Schematics and Behavioral Description for the Advanced EMU (AEMU) Portable Life Support Subsystem (PLSS)

Engineering Directorate
Crew and Thermal Systems Division

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National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
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REVISIONS			
DATE	AUTHOR	DESCRIPTION	REV. LETTER
6/18/2012	C. Campbell	Baseline	N/C
8/21/2017	C. Campbell	-Significant restructuring of content to move the schematic update details and history to CTSD-ADV-1205 -Removed suit port from the operations description -xEMU Schematic, descriptions, and operations updates for PLSS 2.5 design	A

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1.0 INTRODUCTION

The eXploration Extra-vehicular Mobility Unit (xEMU) Portable Life Support System (PLSS) has been in development for ~10 years starting with component technology maturation sponsored by the Exploration Technology Development Program (ETDP) beginning in FY2008; the base schematic and technologies were chosen in 2007 after an extensive trade study engaging the full EVA community between the Johnson Space Center and Glenn Research Center. The xPLSS as it is called, has been designed within the confines of currently fieldable technologies to operate in the potential range of environments that could be experienced during a potential exploration mission:

- LEO
  - Microgravity
  - low radiation
  - Vacuum ambient
- Moon – CIS lunar
  - Partial gravity
  - Elevated radiation
  - Vacuum ambient
- Mars
  - Partial gravity
  - Elevated radiation
  - Low pressure CO_2 ambient

For the Mars environment, some additional components will be required but the PLSS is being scarred to accept those components without a significant redesign.

Much like the Apollo EMU, Shuttle/ISS EMU, and early CxP Space Suit Element designs, the AEMU PLSS is part of a larger system composed of a Pressure Garment Subsystem (PGS) and Informatics Subsystem with vehicle interfaces to a traditional airlock like that of the ISS. The PLSS is charged with the same basic life support functions of the previous efforts:

- Pressurization
- Oxygen ventilation
- Carbon dioxide, water, and trace contaminant removal
- Thermal control

The detailed requirements for these functions are housed in the PLSS Development Requirements, CTSD-ADV-780 (NASA, 2015).

This document provides an overview of the xPLSS, its basic operation, and provides operational procedural sequences.

2.0 XEMU PLSS SCHEMATIC DESCRIPTION

The AEMU PLSS pneumo-hydraulic schematic consists of the following basic loops:

- Primary Oxygen Loop
- Secondary Oxygen Loop
- Oxygen Ventilation Loop
- Thermal Control Loop
- Auxiliary Thermal Control Loop
- Vacuum Access Manifolds

Together, these loops perform the critical life support functions that enable autonomous operation separated from a vehicle. In subsequent sections, the schematic and function of the subject loops will be explained in detail.

