SERFE Ground Unit EVA Series after Three Year Spacesuit Stowage Period

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NASA's spacesuit government reference design for returning to the Moon is called the Exploration Extravehicular Mobility Unit (xEMU). The xEMU subassembly that provides life support, such as oxygen and thermal control, is the Portable Life Support System (PLSS). Inside the PLSS is a new technology that NASA wanted to test to provide cooling to the crew during EVAs (ExtraVehicular Activity). This technology is called the Spacesuit Water Membrane Evaporator (SWME). In order to test SWME in an improved thermal control loop (TCL) both on Earth and in Space, the Spacesuit Evaporation Rejection Flight Experiment (SERFE) was created. The Ground unit, or testbed at Johnson Space Center (JSC), tested the cooling technology in Earth's gravity, while the Flight unit, or payload on the International Space Station (ISS), tested the cooling technology in micro-gravity. Since fluids flow differently in micro-gravity, testing in both environments would provide important data for improving cooling performance during EVAs. Both units completed 25 simulated EVAs with the same settings so SWME performance on the ground could be compared to the ISS. The Flight unit was completed first and performed EVAs on the ISS between 2020 and 2022. The Ground unit performed EVAs between 2021 and 2022. When the Flight unit came back from the ISS, it was taken apart for analysis. This analysis looked at how well SWME was able to maintain its heat rejection capability after various dwell times, such as a 90 day Airlock Coolant Loop Recovery (ALCLR) cycle, when the Extravehicular Mobility Unit (EMU) currently on the ISS would normally need maintenance. After a three year simulated spacesuit dwell, the Ground unit performed another EVA series in 2025 to test SWME's shelf life. The results from this test series will inform mission planning as NASA plans to go back to the Moon and beyond.

Acronyms and Nomenclature

ALCLR	=	Airlock Coolant Loop Recovery
Cl^-	=	Chloride
EMU	=	Extravehicular Mobility Unit
EVA	=	ExtraVehicular Activity
I_2	=	Iodine
I^-	=	Iodide
ISS	=	International Space Station
JSC	=	Johnson Space Center
LCVG	=	Liquid Cooling Ventilation Garment
PLSS	=	Portable Life Support System
SERFE	=	Spacesuit Evaporation Rejection Flight Experiment
Si	=	Silicon
SWME	=	Spacesuit Water Membrane Evaporator
TCL	=	Thermal Control Loop
TIC	=	Total Inorganic Carbon

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TOC = Total Organic Carbon
VES = Vacuum Exhaust System
xEMU = Exploration Extravehicular Mobility Unit

I. Introduction

THE Spacesuit Evaporation Rejection Flight Experiment (SERFE) is a high-fidelity experiment that tests some of the latest technology of the Exploration Extravehicular Mobility Unit (xEMU), which is NASA's government reference design of a next-generation spacesuit. The SERFE Flight unit and its SWME heat rejection technology was tested periodically on the ISS within an almost 2-year period. Non-operating time, or quiescent dwell periods, simulated spacesuit stowage periods. The "SERFE Overview" paper documents how SWME cooling technology works and is implemented into the SERFE Unit. [1] While a simulated crew member (heater representing an astronaut's metabolic output) is performing a simulated Extravehicular Activity (EVA) (SWME is exposed to vacuum through the Vacuum Exhaust System (VES)), warm water is pumped through SERFE's Liquid Cooling and Ventilation Garment (LCVG) simulator by one of its two water pumps. When the SWME fibers are exposed to vacuum during the EVA, warm water vapor is exhausted into space and cools the TCL. During dwell periods, corrosion, microbial growth, and polymer leaching can occur when the system is at ambient temperatures, water is not circulating in the TCL, and the water loop is not experiencing degassing through the SWME membranes to vacuum. Dwell periods, such as an EMU 90-day Airlock Cooling Loop Recovery (ALCLR) cycle, were therefore included in the test profile to see how well the system performed after these spacesuit stowage periods.

Figure 1. SERFE Flight Unit (S/N 1001) and Ground Unit (S/N 1002) at JSC.

