Performance of the Extravehicular Mobility Unit (EMU) Airlock Coolant Loop Remediation (A/L CLR) Hardware - Final

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An EMU water processing kit (Airlock Coolant Loop Recovery – A/L CLR) was developed as a corrective action to Extravehicular Mobility Unit (EMU) coolant flow disruptions experienced on the International Space Station (ISS) in May of 2004 and thereafter. A conservative duty cycle and set of use parameters for A/L CLR use and component life were initially developed and implemented based on prior analysis results and analytical modeling. Several initiatives were undertaken to optimize the duty cycle and use parameters of the hardware. Examination of post-flight samples and EMU Coolant Loop hardware provided invaluable information on the performance of the A/L CLR and has allowed for an optimization of the process. The intent of this paper is to detail the evolution of the A/L CLR hardware, efforts to optimize the duty cycle and use parameters, and the final recommendations for implementation in the post-Shuttle retirement era.

Nomenclature

A/L CLR	=	airlock coolant loop recovery
CFU	=	colony forming unit
EDS	=	energy dispersive spectrum
EMU	=	Extravehicular Mobility Unit
EVA	=	Extravehicular Activity
F/P/S	=	fan/pump/separator
ISS	=	International Space Station
ITCS	=	internal thermal control system
IX	=	ion exchange
N/A	=	not applicable
NVR	=	non-volatile residue
LCVG	=	liquid cooling and ventilation garment
SEMU	=	Short Extravehicular Mobility Unit
SEM	=	scanning electron microscope
STS	=	Space Transportation System
TC	=	total carbon
TIC	=	total inorganic carbon
TOC	=	total organic carbon

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I. Introduction

THE EMU coolant system circulates water used to reject heat from the crewmember and the equipment. During EVA preparations, the airlock coolant loop provides cooling for the EMU when it is at ambient pressures. The airlock coolant loop contains a heat exchanger and umbilicals to connect to the EMU. The EMU contains the pump and systems to circulate and degas the coolant loop along with the liquid cooling garment to provide cooling to the suited crew member.

The A/L CLR water processing kit was developed as a corrective action to the 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 the prior flow disruptions. A/L CLR water processing kits have been utilized since 2004 as standard operating procedure, with periodic examination of EMU coolant loop water and hardware as a means to determine adequate functionality, optimized processing cycles, and maximized A/L CLR component shelf-life.

This paper is intended to detail the evolution of the A/L CLR hardware and processing cycle, and to summarize more recent efforts to optimize the process. The final post-Shuttle recommendations for the use of the A/L CLR hardware are summarized as well.

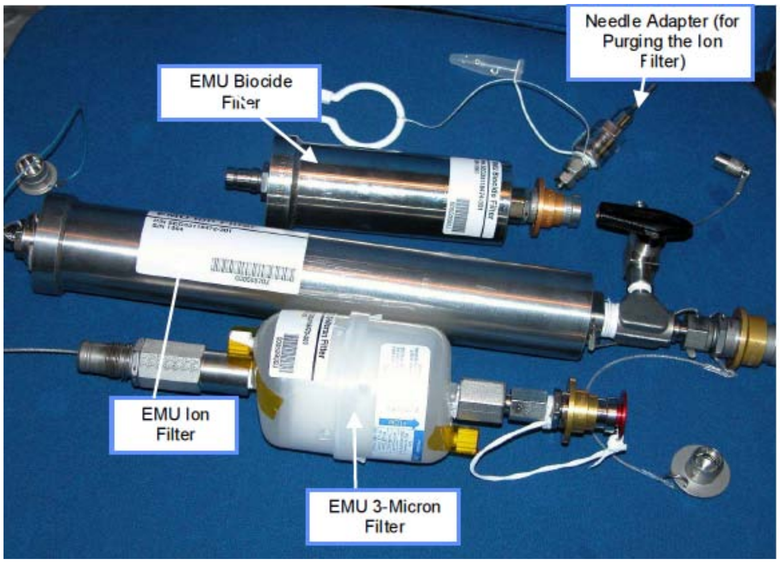

Figure 1: A/L CLR Processing Kit Components

II. Description of the A/L CLR Kit

The A/L CLR water processing kit (see Figure 1) 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. [3,4]

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 / 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]

In service, a 3-micron filter is placed downstream of the EMU Ion Filter to captured 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.

