EFFORTS TO REDUCE INTERNATIONAL SPACE STATION CREW MAINTENANCE FOR THE MANAGEMENT OF THE EXTRAVEHICULAR MOBILITY UNIT TRANSPORT LOOP WATER QUALITY

John W. Steele[1]. David Etter[2] and Tony Rector[3]
Hamilton Sundstrand Space Systems International, Inc., Windsor Locks, CT 06095

Robert Boyle[4] and Christopher Vandezande[5]
NASA Johnson Space Center, Houston, TX 77058

The EMU (Extravehicular Mobility Unit) contains a semi-closed-loop re-circulating water circuit (Transport Loop) to absorb heat into a LCVG (Liquid Coolant and Ventilation Garment) worn by the astronaut. A second, single-pass water circuit (Feed-water Loop) provides water to a cooling device (Sublimator) containing porous plates, and that water sublimates through the porous plates to space vacuum. The cooling effect from the sublimation of this water translates to a cooling of the LCVG water that circulates through the Sublimator. The quality of the EMU Transport Loop water is maintained through the use of a water processing kit (ALCLR – Airlock Cooling Loop Remediation) that is used to periodically clean and disinfect the water circuit. Opportunities to reduce crew time associated with on-orbit ALCLR operations include a detailed review of the historical water quality data for evidence to support an extension to the implementation cycle. Furthermore, an EMU returned after 2-years of use on the ISS (International Space Station) is being used as a test bed to evaluate the results of extended and repeated ALCLR implementation cycles. Finally, design, use and on-orbit location enhancements to the ALCLR kit components are being considered to allow the implementation cycle to occur in parallel with other EMU maintenance and check-out activities, and to extend the life of the ALCLR kit components. These efforts are undertaken to reduce the crew-time and logistics burdens for the EMU, while ensuring the long-term health of the EMU water circuits for a post-Shuttle 6-year service life.

Key Words

ALCLR
EMU
Sublimator
Water
WPA

---

[1]Technical Fellow, Engineering Specialists, Hamilton Sundstrand Space Systems, 1 Hamilton Road, M. S. 1A-2-W66, Windsor Locks, CT 06096-1010
[2] EMU Systems Engineer, Hamilton Sundstrand Space Systems, 1 Hamilton Road. M. S. 1A-2-W66, Windsor Locks, CT 06096-1010
[3] Senior Engineer, Engineering Specialists, Hamilton Sundstrand Space Systems, 1 Hamilton Road, M. S. 1A-2-W66, Windsor Locks, CT 06096-1010
[4] EMU Subsystem Manager, NASA/JSC, Houston, TX 77058
[5] EMU Deputy Hardware Manager, NASA/JSC, Houston, TX 77058

Nomenclature

ALCLR = Airlock Cooling Loop Recovery
DI = deionized
DP = differential pressure
EMU = Extravehicular Mobility Unit
EVA = Extravehicular Activity
FA = Factor Analysis
ISS = International Space Station
LCVG = Liquid Cooling and Ventilation Garment
PCA = Principal Components Analysis
PLSS = Primary Life Support System
ppm = parts per million
LCVG = Liquid Cooling and Ventilation Garment
NVR = Non-volatile residue
PLSS = Primary Life Support System
SSA = Space Suit Assembly
TMG = Thermal Micro-meteoroid Garment
UIA = Umbilical Interface Assembly
USA = United Space Alliance

I. Introduction

The EMU is the spacesuit currently used on the ISS for routine maintenance and contingency EVA. It was first developed for the relatively short-term EVA needs during the pre-ISS Space Shuttle era (7-10 day missions). After a Shuttle return, the EMU could be disassembled, cleaned and put back into service with relatively short cumulative time accumulated on the two water loops. The EMU mission evolved to relatively moderate-term (up to 2-years or more) use during the ISS assembly, and more recently to relatively long-term (6-years) during the current post-Shuttle era, greatly increasing the dwell-time for the water in the EMU water loops.[1]

The transition from short-term (7 – 10 days) to long-term (6-years) use of the EMU hardware has necessitated a focus on proper management of the two water loops, a critical factor in keeping the hardware operational. A water processing kit (ALCLR) has been developed and is currently being used to periodically clean and disinfect the Transport Loop water where the risk of the fouling of intricate components and passages with contaminants is high. Efforts are underway to fine tune the duty cycle of the ALCLR to reduce crew maintenance time based on a review of prior performance data and the use of ground test bed hardware. Furthermore, an assessment of a fixed installation of the ALCLR into the EMU backpack, within on-orbit EMU interface hardware or as a stand-alone unit has been conducted.

This paper provides a summary of the testing and evaluation that has been done or is underway to ensure the proper maintenance of the EMU transport water loop. This activity supports efforts to reduce ISS crew maintenance time and to reduce re-supply needs for the long-term use of the EMU hardware on the ISS post-Shuttle.

II. Description of the EMU and it's ISS Mission

The EMU system is comprised of two main assemblies, the pressure garment (also known as the Space Suit Assembly or SSA) and the Portable Life Support System (PLSS). As seen in Figure 1, the two assemblies are covered in an outer garment (the Thermal Micro-meteoroid Garment or TMG) that acts as a barrier both to the thermal extremes of space and to impacts due to micro-meteoroids, cuts and punctures.

