SERFE Ground Unit EVA Series after Three Year Spacesuit Stowage Period

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Agenda

- Introduction
- Ground Unit EVA Series 7
  - Thermal/Fluids Performance
  - Water Quality
- Forward Plan
- Conclusion
- Acknowledgements
- References

SERFE Flight Unit installation on ISS in 2020.
[Keeping Cool in Space - YouTube]

Introduction

- **SERFE evaluated new SWME cooling technology to keep astronauts cool in xEMU**
  - FLIGHT unit
  - GROUND unit
- **SWME**
  - Tech dev
    - ↓ TCL maintenance
    - ↓ TCL sensitivity to water quality
    - ↑ PLSS lifespan over current EMU on ISS
- **SERFE similar to xEMU primary TCL**
  - Key design features & highest fidelity source to test quiescent storage of SWME for return to Moon & beyond

NOTE: See Backup: Overview Graphic for link

SERFE: Space Evaporation Rejection Flight Experiment
SWME: Suit Water Membrane Evaporator
xEMU: eXploration Extravehicular Mobility Unit
(NASA's prototype advanced exploration suit)

Introduction

- **Tested GROUND unit after 3 year "suit" stowage period in 2026 to test SWME shelf life**
  - During dwells, corrosion, microbial growth, & polymer leaching can occur at ambient temperatures
- **Successfully evaluated SWME heat rejection, degassing, water quality**

NOTE: Results should be compared to earlier SERFE papers & analyses (see References)[1,2,3,4]

SERFE Flight Unit and Ground Unit at JSC.[5]

Introduction

- **Testing Profiles**
  - 25 simulated EVAs
  - 6 weeks of "EVAs"
  - SWME heat rejection & degassing
  - Water samples
  - Dwell times
    - 90 day ALCLR
    - 210 day

- **GROUND EVA 7**
  - 8/19/25 to 8/21/2025

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

Note: Quiescent duration based on pump circulation, which is typically the water sample taken before or after each EVA series shown.

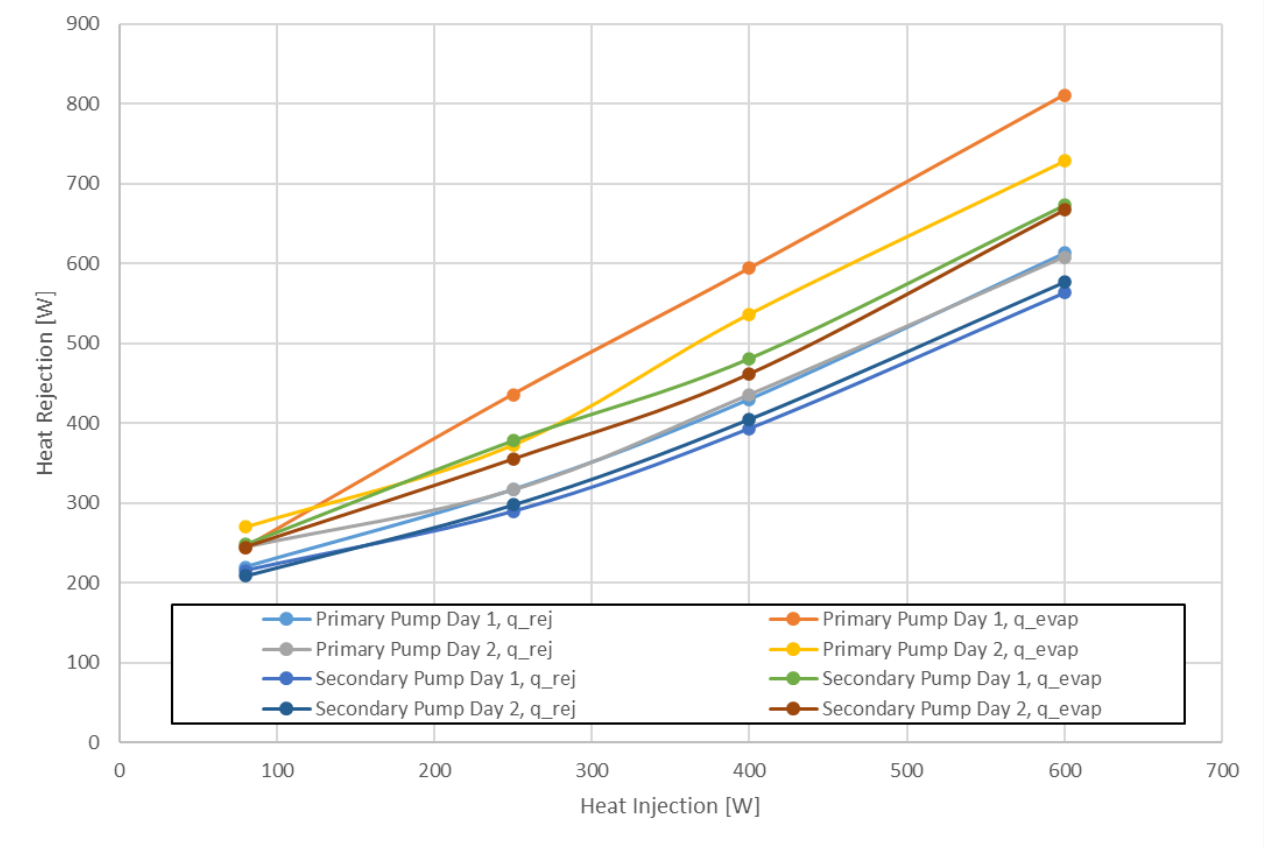
SERFE FLIGHT UNIT (SN 1001)				
EVA series	Dwell (days)	Dates	# of EVAs	Total EVAs
Ground Test Series				
1	18	3/10/20-3/13/20	4	4
Functional	32	4/14/2020	1	5
2	27	5/11/20-5/14/20	4	9
3	25	6/8/20, 6/10/20	2	11
Flight Test Series (ISS - US Lab)				
Functional	150	11/10/2020	1	12
1	N/A	11/11/20-11/14/20	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

