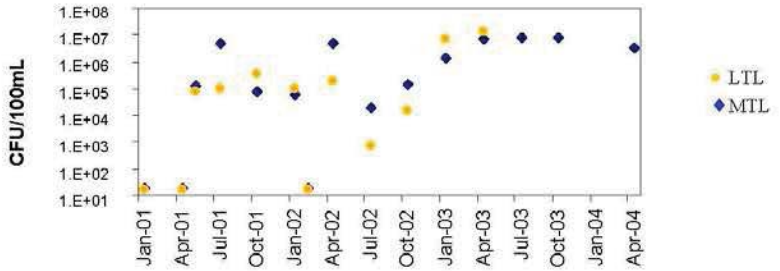

Figure 1-4a. Increase in Microbe Counts in IATCS Loops Coincident with Decreased pH

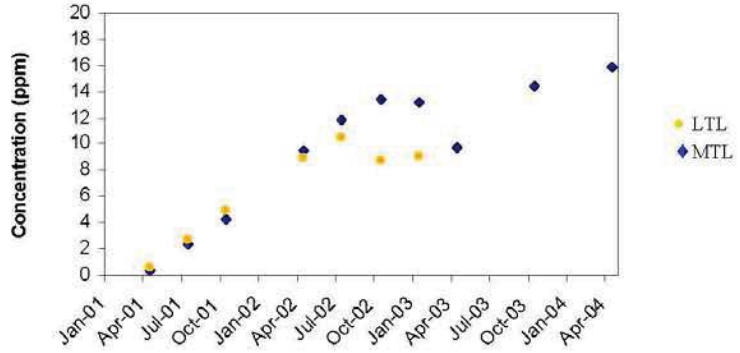

Figure 1-4b. Increase in Dissolved Nickel Ion Content of the IATCS Coolant Loops Coincident with Decreased pH

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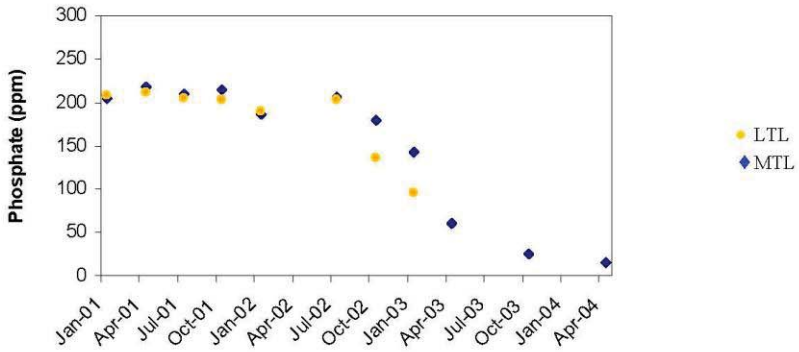

Figure 1-4c. Decrease in Phosphate Concentration in the IATCS Loops following Increases in Dissolved Nickel

The ISS Program requested support in assessing the following:

1. The Program's approach and corrective actions proposed to address the observed chemical changes to the IATCS coolant chemistry.
2. The potential for component life reduction.
3. Possible revisions in the requirements for crew protection and intervention.

The approach is to provide collaborative support in three principal areas:

- Assist in the determination of an antimicrobial selection for Node 2 and U.S. Laboratory.
- Provide an assessment of the likelihood of additional corrosion and its impact on the performance and integrity of the IATCS.
- Provide a proactive assessment of the effect of having quantities of coolant from the different modules intermingling when equipment racks and experiments are moved between laboratories.

This report provides global recommendations on system investigations (Section 12.1), specific recommendations on the principal areas under assessment (Section 12.2), and a number of collateral recommendations on issues integral to the safe operation of the IATCS (Section 11.8). It is recognized that the IATCS is a complex system with chemical and performance responses not readily predictable under the current investigation structure. Therefore, the NESC team has

adopted the governing tenets of *protect the crew, proceed with caution as to do no harm,* and *act only when necessary.*

Seven antimicrobials are recommended for characterization against the reference antimicrobial of glutaraldehyde:

- Iodine
- Iodine/Silver
- Hydrogen Peroxide/Silver
- Silver on a ceramic bed matrix
- Orthophthalaldehyde
- Isothiazolones
- Chlorhexidine

The cleanliness control approaches for rack and equipment transfers between the IATCSs are based on mass/contaminate balance calculations, interface pretreatment regimens, and crew hygiene protocols.

The collateral recommendations (refer to Section 11.8) on synergistic components of the IATCS coolant chemistry address the following issues:

- Glutaraldehyde toxicity assessment.
- Borate/carbonate buffer additions.
- Node 2 antimicrobial implementation.
- Nickel Removal Assembly (NiRA) and Phosphorous Removal Assembly (PhosRA) characterization and implementation.
- Corrosion monitoring equipment for ground-based systems.
- Long-term antimicrobial development.
- Comprehensive ground test roadmap for potential bio- and chemical-fouling, and corrosion damage problems.

NESC Request No. 04-018-E

Appendix B. Executive Summary from NESC Report RP-05-121: Recovery Plan for Extravehicular Mobility Unit and International Space Station Airlock Coolant Loop Review for Return-to-flight Technical Assessment Report

4.0 Executive Summary

Problem

Two of the three EMU Airlocks onboard the ISS have suffered coolant pump failures. A Tiger Team, with a NASA Engineering and Safety Center (NESC) consultant, was formed to determine the cause of failure and to determine a recovery/maintenance plan. The NESC consultant was requested by Mr. William Readdy, the Associate Administrator for Space Operations Mission Directorate, to evaluate the ISS EMU flow recovery and maintenance plan.

The EMU #13 coolant flow failed during a two-crew don and doff evaluation on May 28, 2003. The EMU gas trap was removed and return to ground for analysis. Priviously, EMU #13 was used for four Extravehiclar Activities (EVA) on the ISS Airlock Extravehicle (EV) coolant loop #1 of the Service and Performance Checkout Unit (SPCU) heat exchanger. EMU #05 water coolant flow failed on May 19, 2004, during a two-crew don and doff evaluation on EV loop #2. EMU #05 had not been used for an EVA but did have a functional checkout on EV loop #2 eight months earlier. EMU #11 was used for four EVAs and was operated on both EV loops but continued to operate. Analysis of the EMU currents verified that EMU #05 and #13 pump rotors were not turning. The two rotors were removed and returned to the ground for analysis. Evidence from the rotors indicated that iron oxide, nickel salts, and biomass caused a seizure of the pump rotors. A significant "other finding" was the growth of the pump rotors length. (Note: Post STS-114 – EMU 3011 pump failed when tested on the ground.) The growth in the length reduced the clearance for the rotor axial ends making it more sensitive to the particulate and biofilm buildup that prevented the rotor rotations.

Summary

EMU certification testing for long term and multiple EVAs usage did not include the long ISS wet down times between the EVAs and did not consider the permeation of CO_2 into the coolant loops. The certification testing time was for a few months vs the two years wetted time on ISS and the test loop did not have the lower pH water and the induced bacteria. Past Shuttle EMU usage had short wetted times (~1-2 months) and bacteria exposures before the EMUs and Orbiter coolant loops were flushed and cleaned on the ground.

The recovery plan to filter the particulate, to remove ions, and to add Iodine will not remove all of the biofilm that currently exists in the EV loops but it will reduce it, and the removal of ions will slow its re-growth. The near term EMU usage on ISS with particulate and some biofilm control should prevent any quick reoccurrence of the same problems.

NESC Request No. 05-027-E

Corrective Actions in Place

The SPCU heat exchanger was replaced with an upgraded unit. New EMUs with redesigned pump rotors and the EV coolant loop conditioning hardware were delivered on STS-114. The EV loop fluids were filtered, deionized, and Iodinated. Both the ISS Airlock EV loops and the STS-114 EMUs are ready for EVA use. There is an operational plan in place to control contaminants and a rotor design solution is in-place

Recommendations

NESC recommended non-permeable covers to prevent the drop in the coolant water pH level and to build a ground test bed. Neither of these has been implemented and this leaves some uncertainly for the prevention of loss of ISS EMU cooling especially by biofilm fouling.

NESC recommended long-term testing by building a test bed that has flight like EV and EMU coolant loop items. This is important in order to understand the biofilm control, corrosion, and risks for the loss of cooling. No testing is planned at this time by Engineering and the EVA office.

Other NESC recommendations were implemented; testing of EMU for Iodine exposure, testing material coupons with flight water chemistry, and testing of the Qualification SPCU heat exchanger with lower pH water (found corrosion risk).