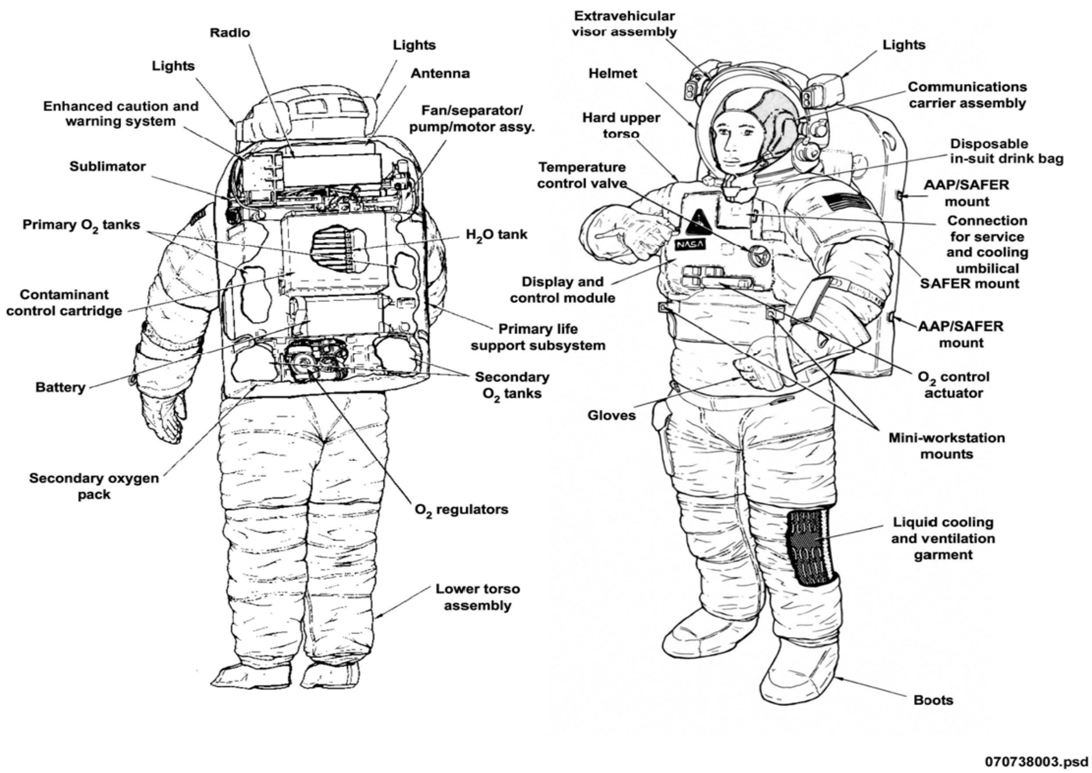


Figure 1: EMU high-level description illustrating the various components of the EMU pressure garment and life support assemblies.
(Source: NASA EMU, LSS, and SSA Databook Rev P.)

The SSA provides the pressurized environment, thermal management and pressurized mobility for the astronaut wearing the suit. This assembly is comprised of layers of materials which provide several functions. Innermost is a coated nylon bladder which retains the pressurized gas inside the suit. Surrounding the bladder is a pressure restraint garment which carries the load of the suit pressure. Outside the restraint are five layers of rip stop scrim and aluminized Mylar, which provides thermal isolation. Finally, the TMG surrounds these inner layers. Remarkably, the thickness of these layers does not exceed half an inch, yet the SSA enables astronauts to perform complex tasks like the intricate and delicate repairs to the Hubble Telescope or the brute force replacement of a Pump Module on the ISS.

The PLSS, which many engineers would agree to be a work of art in the exercise of functionality and packaging, provides the life support, power and communication systems. The main subsystems that are found in the PLSS are the space-to-space radio, the high-pressure primary and secondary oxygen tanks, the primary and secondary water tanks for cooling, the fan/pump/separator, the METOX canister for CO2 removal, and the water Sublimator for cooling. These systems are monitored by the Enhanced Caution and Warning System (ECWS) and controlled by the spacewalker using the Display and Control Module (DCM). The PLSS is sized to support most astronauts for a seven hour EVA with and hour contingency; however, the actual maximum length of the EVA is determined the individual metabolic rate of the astronauts and the thermal environment of the EVA.

The ISS EMU was originally developed for use on the U.S. Space Shuttle to mitigate failure scenarios where the Shuttle payload bay doors failed to close and lock properly prior to atmospheric re-entry. This initial risk mitigation required that the suit be able to pass through the Shuttle hatch openings to the crew cabin, which in turn sized the width and depth of the suit and PLSS assembly. The EMU has since evolved from a suit to help secure the Shuttle, to one capable of deploying, capturing and repairing satellites, and enabling astronauts to assemble and repair the ISS.[1]

As part of the evolutionary process to meet the expanding mission objectives of the EMU, the once single-mission operational certification (launch, EVA(s), land, refurbish) was incrementally extended to a mission life of multiple years on the ISS. The evolving mission of the suit has led to many changes to EMU components over the years. Those changes will not be addressed here; rather this paper will focus on impacts to the EMU transport water loop resulting from the life extension of the system, the on-orbit maintenance frequency and the development of on-orbit maintenance hardware (ALCLR hardware), required to keep the EMU system operational.

The Joint Airlock in the U.S. segment of the ISS provides for EVA operations, and the continuous flight of the ISS requires spacesuits to be left on-board for longer periods of time than the suit's original Shuttle certification allowed. The operational concept for the EMU evolved to launch EMUs on a Shuttle, leave a compliment of suits on ISS when the Shuttle un-docked, then on a subsequent Shuttle mission, replace and return those ISS suits to the ground for maintenance and refurbishment.[1]

To support continuous operation of the ISS, in 2000 the period of EMU maintenance cycles was extended from the 1-3 EVAs of a Shuttle mission to one year and 25 EVAs. Then in 2002 the maintenance interval was extended again to 2 years. In 2007 the certification was further extended to 3 years based upon significant engineering and maintenance data that suggested that this was possible.