A second unit, the SERFE Ground Unit, was tested in conjunction with the Flight unit at Johnson Space Center (JSC). See Figure 1. Both units performed 25 simulated EVAs with matching settings; Table 1 summarizes the Flight and Ground unit testing profiles. A "Tel/comm check" test assessed power-on and instrumentation functionality, while a "Functional" test did not assess heat rejection capability but did assess all other operational functionality of the SERFE unit. Numbered entries in the "EVA series" column show when multiple EVA were carried out consecutively to simulate a mission timeline without a significant dwell time. When the Flight Unit returned from the ISS in 2022, it was disassembled at JSC and inspected for signs of material and performance degradation. These results are discussed in the "SERFE PLSS Component Lessons Learned from ISS" paper.[4] It was decided to keep the Ground unit as a testbed so the spacesuit team could test SWME's shelf life. The Ground unit contained the longest quiescent PLSS water loop to date. The Ground unit was powered on after a three-year simulated spacesuit dwell in April of 2025. The Ground unit came on but could not communicate with the Thermal Loop Controller CON-450 that controls the water pumps of the TCL. These water pumps are needed to circulate water and test SWME heat rejection. In June of 2025, the team was able to replace the Ground unit CON-450 with a spare unit. Investigation into why the Ground unit CON-450 processor failed is in work, however the xEMU CON-450 design uses a different processor so failure of the SERFE Ground unit CON-450 is not concerning in regard to the xEMU design maturity. The team successfully performed SERFE Ground unit simulated EVA series 7 from August 19, 2025 to August 21, 2025. Results from that test series will be discussed here. The SERFE experiment will provide a useful reference for development of future spacesuits as NASA goes back to the Moon and beyond and spacesuits experience long dwell times. A three-year dwell could represent the time anticipated between a final test on the ground, storage, launch, and then activation as part of an advanced exploration mission.

Table 1. Testing profiles for SERFE Flight and Ground Units (EVA Series 1 to 6).

SERFE FLIGHT UNIT (SN 1001)				
EVA series	Dwell (days)	Dates	# of EVAs	Total EVAs
Ground Test Series				
1	18	3/10/20-3/13/20	4	4
Functional	32	4/14/2020	1	5
2	27	5/11/20-5/14/20	4	9
3	25	6/8/20, 6/10/20	2	11
Flight Test Series (ISS - US Lab)				
Functional	150	11/10/2020	1	12
1	N/A	11/11/20-11/14/20	4	16
2	92	2/22/21-2/25/21	4	20
3	30	4/5/21-4/8/21	4	24
Tel/Comm check	N/A	8/3/2021	--	--
Tel/Comm check	N/A	10/18/2021	--	--
4	211	11/15/21 - 11/19/21	4	28
Tel/Comm check	N/A	12/27/2021	--	--
5	45	1/4/22 - 1/7/22	4	32
6	91	4/11/22 - 4/15/22	5	37

SERFE GROUND UNIT (SN 1002)				
EVA Series	Dwell (days)	Dates	# of EVAs	Total EVAs
Ground Test Series				
Functional	50	9/8/2020	1	1
1	7	9/15/20-9/18/20	4	5
2	38	10/27/20-10/30/20	3	8
3	39	12/8/20-12/11/20	4	12
Flight Test Series (PLSS Development Lab)				
1	44	1/25/21-1/28/21	4	16
2	5	2/2/21-2/5/21	4	20
3	47	3/24-3/26/21, 3/29/21	4	24
4	210	10/25/2021 - 10/28/21	4	28
5	46	12/13/21 - 12/16/21	4	32
6	81	3/7/22 - 3/14/22	5	37

Many xEMU technologies like SWME have been a part of development efforts to reduce maintenance, decrease the sensitivity of the performance of the TCL to water quality issues, and increase the PLSS lifespan over the current EMU on ISS.[1] The EMU has had failures due to water quality issues, so ISS operations include water system maintenance, such as the ALCLR scrub of the LCVG, and ensuring source water used to charge an EVA suit follows JSC-66695 EMU Water Specification.[3] One of the main goals of the SERFE project has been to increase robustness and life of TCL technologies.

II. Ground Unit EVA Series 7

A. Thermal/Fluids Performance

The following section provides details on the thermal/fluids performance of the SERFE Ground unit during EVA Series 7. During this test series, the SERFE team performed four heat rejection sweeps to see how well SWME performed after a 3-year simulated spacesuit stowage period. Two EVAs tested the primary water pump PMP-423 and two EVAs tested the secondary water pump PMP-422. Each EVA included assessing heat rejection performance under 80W, 250W, 400W, and 600W targeted thermal loads, which is a parametric sweep used for assessing performance. During each EVA test day, an air injection test was performed prior to heat rejection testing using gas injection pump PMP-2123 to test SWME's degassing ability after such a long dwell. Each air injection test pumped 1 L of air into SERFE's LCVG simulator over 5 minutes and then gave SWME 10 minutes for degassing. One liter of air corresponds to the volume of an LCVG as if it were attached to the PLSS without any water in it.[1]

The primary thermal performance measures tracked in SERFE testing were the maximum capable SWME heat rejection, as well as the temperature of water exiting the SWME, recorded by temperature sensor TS-439. The maximum heat rejection capability was typically tested twice per test series when a heat input of 600 Watts was provided to the water loop. In combination with ambient heat gains, this would provide a heat input beyond what the SWME could handle based on predicted operational capacity, while still maintaining an exit water temperature of 50 °F (temperature goal for astronaut comfort). The heat rejection of the SERFE ground unit was calculated in 2 methods, the first by manner of a heat balance across the SWME (Equation 1) and the second based upon the mass flow into the system to maintain water levels (Equation 2). The calculated values for heat rejection for the entirety of this test series are shown below in Figure 2.