Lessons Learned

Liquid systems must be tested per the planned usage timetable (exposure time between EVAs) for corrosion and biofilm contamination sensitivity in the flight environment (elevated CO2 level).

BNi-3 Nickel braze compound is not compatible with stainless steel in water loops of stack fin-plate heat exchanger designs.

NESC Request No. 05-027-E

Appendix C. Apollo and Space Shuttle Water Systems Description

Apollo

Command Module (CM)

Potable water for the Apollo CM was generated by three alkaline fuel cells, which use a porous matrix cell instead of a membrane like that used in the hydrogen Orbital Replaceable Unit (ORU) electrolyzer. Fuel cell water was routed to either the potable water tank or the waste water tank if the potable water tank was full. The potable water tank supplied the drinking water to the crew and water to the cooler evaporator. The tanks and components of the water system were made with 6061 aluminum (Al). The potable water system was not disinfected before use. Prelaunch and during flight, chlorine was injected daily into the water using sodium hypochlorite at 5000 mg/l as a biocide. The tanks were filled with deionized (DI) approximately 5 days prior to launch. Prior to servicing, the water was filtered through particulate filters, charcoal filters, two mixed-bed IX units, and a 0.22 micron bacterial filter. The water was then treated with 12 mg/l sodium hypochlorite and allowed to dwell for 4 hours, after which it was drained and refilled with DI. At water servicing and at three hours prior to lift-off, a 30-cc ampoule of sodium hypochlorite (5000 mg/l as chlorine) was added to the system. Water sampling prior to the chlorine introduction on the launch day showed no chlorine and a very high count of microorganisms. This indicated that the chlorine interacted with the tank aluminum.

Lunar Module (LM)

The water management system for the LM provided drinking water as well as water used in the sublimator for cooling. As there was no water production in the LM during flight, all water for the mission was loaded into the three storage tanks prior to launch. Most of the components in the LM water management system were fabricated from Alodine®-treated 6061 Al.

Space Shuttle

Supply Water System (SWS)

The SWS consists of four stainless steel 20-gallon tanks and associated valves and tubing. One of the tanks, Tank A, was used to supply drinking water. All four tanks supplied water to the Flash Evaporator System (FES), but typically Tank B was used for that purpose with Tanks C and D held in reserve for extra deorbiting FES water. Each tank was pressurized with nitrogen using a metal bellows. During flight, water was created by the fuel cells and flowed through a microbial check valve (MCV) into Tank A until full, then into the other tanks (but not through the MCV). The MCV was a resin bed with iodine impregnated fiberglass beads. As the water flowed through the beads, the iodine leached out and maintained a constant iodine level in the water. The tanks were loaded with water before the Orbiter was rolled out to the launch pad (~3–4 months prior to launch). The ground support equipment (GSE) unit used to treat and transfer the water to Orbiter system contained a large tank that was evacuated prior to filling to

minimize free gas and was maintained below ambient pressure. The GSE was filled through a Millipore super Q (inlet filter, two deionize beds, and a final 0.22-µ bacteria filter). Once filled, the iodine was added to a level of 20–30 mg/l to disinfect and dwelled for 4 hours. However, the iodine probably only killed the free bacteria and might have reduced any biofilms present but did not eliminate them. After the 4-hour dwell, the high biocide water was drained and the GSE refilled with water containing 4–7 mg/l iodine. The water was loaded on to the vehicle through a 0.22-µ filter at the Orbiter interface. The Orbiter water system also underwent a 20–30-mg/l high-biocide dwell prior to each flight's water loading. The iodine level would sometimes decrease, and when the water was sampled, microorganisms were present.

Water Coolant Loops (WCLs)
The WCL GSE was serviced through a super-Q system and a bacterial filter. The super-Q was a typical lab deionizing system consisting of a 50–100-µm prefilter cartridge, two deionizing cartridges, and a final 0.22-µm filter. While in the GSE, the water was circulated through a deoxygenating cartridge to achieve the 0.3-mg/l oxygen requirement. After pulling a vacuum on the WCL, the water was loaded through another 0.22-µm filter.

Shuttle Waste Water System (WWS)
The shuttle waste tank was identical to the potable water tanks and was located next to them under the middeck floor of the Orbiter. It was used to store crew urine from the waste collection system and humidity condensate. As was done with excess potable water, the waste water was periodically dumped overboard during flight.

Appendix D. Component 1 Samples Microbiology Report

NASA/Johnson Space Center
Houston, Texas
Microbiology Laboratory

NESC Component 1 Water Sampling

Client: Bekki Bruce

Contact Info: NASA/JSC Houston, TX 77058

Contact Phone: 281-244-5255

Lab Report No: 131430004

NESC Component 1 Water Sampling

Sample Receipt Date: May 23, 2013

Collection Date	Source Sample	Quantification*	Microorganism Isolated (raw count)
22 May 2013	Bacteria - Water Component 1 Leg B-D WAFAL ID: 2013-0523-005 Lab ID# 131430004	1.0 CFU/10 ML	Ralstonia pickettii (1)
22 May 2013	Fungi - Water Component 1 Leg B-D WAFAL ID: 2013-0523-005 Lab ID# 131430005	<1 CFU/10 ML	
22 May 2013	Bacteria - Water Component 1 Leg B-C WAFAL ID: 2013-0523-006 Lab ID# 131430006	<1 CFU/10 ML	
22 May 2013	Fungi - Water Component 1 Leg B-C WAFAL ID: 2013-0523-006 Lab ID# 131430007	<1 CFU/10 ML	
22 May 2013	Bacteria - Water Component 1 Leg E WAFAL ID: 2013-0523-007 Lab ID# 131430008	<1 CFU/5 ML	
22 May 2013	Fungi - Water Component 1 Leg E WAFAL ID: 2013-0523-007 Lab ID# 131430009	<1 CFU/5 ML	
29 April 2013	Bacteria - Water Trip Blank WAFAL ID: 2013-0523-003 Lab ID# 131430010	<1 CFU/20 ML	
29 April 2013	Fungi - Water Trip Blank WAFAL ID: 2013-0523-003 Lab ID# 131430011	<1 CFU/20 ML	
22 May 2013	Bacteria - Water Water Cart 5 WAFAL ID: 2013-0523-004 Lab ID# 131430012	2.7 X 10^1 CFU/20 ML	Ralstonia pickettii (27)
22 May 2013	Fungi - Water Water Cart 5 WAFAL ID: 2013-0523-004 Lab ID# 131430013	<1 CFU/20 ML	
23 May 2013	Bacteria - Water Negative Control Lab ID# 131430014	<1 CFU/100ML	
23 May 2013	Fungi - Water Negative Control Lab ID# 131430015	<1 CFU/100 ML	

*Quantifications are based on a standard 48-hour incubation period for bacterial isolates and 5-day incubation period for fungal isolates unless otherwise specified in the comments section.

Comments: EML-WI-001, 002, and 008 were utilized to performed the requested analysis.

The identifications of water-borne bacteria in the report were performed by a molecular based method and are not accredited by AIHA.

REPORTING LIMITS

LOWER **UPPER**

NASA/Johnson Space Center
Houston, Texas
Microbiology Laboratory

AIR	< 6.0 CFU/m3	7261 CFU/m3
SURFACE	< 7.5 CFU/25 cm2	N/A
BULK	< 62.5 CFU/x grams	N/A
WATER	< 1 CFU/ml	N/A

Original Signed by:
Doug Botkin - EML Lead

The JSC Environmental Microbiology Laboratory is accredited by the American Industrial Hygiene Association (AIHA) in the Environmental Microbiology Laboratory Accreditation Program (EMPAT) for Fields of Testing as documented by the Scope of Accreditation Certificate. AIHA accreditation complies with ISO/IEC Standard 17025 requirements, but this does not imply ISO certification or registration. Accreditation Expires: 11/01/2013. AIHA only accreditates culture-based identification methods. The laboratory is also accredited by the National Environmental Laboratory Accreditation Committee through the Texas Commission on Environmental Quality for Fields of Testing as documented by the Scope of Accreditation Certificate. Certificate Number:T104704452-11-3, Expires 2/28/2014

Unless otherwise stated, all samples tested were in acceptable conditions and the reported results have not been corrected for contamination based on field blank or other analytical blank. The estimate of uncertainty is not reported unless specifically requested by the customer. The reported results are related only to the samples tested.