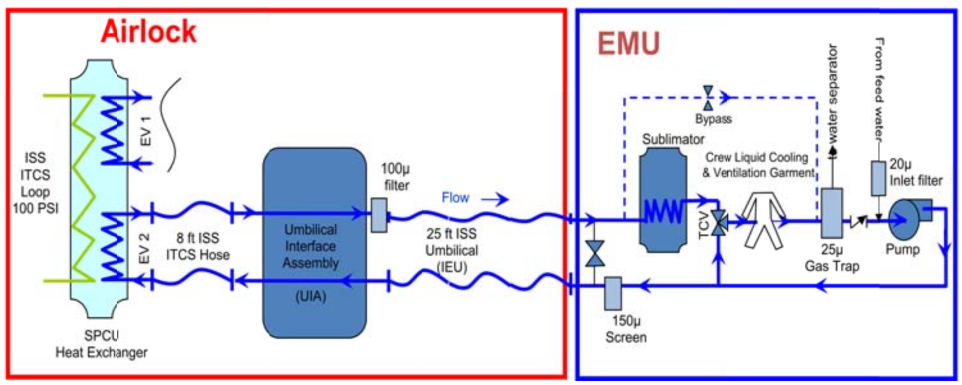
NASA's decision to retire the Shuttle fleet required another evolution of the EMU operations concept. The complement of EMUs on ISS was increased from three to four, and an effort to integrate and certify the EMU for launch on the Japanese HTV was started. Until return capability for the EMU on an international or commercial vehicle becomes operational, the EMUs will be discarded when their life expires. In order to support the ISS to 2020 with the current inventory of EMUs, a new round of life extension took place in 2008 to extend the operational certification out to 6 years.[1]

In order to qualify the EMU hardware to meet the longer 6-year maintenance interval on-orbit in the ISS, the hardware is required to go through additional ground processing. This processing includes cleaning or replacing water filters along with the stripping and recoating areas of known susceptibility to corrosion (the water tank walls, aluminum horn, and Sublimator flange). These steps restore this hardware to the best possible condition right before a launch (Shuttle or alternate vehicle).[1, 8]

III. Description of the EMU Transport Water Loop

The EMU Feed-water loop provides water to a Sublimator porous plate for system cooling. Heat is rejected by the sublimation of the Feed-water water to the vacuum of space. The Feed-water tank provides roughly 8.4 lbs of water for cooling along with storing crew respiration and perspiration condensate from the ventilation loop. The Transport Water Loop transfers the crew heat load to a Sublimator for cooling. Crew thermal comfort is manually controlled by varying the Transport Water flow to the Sublimator. (see Figure 2)

EMU & Airlock Transport Water Loop



EMU Feed water Loop

Figure 2: EMU Transport Water Plumbing Schematic

Maintaining the EMU transport water loop for long-term (6 year) operation presents the EMU team with significant challenges. The known risks to the loop, risks inherent in the current ISS mission, can be identified by past failures and by examining the interfaces between the EMU and ISS systems. The Fan/Pump/Separator and key transport loop filters have failed due to contaminants and corrosion products that are produced by EMU wetted components and by the ISS Airlock's Low Temperature Loop Heat Exchanger, which provides cooling water for suited crewmembers prior to activating the EMU's Sublimator. These failures are made more likely by extended stagnation time of the water in the EMU water loops.[2]

In the past there have been issues with water originating from ISS spanning from contamination from the airlock heat exchanger, to unexplained increases in TOC. Each of these events was unexpected and required post-event remediation, new maintenance procedures, and hardware and (ground) testing to keep the EMU system viable.[2]

In 2003 EMU serial numbers 3005, 3011 & 3013 were left on-board the ISS after the Columbia accident and began to experience significant performance degradation and failure within approximately a year after being initially charged with water and launched to the ISS. The EMU hardware fan/pump/separators were not able to function. After extensive testing of the water in the system, and invasive forensic determination of the source of contaminates that had deposited on the fan blade, it was determined that the ISS Airlock heat exchanger was releasing nickel and silicon into the water and redepositing in the EMU fan/pump/separator along with biological material. After this event the development of the ALCLR hardware aided in removing the free ionic material in the water originating from the Airlock and provided a periodic disinfection capability. Through periodic testing via water samples and examination of EMUs returned from orbit, the ALCLR hardware is an effective mitigation to the EMU Feed-water contamination.[2, 3, 4, 5]

IV. Risk Reduction for Transport Water Loop

A. ALCLR Development and Implementation

The ALCLR water processing kit was developed as a corrective action to EMU coolant loop flow disruptions experienced on the ISS in May of 2004 and thereafter. The components in the kit are designed to remove the contaminants that caused prior flow disruptions. ALCLR water processing kits have been utilized since 2004 as standard operating procedure. Periodic analysis of EMU coolant loop water and hardware examinations as a means to determine adequate functionality, optimized processing cycles, and ALCLR component shelf-life.[2]

The ALCLR water processing kit (see Figure 3) was devised to scrub and remediate the various chemical and biological contaminants and byproducts that were found to have fouled the magnetically coupled pump in the EMU Transport Loop Fan/Pump/Separator. The heart of the kit is the EMU Ion Filter, which is a 50:50 by volume packed bed of mixed anion/cation exchange resin and activated carbon. This component is periodically installed into the EMU and Airlock Heat Exchanger coolant loop and serves the purpose of removing inorganic and organic constituents such as nickel and iron corrosion products, and organic acids with the ion exchange resin. Furthermore, uncharged organic contaminants are removed with the activated carbon.[3]