Testing Profiles for SERFE FLIGHT & GROUND units (EVA Series 1 to 6).[5]

Ground test series: Testing at JSC
Flight test series: FLIGHT unit tested on ISS & GROUND unit tested at JSC

GROUND EVA Series 7

- **Thermal/Fluids Performance**
  - Primary thermal performance measures
    - Max capable SWME heat rejection
    - Temp of water exiting SWME (TS-439)
  - 4 EVAs
    - 2 with PMP-423
    - 2 with PMP-422
  - Air injection
    - 1L of air
  - Heat rejection performance
    - @80/250/400/600W
  - Goal
    - TS-439 maintain within 50F +/- 1deg

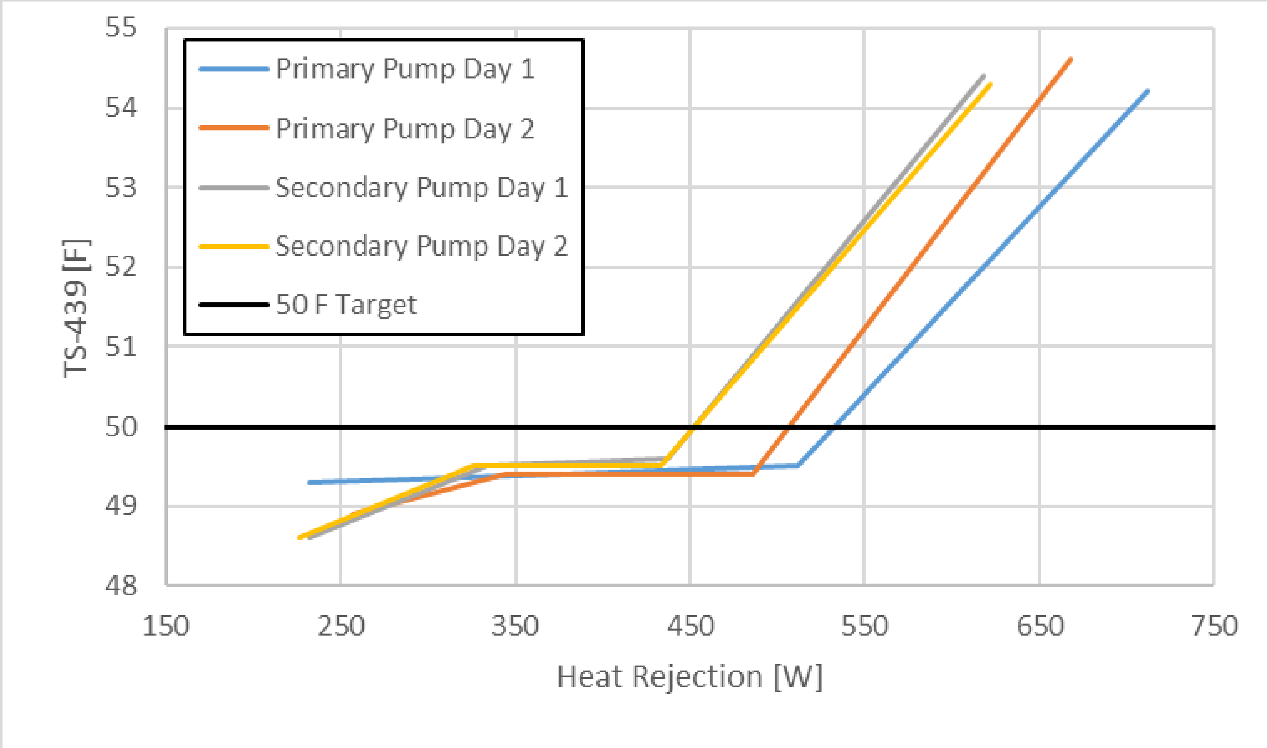


Calculated Heat Rejection of SERFE Ground Unit.[5]

Notes: Heat gain of the SERFE TCL loop from on-board avionics heat/in-leak from lab ambient to the cold-water lines are cause of difference between heat rejection & heat injection.

GROUND EVA Series 7

- **Thermal/Fluids Performance**
  - Visualize the relationship between heat rejection & outlet temperature
    - Averages heat rejection values for given test point
    - Plots TS-439 CON-450 tries to maintain 50F



SWME Outlet Temperature as a function of Heat Rejection.[5]

Note: Heat rejection and TS-439 are averaged over last minute of 600-Watt heat input tests.