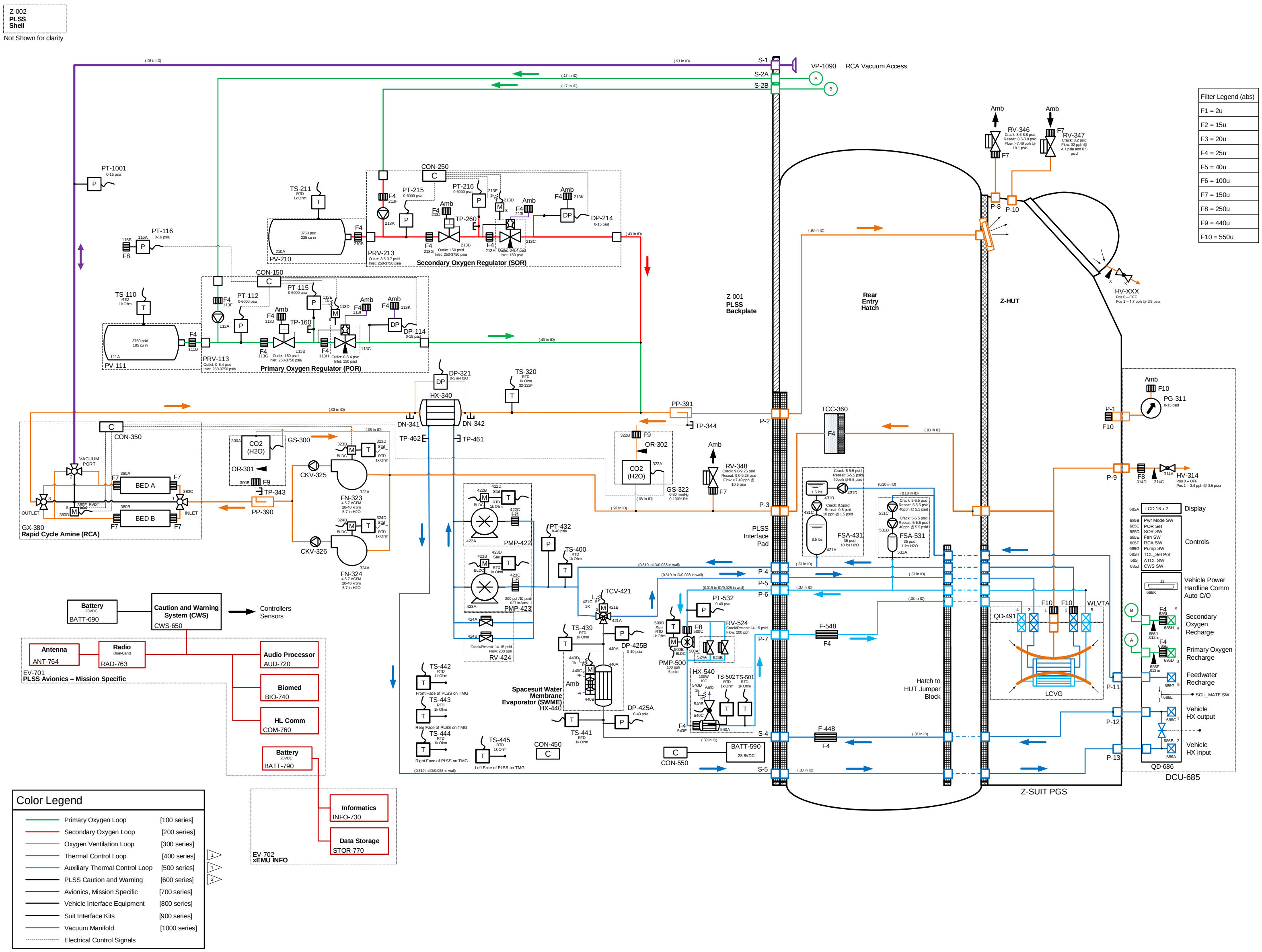


Figure 2-1 - xEMU PLSS Pneumo-Hydraulic Schematic

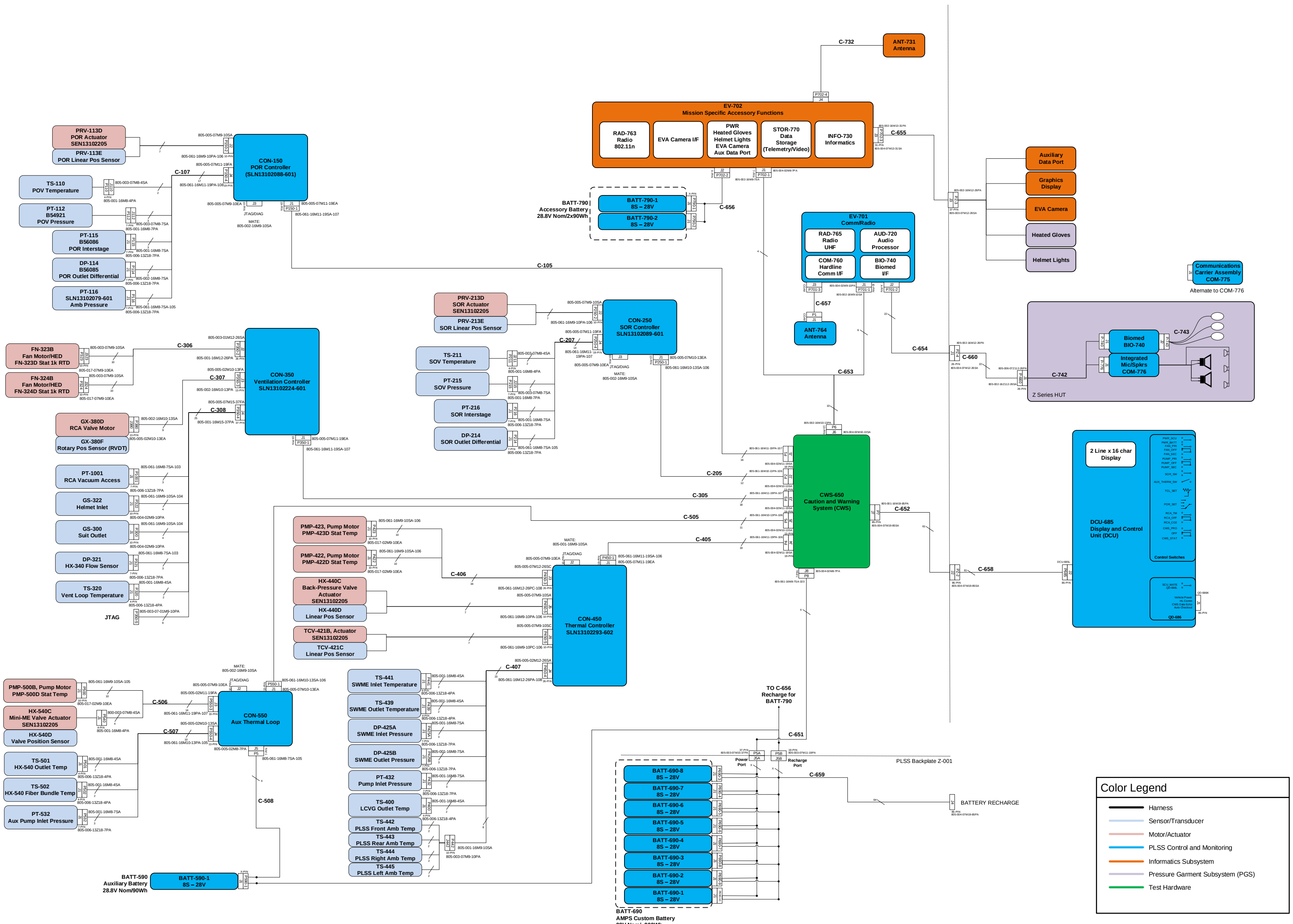


Figure 2-2 - xEMU PLSS Harness Diagram

2.1 PLSS COMPONENT NOMENCLATURE DEFINITION

The AEMU PLSS schematic utilizes a simplified nomenclature definition as follows:

CCC-LLNN

CCC = Component Type Identifier
LL = Loop Identifier
NN = Physical Component Identifier

Filters are not called out separately from their larger assemblies but rather are denoted by filter rating as shown in Table 5.1-3.

Component Type Identifiers "CCC"	Component
CKV	Check Valve
CON	Controller
DN	Drain Port
DP	Differential Pressure Transducer
FM	Flow Meter
FN	Fan
FSA	Feedwater Supply Assembly
GS	Gas Sensor
GX	Gas Exchange Scrubber
HV	Hand Valve
HX	Heat Exchanger
OR	Orifice
P	Port
PG	Pressure Gauge
PMP	Pump
PRV	Pressure Regulating Valve
PP	Pitot Probe
PT	Pressure Transducer
PV	Pressure Vessel
QD	Quick Disconnect
RV	Relief Valve
S	Feed-through
SOV	Solenoid Operated Valve
TCC	Trace Contaminant Control
TCV	Thermal Control Valve
TP	Test Port
TS	Temperature Sensor
VP	Vacuum Access Port