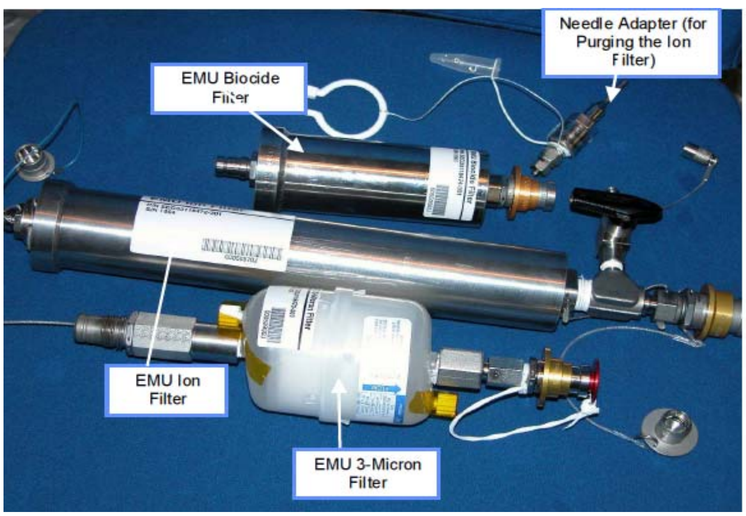


Figure 3: ALCLR Processing Kit Components

In service, a 3-micron filter is placed downstream of the EMU Ion Filter to capture fines from the packed bed prior to return of the polished water to the EMU Transport Loop. After scrubbing with the EMU Ion Filter, the EMU Biocide Filter is installed to add residual iodine biocide for microbial control. The EMU Biocide Filter is a packed bed of ion exchange resin impregnated with iodine.

B. ALCLR Cycle Enhancement – Data Review

An effort to data-mine and/or generate data to potentially justify an extension of the 90-day or less ALCLR storage cycle for the EMU hardware on the ISS was undertaken. That effort encompassed a review of existing data to identify data trends, specific gaps in the knowledge base, and a targeted acquisition of the gap data if that was indicated.

The result of that effort was a detailed acquisition and review of all data pertinent to every EMU and ALCLR bed that was on the ISS for greater than three months since the 2004 implementation of the ALCLR. That data was organized into a spread sheet for ease of review, calculations, graphics and search capability.[6]

The data for each evaluated EMU and each utilized ALCLR bed, included launch and return dates, flight identification, number of uses and when, storage intervals, EVA profiles, ALCLR cycle profiles and ALCLR bed profiles. Furthermore, EMU Transport Loop chemical and microbial analysis results, sample grab dates and contaminant links to potential primary sources were included. Finally, the results of the examination of all pertinent hardware that is sensitive to trace contaminants (Item-123 Fan/Pump/Separator, Item-141Gas Trap and Item-127 Pump Inlet Filter) associated with each of the EMUs of interest; along with examination dates was included.[6]

The first phase of the study suggested a high correlation between the health of an EMU Transport Loop and the number of EVA's conducted with the hardware, particularly if the sampling/examinations occurred post-EVA with no subsequent ALCLR. The data also indicated a weak correlation between health of the EMU Transport Loop and the time between ALCLR events (storage cycle), suggesting that an extension to the storage cycle may be low risk.[6]

The goal of the second phase of the study was to utilize more sophisticated statistical tools on the acquired dataset. The analyses that were conducted were a PCA (Principal Components Analysis) and a FA (Factor Analysis). Those analysis tools were used to examine the relationships between a set of variables (in the case of this study – the water quality parameters) to determine if they tracked one another, and to determine if they should be weighed equally.

The PCA and FA analyses of the data acquired during the initial phase appeared to refute the first phase interim conclusions. Storage cycle was, in fact determined to be a more important consideration with respect to SEMU Transport Loop health and as such, the study did not yield data supportive of a risk-free extension to the 90-day ALCLR storage cycle.[9]

The study yielded a better understanding of the importance of the specific water analysis parameter NVR (non-volatile residue), and the fact that it demonstrated a dual character depending on the last event that occurred with the EMU (see Figure 4). If the last event was an EVA, the NVR appeared to start off high, and declined as a function of water dwell time in the loop. This suggested that the sources of the contaminants (the ISS Airlock Heat Exchanger and the Astronaut) initially contributed a significant amount of contaminants to the water and those contaminants then precipitated onto the wetted surfaces of the Transport Loop (including the Item-123 Fan/Pump/Separator). On the other hand, if the last event was an ALCLR scrub, the NVR appeared to start off low, then increase as a function of water dwell time in the loop. This suggested that the ALCLR cleaned the water to a high purity level, and a driving force was created to cause the precipitates on the wetted surfaces to re-dissolve (rebound).[9]

The results of this study lead to a recommendation to ALCLR scrub the EMU Transport Loop within1-week of an EVA to minimize precipitate build-up. Furthermore, the results have lead to an additional evaluation of whether repeated ALCLR scrubs with no EVA activity over a relatively long period of time will lead to a reduced rebound of precipitated NVR such that the ALCLR cycle could be extended for EMU hardware in long-term storage on the ISS.[9]