$$q_{Rej.} = \dot{m}_{flow} * c_p * \Delta T \quad (1)$$
$$q_{Evap.} = \dot{m}_{fill} * h_v \quad (2)$$

Where,

$\dot{m}_{flow}$ is the bulk mass flow of water through SWME (kg/s)
c_p is the specific heat of water, referenced at the average temperature in SWME (kJ/kg-K)
ΔT is temperature difference across the SWME (K)
$\dot{m}_{fill}$ is the mass flow of water into the SERFE unit which tops off the SERFE water level (kg/s)
h_v is the heat of vaporization of water, referenced at the average temperature in SWME (J/g)

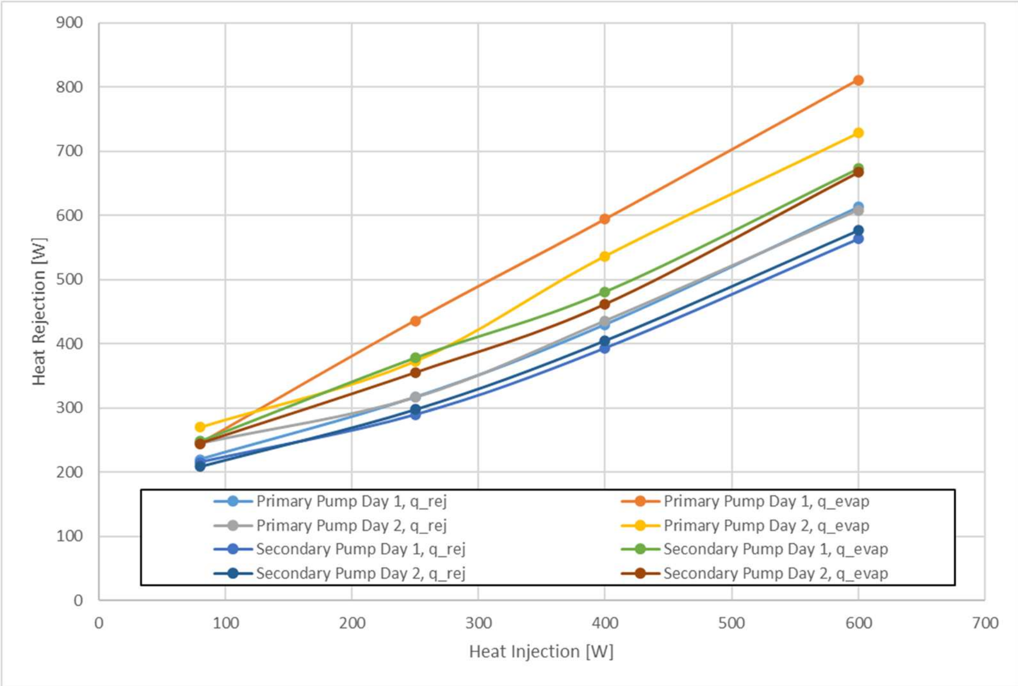


Figure 2: Calculated Heat Rejection of SERFE Ground Unit

As expected, as heat injection increased the heat rejection also increased as the Thermal Loop Controller CON-450 opened the SWME back pressure valve to allow for higher amounts of evaporation to occur within the SWME evaporator cartridge. The heat gain of the SERFE loop, from both on-board avionics heat and in-leak from lab ambient to the cold-water lines are the cause of the difference between heat rejection and heat injection. Figure 3 below averages the heat rejection values for a given test point and plots TS-439 against them to visualize the relationship between heat rejection and outlet temperature. The CON-450 tries to maintain a 50-degree Fahrenheit outlet temperature, but past a certain level of heat rejection the outlet temperature could not be maintained at that level. The discrepancy between the calculated heat rejected and the calculated heat evaporated is due to experimental uncertainty, principally the mass flow meter which measured the in-flow which maintained SERFE Ground Unit water levels. This mass flow meter has an uncertainty specification of 5%, however previous testing of the SERFE Ground Unit which compared the meter's reported values to mass measurements of the water supply observed an uncertainty as high as 45%, though most measurements had an uncertainty between 10 to 20%. It is possible that after the 3-year dwell period this flow meter has drifted from its initial calibration and has a greater uncertainty than previously identified.