GROUND EVA Series 7

- **Thermal/Fluids Performance**
  - Flow rate (pph)
    - Bulk mass flow rate
      - Based off of pump RPMs
      - Different for each pump

NOTE: For more details on each value, see “SERFE Thermal Performance Results” paper. [2]

	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

SERFE Ground Unit Performance.[5]

Note: 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.

GROUND EVA Series 7

Heater Setting	2022 Average 80 W	2022 Average 250 W	2022 Average 400 W	2022 Average 600 W	2025 Average 80 W	2025 Average 250 W	2025 Average 400 W	2025 Average 600 W	2022 to 2025 Percent Change [%] 80 W	2022 to 2025 Percent Change [%] 250 W	2022 to 2025 Percent Change [%] 400 W	2022 to 2025 Percent Change [%] 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

Comparison of 2022 and 2025 SERFE Ground Unit Performance.[5]

Notes: Heat rejection and TS-439 are averaged over last minute of 600-Watt heat input tests.

- **Thermal/Fluids Performance**
  - ↓ Heat rejection (SWME Rejection)
  - ↑ Vacuum pressure (PT-2001)

NOTE: Heat rejection capacity of SERFE is inversely proportional to vacuum pressure

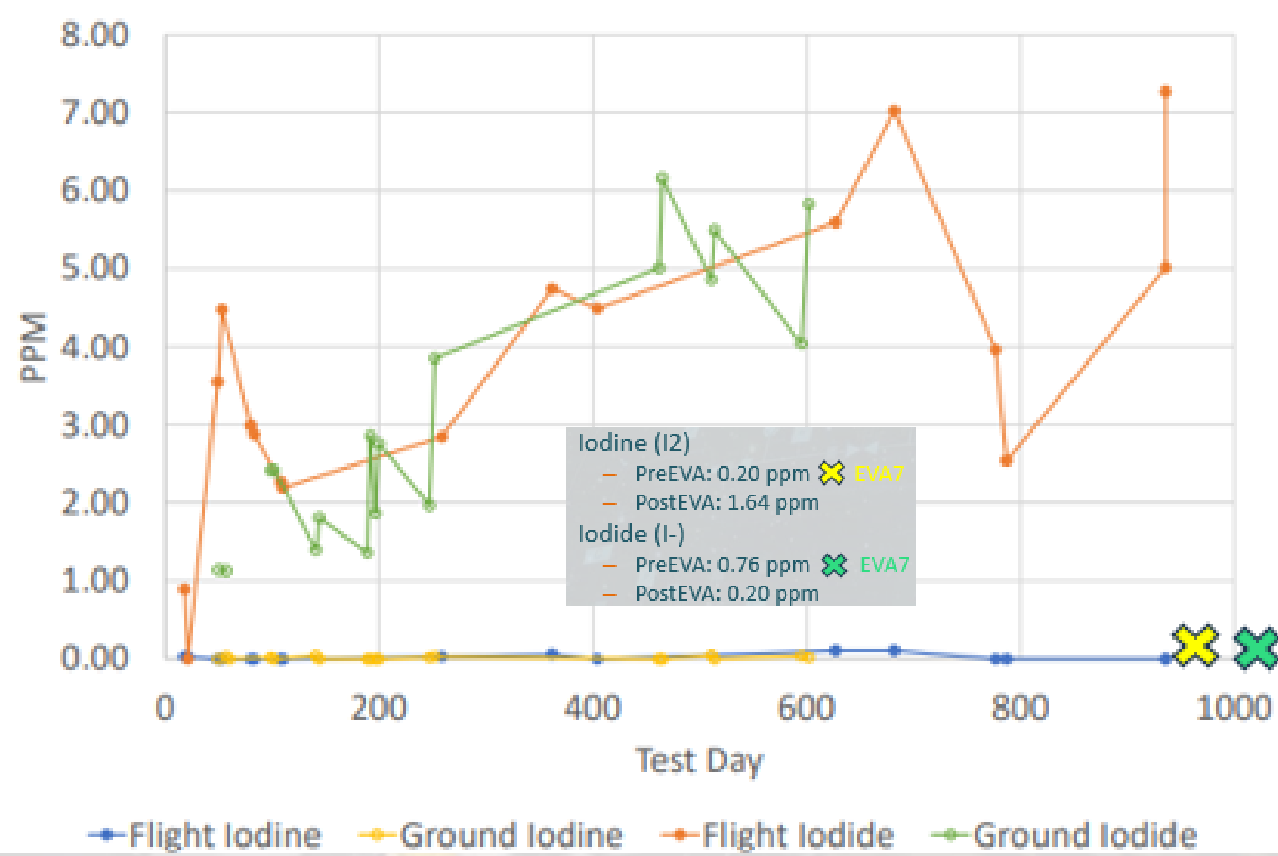
- TS-439 should maintain within 50F +/- 1deg
  - Averaged higher than EVA Series 6 in 2022

NOTE: Thermal loop controller CON-450 was swapped in GROUND unit

GROUND EVA Series 7

- **Water Quality**
  - ➢ Degrades over time in TCL
    - Some constituents continually increase
    - Some stabilize at levels not normally acceptable in spacesuit
  - ➢ Pre-EVA & post-EVA samples

- **Water Quality**
  - – Iodine is active biocide for water in loop
    - Expect decrease as Iodine converts to Iodide
      - – Periodic addition of Iodine during ALCLR