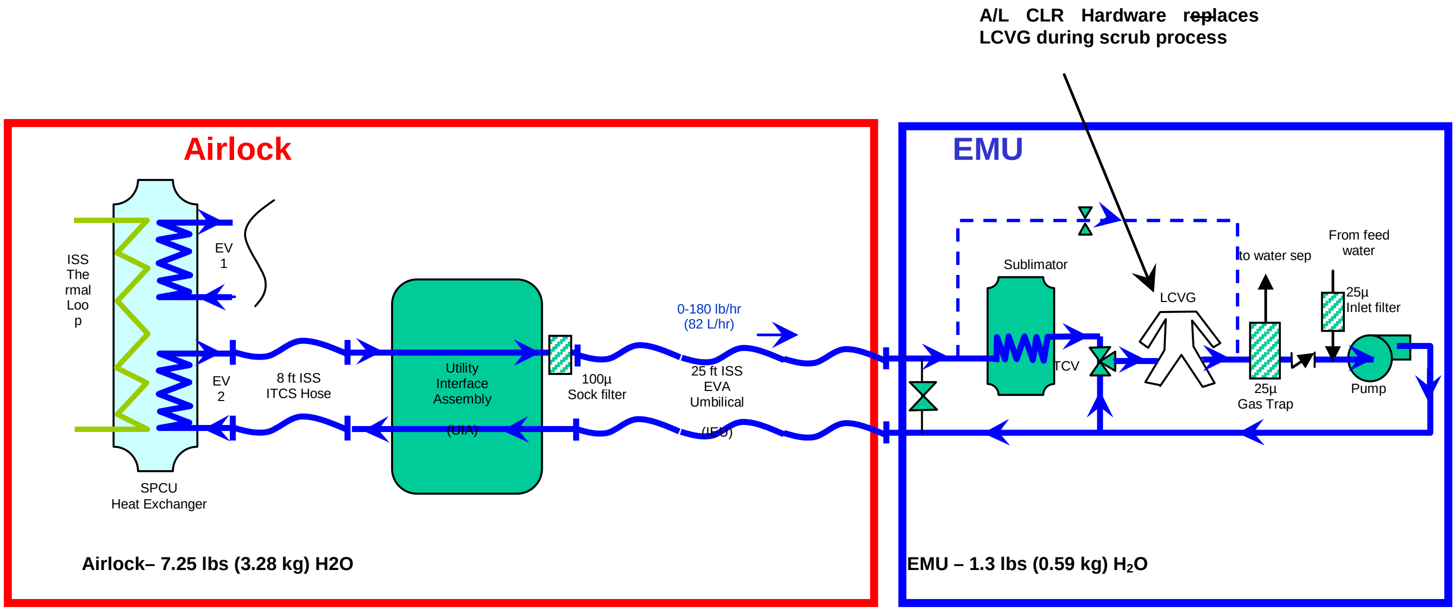

Figure 2 – Coolant Loop Schematic and A/L CLR Location

III. A/L CLR Kit Requirements

An initial A/L CLR use schedule was devised in 2004 based on results from prior EMU Transport Loop water analysis results, the analysis findings from the coolant flow failure investigation, and interaction with the EVA and ISS logistics communities. That use schedule was revised in 2007 after an evaluation of the initial performance of the A/L CLR hardware with two EMUs that were on-orbit for 14-months and are summarized in Table 1. [5,6]

Activity	Item	Initial Requirements 2004	Revised Requirements 2007	Revised Requirements 2009
Max stagnation time	EMU	90-days	180-days	90-days
Pre-EVA scrub	EMU	≤ 2-weeks	≤ 4-weeks	≤ 4-weeks
Post-EVA scrub	EMU	≤ 2-weeks	≤ 2-weeks	≤ 2-weeks
Number of uses	Ion bed	4	8	8 (new resin 4 (old resin)
Shelf life after first use	Ion bed	2-years	2-years	2-years
Number of uses	3-micron filter	1	Target 8 (verify after 4)	12
Shelf life after first use	3-micron filter	N/A	Use within 2-years after first use	Use within 3-years after first use

Table 1. Preliminary and Revised A/L CLR Kit Use Schedules

A. Initial 2004 Requirements and 2007 Revisions to the A/L CLR Kit Use Schedule

The initial maximum stagnation time for an EMU on-orbit was set at 90-days before an A/L CLR scrub cycle was initiated. That was revised to 180-days in 2007 after the evaluation of the first two EMUs that underwent this processing for 14-months. Furthermore, the A/L CLR scrub requirement was initially set at ≤ 2 -weeks before a scheduled EVA and that was revised to ≤ 4 -weeks before a scheduled EVA. Finally, an A/L CLR scrub requirement was initially set at ≤ 2 -weeks after a series of EVA's occurring within 2-weeks of one another, and that has been maintained. [5,6]

The number of uses of the Ion Bed was initially set at 4, which was a conservative estimate based on prior EMU Transport Loop coolant water analysis results. A revision to 8 uses was made in 2007 after the ion exchange resin and charcoal capacities from two 4-use A/L CLR beds was conducted. Shelf life of the ion bed was set at 2-years after the first use and that has been maintained since 2004. [5,6]

The number of uses of the 3-micron filter was initially set at 1 with the item not used thereafter. That was revised to 4 as a result of the initial series of uses in 2007, with the goal to target 8 uses after further evaluation. [5,6,8]