Questions and comments concerning this report should be directed to Duane L. Pierson at the JSC Microbiology Lab. at 281-483-7166 or duane.l.pierson@nasa.gov

Appendix E. Component 3 Samples Microbiology Report

NASA/Johnson Space Center
Houston, Texas
Microbiology Laboratory

NESC Boeing ORUs

Client: Bekki Bruce

Contact Info: 2101 NASA PKWY Houston, TX 77058

Contact Phone: 281-244-5255

Lab Report No: 131220005

NESC Boeing ORUs

Sample Receipt Date: May 02, 2013

Collection Date	Source Sample	Quantification*	Microorganism Isolated (raw count)
29 April 2013	Bacteria - Water Component 3 Water Sample Legs A1 & A2 Lab ID# 131220005	<1 CFU/1 ML	
29 April 2013	Fungi - Water Component 3 Water Sample Legs A1 & A2 Lab ID# 131220006	<1 CFU/1 ML	
29 April 2013	Bacteria - Water Component 3 Water Sample QD Sampling Setup Lab ID# 131220007	<1 CFU/1 ML	
29 April 2013	Fungi - Water Component 3 Water Sample QD Sampling Setup Lab ID# 131220008	<1 CFU/1 ML	
29 April 2013	Bacteria - Water Component 3 Water Sample Water Cart (WC5) WAFAL ID: 2013-0502-005 Lab ID# 131220009	<1 CFU/1 ML	
29 April 2013	Fungi - Water Component 3 Water Sample Water Cart (WC5) WAFAL ID: 2013-0502-005 Lab ID# 131220010	<1 CFU/1 ML	
29 April 2013	Bacteria - Water Negative Control Lab ID# 131220011	<1 CFU/100 ML	
29 April 2013	Fungi - Water Negative Control Lab ID# 131220012	<1 CFU/ 100 ML	

*Quantifications are based on a standard 48-hour incubation period for bacterial isolates and 5-day incubation period for fungal isolates unless otherwise specified in the comments section.

Comments: EML-WI-001 and 002 were utilized to perform the requested analysis.

REPORTING LIMITS

	LOWER	UPPER
AIR	< 6.0 CFU/m3	7261 CFU/m3
SURFACE	< 7.5 CFU/25 cm2	N/A
BULK	< 62.5 CFU/x grams	N/A
WATER	< 1 CFU/ml	N/A

Original Signed by:
Doug Botkin - EML Lead

NASA/Johnson Space Center
Houston, Texas
Microbiology Laboratory

The JSC Environmental Microbiology Laboratory is accredited by the American Industrial Hygiene Association (AIHA) in the Environmental Microbiology Laboratory Accreditation Program (EMPAT) for Fields of Testing as documented by the Scope of Accreditation Certificate. AIHA accreditation complies with ISO/IEC Standard 17025 requirements, but this does not imply ISO certification or registration. Accreditation Expires: 11/01/2013. AIHA only accreditates culture-based identification methods. The laboratory is also accredited by the National Environmental Laboratory Accreditation Committee through the Texas Commission on Environmental Quality for Fields of Testing as documented by the Scope of Accreditation Certificate. Certificate Number:T104704452-11-3, Expires 2/28/2014

Unless otherwise stated, all samples tested were in acceptable conditions and the reported results have not been corrected for contamination based on field blank or other analytical blank. The estimate of uncertainty is not reported unless specifically requested by the customer. The reported results are related only to the samples tested.

Questions and comments concerning this report should be directed to Duane L. Pierson at the JSC Microbiology Lab. at 281-483-7166 or duane.l.pierson@nasa.gov

Appendix F. Component 1 Samples Chemical Analysis Report

Water Analysis Report

Project: NESC WRS ORU Investigation

JSC SAMPLE NO. :	2013-0523-003	SAMPLE TIME:	Not Specified
SUBMITTED BY:	D. Gazda	SAMPLE DATE:	4/29/2013
SAMPLE DESCRIPTION:	Trip blank sample for Component 1	SAMPLE LOCATION:	Component 1

Method	Conc.	Units	Reporting Limit	Analyst
TOC (Sievers)				
Total Inorganic Carbon (TIC)	<300	µg/L	300	EL
Total Organic Carbon (TOC)	<100	µg/L	100	
Iodine (LCV)				
Total I	<0.05	mg/L	0.05	EL
Iodine	<0.05	mg/L	0.05	
Iodide	<0.05	mg/L	0.05	
Trace Metals (ICP-MS)				
Aluminum	1	µg/L	1	CMK
Antimony	<2	µg/L	2	
Arsenic	<1	µg/L	1	
Barium	<1	µg/L	1	
Beryllium	<1	µg/L	1	
Cadmium	<1	µg/L	1	
Chromium	<1	µg/L	1	
Cobalt	<1	µg/L	1	
Copper	2	µg/L	1	
Iron	<3	µg/L	3	
Lead	<1	µg/L	1	
Manganese	1	µg/L	1	
Mercury	<0.5	µg/L	0.5	
Molybdenum	<1	µg/L	1	
Nickel	<1	µg/L	1	
Selenium	<1	µg/L	1	
Silver	<1	µg/L	1	
Zinc	3	µg/L	1	
Minerals (ICP-MS)				
Calcium	0.01	mg/L	0.01	CMK
Magnesium	<0.01	mg/L	0.01	
Phosphate (as P)	<0.01	mg/L	0.01	
Potassium	<0.01	mg/L	0.01	
Sodium	<0.01	mg/L	0.01	
Anions (IC)				
Bromide	<0.1	mg/L	0.1	DEZ
Chloride	<0.5	mg/L	0.5	
Fluoride	<0.1	mg/L	0.1	
Nitrate (as N)	<0.2	mg/L	0.20	
Sulfate	<0.5	mg/L	0.5	
Phosphate (as P)	<0.1	mg/L	0.1	

Water & Food Analytical Laboratory
NASA / Johnson Space Center

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Water Analysis Report

Project: NESC WRS ORU Investigation

JSC SAMPLE NO. :	2013-0523-003	SAMPLE TIME:	Not Specified
SUBMITTED BY:	D. Gazda	SAMPLE DATE:	4/29/2013
SAMPLE DESCRIPTION:	Trip blank sample for Component 1	SAMPLE LOCATION:	Component 1

Method	Conc.	Units	Reporting Limit	Analyst

NOTES:
NA= Not analyzed
ND= None detected
MI= Matrix interference
The less than symbol (<) indicates that the concentration is less than the reporting limit for that parameter.
If the sample required dilution and the concentration is less than the reporting limit, the concentration will be reported as a < value which is the reporting limit multiplied by the dilution factor for that parameter.

REMARKS: Sample received in 250 mL FEP bottle with headspace.

Reviewed By: _____ **Date:** _____

Approved By: _____ **Date:** _____

Water & Food Analytical Laboratory
NASA / Johnson Space Center

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Water Analysis Report

Project: NESC WRS ORU Investigation

JSC SAMPLE NO. : 2013-0523-004
SUBMITTED BY: D. Gazda
SAMPLE DESCRIPTION: Sample from Water Cart 5
SAMPLE TIME (24 hr): 09:32
SAMPLE DATE: 5/22/2013
SAMPLE LOCATION: Component 1

Method	Conc.	Units	Reporting Limit	Analyst
TOC (Sievers)				
Total Inorganic Carbon (TIC)	<300	µg/L	300	EL
Total Organic Carbon (TOC)	<100	µg/L	100	
Iodine (LCV)				
Total I	<0.05	mg/L	0.05	EL
Iodine	<0.05	mg/L	0.05	
Iodide	<0.05	mg/L	0.05	
Trace Metals (ICP-MS)				
Aluminum	<1	µg/L	1	CMK
Antimony	<2	µg/L	2	
Arsenic	<1	µg/L	1	
Barium	<1	µg/L	1	
Beryllium	<1	µg/L	1	
Cadmium	<1	µg/L	1	
Chromium	<1	µg/L	1	
Cobalt	<1	µg/L	1	
Copper	3	µg/L	1	
Iron	<3	µg/L	3	
Lead	<1	µg/L	1	
Manganese	<1	µg/L	1	
Mercury	<0.5	µg/L	0.5	
Molybdenum	<1	µg/L	1	
Nickel	<1	µg/L	1	
Selenium	<1	µg/L	1	
Silver	<1	µg/L	1	
Zinc	2	µg/L	1	
Minerals (ICP-MS)				
Calcium	<0.01	mg/L	0.01	CMK
Magnesium	<0.01	mg/L	0.01	
Phosphate (as P)	<0.01	mg/L	0.01	
Potassium	<0.01	mg/L	0.01	
Sodium	<0.01	mg/L	0.01	
Anions (IC)				
Bromide	<0.1	mg/L	0.1	DEZ
Chloride	<0.5	mg/L	0.5	
Fluoride	<0.1	mg/L	0.1	
Nitrate (as N)	<0.2	mg/L	0.20	
Sulfate	<0.5	mg/L	0.5	
Phosphate (as P)	<0.1	mg/L	0.1	

Water & Food Analytical Laboratory
NASA / Johnson Space Center

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Water Analysis Report

Project: NESC WRS ORU Investigation

JSC SAMPLE NO. :	2013-0523-004	SAMPLE TIME (24 hr):	09:32
SUBMITTED BY:	D. Gazda	SAMPLE DATE:	5/22/2013
SAMPLE DESCRIPTION:	Sample from Water Cart 5	SAMPLE LOCATION:	Component 1

Method	Conc.	Units	Reporting Limit	Analyst

NOTES:
NA= Not analyzed
ND= None detected
MI= Matrix interference
The less than symbol (<) indicates that the concentration is less than the reporting limit for that parameter.
If the sample required dilution and the concentration is less than the reporting limit, the concentration will be reported as a < value which is the reporting limit multiplied by the dilution factor for that parameter.