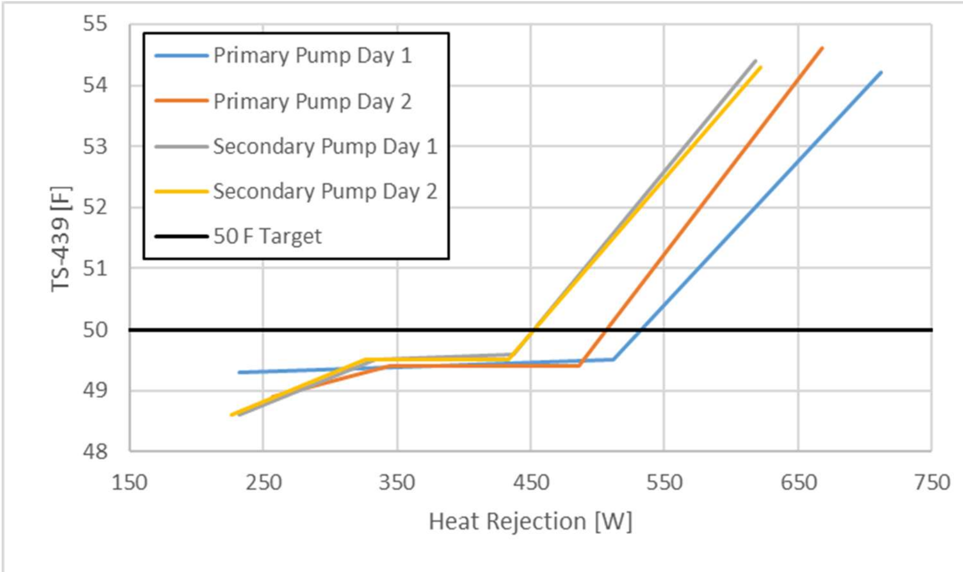


Figure 3: SWME Outlet Temperature as a function of Heat Rejection

While heat rejection of the SERFE ground unit, along with the SWME outlet temperature, are the primary values of interest, there were other data values which were relevant towards assessing the health of the Ground unit after a 3-year quiescent stowage. These values are reported below in Table 2**.** For more details on each value, see "SERFE Thermal Performance Results" paper. [2] All reported variables were averaged over the last minute of the heat rejection test point to ensure that the SERFE ground unit had reached a steady-state operation. The performance of the SERFE Ground unit was consistent when operating on the secondary pump, however there is a discrepancy when comparing the two EVAs operating on the primary pump. The cause of this has not been identified at this time.

Table 2: SERFE Ground Unit Performance

	8/19/2025 (Pri Pump)				8/20/2025 (Sec. Pump)			
Heater Setting	80 W	250 W	400 W	600 W	80 W	250 W	400 W	600 W
SWME Rejection (W)	**219.6**	**316.7**	**429.8**	**612.7**	**215.5**	**289.6**	**393.4**	**563.4**
SWME Evap Rej. (W)	**244**	**435.7**	**593.7**	**811.1**	**248.3**	**378.4**	**481.1**	**672.8**
BPV Potentiometer (counts)	3801	4651	5322	8685	3925	4637	5260	8624
BPV Step Count (counts)	2980	3836	4530	8000	3153	3881	4516	8000
PT-2001 (torr)	1.996	3.458	4.544	6.228	2.168	3.43	4.476	6.188
TS-441 (°F)	51.6	53.7	55.4	62.5	50.9	53.5	55.1	62.3
TS-439 (°F)	49.3	49.4	49.5	54.2	48.6	49.5	49.6	54.4
Flow Rate (pph)	251.3	251.5	251.5	251.9	242.5	242.1	242.5	243.2
Heater Output (W)	83	239	340	518	87	239	338	526
Heater Flow Rate (pph)	226.4	219.8	218.8	216.8	226.4	228.7	227.3	228.3
Heater Power (W)	85	269	432	650	85	269	432	650
	8/20/2025 (Pri. Pump)				8/21/2025 (Sec. Pump)			
Heater Setting	80 W	250 W	400 W	600 W	80 W	250 W	400 W	600 W
SWME Rejection (W)	**245.4**	**316.7**	**435.6**	**607.5**	**208.9**	**297.9**	**405.2**	**576.8**
SWME Evap Rej. (W)	**269.7**	**372.5**	**536.4**	**728.1**	**244.3**	**354.7**	**461.4**	**666.8**
BPV Potentiometer (counts)	4007	4767	5480	8466	3024	4623	5336	8658
BPV Step Count (counts)	3404	4173	4903	8000	3856	3840	4584	8000
PT-2001 (torr)	2.32	3.574	4.586	6.196	2.02	3.418	4.51	6.156
TS-441 (°F)	51.4	53.7	55.3	62.8	50.8	53.7	55.2	62.4
TS-439 (°F)	48.9	49.4	49.4	54.6	48.6	49.5	49.5	54.3
Flow Rate (pph)	251.7	251.3	251.5	252.3	243.2	242.8	242.6	243.9
Heater Output (W)	85	246	345	519	87	249	340	520
Heater Flow Rate (pph)	194.6	195.1	197.3	190.7	213.8	217.7	215.8	216.7
Heater Power (W)	90	269	432	650	85	269	432	650

Of particular interest regarding performance is the mass flow rates within SERFE. The bulk mass flow rate, labeled as just "Flow Rate (pph)" in the table, is calculated based off pump RPMs, with each pump having an independent equation. Since equations which were developed to calculate this flow rate were not re-evaluated as part of this test series, it is possible that after the stowage period that the flow rate calculation may have some additional uncertainty compared to when they were first implemented into the SERFE ground unit.