B. 2009 Revisions to the A/L CLR Kit Use Schedule

An evaluation of samples associated with SEMU Hardware that flew for 21-months on ISS (SEMU 3006 and SEMU 3008) that had undergone more liberal A/L CLR cycles of 180-days maximum stagnation time, was conducted in 2009 and reported on. The more liberal A/L CLR use requirements that were conducted (particularly the extended stagnation time of up to 180-days) was deemed less than adequate and needed to again be revised. The samples associated with SEMU 3008 in particular (Transport Water Loop water, the I-123 Fan/Pump Separator Rotor, the I-141 Gas Trap, and the Item-127 Inlet Filter) exhibited indications of contamination that could lead to the type of Transport Loop flow disruption experienced in 2004 (rotor slightly "gritty", poor water quality, observance of precipitates and scale). [7,8]

The primary distinction between SEMU 3006 and SEMU 3008 was the longer periods of time that the SEMU 3008 Transport Loop water remained stagnant (back-to-back periods of time of 134-days and 141 days respectively vs. only one occurrence of 90-days stagnation for SEMU 3006) during their 21-months of ISS use. The loosening of stagnation time from 90-days to 180-days per SVHS 5861 recommendation therefore needed to be revised. A move back to a stagnation time of "not-to-exceed" 90-days was recommended and has been in place since then.

Additional A/L CLR kit changes with respect to the 3-micron filter downstream from the bed and the A/L CLR use cycle with respect to "old" vs. "new" ion exchange resin were made in 2009 and are detailed in Table 1 as well. [8]

C. Post Shuttle A/L CLR Kit Use Schedule

The program directive in 2009 was to continue to evaluate EMU and A/L CLR hardware until the end of the Space Shuttle Program, and to make a final set of recommendations for A/L CLR use based on this additional data set and all prior findings. In particular, deviations (planned or with waivers) to the < 90 day A/L CLR scrub requirements as a minimum were to be evaluated to determine if a middle ground in-between a < 90-day vs. < 180-day minimum A/L CLR scrub were an option.

The primary focus of this paper is to provide the data that led to the final date set for performance of the A/L CLR hardware and to communicate the final set of recommendations for the use of the A/L CLR kit post-Shuttle.

IV. Maximum Stagnation Time Requirement

The water stagnation dwell time in EMU hardware from 2008 to present was evaluated with respect to impact on Transport Loop water quality and Item-123 Fan/Pump Separator performance and the extent of precipitate deposits if present. Specific focus was on EMU hardware that exceeded the < 90 –day water stagnation period requirement of 2009 to determine if there could be a case made to gravitate to a permissible stagnation period between 90 – 180 days. Table 2 is a summary of the EMU hardware taken into account for this exercise.

A. Prior Transport Loop Water Samples

The data acquired from the analysis of EMU Transport Loop water prior to A/L CLR, after the initial A/L CLR cycle (< 90-day scrub minimum), and the extended A/L CLR cycle (< 180-day scrub minimum applied to SEMU 3006 & 3008) is shown in Table 1.

Return Flight	Date of Return	SEMU	Number of EVAs	Stagnation Times > 90-days
STS-121	03/2008	1) SEMU 3006 2) SEMU 3008	1) 14 2) 11	1) One: 90-days 2) Two: 134 & 141 days
STS-126	11/2008	1) SEMU 3003 2) SEMU 3018	1) 6 2) 13	1) One: 123-days 2) Four: 101, 109, 118, 148 days
STS-119	03/2009	1) SEMU 3004	1) 3	1) One: 170-days
STS-128	09/2009	1) SEMU 3005	2) 10	1) One: 92-days
STS-129	11/2009	1) SEMU 3006 2) SEMU 3011	1) 4 2) 0	1) One: 149-days 2) One: 135-days

Table 2. EMU Hardware 03/2008 – Present With > 90-Day Water Stagnation Time

Parameter	Pre A/L CLR (max)	Pre A/L CLR (ave)	Initial A/L CLR SEMU 3009	Initial A/L CLR SEMU 3010	Extended A/L CLR SEMU 3006	Extended A/L CLR SEMU 3008
General						
pH (units)	5.04 (lowest)	6.63	5.78	6.36	5.85	6.50
Conductivity (umho)	**41.0**	**19.1**	7.81	7.37	9.27	**33.46**
Cations						
Na	0.98	0.98	<0.10	<0.10	<0.01	<0.01
NH_4	6.24	3.84	<0.10	<0.10	**0.86**	**2.38**
K	3.55	1.72	<0.10	<0.10	<0.01	0.19
Mg	0.022	0.022	<0.10	<0.10	0.04	0.07
Ca	2.09	2.03	0.38	0.41	<0.01	<0.01
Anions						
F	0.43	0.25	<0.10	<0.10	<0.01	<0.01
Cl	0.66	0.40	<0.10	<0.10	<0.01	0.02
NO_2	-	-	<0.10	<0.10	<0.01	<0.01
NO_3	-	-	<0.10	<0.10	<0.01	<0.01
PO_4	1.58	1.17	<0.10	<0.10	<0.01	<0.01
SO_4	2.03	1.33	<0.10	<0.10	**0.28**	**1.91**
Metals						
Al	1.35	0.89	0.094	0.072	<0.05	<0.05
Cr	0.02	0.02	<0.05	<0.05	<0.05	<0.05
Fe	-	-	<0.05	<0.05	<0.05	<0.05
Ni	6.43	4.16	0.614	0.601	0.48	**1.76**
Si	5.42	4.62	0.258	0.244	**0.40**	**0.57**
Zn	0.058	0.054	<0.05	<0.05	<0.05	<0.05
Other						
Microbial (CFU/100 ml)	3.0×10^7	1.5×10^7	1.3×10^4	1.5×10^5	2.9×10^5	2.4×10^3
I_2	0.66	0.58	<0.20	<0.20	<0.10	<0.10
I^-	-	-	0.823	0.823	0.73	0.54
Total Iodine	-	-	0.823	0.823	0.73	0.54
NVR	71.0	60.8	0.8	2.4	0.76	**2.36**
TC	32.64	28.79	2.29	2.22	-	-
TIC	10.45	5.60	0.76	0.70	-	-
TOC	30.5	23.3	1.53	1.52	**3.35**	**6.51**