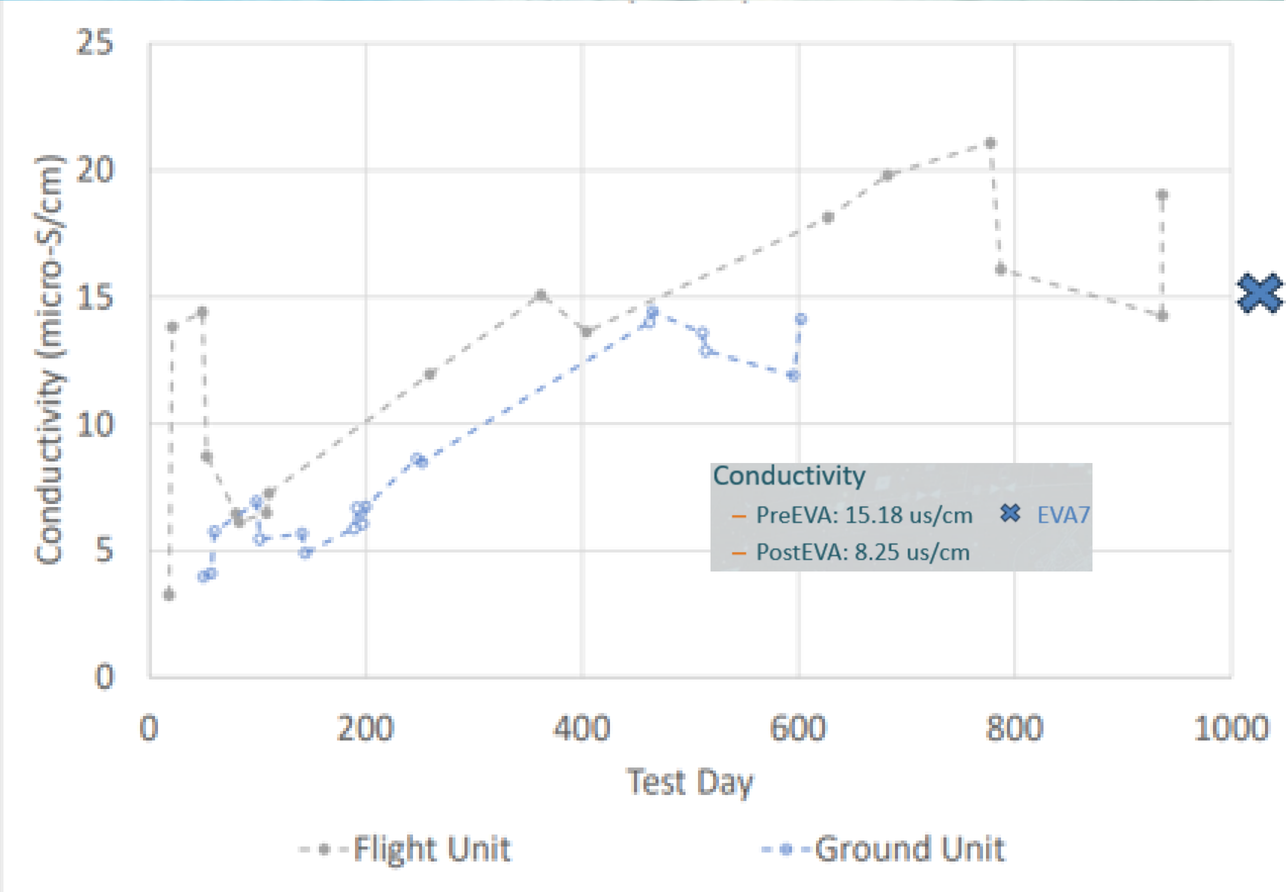


Iodine (I2) and Iodide (I-) water quality.[5]

Note: Time axis in test days = # of days after final pre-test water flush

GROUND EVA Series 7

- **Water Quality**
  - Long-term rise in conductivity anticipated
    - Buildup of non-volatile contaminants
      - Increase in water loop where water is continually evaporated
  - Many constituents are metals
    - Corrosion byproducts?
  - SERFE TCL wetted metallics
    - Stellite 6b (cobalt, nickel, iron, aluminum, chromium, manganese, molybdenum)
    - Hastelloy C276 (nickel, molybdenum, chromium)
    - 316L stainless steel (iron, chrome, nickel, molybdenum)