Comparison to the previous SERFE ground unit performance was carried out and is tabulated below in Table 3. A key parameter which changed is the heat rejection of the SERFE ground unit for both methods of calculation for a given setpoint. It should be noted that for the 80, 250, and 400 Watt heater setpoint that the heater injection was less than the previous years which accounts for part of the reduction in heat rejection. Another key change in performance is that the vacuum pressure measured by the SERFE ground unit was significantly higher compared to the test data prior to the stowage period. Since the heat rejection capacity of SERFE is inversely proportional to the vacuum pressure, this is the likely driver of the reduction in heat rejection. Two other key parameters which had significant change are the bulk mass flow rate and heater flow rate, which were approximately 14.7% and 7.9% higher, respectively. An interesting change that was observed what that the heater electrical power draw was higher on average by approximately 5%, but the thermal output of the heater was lower on average by approximately 3%. Finally, an interesting trend which was observed is that the outlet temperature of the evaporator was hotter than prior testing. The SERFE ground unit controls the Back-Pressure Valve (BPV) position to maintain a 50-degree Fahrenheit setpoint with a 1.5-degree Fahrenheit control band. Prior to the quiescent stowage period, there was some over-cooling observed for the 80 and 250 Watt test points. During this round of testing, there was no overcooling under those test points observed.

Table 3: Comparison of 2022 and 2025 SERFE Ground Unit Performance

	2022 Average				2025 Average				2022 to 2025 Percent Change [%]			
Heater Setting	80 W	250 W	400 W	600 W	80 W	250 W	400 W	600 W	80 W	250 W	400 W	600 W
SWME Rejection (W)	**246.405**	**381.245**	**483.38**	**654.755**	**222.35**	**305.225**	**416**	**590.1**	**-9.76**	**-19.94**	**-13.94**	**-9.87**
SWME Evap Rej. (W)	**262.69**	**437.53**	**531.94**	**683.065**	**251.575**	**385.325**	**518.15**	**719.7**	**-4.23**	**-11.93**	**-2.59**	**5.36**
BPV Potentiometer (counts)	3662.5	4531.5	5490	8029	3689.25	4669.5	5349.5	8608.25	0.73	3.05	-2.56	7.21
BPV Step Count (counts)	3365.5	4348	5385.5	8000	3348.25	3932.5	4633.25	8000	-0.51	-9.56	-13.97	0.00
PT-2001 (torr)	1.875	2.97	3.75	5.035	2.126	3.47	4.529	6.192	13.39	16.84	20.77	22.98
TS-441 (°F)	51.475	53.375	55.435	64.105	51.175	53.65	55.25	62.5	-0.58	0.52	-0.33	-2.50
TS-439 (°F)	47.555	47.285	47.705	53.63	48.85	49.45	49.5	54.375	2.72	4.58	3.76	1.39
Flow Rate (pph)	215.65	215.455	215.4	216.03	247.175	246.925	247.025	247.825	14.62	14.61	14.68	14.72
Heater Output (W)	97.6	243.585	343.685	515.37	85.5	243.25	340.75	520.75	-12.40	-0.14	-0.85	1.04
Heater Flow Rate (pph)	200.52	200.25	198.325	196.685	215.3	215.325	214.8	213.125	7.37	7.53	8.31	8.36
Heater Power (W)	97.885	255.655	387.105	563.325	86.25	269	432	650	-11.89	5.22	11.60	15.39

SERFE Water Usage is measured via the flow meter (FM-2034A) which maintains water supply to the test article during operations. See Table 4 for water usage during Ground unit EVA 7. Note that on August 20, 2025, the Ground unit performed 2 Heat Rejection sweeps, which is why the water usage is significantly higher.

The degassing performance of SERFE is another measure of SWME membrane performance, since it shows how much the membrane porosity impedes removal of fluid other than water (in this case air).[2] During each day of SERFE Ground EVA 7, approximately 1 L of air was injected over approximately 5 minutes. The goal is to degas the TCL loop under 10 minutes. The volume of gas injected is recorded along with the estimated degassing time according to each SERFE bubble detector. The Flight Unit sensors were always able to degas the TCL in under 10 minutes[2]. During Ground EVA 7, the Ground Bubble detectors never showed degassing of the TCL in less than 10 minutes. However, the bubble detectors on the Ground Unit have a history of being very unreliable and rarely provided a bubble "not detected" status during a gas injection testing mode[2]. Beyond thermal performance, SERFE Ground EVA 7 degassing performance was found to be inconsistent, most likely due to the reliability of the bubble detector sensors.

Table 4. SERFE Ground EVA Series 7 water usage.