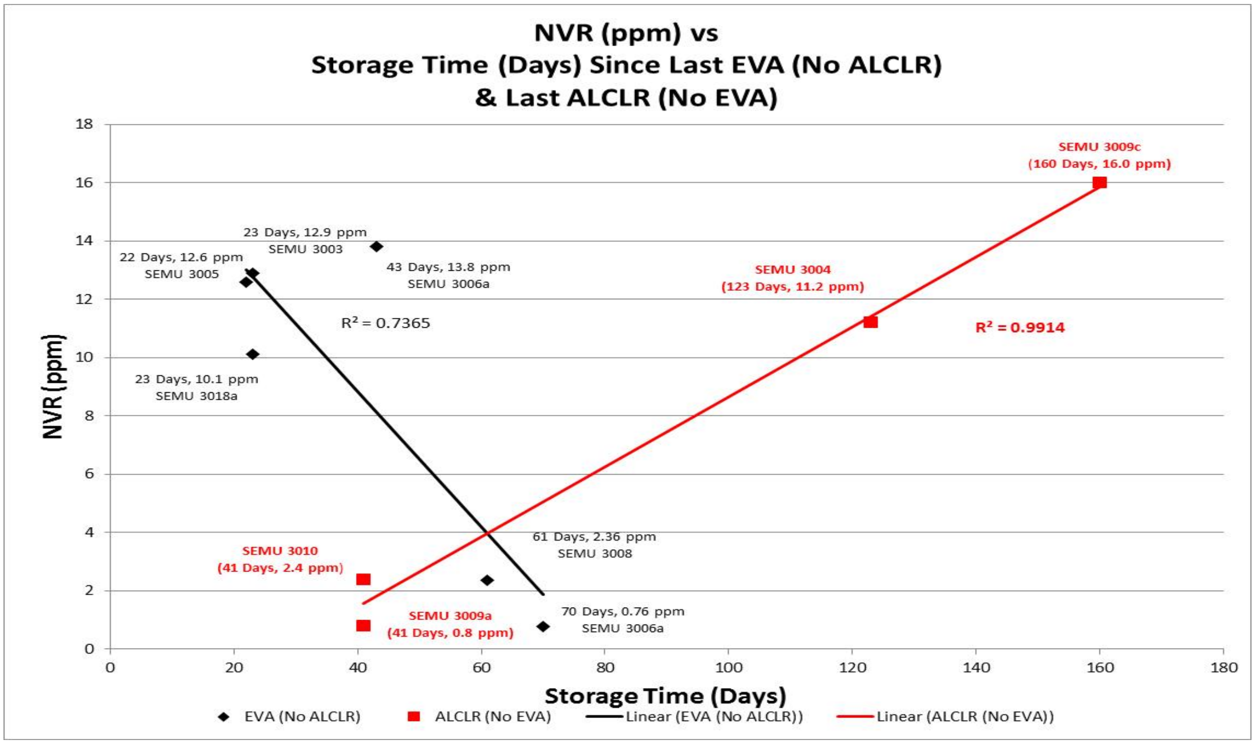


Figure 4: NVR vs. Storage Days Populations #1 (red) and #2 (black)

C. ALCLR Cycle Enhancement – SEMU 3009 Test Bed

EMU 3009 was returned to the ground on STS-135 after two years on the ISS and 8-EVAs. That unit underwent an extended storage time after it underwent an ALCLR scrub shortly after ground return. The unit is now undergoing repeated 90-day storage cycles followed by sample grabs and analysis, then ALCLR scrub cycles, to determine if the repeated cycles will reduce the rebound of the precipitate that has built up on the wetted surfaces. The results of this effort as well as disassembly and examination of all pertinent hardware (Item-123 Fan/Pump/Separator, Item-141- Gas Trap and Item-127 Inlet Filter) will figure into the final decision on the potential for ALCLR cycle storage time relief for long-term ISS EMU hardware not in frequent use.

PENDING NEW DATA

D. ALCLR Fixed Bed Study

The ALCLR process involves a hands-on, crew-time intensive set of steps to scrub the Transport Loop water with a combination ion exchange/activated carbon bed. This is followed by a separate addition of iodine biocide with a bed packed with iodine dispersing resin. Processing requires the use of a third component, a 3-micron filter cartridge, which protects the EMU from ion exchange resin and activated carbon bed fines that can potentially be swept from the two beds. Besides crew-touch time, the components of the process also represent an expendable launch weight burden. ALCLR processing can occur up to two times per 90-day period during EVA activity, and once per 90-day period during storage times when no EVAs are occurring.

A goal of the ISS Program is to reduce crew maintenance time up to 50% to allow for primary mission activities. Additionally, a reduction in launch weight burden for expendables is desirable due to limited launch vehicle constraints. The intent of this study was to examine the feasibility of reducing the crew time associated with ALCLR by investigating alternate means of performing the process. Changes to the ALCLR component sizing and geometry were evaluated, as was the installation of the kit components in areas in or around the ISS Airlock, and as a stand-alone scrubbing unit. The various options were traded against criteria such as crew touch-time, resupply needs (up-mass vs. time), complexity of the approach, impact to EMU hardware life, technical maturity of the approach, certification implications and future mission application.

The current ALCLR process requires an estimated 40-hours of actual crew touch time per year and requires the use of 14.6 lbs of expendables per year in a four EVA series per year scenario. Over the course of the ISS life, the use of the ALCLR in its present state represents up to 640 hours of crew touch time through the year 2028. This represents a significant cost in crew touch time that can be significantly reduced based on the findings of this study.[7, 10]

Three separate packaging approaches for the ALCLR components (beds, and filter) were evaluated in detail. The first approach, referred to as the “As Is Approach”, was to keep all of the ALCLR components as-is, utilizing two separate packed beds; one for scrubbing, the other for iodine addition. This approach maintained a separate 3-micron filter cartridge down-stream of the packed beds to ensure that resin fines do not enter the EMU Transport Loop.

The second packaging approach, referred to as the “Optimized Packed Approach”, maintains two separate packed beds, but the ion exchange resin / activated carbon ratio in the packed bed would be optimized for historically observed EMU contaminants. The current 50:50 by volume mix of ion exchange resin/activated carbon is changed to an 80:20 by volume mix of ion exchange resin/activated carbon, The 3-micron filter would be drastically reduced in size as well with the use of a pleated stainless steel filter incorporated into the bed ion exchange resin/activated carbon bed itself. Finally, the bed size would be increased to provide a final capacity for 20-ALCLR events.