REMARKS: Sample received in 250 mL FEP bottle with headspace.

Reviewed By: _____ **Date:** _____

Approved By: _____ **Date:** _____

Water & Food Analytical Laboratory
NASA / Johnson Space Center

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Water Analysis Report

Project: NESC WRS ORU Investigation

JSC SAMPLE NO. : 2013-0523-005
SUBMITTED BY: D. Gazda
SAMPLE DESCRIPTION: Sample from Leg B - D
SAMPLE TIME (24 hr): 08:52
SAMPLE DATE: 5/22/2013
SAMPLE LOCATION: Component 1

Method	Conc.	Units	Reporting Limit	Analyst
TOC (Sievers)				
Total Inorganic Carbon (TIC)	1020	µg/L	300	EL
Total Organic Carbon (TOC)	33900	µg/L	100	
Iodine (LCV)				
Total I	10.4	mg/L	0.05	EL
Iodine	<0.05	mg/L	0.05	
Iodide	10.4	mg/L	0.05	
Trace Metals (ICP-MS)				
Aluminum	22	µg/L	1	CMK
Antimony	<2	µg/L	2	
Arsenic	<1	µg/L	1	
Barium	3	µg/L	1	
Beryllium	<1	µg/L	1	
Cadmium	<1	µg/L	1	
Chromium	15	µg/L	1	
Cobalt	1	µg/L	1	
Copper	29	µg/L	1	
Iron	213	µg/L	3	
Lead	<1	µg/L	1	
Manganese	295	µg/L	1	
Mercury	<0.5	µg/L	0.5	
Molybdenum	2	µg/L	1	
Nickel	1560	µg/L	1	
Selenium	<1	µg/L	1	
Silver	<1	µg/L	1	
Zinc	9	µg/L	1	
Minerals (ICP-MS)				
Calcium	0.81	mg/L	0.01	CMK
Magnesium	0.13	mg/L	0.01	
Phosphate (as P)	0.04	mg/L	0.01	
Potassium	1.17	mg/L	0.01	
Sodium	0.38	mg/L	0.01	
Anions (IC)				
Bromide	<0.1	mg/L	0.1	DEZ
Chloride	<0.5	mg/L	0.5	
Fluoride	MI	mg/L	0.1	
Nitrate (as N)	<0.2	mg/L	0.20	
Sulfate	0.8	mg/L	0.5	
Phosphate (as P)	<0.1	mg/L	0.1	

Water & Food Analytical Laboratory
NASA / Johnson Space Center

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Water Analysis Report

Project: NESC WRS ORU Investigation

JSC SAMPLE NO. :	2013-0523-005	SAMPLE TIME (24 hr):	08:52
SUBMITTED BY:	D. Gazda	SAMPLE DATE:	5/22/2013
SAMPLE DESCRIPTION:	Sample from Leg B - D	SAMPLE LOCATION:	Component 1

Method	Conc.	Units	Reporting Limit	Analyst

NOTES:
NA= Not analyzed
ND= None detected
MI= Matrix interference
The less than symbol (<) indicates that the concentration is less than the reporting limit for that parameter.
If the sample required dilution and the concentration is less than the reporting limit, the concentration will be reported as a < value which is the reporting limit multiplied by the dilution factor for that parameter.

REMARKS: Matrix interference with F result - Iodate interferes with fluoride peak. Sample received in 250 mL FEP bottle with headspace.

Reviewed By: _____ **Date:** _____

Approved By: _____ **Date:** _____

Water & Food Analytical Laboratory
NASA / Johnson Space Center

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Water Analysis Report

Project: NESC WRS ORU Investigation

JSC SAMPLE NO. : 2013-0523-006
SUBMITTED BY: D. Gazda
SAMPLE DESCRIPTION: Sample from Leg B - C
SAMPLE TIME (24 hr): 09:00
SAMPLE DATE: 5/22/2013
SAMPLE LOCATION: Component 1

Method	Conc.	Units	Reporting Limit	Analyst
TOC (Sievers)				
Total Inorganic Carbon (TIC)	887	µg/L	300	EL
Total Organic Carbon (TOC)	69700	µg/L	100	
Iodine (LCV)				
Total I	1400	mg/L	0.05	EL
Iodine	4.80	mg/L	0.05	
Iodide	1400	mg/L	0.05	
Iodine (ICP-MS)				
Total I	1640000	µg/L	1	CMK
Trace Metals (ICP-MS)				
Aluminum	49	µg/L	1	CMK
Antimony	<20	µg/L	2	
Arsenic	17	µg/L	1	
Barium	<10	µg/L	1	
Beryllium	<10	µg/L	1	
Cadmium	<10	µg/L	1	
Chromium	228	µg/L	1	
Cobalt	<10	µg/L	1	
Copper	26	µg/L	1	
Iron	438	µg/L	3	
Lead	<10	µg/L	1	
Manganese	212	µg/L	1	
Mercury	<5	µg/L	0.5	
Molybdenum	<10	µg/L	1	
Nickel	2130	µg/L	1	
Selenium	<10	µg/L	1	
Silver	16	µg/L	1	
Zinc	139	µg/L	1	
Minerals (ICP-MS)				
Calcium	0.32	mg/L	0.01	CMK
Magnesium	0.21	mg/L	0.01	
Phosphate (as P)	1.50	mg/L	0.01	
Potassium	445	mg/L	0.01	
Sodium	1.91	mg/L	0.01	
Anions (IC)				
Bromide	0.2	mg/L	0.1	DEZ
Chloride	<0.5	mg/L	0.5	
Fluoride	MI	mg/L	0.1	
Nitrate (as N)	<0.2	mg/L	0.20	
Sulfate	<0.5	mg/L	0.5	
Phosphate (as P)	1.3	mg/L	0.1	

Water & Food Analytical Laboratory
NASA / Johnson Space Center

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Water Analysis Report

Project: NESC WRS ORU Investigation

JSC SAMPLE NO. :	2013-0523-006	SAMPLE TIME (24 hr):	09:00
SUBMITTED BY:	D. Gazda	SAMPLE DATE:	5/22/2013
SAMPLE DESCRIPTION:	Sample from Leg B - C	SAMPLE LOCATION:	Component 1

Method	Conc.	Units	Reporting Limit	Analyst

NOTES:

NA= Not analyzed
ND= None detected
MI= Matrix interference
The less than symbol (<) indicates that the concentration is less than the reporting limit for that parameter.
If the sample required dilution and the concentration is less than the reporting limit, the concentration will be reported as a < value which is the reporting limit multiplied by the dilution factor for that parameter.

REMARKS: Matrix interference with F result - Iodate interferes with fluoride peak. Slight negative bias (matrix interference) with silver recovey (MS recovery 72%). Sample received in 250 mL FEP bottle with headspace. Sample had obvious yellow color.