Water Usage			
Date	8/19/2025	8/20/2025	8/21/2025
Water Usage [L]	1.749	3.16	1.801
Water Usage [kg]	1.748	3.159	1.800
Time [min]	367.7	451.3	436.9

B. Water Quality

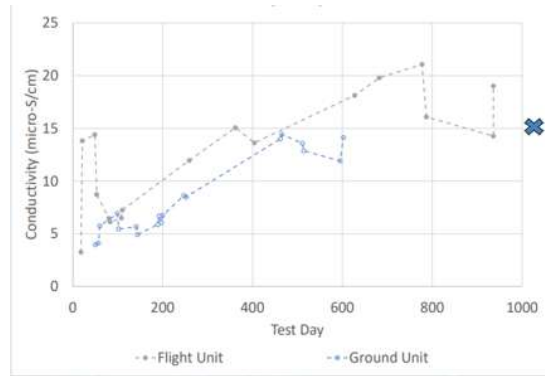
As documented in "SERFE Water Quality Results[3]," water quality inside SERFE's TCL degrades over time. Some constituents continually increase and some stabilize at levels not normally acceptable in a spacesuit. Water quality data for SERFE Ground EVA Series 7 is presented in this section. As usual with simulated SERFE EVAs, a water sample was taken Pre-EVA and Post-EVA from the SERFE Ground unit.

Table 5. SERFE Ground unit Series 7 Pre-EVA and Post-EVA water sample collection summary.

Pre-EVA		Post-EVA	
Type of Analysis	**Volume Collected (mL)**	**Type of Analysis**	**Volume Collected (mL)**
full chemistry	250	full chemistry	150
microbial	250	microbial	50
volatile/semi-volatile organics	250	volatile/semi-volatile organics	150
nonvolatile organics	250	nonvolatile organics	100
Total	**1000**	**Total**	**450**

The water quality analysis performed for both SERFE units was tested for many contaminants and chemicals. The most important of these were: iodine, iodide, silicon, and chloride concentrations; water conductivity; Total Organic and Inorganic Carbon (TOC/TIC); and the microbial count. [3] See below collection of plots for most of this data. Note that the time axis is in test days, which normalizes the time scale of both units to the number of days after the final pre-test water flush performed on each SERFE unit.

Many of the measured variables increased over time for both SERFE Flight and Ground units. In general, the trends accompanying these increases were similar between the two units, however there are some discrepancies. Beginning with the iodine and iodide concentrations, there is very little change in iodine relative to iodide, which is expected as the former converts to the latter following interaction with other wetted materials in the system. It was noted that during previous SERFE testing that sampling large volumes of water likely removed iodide-heavy water and replaced it with unused, iodinated water. [3] See Table 5 for quantity of water sampled prior to SERFE Ground unit EVA 7.



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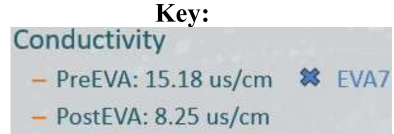
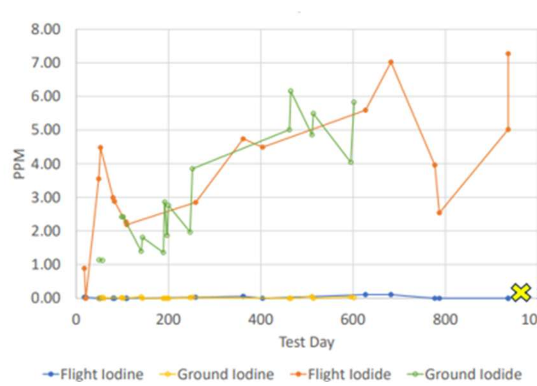


Figure 5. Conductivity water quality results of SERFE Ground unit EVA Series 7 (added to graph of Flight and Ground unit EVAs 1 to 6).

For Pre-EVA samples, the team had planned to take smaller water samples but the toggle for the water sample pump switch that would normally provide 75mL of water at a time was not working (the water sample pump switch was not essential to SERFE operations so failure was not investigated). Since the water sample pump switch was not working, a test engineer had to start and stop each water pump by issuing manual commands. The team could not take a water sample without priming the water pumps (circulating each water pump for 5 minutes each), so the team essentially flushed the SERFE water loop. For Post-EVA samples, the team was able to take more controlled water samples (minimum amount of water sample needed for analysis).

Fresh water was added to the system with iodine between 1 to 4 ppm during the EVA. This is the active biocide for the water in the loop. Unfortunately, iodine reacts quickly with the wetted materials in the system (like the high surface area polypropylene SWME fibers) or evaporates across the SWME membranes. Iodine readings are effectively 0 ppm, or below the detection level throughout the life of both SERFE units. Ground unit EVA 7 continues this trend. See Figure 4. Iodine added to SERFE represents periodic disinfection of water and not a residual, long-term biocide. Of note is that for EMU cooling water, biocidal iodine is rarely observed in water returned from orbit (low-level iodide is from 1 to 2 ppm). So, this is the driver for periodic addition of iodine to EMU coolant loop on orbit via the ALCLR process.