Table 3. A/L CLR Serviced Transport Loop Water – Past Data

B. 12/02/08 - Present Transport Loop Water Findings

The data acquired from the analysis of EMU Transport Loop water from 12/02/08 – Present (water from EMU hardware that underwent an extended stagnation period of > 90-days prior to A/L CLR scrub) is shown in Table 2. Although the requirement for A/L CLR scrub was <90-day scrub minimum, these are instances where this requirement was either not applied due to requirement implementation timing (SEMU 3003 & 3018) or not implemented through waiver (SEMU 3004, 3005 and 3011).

Parameter	SEMU 3003 STS-126 Return	SEMU 3018 STS-126 Return	SEMU 3004 STS-119 Return	SEMU 3005 STS-128 Return	SEMU 3011 STS-129 Return
General					
pH (units)	6.30	6.30	5.60	6.80	6.50
Conductivity (umho)	**21.0**	**23.0**	6.57	7.20	**58.6**
Cations					
Na	<0.1	<0.1	<0.1	<0.1	-
NH_4	**2.47**	**2.47**	0.02	**0.9**	-
K	<0.1	<0.1	0.15	<0.1	-
Mg	<0.1	<0.1	<0.1	<0.1	-
Ca	<0.1	<0.1	<0.1	<0.1	-
Anions					
F	<0.1	<0.1	<0.1	<0.1	-
Cl	<0.1	<0.1	<0.1	<0.1	-
NO_2	<0.1	<0.1	<0.1	**0.2**	-
NO_3	<0.1	<0.1	0.13	<0.1	-
PO_4	<0.1	<0.1	<0.1	<0.1	-
SO_4	**0.45**	**0.54**	0.11	<0.1	-
Metals					
Al	<0.05	<0.05	<0.1	<0.1	<0.1
Cr	<0.05	<0.05	<0.1	<0.1	<0.1
Fe	<0.05	<0.05	<0.1	<0.1	<0.1
Ni	**1.25**	**0.81**	0.17	0.3	**1.84**
Si	**0.39**	**0.35**	0.73	0.4	**0.46**
Zn	<0.05	<0.05	<0.1	<0.1	<0.1
Other					
Microbial (CFU/ 100 ml)	1.4×10^4	3.7×10^3	4.3×10^3	1.6×10^4	1.6×10^4
I_2	<0.16	<0.16	<0.2	0.1	-
I^-	0.22	0.53	0.67	1.2	-
Total Iodine	0.22	0.53	0.67	1.3	-
NVR	**12.9**	**10.1**	**11.2**	**12.6**	**18.6**
TC	7.70	8.16	5.91	8.0	-
TIC	3.40	4.01	1.53	2.5	-
TOC	**4.30**	**4.15**	**4.38**	**5.5**	**5.13**

Table 4. A/L CLR Serviced Transport Loop Water – 12/02/08 - Present

C. Prior Item-123 Fan/Pump/Separator Findings

Data from the disassembly of the first I-123 Fan/Pump/Separators from EMU hardware that the relaxed <180-day stagnation period applied to was previously reported. In the context of linking transport loop stagnation time to hardware impact, it is worth revisiting this data. [7]

1. SEMU 3006 – STS-121 Return 03/2008

The Item-123 Fan/Pump/Separators from each of the first > 90 day but < 180 day water stagnation EMUs (3006 and 3008) were disassembled, examined, dimensionally checked and sampled at the USA Flight Crew Equipment Facility in Houston in May of 2008. Examinations were conducted with the unaided eye and microscopically. Sampling included surface swabs for microbial analyses and SEM/EDS for elemental analysis. Sampling also included chemical analysis of small volumes of water using Ion Chromatography, Inductively Coupled Plasma Spectroscopy, and other laboratory standard methods.[7]

Though the water stagnation period for SEMU 3006 had been relaxed to < 180-days, there was only one incident of this hardware reaching a 90-day water stagnation period. As such, this hardware essentially represents what would be expected with the maintenance of a < 90-days water stagnation period.