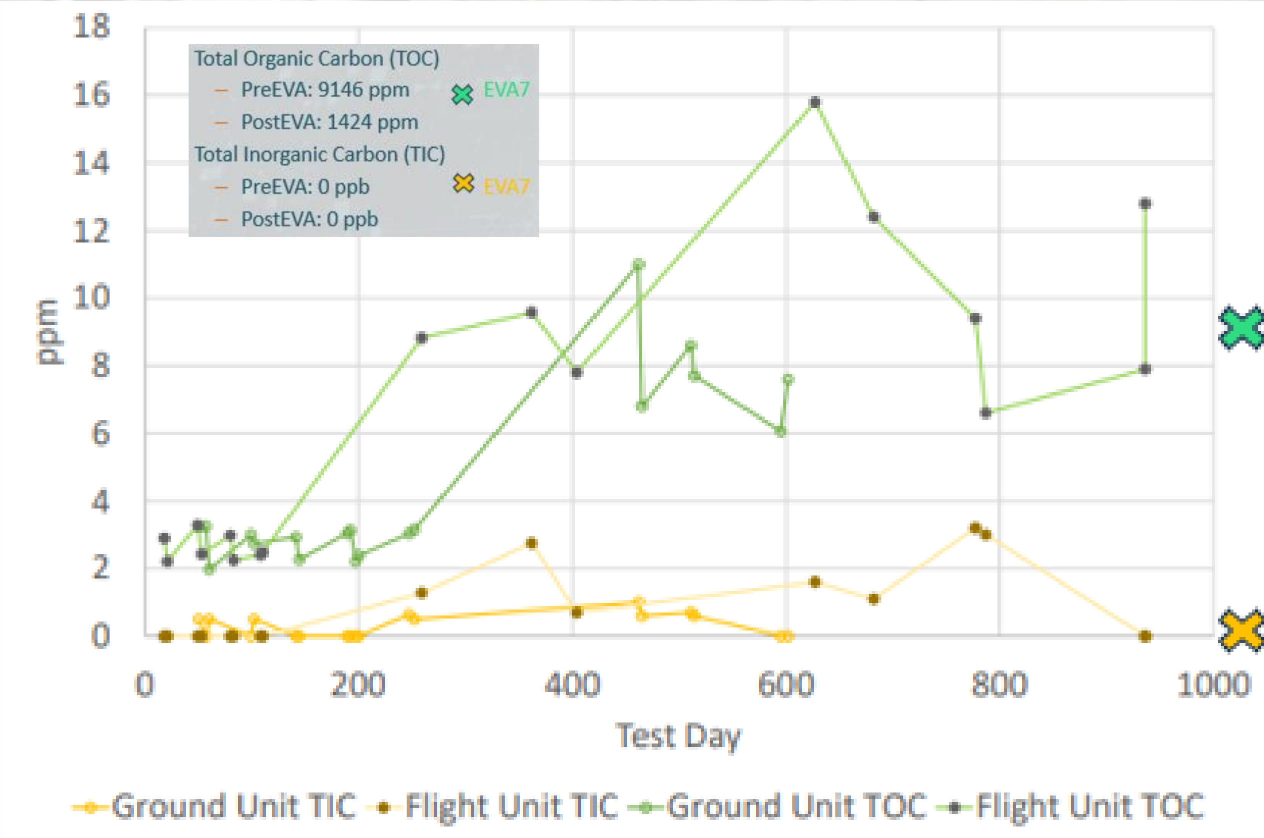


Conductivity water results.[5]

Note: Time axis in test days = # of days after final pre-test water flush

GROUND EVA Series 7

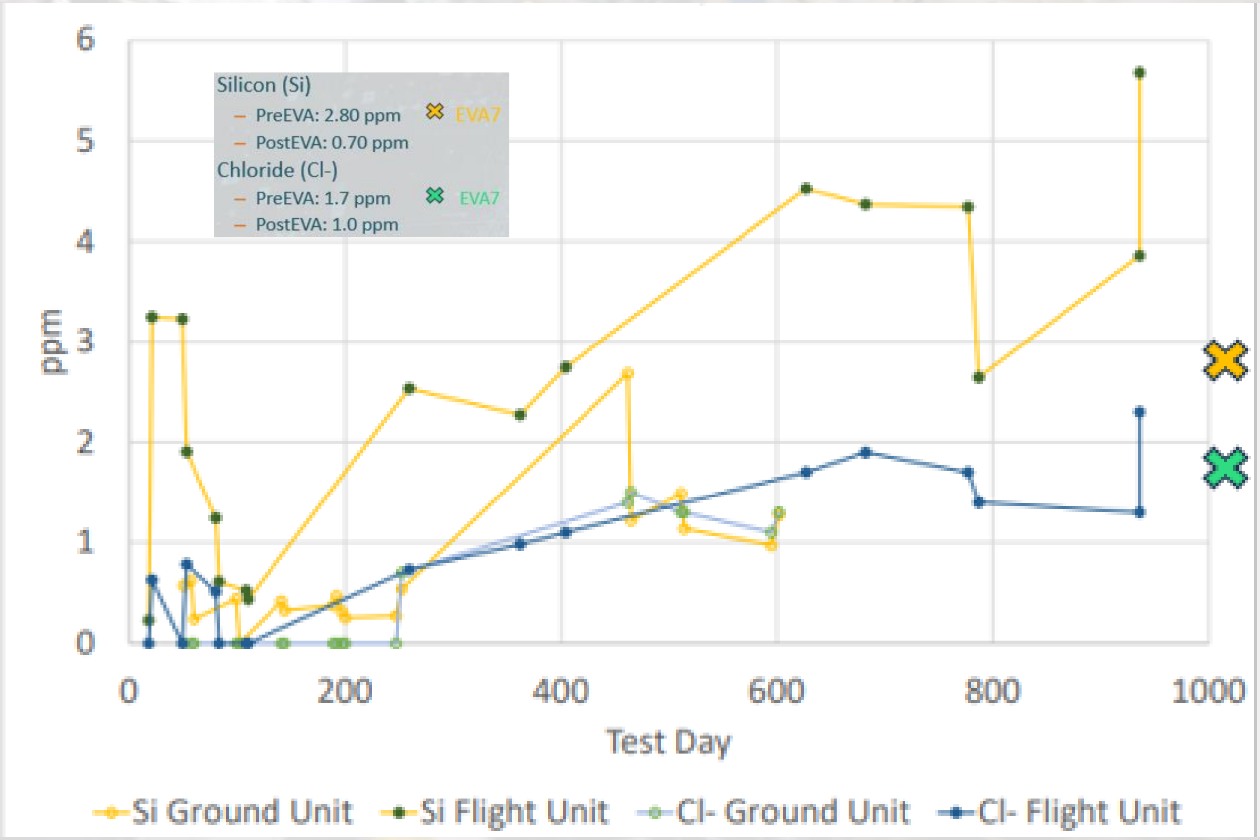
- **Water Quality**
  - TOC & TIC rise to higher values than expected in both SERFE units
    - EA9313 epoxy resin used in LCVG simulator?
  - TOC rises after long quiescent periods
    - Stabilizes when system operated regularly
  - TIC levels usually undetectable (<0.5 ppm)
    - Normal for water system