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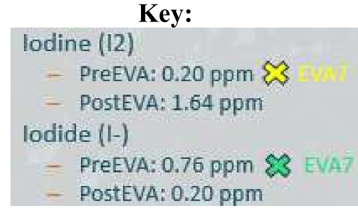

Figure 4. Iodine (I2) and Iodide (I-) water quality

The water conductivity displayed similar behavior to the iodide concentration for both SERFE Flight and Ground units. A large peak followed by a drop provides further evidence to the theory that this is due to incidental water loop flushing. A long-term rise in conductivity is anticipated as the buildup of non-volatile contaminants increases in a water loop where water is continually evaporated. Many of the constituents are metals and maybe corrosion byproducts. SERFE TCL wetted metallics include: Stellite 6b (cobalt, nickel, iron, aluminum, chromium, manganese, molybdenum), Hastelloy C276 (nickel, molybdenum, chromium), and 316L stainless steel (iron, chrome, nickel, molybdenum). Ground unit EVA 7 continues this trend. See Figure 5.

Concentrations of TOC and TIC have historically risen to much higher values than expected in both SERFE units for a water system. The cause has been discussed in previous papers, but to summarize, the most likely source was the EA9313 epoxy resin used in the LCVG simulator[3]. TOC appears to rise after long quiescent periods, but the values start to stabilize when the system is operated more regularly. TIC levels are usually undetectable (below 0.5 ppm), and this is normal for a water system[3]. Ground unit EVA 7 continues this trend. See Figure 6.

The presence of silicon and chloride in the water loop can be of concern. The presence of silicon likely indicates the degradation of the Ethyl-Vinyl Acetate (EVA) tubing in the water loop that makes up the LCVG simulator. Chloride can contribute to metal corrosion. The likely source of Chloride is the EA9313 epoxy resin used in headers of the LCVG simulator since a vacuum bake out was not performed like it was on the SWME cartridge. Both constituents rose in concentration over the life of both SERFE units and are higher than typical EMU water, which is in the range of 1 to 2 ppm. Ground unit EVA 7 continues this trend. See Figure 7.

The final contaminants to make note of are microbes. Both SERFE units normally showed values typically in the range of $1x\ 10^5$ to $1x\ 10^6$ CFU/mL. For comparison, EMU water is typically in the range of $7.5x\ 10^1$ to $2.9x\ 10^5$, with an average of around $1.0x\ 10^3$ CFU/mL. Ground unit EVA 7 continues this trend with a Pre-EVA value of 4.5×10^5 CFU/mL and a Post-EVA value of 2.5×10^4 CFU/mL. Previously identified microbes in the Ground unit were Ralstonia picketti, Caulobacter species, unidentified gram-negative rod, Bradyrhizobium Denitrificans, Sphingomonas echinoides, and Burkholderia species. These film-forming bacteria are commonly found in water systems, including the EMU coolant loop. This test series found Ralstonia picketti, unidentified gram-negative rod, Burkholderia species, and Ralstonia insidiosa in the SERFE Ground Unit. These bacteria are descriptive of water-borne microorganisms but pose little-to-no risk to crew health.

Another important aspect to look at in SERFE water is surface tension. SWME membrane performance will be impacted if the fluid reaches 60 dynes/cm. Values for Flight and Ground testing have been typically near the nominal surface tension value of water at 72.2 dynes/cm, but they have shown a slight decrease over time. In SERFE Ground EVA 7, the surface tension value for Pre-EVA was 70.99 dynes/cm and Post-EVA value was 72.22 dynes/cm. Since current surface tension is not close to the value of 60 dyne/cm, SWME membranes should be functioning nominally.

Overall, the water quality data for SERFE shows that the water loop in both Flight and Ground units can have a significant buildup of contaminants, especially TOC and microbes. When compared to typical EMU water, SERFE water quality is not as tightly controlled as historical spacesuit life support systems. However, life support technologies, such as the SWME, have continued to perform well, even after a simulated 3-year spacesuit stowage period. It should be noted that a detailed discussion on the water quality results observed here in regards to a flight configuration xEMU was outside the scope of this paper, however the SERFE units were constructed using expected xEMU flight materials when possible.

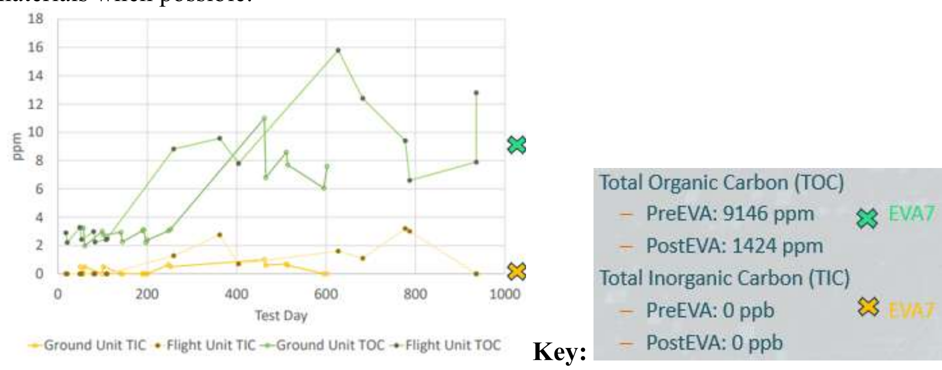

Figure 6. Total Organic Carbon (TOC) and Total Inorganic Carbon (TIC) water quality results of SERFE Ground unit EVA Series 7 (added to graph of Flight and Ground unit EVA Series 1 to 6).