Reviewed By: _____ **Date:** _____

Approved By: _____ **Date:** _____

Water & Food Analytical Laboratory
NASA / Johnson Space Center

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Water Analysis Report

Project: NESC WRS ORU Investigation

JSC SAMPLE NO. : 2013-0523-007
SUBMITTED BY: D. Gazda
SAMPLE DESCRIPTION: Sample from Leg E
SAMPLE TIME (24 hr): 09:30
SAMPLE DATE: 5/22/2013
SAMPLE LOCATION: Component 1

Method	Conc.	Units	Reporting Limit	Analyst
Iodine (LCV)				
Total I	0.17	mg/L	0.05	EL
Iodine	<0.05	mg/L	0.05	
Iodide	0.12	mg/L	0.05	
Trace Metals (ICP-MS)				
Aluminum	<4	µg/L	1	CMK
Antimony	<8	µg/L	2	
Arsenic	<4	µg/L	1	
Barium	5	µg/L	1	
Beryllium	<4	µg/L	1	
Cadmium	<4	µg/L	1	
Chromium	41	µg/L	1	
Cobalt	<4	µg/L	1	
Copper	<4	µg/L	1	
Iron	<12	µg/L	3	
Lead	<4	µg/L	1	
Manganese	19	µg/L	1	
Mercury	<2	µg/L	0.5	
Molybdenum	8	µg/L	1	
Nickel	722	µg/L	1	
Selenium	<4	µg/L	1	
Silver	<4	µg/L	1	
Zinc	<4	µg/L	1	
Minerals (ICP-MS)				
Calcium	0.89	mg/L	0.01	CMK
Magnesium	0.13	mg/L	0.01	
Phosphate (as P)	0.53	mg/L	0.01	
Potassium	0.12	mg/L	0.01	
Sodium	0.88	mg/L	0.01	
Anions (IC)				
Bromide	<0.1	mg/L	0.1	DEZ
Chloride	<0.5	mg/L	0.5	
Fluoride	MI	mg/L	0.1	
Nitrate (as N)	<0.2	mg/L	0.20	
Sulfate	<0.5	mg/L	0.5	
Phosphate (as P)	0.2	mg/L	0.1	

Water & Food Analytical Laboratory
NASA / Johnson Space Center

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Water Analysis Report

Project: NESC WRS ORU Investigation

JSC SAMPLE NO. :	2013-0523-007	SAMPLE TIME (24 hr):	09:30
SUBMITTED BY:	D. Gazda	SAMPLE DATE:	5/22/2013
SAMPLE DESCRIPTION:	Sample from Leg E	SAMPLE LOCATION:	Component 1

Method	Conc.	Units	Reporting Limit	Analyst

NOTES:
NA= Not analyzed
ND= None detected
MI= Matrix interference
The less than symbol (<) indicates that the concentration is less than the reporting limit for that parameter.
If the sample required dilution and the concentration is less than the reporting limit, the concentration will be reported as a < value which is the reporting limit multiplied by the dilution factor for that parameter.

REMARKS: Matrix interference with F result - Iodate interferes with fluoride peak. Sample received in 125 mL FEP bottle with headspace.

Reviewed By: _____ **Date:** _____

Approved By: _____ **Date:** _____

Water & Food Analytical Laboratory
NASA / Johnson Space Center

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wyle

WATER AND FOOD ANALYTICAL LABORATORY
CHAIN OF CUSTODY FORM

3111

Project/Mission: NESC Component 1 water sampling **Work Pkg. ~~0334~~** **Contact: Gazda** **Phone Number: 36892**

No	Sample Identification (Description/Location)	Sample Date& Time (MM/DD/YY 24 hr time)	Volume (mL)	Analysis to be Performed	Collected By (Signature)	JSC Sample No. (for lab use only)
1	Component 1 Leg B-D	052213 0852	250 175	Chemical and Microbial analyses TOC metals minerals anions LCV micro	HSWL	2013-0523 -005
2	Component 1 Leg B-C	052213 0900	250 115	Chemical and Microbial analyses " "	HSWL	2013-0523 -006
3	Component 1 Leg E	052213 0930	125 55	Chemical and Microbial analyses metals minerals anions LCV micro	HSWL	2013-0523 -007
4	Trip Blank	4/29/13	250	Chemical and Microbial analyses TOC metals minerals anions LCV micro	JSC B37	2013-0523 -003
5	Water Cart 5	052213 0932	250	" "	HSWL	2013-0523 -004
6						
7						
8						
9						
10						

Comments: (refer to item no. if necessary) Used Tripblank for sample by mistake
so used Component 1 bottle for Tripblank C. Mitchell

Relinquished by: _____ **Received by:** _____
Signature Date/Time Signature Date/Time

Relinquished by: _____ **Received for Laboratory by:** _____
Signature Date/Time Signature Date/Time

FRM-WAF-001
Rev# 1

Verify this is the correct version before use

10/27/09
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Appendix G. Component 3 Samples Chemical Analysis Report

Water Analysis Report

Project: NESC WRS ORU Investigation

JSC SAMPLE NO. : 2013-0523-005
SUBMITTED BY: D. Gazda
SAMPLE DESCRIPTION: Sample from Leg B - D
SAMPLE TIME (24 hr): 08:52
SAMPLE DATE: 5/22/2013
SAMPLE LOCATION: Component 1

Method	Conc.	Units	Reporting Limit	Analyst
TOC (Sievers)				
Total Inorganic Carbon (TIC)	1020	µg/L	300	EL
Total Organic Carbon (TOC)	33900	µg/L	100	
Iodine (LCV)				
Total I	10.4	mg/L	0.05	EL
Iodine	<0.05	mg/L	0.05	
Iodide	10.4	mg/L	0.05	
Trace Metals (ICP-MS)				
Aluminum	22	µg/L	1	CMK
Antimony	<2	µg/L	2	
Arsenic	<1	µg/L	1	
Barium	3	µg/L	1	
Beryllium	<1	µg/L	1	
Cadmium	<1	µg/L	1	
Chromium	15	µg/L	1	
Cobalt	1	µg/L	1	
Copper	29	µg/L	1	
Iron	213	µg/L	3	
Lead	<1	µg/L	1	
Manganese	295	µg/L	1	
Mercury	<0.5	µg/L	0.5	
Molybdenum	2	µg/L	1	
Nickel	1560	µg/L	1	
Selenium	<1	µg/L	1	
Silver	<1	µg/L	1	
Zinc	9	µg/L	1	
Minerals (ICP-MS)				
Calcium	0.81	mg/L	0.01	CMK
Magnesium	0.13	mg/L	0.01	
Phosphate (as P)	0.04	mg/L	0.01	
Potassium	1.17	mg/L	0.01	
Sodium	0.38	mg/L	0.01	
Anions (IC)				
Bromide	<0.1	mg/L	0.1	DEZ
Chloride	<0.5	mg/L	0.5	
Fluoride	MI	mg/L	0.1	
Nitrate (as N)	<0.2	mg/L	0.20	
Sulfate	0.8	mg/L	0.5	
Phosphate (as P)	<0.1	mg/L	0.1	
Alcohols/Acetone (Direct Injection GC/MS)				
Acetone	7570	µg/L	200	EL
1-Butanol	<200	µg/L	200	

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Water Analysis Report

Project: NESC WRS ORU Investigation

JSC SAMPLE NO. : 2013-0523-005
SUBMITTED BY: D. Gazda
SAMPLE DESCRIPTION: Sample from Leg B - D
SAMPLE TIME (24 hr): 08:52
SAMPLE DATE: 5/22/2013
SAMPLE LOCATION: Component 1

Method	Conc.	Units	Reporting Limit	Analyst
Alcohols/Acetone (Direct Injection GC/MS)				
2-Butanol	<200	µg/L	200	EL
Ethanol	<200	µg/L	200	
Methanol	<200	µg/L	200	
2-Methyl-1-butanol	<200	µg/L	200	
2-Methyl-2-butanol	<200	µg/L	200	
3-Methyl-1-butanol (Isopentanol)	<300	µg/L	300	
2-Methyl-1-propanol	<200	µg/L	200	
2-Methyl-2-propanol	<200	µg/L	200	
1-Pentanol (Amyl alcohol)	<200	µg/L	200	
2-Pentanol (sec-Amyl alcohol)	<200	µg/L	200	
3-Pentanol	<200	µg/L	200	
1-Propanol	<200	µg/L	200	
2-Propanol	35400	µg/L	200	
Volatiles (P&T/GC/MS)				
Acetone	>1500	µg/L	5	RLG
Acrylonitrile	<50	µg/L	5	
Allyl chloride (3-Chloropropene)	<50	µg/L	5	
Benzene	<50	µg/L	5	
Bromobenzene	<50	µg/L	5	
Bromochloromethane	<50	µg/L	5	
Bromodichloromethane	<50	µg/L	5	
Bromoform	<50	µg/L	5	
Bromomethane	<50	µg/L	5	
2-Butanone (Methyl ethyl ketone)	<50	µg/L	5	
n-Butylbenzene	<50	µg/L	5	
sec-Butylbenzene	<50	µg/L	5	
tert-Buytlbenzene	<50	µg/L	5	
Carbon disulfide	<50	µg/L	5	
Carbon tetrachloride	<50	µg/L	5	
Chloroacetonitrile	<50	µg/L	5	
Chlorobenzene	<50	µg/L	5	
1-Chlorobutane (Butyl chloride)	<50	µg/L	5	
Chloroethane	<50	µg/L	5	
Chloroform	<50	µg/L	5	
Chloromethane	<50	µg/L	5	
2-Chlorotoluene	<50	µg/L	5	
4-Chlorotoluene	<50	µg/L	5	
Dibromochloromethane	<50	µg/L	5	
1,2-Dibromo-3-chloropropane	<50	µg/L	5	
1,2-Dibromoethane (EDB)	<50	µg/L	5	
Dibromomethane	<50	µg/L	5	
1,2-Dichlorobenzene	<50	µg/L	5	
1,3-Dichlorobenzene	<50	µg/L	5	