Rotor S/N NT001 was removed from the SEMU 3006 Item-123 Fan/Pump/Separator (S/N 003). The rotor turned smoothly in the rotor cup via light hand turning, and there were no signs of carbon fines at the bottom of the rotor cup where the carbon bearing interfaces with the internal surface of the rotor, and no signs that "chattering" (vibrate in operation) had occurred during operation. There were minimal wear marks observed on the outer rotor body. There were no signs of precipitate or biofilm deposition on the rotor, the rotor housing wetted surfaces, the rotor cup, or the water inlet and outlet tubes. These findings suggested that the Transport Loop water entering the SEMU 3006 Item-123 was of a quality that would ensure continued functionality of this sensitive and critical hardware that was at the heart of the Transport Water Loop flow performance anomaly detailed in Hamilton Sundstrand internal report SVHS 5642. That was further supported by the SEMU 3006 transport loop water analysis results.[5,7]

2. SEMU 3008 – STS-121 Return 03/2008

In contrast, SEMU 3008 underwent two back-to-back periods of time where the transport loop water was stagnant for >90-days (134 and 141 days respectively). This hardware was really the first look at the viability of relaxing the <90-day stagnation requirement to <180-days.

Rotor S/N N3CO2 was removed from the SEMU 3008 Item-123 Fan/Pump/Separator (S/N 013). There was a slight "grittiness" felt when the rotor was turned in the rotor cup via light hand motion, but for the most part, the rotor turned smoothly. This finding suggested a slight build-up of contaminants and/or particulates in the rotor/rotor cup area, an early indication of the type of Transport Loop flow disruption scenario encountered in late-2004. This data, coupled with the chemical analysis results from the SEMU 3008 Transport Loop water indicated for the first time that relaxation of the allowable transport loop stagnation time may be detrimental. [7]

A small amount of what appeared to be carbon fines appeared at the bottom of the rotor cup where the carbon bearing interfaces with the internal surface of the rotor, indicative that a degree of "chattering" (possibly induced by contaminants) may have occurred during operation. There were some wear marks observed on the outer rotor body. There were no visible signs of precipitate or biofilm deposition on the rotor, the rotor housing wetted surfaces, the rotor cup, or the water inlet and outlet tubes.

D. 12/02/08 – Present Item-123 Fan/Pump/Separator Findings

1. SEMU 3018 – STS-126 Return 11/2008

The Item-123 Fan/Pump/Separator from SEMU 3018 was disassembled, examined, dimensionally checked and sampled at the USA Flight Crew Equipment Facility in Houston in December of 2008. Examinations were conducted with the unaided eye and microscopically. Sampling included surface swabs for microbial analyses and SEM/EDS for elemental analysis. Sampling also included chemical analysis of small volumes of water using Ion Chromatography, Inductively Coupled Plasma Spectroscopy, and other standard laboratory methods.

During the disassembly process, Rotor U9AO disengaged from the rotor cap, so there was no opportunity to lightly turn the rotor in the rotor cup to check for "grittiness". The bond line of the rotor was examined visually and microscopically and appeared intact. There was a moderate amount of light green residue observed on the bottom of the rotor and to the sides of the carbon button itself. An examination of the rotor cup revealed a moderate amount of orange and green residue also observed at the bottom of the rotor cup.

Microbial swabs of the surfaces of the rotor, rotor cup and the pump housing revealed microbial surface counts in the range of $2.3 \times 10^2 – 3.8 \times 10^3$ CFU (colony forming units) per cm^2. SEM/EDS of residue swabs indicated the present of previously observed inorganic compounds (nickel, silicon, aluminum) and organic material.

2. SEMU 3005 – STS-128 Return 09/2009

The Item-123 Fan/Pump/Separator from SEMU 3005 was disassembled, examined, dimensionally checked and sampled at the USA Flight Crew Equipment Facility in Houston in October of 2009. The rotor turned smoothly in the rotor cup with no signs of "grittiness". Minor discoloration was observed at the end of the rotor next to the carbon bearing. Overall, the wetted Fan/Pump/Separator hardware, including the rotor, appeared to be relatively clean.

3. SEMU 3011 – STS-129 Return 11/2009

The disassembly of the Fan/Pump/Separator from SEMU 3011 occurred in January 2009 at the USA Flight Crew Equipment Facility in Houston. There was not an out-of-the-ordinary scheduled hardware inspection, however after the rotor and rotor cup assembly dried, a uniform, white chalky substance that coated the surfaces of the rotor and rotor cup was observed. Swab samples were taken and SEM/EDS analysis and FTIR was utilized to identify the bulk of the residue as nickel, silicon and a fluorocarbon.

A detailed investigation ensued thereafter and it was determined that the ion exchange resin in the A/L CLR beds used for the last couple of transport loop scrubs of SEMU 3011 on orbit was essentially depleted of ion exchange capacity, so the A/L CLR bed was essentially not scrubbing contaminants out of the transport loop water. Cause and corrective actions are detailed in Section V of this paper.