III. Forward Plan

This section will provide a brief summary of the recovery of the SERFE Ground unit and the tentative forward plan for further testing and evaluation of the unit. Continued study of the SWME in a TCL is recommended for possible use in future spacesuits. Since the SERFE Ground unit is the best test bed to continue testing SWME, it was recommended to have additional working CON-450s as backups. Since the Flight CON-450 appears to be operational based on preliminary checks after Flight unit disassembly, the vendor will be requested to perform a full acceptance and inspection and then determine if any rework is required. Since the Ground CON-450 was not operating after a 3-year spacesuit stowage period, the team will work with vendor for as-received acceptance and rework to fix any identified areas.

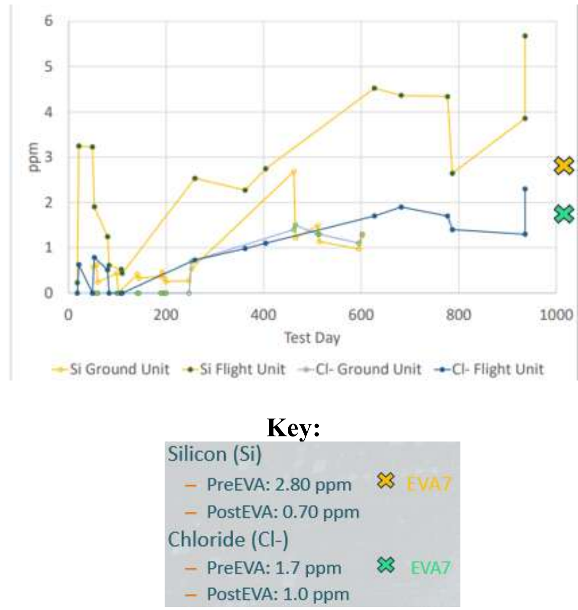

Figure 7. Silicon (Si) and Chloride (Cl-) water quality results of SERFE Ground unit EVA Series 7 (added to graph of Flight and Ground unit EVA Series 1 to 6)

The SERFE Ground unit has been previously stored with the SWME BPV open and the Vacuum Access Valve VAV-2005 closed. This is not reflective of the flight PLSS application and poses excessive corrosion risk for avionics. The test team will leave VAV-2005 open during storage. This will better simulate the condition inside a PLSS with a BPV open (abnormal but bounding storage condition) and reduce corrosion risk for avionics. In January of 2026, the team successfully tested updated settings of the VAV-2005 where it will remain open during storage. A relative humidity RH sensor was placed in VAV-2005 to take readings, with analysis of this data left as future work.

Continued evaporation across the SWME membranes and permeation through the ethyl vinyl acetate tubing in the LCVG simulator are potential sources of water loss during the over 3-year storage period between Ground EVA Series 6 in April 2022 and Ground EVA Series 7 in August 2026. Drying of the SWME cartridges can lead to leaks in the epoxy headers[4]; to mitigate this risk the SERFE Ground Unit water loop will be periodically topped off with iodinated water per JSC-66695. The team last topped off SERFE water in January 2026. Furthermore, a detailed effort to characterize how quiescent stowage directly leads to the observed deltas in performance should be carried out, with the goal to design in mitigation to the identified causes for a flight configuration next-generation spacesuit if possible.

After simulating a 365-day spacesuit storage period, the team will run another simulated EVA series in August 2026 to test SWME function. They will also take Pre- and Post-EVA water samples. It is under consideration to test SERFE yearly to test SWME lifespan for use in advanced exploration missions. When SWME no longer appears to be operational, the SERFE Ground unit will be torn down and inspected for additional lessons learned.

IV. Conclusion

The SERFE Ground Unit underwent a three-year quiescent stowage period, after which a test series investigated the performance of the unit to assess the ramifications of this technology being used in spaceflight. After the stowage period the avionics controller had to be replaced as it could not communicate with the SERFE Unit to operate the water loops. Once the CON-450 was replaced a short EVA series investigated operational capability along with water quality was executed, which revealed a decrease in heat rejection capability of the unit that is likely attributed to the increase in measured vacuum pressure. An assessment as to why the vacuum pressure was significantly higher compared to the pre-stowage test series has been considered but is left as future work. This test series provided insight as to how the SERFE Ground Unit, and therefore SWMEs, perform after long quiescent stowage periods. While the SERFE Ground unit is not an identical replica of the xEMU primary thermal control loop, it replicates all key design features and is the highest fidelity source of data on quiescent storage of water membrane evaporator cooling loops.

Furthermore, all planned testing goals were successfully completed: evaluating SWME heat rejection, degassing capabilities, and assessing water quality.

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