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Water Analysis Report

Project: NESC WRS ORU Investigation

JSC SAMPLE NO. : 2013-0523-005
SUBMITTED BY: D. Gazda
SAMPLE DESCRIPTION: Sample from Leg B - D
SAMPLE TIME (24 hr): 08:52
SAMPLE DATE: 5/22/2013
SAMPLE LOCATION: Component 1

Method	Conc.	Units	Reporting Limit	Analyst
Volatiles (P&T/GC/MS)				
1,4-Dichlorobenzene	<50	µg/L	5	RLG
trans-1,4-Dichloro-2-butene	<50	µg/L	5	
Dichlorodifluoromethane	<50	µg/L	5	
1,1-Dichloroethane	<50	µg/L	5	
1,2-Dichloroethane	<50	µg/L	5	
1,1-Dichloroethene	<50	µg/L	5	
cis-1,2-Dichloroethene	<50	µg/L	5	
trans-1,2-Dichloroethene	<50	µg/L	5	
1,2-Dichloropropane	<50	µg/L	5	
1,3-Dichloropropane	<50	µg/L	5	
2,2-Dichloropropane	<50	µg/L	5	
1,1-Dichloropropanone	<50	µg/L	5	
1,1-Dichloropropene	<50	µg/L	5	
cis-1,3-Dichloropropene	<50	µg/L	5	
trans-1,3-Dichloropropene	<50	µg/L	5	
Diethyl ether	<50	µg/L	5	
Ethylbenzene	<50	µg/L	5	
Ethyl methacrylate	<50	µg/L	5	
Hexachlorobutadiene	<50	µg/L	5	
Hexachloroethane	<50	µg/L	5	
2-Hexanone	<50	µg/L	5	
Iodomethane	<50	µg/L	5	
Isopropylbenzene (Cumene)	<50	µg/L	5	
4-Isopropyltoluene (Cymene)	<50	µg/L	5	
Methacrylonitrile	<50	µg/L	5	
Methyl acrylate	<50	µg/L	5	
Methyl-t-butyl ether (MTBE)	<50	µg/L	5	
Methylene chloride (Dichloromethane)	<50	µg/L	5	
Methyl methacrylate	<50	µg/L	5	
4-Methyl-2-pentanone	<50	µg/L	5	
Naphthalene	<50	µg/L	5	
Nitrobenzene	<50	µg/L	5	
2-Nitropropane	<50	µg/L	5	
Pentachloroethane	<50	µg/L	5	
Propionitrile (Ethyl cyanide)	<50	µg/L	5	
n-Propylbenzene	<50	µg/L	5	
Styrene	<50	µg/L	5	
1,1,1,2-Tetrachloroethane	<50	µg/L	5	
1,1,2,2-Tetrachloroethane	<50	µg/L	5	
Tetrachloroethene	<50	µg/L	5	
Tetrahydrofuran	<50	µg/L	5	
Toluene	<50	µg/L	5	
1,2,3-Trichlorobenzene	<50	µg/L	5	
1,2,4-Trichlorobenzene	<50	µg/L	5	

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Water Analysis Report

Project: NESC WRS ORU Investigation

JSC SAMPLE NO. : 2013-0523-005
SUBMITTED BY: D. Gazda
SAMPLE DESCRIPTION: Sample from Leg B - D
SAMPLE TIME (24 hr): 08:52
SAMPLE DATE: 5/22/2013
SAMPLE LOCATION: Component 1

Method	Conc.	Units	Reporting Limit	Analyst
Volatiles (P&T/GC/MS)				
1,1,1-Trichloroethane	<50	µg/L	5	RLG
1,1,2-Trichloroethane	<50	µg/L	5	
Trichloroethene	<50	µg/L	5	
Trichlorofluoromethane	<50	µg/L	5	
1,2,3-Trichloropropane	<50	µg/L	5	
1,2,4-Trimethylbenzene	<50	µg/L	5	
1,3,5-Trimethylbenzene	<50	µg/L	5	
Vinyl Acetate	<50	µg/L	5	
Vinyl Chloride	<50	µg/L	5	
m & p-Xylene	<100	µg/L	10	
o-Xylene	<50	µg/L	5	

NOTES:
NA= Not analyzed
ND= None detected
MI= Matrix interference
The less than symbol (<) indicates that the concentration is less than the reporting limit for that parameter.
If the sample required dilution and the concentration is less than the reporting limit, the concentration will be reported as a < value which is the reporting limit multiplied by the dilution factor for that parameter.

REMARKS: Matrix interference with F result - Iodate interferes with fluoride peak. Sample received in 250 mL FEP bottle with headspace.

Reviewed By: _____ **Date:** _____

Approved By: _____ **Date:** _____

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Appendix H. Component 1 Leg B-D Sample Follow-up Chemical Analysis Report

Water Analysis Report

Project: NESC WRS ORU Investigation

JSC SAMPLE NO. : 2013-0502-003
SUBMITTED BY: P. Mudgett
SAMPLE DESCRIPTION: Water sample from legs A1 and A2
SAMPLE TIME (24 hr): 13:50
SAMPLE DATE: 4/29/2013
SAMPLE LOCATION: Component 3

Method	Conc.	Units	Reporting Limit	Analyst
Trace Metals (ICP-MS)				
Aluminum	105	µg/L	1	CMK
Antimony	<8	µg/L	2	
Arsenic	<4	µg/L	1	
Barium	<4	µg/L	1	
Beryllium	<4	µg/L	1	
Cadmium	<4	µg/L	1	
Chromium	108	µg/L	1	
Cobalt	<4	µg/L	1	
Copper	5	µg/L	1	
Iron	26	µg/L	3	
Lead	<4	µg/L	1	
Manganese	9	µg/L	1	
Mercury	<0.5	µg/L	0.5	
Molybdenum	34	µg/L	1	
Nickel	4520	µg/L	1	
Selenium	<4	µg/L	1	
Silver	<4	µg/L	1	
Zinc	5	µg/L	1	
Anions (IC)				
Bromide	<0.1	mg/L	0.1	DEZ
Chloride	<0.5	mg/L	0.5	
Fluoride	0.3	mg/L	0.1	
Nitrate (as N)	<0.2	mg/L	0.20	
Sulfate	0.7	mg/L	0.5	
Phosphate (as P)	0.9	mg/L	0.1	

NOTES:
NA= Not analyzed
ND= None detected
MI= Matrix interference
The less than symbol (<) indicates that the concentration is less than the reporting limit for that parameter.
If the sample required dilution and the concentration is less than the reporting limit, the concentration will be reported as a < value which is the reporting limit multiplied by the dilution factor for that parameter.

REMARKS: 30 mL of sample transferred to Micro Lab on 5/2/13.

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Water Analysis Report

Project: NESC WRS ORU Investigation

JSC SAMPLE NO. :	2013-0502-003	SAMPLE TIME (24 hr):	13:50
SUBMITTED BY:	P. Mudgett	SAMPLE DATE:	4/29/2013
SAMPLE DESCRIPTION:	Water sample from legs A1 and A2	SAMPLE LOCATION:	Component 3

Method	Conc.	Units	Reporting Limit	Analyst

Reviewed By: _____ Date: _____

Approved By: _____ Date: _____

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NASA / Johnson Space Center

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Water Analysis Report

Project: NESC WRS ORU Investigation

JSC SAMPLE NO. : 2013-0502-004
SUBMITTED BY: P. Mudgett
SAMPLE DESCRIPTION: Sample from QD sampling set-up
SAMPLE TIME (24 hr): 13:25
SAMPLE DATE: 4/29/2013
SAMPLE LOCATION: Component 3

Method	Conc.	Units	Reporting Limit	Analyst
Trace Metals (ICP-MS)				
Aluminum	9	µg/L	1	CMK
Antimony	<2	µg/L	2	
Arsenic	<1	µg/L	1	
Barium	<1	µg/L	1	
Beryllium	<1	µg/L	1	
Cadmium	<1	µg/L	1	
Chromium	9	µg/L	1	
Cobalt	<1	µg/L	1	
Copper	19	µg/L	1	
Iron	29	µg/L	3	
Lead	<1	µg/L	1	
Manganese	9	µg/L	1	
Mercury	<0.5	µg/L	0.5	
Molybdenum	<1	µg/L	1	
Nickel	17	µg/L	1	
Selenium	<1	µg/L	1	
Silver	<1	µg/L	1	
Zinc	15	µg/L	1	
Anions (IC)				
Bromide	<0.1	mg/L	0.1	DEZ
Chloride	4.7	mg/L	0.5	
Fluoride	0.1	mg/L	0.1	
Nitrate (as N)	<0.2	mg/L	0.20	
Sulfate	0.7	mg/L	0.5	
Phosphate (as P)	<0.1	mg/L	0.1	

NOTES:
NA= Not analyzed
ND= None detected
MI= Matrix interference
The less than symbol (<) indicates that the concentration is less than the reporting limit for that parameter.
If the sample required dilution and the concentration is less than the reporting limit, the concentration will be reported as a < value which is the reporting limit multiplied by the dilution factor for that parameter.