4. SEMU 3006 – STS-2009 Return 11/2009

An unplanned examination of the SEMU 3005 Fan/Pump/Separator was conducted as part of the investigation into the SEMU 3011 residue investigation (Section IV.D.3 of this paper). Overall, the wetted Fan/Pump/Separator hardware, including the rotor, appeared to be relatively clean and the residue build-up observed in the SEMU 3011 Fan/Pump/Separator was deemed to be isolated to that hardware.

Based on these examination findings, the recommendation to adjust the maximum transport loop stagnation time to 180-days, or to some amount of time greater than 90-days appeared to be risky. As such, the recommendation to limit the maximum stagnation time in a SEMU transport loop to < 90-days post-Shuttle appeared warranted to ensure optimal operation of the SEMU hardware on ISS post-Shuttle.

V. ION BED REQUIREMENTS

Several of theA/L CLR beds used for 8-uses from 12/2008 to present underwent ion exchange resin and charcoal capacity testing to validate the 8-use requirement and to determine if there was an opportunity to extend the life of the beds. Nominal uses of the A/L CLR bed resulted in a validation of the 8-use life of the ion exchange resin and charcoal, so no requirement changes in that regard was recommended. There were two off-nominal occurrences related to the A/L CLR ion exchange resin that did result in other requirement changes unrelated to nominal resin life and those occurrences are elaborated on here.

A. SEMU 3011 – STS-129 Return 11/2009 – Fan/Pump Separator Residue

As previously mentioned in Section IV.D.3 of this paper, a white residue was observed on the Item 123 (F/P/S SV787993-14, S/N 010) removed from SEMU 3011. During EMU 3011 ISS tenure on-orbit, three separate ALCLR beds (S/N 1004, 1005 & 1007) were used in scrubbing the coolant loop. The three ALCLR beds were returned from orbit on flights STS-127 (S/N 1004, 1005) and STS-130 (S/N 1007). Each underwent evaluations of bed ion exchange resin capacity following bed disassembly.

Ion exchange capacity was determined from a modification of ASTM 3375-95a "Column Capacity of Particulate Mixed Ion Exchange Materials". Method modification was necessary due to volume constraints of the available resin samples from the A/LCLR filters. Along with the resin from S/N 1004, 1005 and 1007, virgin Purolite NRW36-SC resin was also evaluated for a baseline comparison. Duplicate capacity evaluations were conducted for each resin sample. Data obtained during this testing is displayed in Figure 3. [8]

The virgin resin sample showed a reduction in capacity of 8% during the capacity evaluations, which is likely due to age, as this specific lot was over two years old. In contrast, S/N 1004 and 1005 showed significant reductions of 95% and 80% from vendor specified capacity. This is likely due to the fact that S/N 1004 and 1005 were packed with resin material that had not been stored properly prior to packing of the A/LCLR beds. The improper storage resulted in dehydration of the resin beads, which contributed to a significant reduction in exchange capacity. Additionally, S/N 1004 and 1005 were both used on SEMU 3011 at the end of their on-orbit lives. S/N 1005 had one remaining use left, while the S/N 1004 last use was with 3011. Because such degradation in capacity occurred in both 1004 and 1005, high contaminant loads may have overwhelmed the ion exchange bed, allowing inorganic contaminants to pass through the A/LCLR bed and on to the SEMU 3011. S/N1007, which was packed with new resin material following the findings in September 2006, showed a remaining capacity of 40% of vender specified capacity. While this is a significant reduction in capacity, all indications point to S/N 1007 operating nominally during operation with 3011.[8]

A. Raw Ion Exchange Resin Shelf-Life Discrepancy

A significant other finding from the SEMU 3011 – STS-129 Fan/Pump/Separator white residue finding detailed in Section V.A of this paper was that the ion exchange resin supplier (Purolite) had reduced the ion exchange resin shelf-life from 5-years to 2-years from manufacture. It was determined that there were six affected A/L CLR beds in the field packed with ion exchange resin with expired (Apr. 2010) shelf life as follows:

- S/N 1003 and 1006 on ISS at the time – already used for 6 and 5 A/L CLT scrubs respectively at the time of the finding.
- S/N 1004 and 1007 that were on ISS at the time, neither used at the time of the finding
- S/N 1002 and 1005 that were to be launched on STS-133