Total Organic Carbon (TOC) and Total Inorganic Carbon (TIC) water quality.[5]

Note: Time axis in test days = # of days after final pre-test water flush

- **Water Quality**
  - Silicon & chloride in water loop: concern?
    - Silicon: degradation of Ethyl-Vinyl Acetate (EVA) tubing in water loop that makes up LCVG simulator?
    - Chloride: metal corrosion?
      - EA9313 epoxy resin used in LCVG simulator?
  - Both rose over life of both SERFE units
    - Higher than EMU water (1 to 2 ppm)



Silicon (Si) and Chloride (Cl-) water quality.[5]

Note: Time axis in test days = # of days after final pre-test water flush

GROUND EVA Series 7

- **Water Quality**

➢ SERFE constructed using expected XEMU flight materials when possible

➢ Compared to typical EMU water
  - SERFE water quality is not as tightly controlled as historical spacesuit life support systems

➢ SWME has continued to perform well
  - Even after a simulated 3-year spacesuit stowage period

Forward Plan

- **Continued study of SWME in TCL is recommended for possible use in future spacesuits**
- **SERFE Ground unit previously stored with SWME BPV open & VAV-2005 closed**
  - Leave VAV-2005 open during storage
    - Simulate condition inside PLSS with BPV open to reduce corrosion risk for avionics
    - Relative humidity (RH) sensor placed in VAV-2005 to take readings
- **Continued evaporation across SWME membranes & permeation through EVA tubing in LCVG simulator: potential sources of water loss during 3-year storage period?**
  - Drying of SWME cartridges can lead to leaks in epoxy headers
    - SERFE Ground Unit water loop periodically topped off with iodinated water
- **Characterize how quiescent stowage leads to observed deltas in performance**
  - Design in mitigation to identified causes for next-generation spacesuits

Forward Plan

- **After 365-day spacesuit storage period**
  - Run another simulated EVA series in August 2026
- **Under consideration to test SERFE yearly to test SWME lifespan for use in advanced exploration missions**
  - When SWME no longer operational
    - SERFE Ground unit torn down & inspected for additional lessons learned

Conclusion

- **SERFE Ground Unit underwent a three-year quiescent stowage period**
  - Test series investigated performance to assess use of SWME in long term spaceflight
- **Decrease in heat rejection capability**
  - Due to increase in vacuum pressure?
  - Due to change in SWME membrane performance?
- **SERFE similar to XEMU primary TCL**
  - Key design features & highest fidelity source to test quiescent storage of SWME for return to Moon & beyond
- **Successfully evaluated SWME heat rejection, degassing, water quality**

Questions

- **GTS!**

- **For more information on SERFE:**
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SERFE Flight Unit installation on ISS in 2020.

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  - Ryan Ogilvie
  - Sean Miller