The third packaging approach, referred to as the “Segmented Bed Approach”, utilized a single segmented bed that incorporated activated carbon, ion exchange resin, iodine delivery resin and a final 3-micron filter as a single component (see Figures 5 and 6). Coupling the scrubbing process with the addition of iodine biocide cannot be done with packed beds since a packed bed of activated carbon would remove the bulk of the iodine. A less efficient segmented bed, however, would allow a merging of these functions to simplify the scrubbing process. Iodine would remain in the Transport Loop water functioning as a residual biocide after this processing since the segmented activated carbon is not very efficient in a single pass.[7, 10]

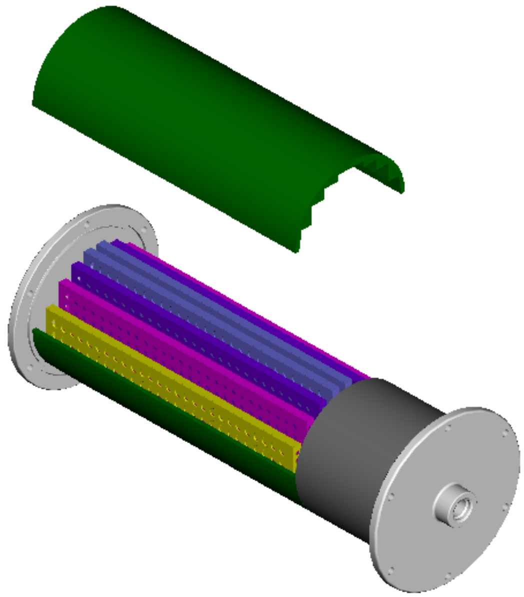
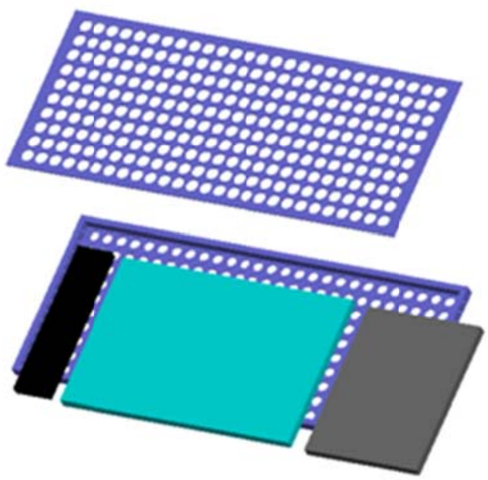


Figure 5: Low Pressure Drop Cassette Style Ion Exchange Bed



Segmented Bed: Typical Cassette Exploded View

Figure 6: Expanded Drawing of a Segmented Bed Cassette

The mass transfer properties of the segmented bed rely on a convective-diffusion approach to remove contaminants from the fluid stream, where the removal kinetics are governed by the re-circulation flow rate of the ALCLR scrubbing activity. Previous modeling of the performance of a similar bed at UTAS has allowed for the development of empirical mass transfer correlations (MTC) to predict the exchange kinetics and treatment times for specific segmented bed geometries. The MTC were further simplified down to a dimensionless correlation that related flow velocity, bed geometry, fluid properties and diffusion of dissolved ionic contaminates. The MTC was used to determine the theoretical run times needed to scrub an ALCLR loop based off an 8-cassette geometric configuration and anticipated flow rates from the EMU Item 123 pump (see Figure 7).[7, 10]

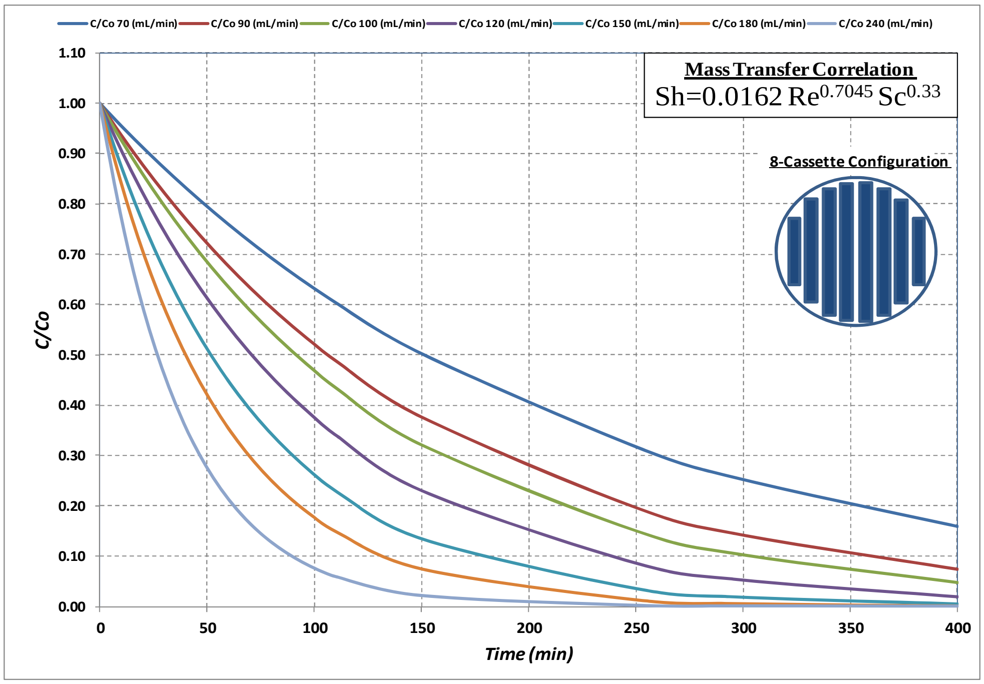


Figure 7: Run Time to Remove Dissolved Ionic Species for an 8-Cassette Segmented Bed Configuration as a Function of Bed Flow Rate

These results showed that at the maximum flow rate of 240 lb/hour, the ionic contaminate load could be 90% removed in under 90 minutes. The removal kinetics were proportional to the flow rate and will decrease as the flow rate slows down. The flow rate will be dependent on the pressure drop of the ALCLR loop. This pressure drop will be a function of the components included in the ALCLR scrubbing event.