REMARKS: 30 mL of sample transferred to Micro Lab on 5/2/13.

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Water Analysis Report

Project: NESC WRS ORU Investigation

JSC SAMPLE NO. :	2013-0502-004	SAMPLE TIME (24 hr):	13:25
SUBMITTED BY:	P. Mudgett	SAMPLE DATE:	4/29/2013
SAMPLE DESCRIPTION:	Sample from QD sampling set-up	SAMPLE LOCATION:	Component 3

Method	Conc.	Units	Reporting Limit	Analyst

Reviewed By: _____ Date: _____

Approved By: _____ Date: _____

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Water Analysis Report

Project: NESC WRS ORU Investigation

JSC SAMPLE NO. : 2013-0502-005
SUBMITTED BY: P. Mudgett
SAMPLE DESCRIPTION: Sample from water cart (WC5)
SAMPLE TIME (24 hr): 13:57
SAMPLE DATE: 4/29/2013
SAMPLE LOCATION: Component 3

Method	Conc.	Units	Reporting Limit	Analyst
Trace Metals (ICP-MS)				
Aluminum	<1	µg/L	1	CMK
Antimony	<2	µg/L	2	
Arsenic	<1	µg/L	1	
Barium	<1	µg/L	1	
Beryllium	<1	µg/L	1	
Cadmium	<1	µg/L	1	
Chromium	<1	µg/L	1	
Cobalt	<1	µg/L	1	
Copper	<1	µg/L	1	
Iron	<3	µg/L	3	
Lead	<1	µg/L	1	
Manganese	<1	µg/L	1	
Mercury	<0.5	µg/L	0.5	
Molybdenum	<1	µg/L	1	
Nickel	<1	µg/L	1	
Selenium	<1	µg/L	1	
Silver	<1	µg/L	1	
Zinc	<1	µg/L	1	
Anions (IC)				
Bromide	<0.1	mg/L	0.1	DEZ
Chloride	<0.5	mg/L	0.5	
Fluoride	<0.1	mg/L	0.1	
Nitrate (as N)	<0.2	mg/L	0.20	
Sulfate	<0.5	mg/L	0.5	
Phosphate (as P)	<0.1	mg/L	0.1	

NOTES:
NA= Not analyzed
ND= None detected
MI= Matrix interference
The less than symbol (<) indicates that the concentration is less than the reporting limit for that parameter.
If the sample required dilution and the concentration is less than the reporting limit, the concentration will be reported as a < value which is the reporting limit multiplied by the dilution factor for that parameter.

REMARKS: 30 mL of sample transferred to Micro Lab on 5/2/13.

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Water Analysis Report

Project: NESC WRS ORU Investigation

JSC SAMPLE NO. :	2013-0502-005	SAMPLE TIME (24 hr):	13:57
SUBMITTED BY:	P. Mudgett	SAMPLE DATE:	4/29/2013
SAMPLE DESCRIPTION:	Sample from water cart (WC5)	SAMPLE LOCATION:	Component 3

Method	Conc.	Units	Reporting Limit	Analyst

Reviewed By: _____ Date: _____

Approved By: _____ Date: _____

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Appendix I. Stagnant Class III MCV Sample Chemistry Report

Water Analysis Report

Project: NESC WRS ORU Investigation

JSC SAMPLE NO. :	2013-0628-002	SAMPLE TIME (24 hr):	15:15
SUBMITTED BY:	D. Gazda	SAMPLE DATE:	6/28/2013
SAMPLE DESCRIPTION:	Water sample from stagnant Class III MCV	SAMPLE LOCATION:	B37

Method	Conc.	Units	Reporting Limit	Analyst
TOC (Sievers)				
Total Inorganic Carbon (TIC)	605	µg/L	300	EL
TOC (O.I.)				
Nonpurgeable Organic Carbon (NPOC)	6560	µg/L	2000	EL
Iodine (LCV)				
Total I	295	mg/L	0.05	EL
Iodine	3.98	mg/L	0.05	
Iodide	291	mg/L	0.05	
Iodine (ICP-MS)				
Total I	770000	µg/L	1	CMK
Minerals (ICP-MS)				
Calcium	0.14	mg/L	0.01	CMK
Magnesium	4.47	mg/L	0.01	
Phosphate (as P)	<0.04	mg/L	0.01	
Potassium	5.13	mg/L	0.01	
Sodium	0.29	mg/L	0.01	

NOTES:
NA= Not analyzed
ND= None detected
MI= Matrix interference
The less than symbol (<) indicates that the concentration is less than the reporting limit for that parameter.
If the sample required dilution and the concentration is less than the reporting limit, the concentration will be reported as a < value which is the reporting limit multiplied by the dilution factor for that parameter.

REMARKS:

Reviewed By: _____ **Date:** _____

Approved By: _____ **Date:** _____

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Appendix J. ISS Risk Matrix

SSP 50175 Rev C-1 Page 2 of 2

ISS PROGRAM RISK SCORECARD

RM Definitions & Terms

Risk Management (RM) - An organized, systematic decision-making process that efficiently identifies risks, assesses or analyzes risks, and effectively reduces or eliminates risks to achieve program goals.

Risk Types

Risk- A future event with a negative consequence that has some **probability** of occurring. A risk poses a threat to the crew or vehicle safety, program cost, schedule or major mission objective. An item whose resolution is unlikely without focused management attention.

Watch Item - An immature risk whose complete scope, likelihood and consequences are not clearly understood.

Concern- A concern is a candidate risk where insufficient information available to assess and define mitigation plans. A candidate risk remains a concern until the risk is analyzed and reviewed by management for escalation.

Escalation Levels

Top Program Risk- Significantly affects the cost, schedule, mission success or safety of flight and/or requires substantial Program resources.

Top Organizational Risk- Primarily risks deemed to have the greatest significance to a Program organization.

Top Sub-Organizational Risk- Primarily risks deemed to have the greatest significance to a project.

ISS RM Key Process Steps for Risk Owners

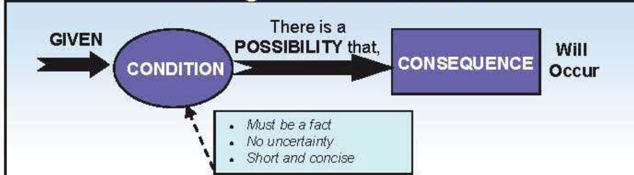
Review and update records on a monthly basis

- Risks initially entered as a concern
- Risk Owners document risks, watch items and concerns. This includes documenting mitigation steps, updating status, making recommendations, documenting closure or acceptance rationale, and keeping management informed utilizing the ISS risk database.
- Questions to ask yourself when updating your risk:
  - Are your mitigation plans satisfactory and on schedule?
  - Is your status up to date?
  - Are your ECD's current (general and mitigation tasks)?
  - Has the L x C changed?
  - Should any of your concerns, watch items or risks be escalated?
  - Can this risk be closed or should it be accepted? If so, make recommendation to mgt.