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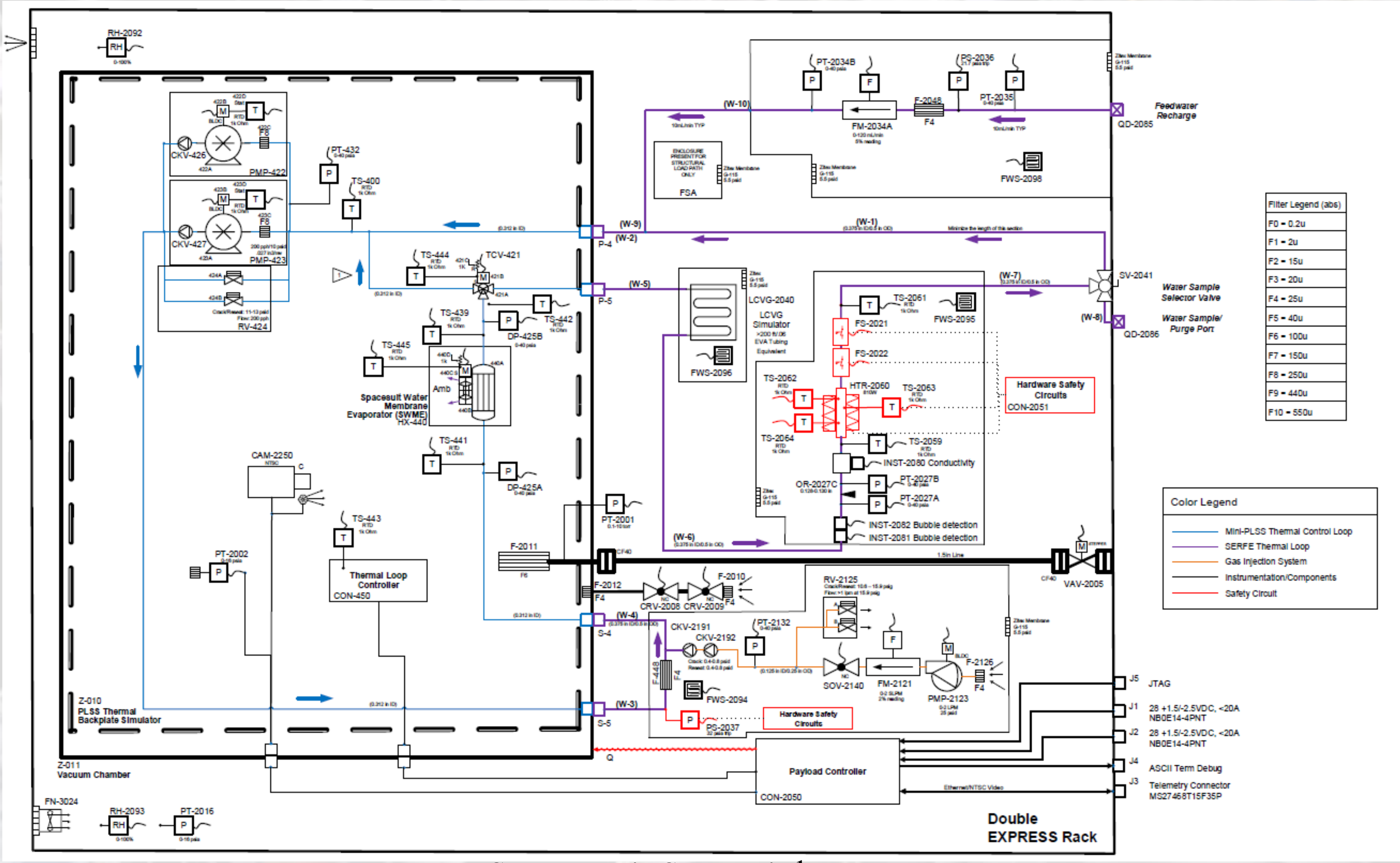
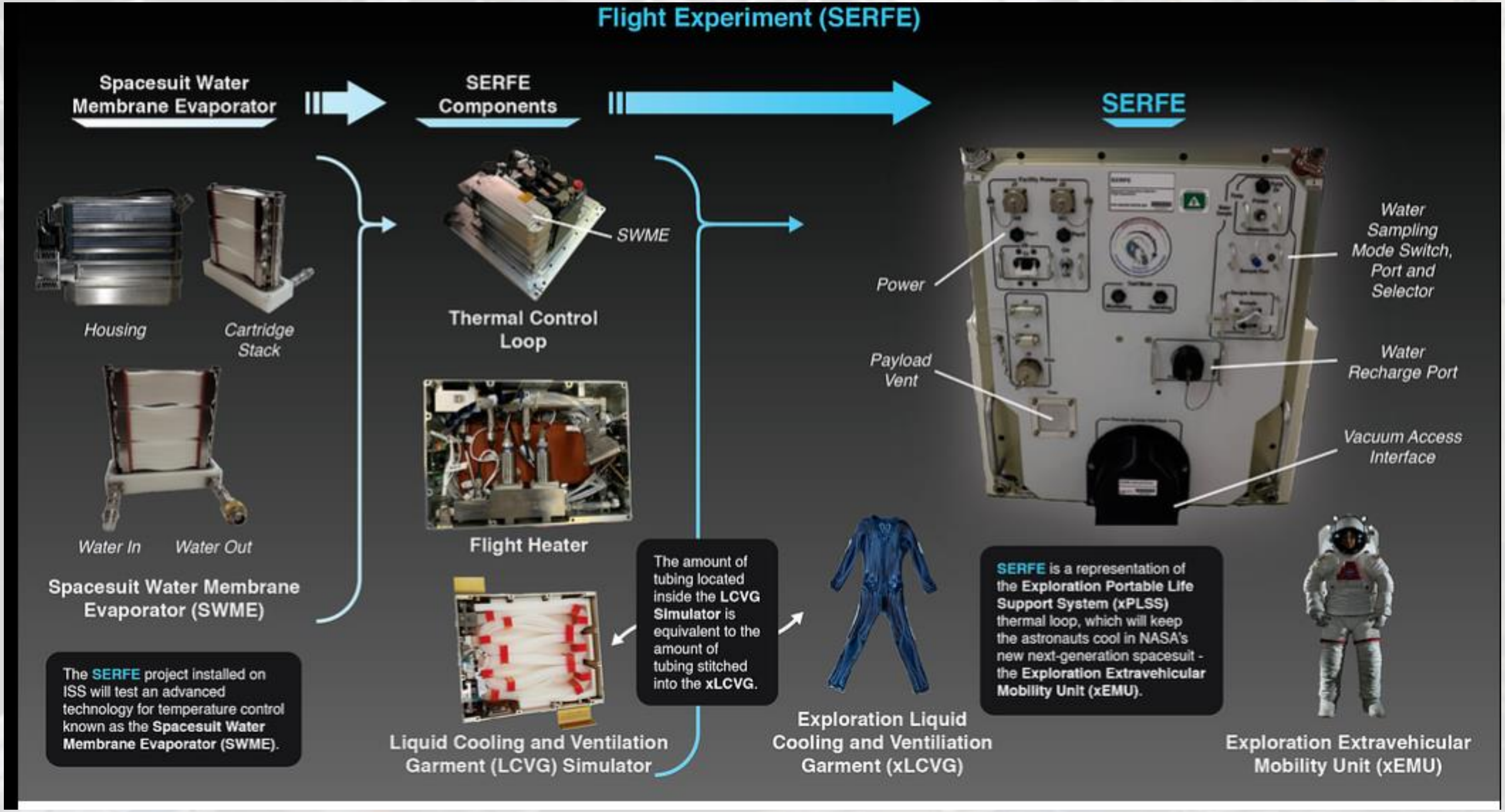