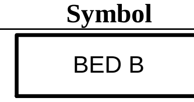
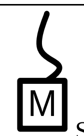
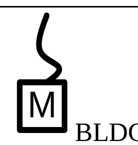
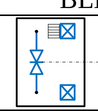
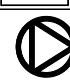
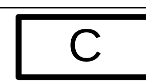
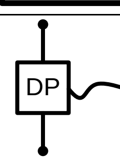
Table 5.1-1 – Component Type Identifiers

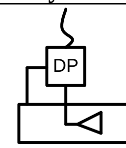
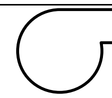
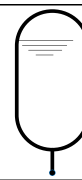
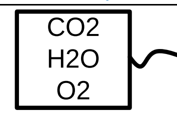
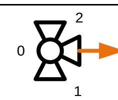
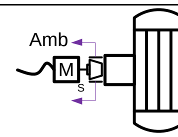
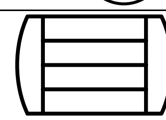
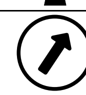
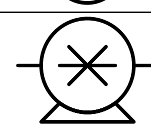
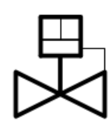
Loop Identifiers	**“LL”**
Primary Oxygen Loop	1
Secondary Oxygen Loop	2
Oxygen Ventilation Loop	3
Thermal Control Loop	4
Auxiliary Thermal Control Loop	5
Vacuum Manifold	10

Table 5.1-2 –Loop Identifiers

Filter Identifier	**Rating**
F1	2µ
F2	15µ
F3	20µ
F4	25µ
F5	40µ
F6	100µ
F7	140µ
F8	200µ
F9	440µ
F10	550µ

Table 5.1-3 – Filter Identifiers

Component	**Identifier**	**Symbol**
Amine CO2/H2O Scrubber Bed	---	
Motor Actuator (Stepper motor-based)	---	
Motor Actuator (Brushless DC motor)	---	
Multiple QD Connector with closed when mated valve	---	
Check Valve	CKV	
Controller	CON	
Differential Pressure Transducer	DP	
Filter	F	

Component	**Identifier**	**Symbol**
Flow meter	FM	
Fan	FN	
Feedwater Supply Assembly (water accumulator bladder)	FSA	
Gas Sensor	GS	
Hand Valve (3-way)	HV	
Evaporator with stepper actuator poppet style back-pressure valve	HX	
Heat Exchanger (air to water)	HX	
Orifice	OR	
Pressure Gauge	PG	
Pump	PMP	
Pitot Probe	PP	
Pressure Regulating Valve (with piston-based outlet pressure sense)	PRV	
Pressure Regulating Valve (with bellows/diaphragm-based outlet pressure sense and ambient pressure reference)	PRV	

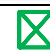
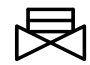
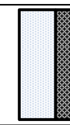
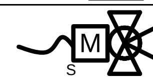
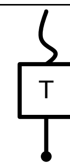
Component	**Identifier**	**Symbol**
Pressure Transducer	PT	
Pressure Vessel	PV	
Quick Disconnect	QD	
Relief Valve (Proportional in-line)	RV	
Trace Contaminant Control	TCC	
Thermal Control Valve (stepper motor actuated diverting valve)	TCV	
Temperature Sensor	TS	
Vacuum Access Port	VP	