ISS Risk Management Reference

IRMA (ISS Risk Management Application) is a database used to document, track and report program management risks, watch items and concerns. IRMA permissions are based on the individuals role and area of responsibility. Information regarding ISS Program Risk Management and IRMA can be found in the **Program Risk Management Plan SSP 50175** and online at: http://iss-www.jsc.nasa.gov/nwo/sma/home/web

Writing A Risk Statement



ISS Risk Database Requirements & User Roles

Mandatory Field	Concern	Watch Item	Risk
1. Title	✓	✓	✓
2. Description/Context		✓	✓
3. Risk Statement	✓	✓	✓
4. ECD		✓	✓
5. Most Likely Mit. Cost (1)			✓
6. High and Low Mit. Cost (1)			✓
7. Mit. Budget Amount (1)			✓
8. Contr			✓
9. Cost Level			✓
10. Likelihood Score		✓	✓
11. Consequence Score		✓	✓
12. Impact/Consequence			✓
13. Closure/Acceptance Criteria		✓	✓
14. Flights Affected	✓	✓	✓
15. Orgs Affected		✓	✓
16. Current Status			✓
17. Mitigation Plan Overview			✓
18. Mitigation Tasks (3)			✓

Note: If Cost Threat is selected as "Yes", Cost category and Cost Level are mandatory.
1. At least one Fiscal Year (FY) of cost information
2. At least one consequence score (cost, schedule, technical)
3. At least one mitigation task entered. In addition, for each task entry, need Task Description, MO & ECD.

Capabilities

Role	Enter & Update an Item	Elevate to a WI	Elevate a Risk	Close WI	Close Risks	Close Concerns	Elevate to TPR	Elevate to TOR	Elevate to TSOR	Receive E-mails	Unlock Passwords	Assign Yes/No to Cost Threats
Org Users	✓					✓				Items owned by user		
Sub Org POCs	✓	✓		✓		✓			✓	Items owned by sub-org		
Org POCs	✓	✓	✓	✓	✓	✓		✓	✓	Items owned by org & items where designated as affected org		
BPOC	✓	✓	✓	✓	✓	✓		✓	✓	Items with costs identified		✓
Sys Admin	✓	✓	✓	✓	✓	✓	✓	✓	✓	All items	✓	✓

01/03/07

Appendix K. Spacecraft Water Exposure Guideline for Isopropyl Alcohol

ISOPROPYL ALCOHOL (IPA)

Physical and Chemical Properties (HSDB)

Molecular formula	C3H8O
Molecular weight	60.09
Density	0.78505 g/cm3 @ 20°C
Boiling point	82.5 degC
Vapor pressure	44 mg Hg@ 25 degC
Solubility:	Infinitely soluble at 25 degC
Air Odor threshold	22 ppm
Taste:	A slightly bitter taste
Metabolites	Acetone

Conversion factor (for air): 1 ppm = 2.45 mg/m3 at 25 deg C

Purpose: Derive an interim short-term guideline levels for IPA ingestion via drinking water

Background:

Generally IPA is considered a low toxicity material and hence it has been used extensively for various purposes. There is a considerable body of information on the general biological effects of IPA in animal models of acute, subchronic, and chronic exposures (via inhalation or via ingestion) and in accidental exposures (intoxication) in humans. The toxic effects primarily include CNS effects (neurological) such as dizziness, poor coordination (disorientation), headache and hypoactivity (motor activity) and depressed respiration. Chronic effects or exposure to large amounts acutely also lead to delayed liver and kidney effects, especially the later (acute tubular necrosis). As the purpose of this write up is for an interim SWEG for water, effects such as irritation to eye, throat, skin and respiratory tract from inhalation exposures would not be discussed as such sensory irritation data are not relevant to ingestion.

A literature survey indicates that there are several inhalation studies done on rodents to assess toxicity and also in humans primarily to determine pharmacokinetic parameters. Rats exposed for 6 hours to 0, 500, 1500, or 5000 ppm of IPA showed significant decreases in motor function in groups exposed to 1500 ppm and above. The 500 ppm exposed groups was not affected. Narcosis (a condition of deep stupor or unconsciousness) was also noted in rats exposed to 1500 ppm in another study. A NOAEL (a no-observed adverse effect level) of 500 ppm was identified. Oral LD50 doses of 2000 mg/kg and 3600 mg/kg have been reported for rats and mice respectively.

IPA is rapidly metabolized by alcohol dehydrogenase (ADH) to acetone in the liver. Both the parent compound and the metabolite have some similar toxic effects. As the affinity of ADH for IPA is only $1/10^{th}$ of that for ethanol, IPA can be expected to me more toxic to the CNS (depressant) because it is not removed as quickly. The serum half-life of 2.5 hrs to 8 hours shows

that it remains in the system for quite some time. In addition one must consider that acetone is cleared much more slowly than IPA. At large does, acetone may lead to severe metabolic acidosis. It has been reported that 80% of an oral dose gets absorbed within 30 min of ingestion and 20 to 50% (more at the higher dose) of the absorbed dose is excreted unchanged.

Monaghan et al (1995) reported that three healthy male adults ingested 0.6 ml of 70% IPA (0.33 grams) in 240 ml of water over 5 min and blood samples were taken up to 24 hrs for pharmacokinetic studies. In another study by Lacouture et al.(1989) three male subjects ingested 0.4 ml of 70% IPA (0.22 grams) over 10 min in orange juice. No adverse effects were reported. Another study (IARC monograph) described that oral intake of low doses of 2.6 or 6.4 mg/kg bwt of IPA by groups of 8 men for 6 weeks had no effect on blood cells, serum or urine parameters, and subjects did not report any subjective symptoms.

Derivation of Interim SWEG: US EPA has not established an MCL, MCLG or health advisory (HA) for IPA by ingestion via drinking water. The Wisconsin Department of Health Services proposed a life-time Health Advisory of 3.5 mg/L for IPA, but the endpoint is not clear. However, EPA, based on subchronic drinking water study in rats developed an oral RfD for acetone, the metabolite of IPA, which can be used as a surrogate for IPA. Studies in which rats were exposed to various concentrations of IPA by inhalation where CNS effects were assessed identified a NOAEL of 500 ppm. However this was based on a single 6-hr exposure. Other sub-chronic and chronic inhalation studies on rats involved reproductive and developmental effects as end points and could not directly be used. Furthermore, the PBPK modeling studies for IPA and acetone using rat inhalation data and extrapolation to humans revealed that rat to human extrapolations required significant adjustments to the rat metabolic parameters to reproduce the model fit of human experimental data. Also other oral gavage studies with IPA used pregnant rats and rabbits. Others are multigenerational reproductive and developmental studies with IPA which are not useful for the purpose of this document.

Hence, it was decided to use existing human oral exposure data which appears to be useful for deriving a short-term interim SWEG.

Two studies described above were considered as the basis for the deriving the Interim SWEG for IPA (Lacouture et al.,1989; Monaghan et al., 1995)

1-d SWEG for CNS effects:

1) Dose: 0.6 ml of 70% IPA = 330 mg of IPA/d

   1-day SWEG: 330 mg / 2.8L/d = 118 mg/L (where 2.8L is the nominal potable water use/d)

2) Dose : 0.4 ml of 70% IPA = 220 mg of IPA/d

1-day SWEG: 220 mg/2.8L/d = 78.5 mg/d (where 2.8L is the nominal potable water use/d)

Since even with the higher dose, no effects were reported by the subjects even at 24 hours, it was decided to use 118 mg/L as the 1-d SWEG.

10-d Interim-SWEG for CNS and other off-nominal clinical chemistry:
According to the IARC monograph (1977), in a human exposure study, daily oral intake of low doses (2.6 or 6.4 mg/kg bwt) of IPA by groups of 8 men for 6 weeks had no effect on blood cells, serum, or urine parameters. There were also no subjective symptoms.

Using the value of 6.4 mg/kg bwt as the NOAEL and using a nominal body weight of 70 kg, the dose per day is calculated as 448 mg/d and using the lower dose of 2.6 mg/kg bwt, the total dose per days is 182 mg/d

Using a nominal potable water use of 2.8L per day, the acceptable concentration would be in the range 65 mg/L/d to 160 mg/L/d.

To be consistent with the derived 1-d value, 65 mg/L per day is proposed as the 10-d interim-SMEG.

As the primary endpoint for short term exposures is the neurological effects and as these effects may not be related to cumulative exposure, the 10-d value seems valid.

SUMMARY:

Duration	Interim-SWEG
1-day	118 mg/L/d
10-day	65 mg/L/d

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14. ABSTRACT

The International Space Station (ISS) Program requested the NASA Engineering and Safety Center (NESC) to evaluate the risks posed by the practice of long-term wet storage of ISS Environmental Control and Life Support (ECLS) regeneration system orbital replacement units (ORUs). The ISS ECLS regeneration system removes water from urine and humidity condensate and converts it into potable water and oxygen. A total of 29 ORUs are in the ECLS system, each designed to be replaced by the ISS crew when necessary. The NESC assembled a team to review the ISS ECLS regeneration system and evaluate the potential for biofouling and corrosion. This document contains the outcome of the evaluation.

15. SUBJECT TERMS
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