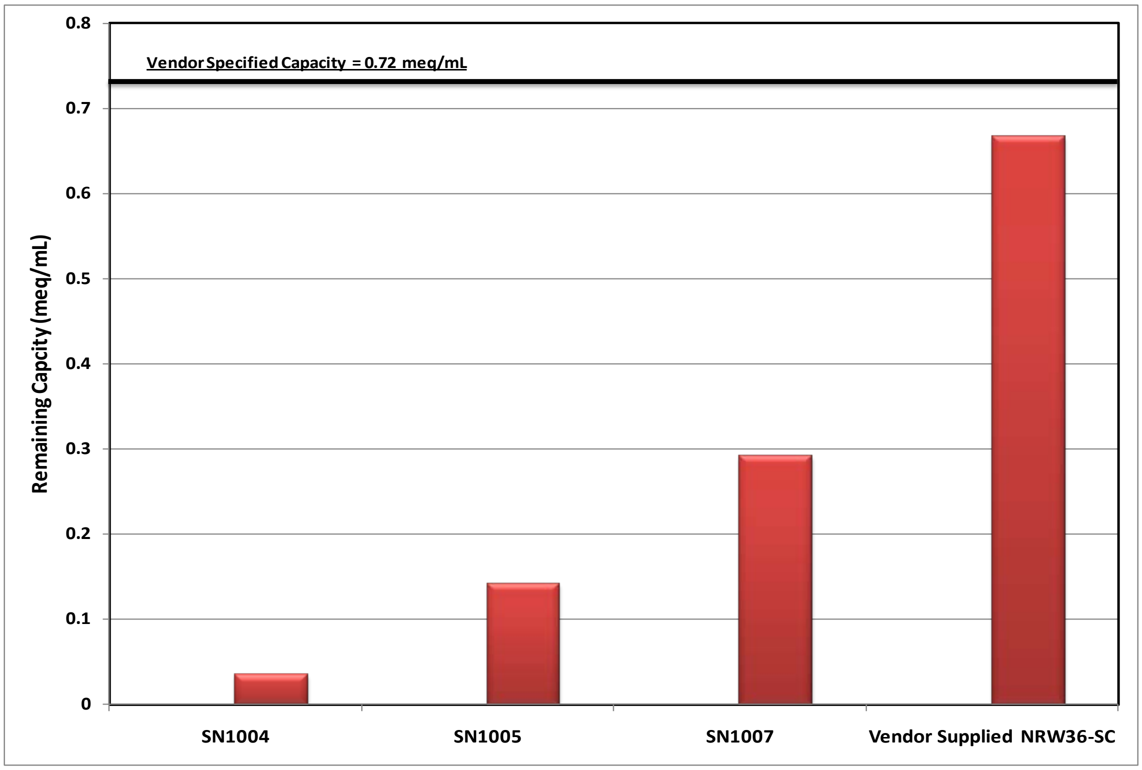

Figure 3. Ion Exchange Resin Capacity – A/L CLR Beds S/N 1004, 1005 and 1007

Freshly expired (Apr.2010) ion exchange resin underwent capacity testing at the time of the finding (Jul. 2010). Coupled with prior date, it was determined that there was an estimated 6% ion exchange capacity loss per year post-shelf life, leading to a recommendation to reduce the number of permissible A/L CLR bed uses by 1 per year for each year post shelf life expiration. A/L CLR beds S/N 1003 and 1006 were returned after 8 nominal uses and underwent capacity testing to validate the recommendation. [9]

The ion exchange resin capacity findings after 8-uses for A/L CLR beds 1003 and 1006 were 45% and 40% reductions (55% and 60% remaining) respectively. The recommendation at the time was to limit to a 70% reduction in IX resin capacity (30% remaining) as fully spent. This was to minimize the possibility of bed break-through and to add conservatism. Based on these findings , the recommendation to reduce the number of permissible A/L CLR bed uses by 1 per year for each year post shelf life was validated and deemed conservative The recommendation appeared to be conservative, and as such, an updated recommendation to reinstate the 8-uses for the remaining four affected A/L CLR beds (two in use on ISS and two that were pending launch on STS-133), and not impose a reduction in number of uses based on time post-shelf life.[9, 10]

Based on these findings, the recommendation for A/L CLR bed shelf-life was changed to the following:

- Pack beds with ion exchange resin manufactured within 1-year of the bed packing date.
- The shelf-life of a freshly packed A/L CLR bed was changed to 2-years after packing or 8 A/L CLR uses, whichever came first.

VI. A/L CLR REQUIREMENTS WITH NO CHANGES

A. 3-Micron Filters

Several 3-micron filters were returned from flight from 2008 to present. This filter resides down-stream from the A/L CLR bed during the SEMU transport loop scrubbing process. All examined filters were found to be relatively clean with small amounts of fractured ion exchange resin beads the only remarkable finding. As such, there was no driver to change the current requirements for 12-uses and to use within 2-years after the first use.

B. Pre and Post EVA Scrubs

The current requirements are to conduct an A/L CLR scrub of an SEMU transport loop within 4-weeks before an EVA, and to conduct an A/L scrub of an SEMU transport loop within 2-weeks after an EVA. There were no findings in the course of this evaluation time period that would drive a change in those requirements.