This study also evaluated a number of optional locations for the ALCLR bed options; in the PLSS itself, in the Airlock in one of several locations, and as a stand-alone unit. Furthermore, the pros and cons of using stand-alone pumps vs. using the EMU Fan/Pump/Separator itself were evaluated as well.

From a location perspective, there was no available real estate to allow for the incorporation of an ALCLR packed bed within the PLSS (a segmented bed was out of the question due to size).

Furthermore, this approach would result in an unacceptable pressure drop and would also result in an increase to estimated crew touch time due to the need for periodic bed change out. Real estate availability also ruled out other locations such as in the UIA Panel and above the UIA Panel. Four perspective location/pump approaches were found to be feasible (alongside the Airlock UIA panel using the EMU pump, in the Equipment Locker using the EMU pump, stand-alone using the EMU pump, and stand alone using a standalone pump.

The four perspective location/pump approaches were combined with the three identified component packaging concepts for a total of 12 combinations that underwent a detailed trade study.

The twelve potential location/bed type combinations are detailed below.

Existing ALCLR Components

Location – Airlock Heat Exchanger Equipment Locker
Location – Airlock – Sides of UIA Panel
Location – Stand-alone – Use EMU I-123 Pump
Location – Stand-alone – Dedicated Pump

Optimize the ALCLR Components, but Maintain Two Packed Beds

Location – Airlock Heat Exchanger Equipment Locker
Location – Airlock – Sides of UIA Panel
Location – Stand-alone – Use EMU I-123 Pump **(Option 3)**
Location – Stand-alone – Dedicated Pump

A Single Segmented Bed

Location – Airlock Heat Exchanger Equipment Locker
Location – Airlock – Sides of UIA Panel **(Option 1)**
Location – Stand-alone – Use EMU I-123 Pump
Location – Stand-alone – Dedicated Pump **(Option 2)**

Ultimately, three permanent ALCLR scrubber bed configuration / location options were down-selected, each of which had been evaluated for two usage models that bound the EVA use from now until 2028. Of these three options, one had the greatest benefits in touch time (Option 1), one has the least number of ALCLR events that require scheduling (Option 2), and one had the least certification impact (Option 3). Schematics for the three options are shown in Figures 8, 9 and 10. Trade highlights for the three options are summarized in Table 1.[7, 10]

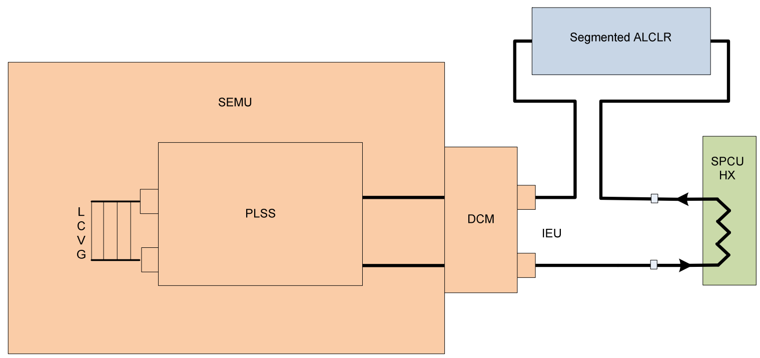


Figure 8: Option 1 – Schematic of ALCLR Located in the Airlock Near UIA Using a Segmented Bed