SERFE Fluid Schematic.[1]

Backup: Overview Graphic



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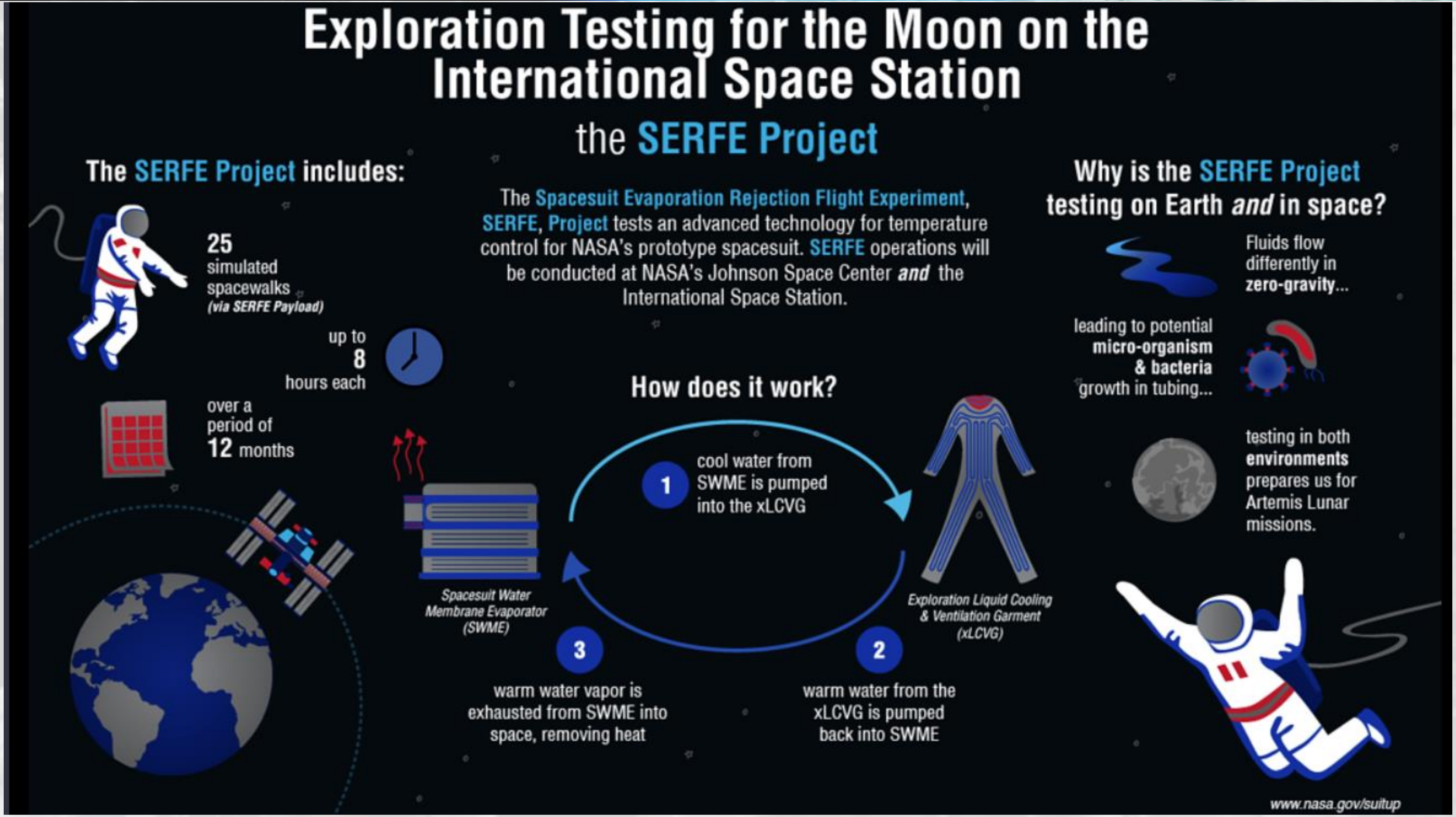
Backup: SWME Overview



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