VII. CONCLUSIONS

The Table 3 chemical analysis data exhibits the distinction between SEMU hardware that does not undergo a periodic transport loop A/L CLR scrub process. Prior to the implementation of A.L CLR, the conductivity (41.0 umho maximum, and 19.1 umho average), an indication of the presence of ionic species, was relatively high. Typical ion contaminants included ammonium, sodium, potassium, fluoride, chloride, phosphate, sulfate, aluminum, nickel and silicon. After the incorporation of the ≤ 90 day A/L CLR cycle, conductivity findings on the SEMU transport loop water (exemplified in Table 3 SEMU 3009 and 3010), were reduced to < 8 umho, with most of the previously mentioned ionic species at below detection limits. Prior history has shown that poor water quality coupled with extended duration water stagnation periods has lead to the ceasing up the I-123 Fan/Pump/Separator, resulting in a non-functioning SEMU transport loop. [1-3]

Prior to A/L CLR implementation, TOC, NVR and microbial levels were relatively high – 23.3 ppm average for TOC (30.5 ppm maximum), 60.8 ppm ppm average for NVR (71.0 ppm maximum) and 1.3×10^7 CFU / 100 ml average (3.0×10^7 CFU /100 ml) respectively. After the incorporation of the ≤ 90 day A/L CLR cycle, TOC values have been typically < 2.0 ppm, NVR and microbial levels < 2×10^5 CFU / 100 ml.

A review of the Table 2, 3 and 4 data shows that when A/L CLR scrub cycles of ≤ 90 day are adhered to (SEMU 3006 STS-121 return no periods with > 90 days water stagnation; SEMU 3005 STS-128 return, one A/L CLR cycle after 92-day water stagnation), the transport loop water quality has remain good. Once longer transport loop water stagnation periods > 90-days are experienced as with SEMU 3008 STS-121 return (134 and 141 back-to-back stagnation periods), SEMU 3003 and 3018 STS-126 return (water stagnation periods ranging from 101 – 148 days), and SEMU 3011 STS-129 return (water stagnation period of 135-days – but with the extenuating circumstance of two A/L CLR beds with limited capacity), significantly poorer water quality was observed.

Examinations of the I-123 Fan/Pump/Separator SEMU hardware post-flight yielded findings that paralleled those observed with the SEMU transport loop water. When the SEMU hardware underwent A/L CLR scrub cycles with < 90-day water stagnation periods for the transport loop water, as with SEMU 3006 STS-121 return and SEMU 3005 STS-128 return, the I-123 Fan/Pump/Separator hardware appeared to be relatively free of precipitate deposits and the rotor in the magnetically coupled pump spun smoothly with light finger turn. In contrast, when the SEMU hardware underwent A/L CLR scrub cycles with significantly > 90-days transport loop stagnation periods, as with SEMU 3008 STS-121 return, SEMU 3018 STS-126 return, and SEMU 3011 STS-129 return, precipitate deposits were observed. In one case (SEMU 3008 STS-121 return), the Item-123 Fan/Pump/Separator rotor exhibited a degree of "grittiness" upon lightly spinning the rotor in the rotor cup. This is considered an early sign of what may have eventually resulted in a ceased rotor had the > 90-day water stagnation periods continued or were repeated.

A significant conclusion drawn from the last two years of SEMU transport loop water analyses and Item-123 Fan/Pump/Separator examinations is that the recommendation to adjust the maximum transport loop stagnation time to180-days, or to some amount of time greater than 90-days would be risky. As such, the recommendation to limit the maximum stagnation time in a SEMU transport loop to < 90-days post-Shuttle appears warranted to ensure optimal operation of the SEMU hardware.

Two incidents with the A/L CLR bed ion exchange resin that impact the A/L CLR bed requirements occurred during the 2008 – present evaluation period. In one occurrence, a residue found in the SEMU 3011 Fan/Pump/Separator that was returned on STS-129 was linked to improperly stored and expended ion exchange resin in two A/L CLR beds. The ion exchange resin had dried and had lost a significant amount of ion exchange capacity. A recommendation to repackage received ion exchange into moisture barrier containers was made. That recommendation has since been implemented. Also, due to a shelf-life change by the supplier of the ion exchange resin from 5-years, to 2-years, a recommendation was made to purchase recently manufactured ion exchange resin (within 1- year of manufacture) for A/L CLR bed packing, and to limit shelf-life to 2-years after packing or 8 A/L CLR uses..

Final requirements were therefore proposed for use of the A/L CLR hardware in the post-Shuttle era (see Table 5)

Activity	**Item**	**Initial Requirements 2004**	**Final Requirements 2011**
Max stagnation time	EMU	90-days	90-days
Pre-EVA scrub	EMU	≤ 2-weeks	≤ 4-weeks
Post-EVA scrub	EMU	≤ 2-weeks	≤ 2-weeks
Number of uses	Ion bed	4	8
Shelf life after first use	Ion bed	2-years	N/A
Shelf Life After Packing	Ion Bed	N/A	2-years
Ion Exchange Resin	Ion Bed	N/A	• Purchase within 1-year of manufacture • Upon receipt, transfer to moisture barrier storage
Number of uses	3-micron filter	1	12
Shelf life after first use	3-micron filter	N/A	Use within 3-years after first use

Table 5. Initial and Proposed Final A/L CLR Component Requirements

VIII. REFERENCES

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[8] Rector, T., 'Post Flight Analysis of AL CLR Beds", Hamilton Sundstrand Internal Document SVME: 6436, 06/30/2010.

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[10] PENDING MEMO