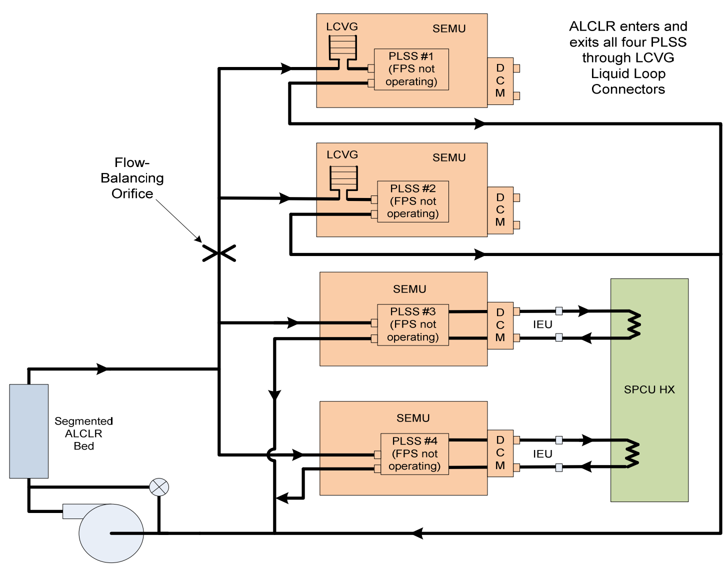


Figure 9: Option 2 - Schematic Segmented Bed Stand Alone

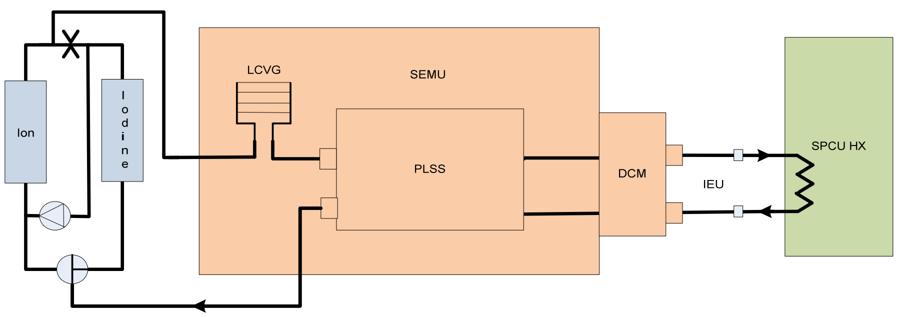


Figure 10: Option 3 – Dual Packed Bed, Stand Alone, Use EMU I-123 Pump

Option Number/ Description	1) Segmented Bed Airlock – Sides of UIA Panel	2) Segmented Bed Stand Alone Dedicated Pump	3) Dual Packed Bed Stand Alone Use EMU I-123 Pump
Bed Type	Segmented (Couples scrubbing & iodination into one bed)	Segmented (Couples scrubbing & iodination into one bed)	Two Optimized Packed Beds
Pump	EMU	Self-Contained	EMU
Major Benefits	No setup time. Pre-EVA scrub occurs during pre-breathe	ALCLR 4 suits at once. Set it and forget it.	Proven technology
Time Savings (After Initial Installation)	41-54%	27-53%	15-17%
Cert Impact	Medium due to vehicle modification	High due to EMU modification and Pump development	Minor due to bed change
Consumable Mass Savings	0-21%	0-21%	17-38%
Cost	Medium	High	Low

Table 1: Benefits Summary of the Three Selected Options

As shown in Table 1, the greatest crew touch time savings was provided by Option 1, where the time savings were 41 to 54%. A range of touch time and consumable mass savings values was provided since calculations were made for two different EVA usage models. The present 640-hour crew touch time estimate through the year 2028 could be reduced to 353 hours (including installation time) for Option 1.

The greatest consumable launch weight reduction is provided by Option 3, where the 234 pounds of launch weight through the year 2028 can be reduced to 143 pounds (a savings of 90 pounds of launch weight or a 38% reduction).[7, 10]

V. Summary

The mission of the EMU has evolved over the years, from an up/down 7-10 day Shuttle contingency system with a revamp once on the ground, to a 25-EVA/6-year mission on the ISS with minimal servicing. This mission expansion has resulted in significant challenges to the maintenance of the water quality in the EMU transport water loop. A number of efforts have been undertaken to minimize EMU performance risk related to transport loop water quality degradation. Those efforts include the development and implementation of hardware to scrub and disinfect water in the EMU Transport Loop and a fine-tuning of the scrub/disinfect process based on data review and a ground test bed. This effort is to potentially provide relief to the frequency of the ALCLR cycle, particularly with long-term stored EMU hardware on orbit. Furthermore, design, use and on-orbit location enhancements to the ALCLR kit components were considered to allow the implementation cycle to occur in parallel with other EMU maintenance and check-out activities. This approach would potentially allow an extension to the life of the ALCLR kit components, a significant reduction in crew touch time, and a reduction of required up mass for the ALCLT scrub/disinfection process. These approaches to reduce crew maintenance time and to reduce launch weight are currently being evaluated by the Program.

References

[1] West, William, Witt, Vincent, Chullen, Cinda, AIAA-2010-6130-610, EVA 2010: Preparing for International Space Station EVA Operations Post-Space Shuttle Retirement.

[2] Lewis, J. F., Cole, H., Cronin, G., Gazda, D. B., Steele, J. W., "Extravehicular Mobility Unit (EMU)/ International Space Station (ISS) Coolant Loop Failure and Recovery", ICES Paper, 2006-01-2040.

[3] Steele, J.W., Rector, T., "Airlock Cooling Loop Recovery (A/L CLR) Sampling and Analysis Results – Phase II", Hamilton Sundstrand Internal Document SVME: 6057H.

[4] Steele, J. W., Gazda, D. B., Lewis, J. F., Rector, T., "Performance of the Extravehicular Mobility Unit (EMU) Airlock Coolant Loop Recovery (ALCLR) Hardware, ICES Paper, 08ICES-0023.

[5] Steele, J. W., Gazda, D. B., Lewis, J. F., Rector, T., "Performance of the Extravehicular Mobility Unit (EMU) Airlock Coolant Loop Recovery (ALCLR) Hardware - Final, AIAA 2011-5259.

[6] Steele, J. W., "DO 22 - "EMU ALCLR Scrub Interval Study – Interim Report", 12/2011, Hamilton Sundstrand Internal Document SVME: 6625E.

[7] Kalnenieks, P. T., DO 24 "Special Study for Incorporation of a Permanent ALCLR Scrubber Bed" - Interim Report, 01/2012, Hamilton Sundstrand Internal Document.

[8] Steele, J. W., Etter, D., Hill, T., Rector, T., Wells, K., "Management of the Post-Shuttle Extravehicular Mobility Unit (EMU) Water Circuits", ICES Paper AIAA-2012-3593.

[9] Steele, J. W., "DO 22- EMU ALCLR Scrub Interval Study – Final Report", 08/01/12, Hamilton Sundstrand Internal Document SVME: 6709REVC.

[10] Rector, T., Steele, J. W., "DO 24 – Special Study for the Incorporation of a Permanent ALCLR Bed – Final Report", 04/05/12, Hamilton Sundstrand Internal Document SVME: 6654.