Table 5.1-4 – Schematic Symbols

2.2 PRIMARY OXYGEN LOOP

The primary oxygen loop provides oxygen for pressurization, metabolic consumption, and leakage make-up. It also provides gas at flowrates up to 5.6 pph to facilitate denitrogenation purge using the suit purge valve. It consists of two main components, the Primary Oxygen Regulator (POR) and the Primary Oxygen Vessel (POV) with associated instruments and brackets/connections. For in-situ charging, the loop accepts gaseous oxygen from QD-686/886 with a nominal charge pressure of 3000 psia at 60°F and a maximum design pressure of 3750 psia based on thermal excursion post charging, without demand to 145°F. The gaseous recharge rate is limited by multiple orifices in the recharge path including one integral with QD-686 as well as one located at the base of the SCU-801, all intended to limit adiabatic compression heating during the recharge process. Reverse leakage from the tankage is protected by both a check valve integrated into the POR as well as the QD-686 poppet which is closed when the SCU is demated from the DCU. The POV stores ~1.7 lbm of usable oxygen which is then fed to the POR, a two-stage motor-settable mechanical regulator capable of being remotely set to ~8000 set-points between 0 (shut-off) and 8.4 psid; nominal EVA set-pressures will be in the range of 4.1-8.4 psid with 4.3 psid being the historical set-point known from Shuttle/ISS EMU. The specific set-points used are dictated by inputs to the Primary Oxygen Regulator Controller, CON-150 via the POR_SET switch on the Display and Control Unit (DCU). The crew has the ability to set the POR to OFF (0 psid), 0.4, 0.9, 4.3, 6.2, and 8.2 psid via the POR_SET control and the exploration mission can define the specifics of those set-points to any variant within the 8000 step range between 0-8.4 psid. The POR_SET provides 6 discrete IO lines toggled from the knob connected to 3 DPDT micro-switches enabling the input commanding and logic to tolerate multiple discrete bit-flips without issuance of a false positioning command. When operating, the outlet of the regulator is fed directly into the oxygen ventilation loop just upstream of the interface pad between the PLSS and HUT hatch where it, in short order, is routed to the helmet inlet in the PGS. The POV includes an RTD measuring wall temperature to improve the determination of available oxygen mass during usage. The POR includes inlet, interstage, and outlet pressure transducers to assess the health of the regulators and provide feedback to the regulator controller, CON-150. An ambient pressure sensor, PT-116 is not physically attached to the POR but provides a feedback signal to CON-150. The linear actuator used to set the outlet pressure includes a secondary linear position sensor that is physically integrated with the drive shaft in order to validate positioning of the load spring. The motor phase currents are also monitored by the controller to validate in-family performance throughout life of operations. The CON-150 monitors all of the sensors attached to the regulator, commutates the linear actuator to set the pressure, accepts commands for the pressure set-point directly via physical switch throws on the DCU, locally identifies and reacts to faults within the controller, and sends telemetry back to the Caution and Warning System (CWS) for further fault detection and computation.

2.3 SECONDARY OXYGEN LOOP

The secondary oxygen loop provides the redundancy for oxygen loop life support functions but at a lower ventilation loop pressure and it provides redundancy for the remainder of the ventilation loop life support functions via open loop oxygen ventilation flow through the suit purge valve. The loop provides oxygen for pressurization, metabolic consumption, leakage make-up, carbon dioxide washout, as well as, humidity and trace contaminant control. Like the primary oxygen loop, the secondary oxygen loop consists of two main components, the Secondary Oxygen Regulator (SOR) and the Secondary Oxygen Vessel (SOV) with associated instruments and brackets/connections. For in-situ charging, the loop accepts gaseous oxygen from a dedicated port on QD-686 which is mated on the SCU side of the QD-886, fully isolating the primary and secondary oxygen loops when the SCU is not present. Like the POV, the SOV possesses a nominal charge pressure of 3000 psia and a maximum design pressure of 3750 psia based on thermal excursion post charging, without demand to 145°F. The SOV stores ~1.7 lbm of usable oxygen which is then fed to the SOR, an identical regulator design to the POR, a two-stage motor-settable mechanical regulator capable of being remotely set to ~8000 set-points between 0 (shut-off) and 8.4 psid with a nominal set pressure of 3.7 psid. The SOR operates as a nested regulator set to 3.5-3.7 psid, ~0.4 psid below the POR nominal set range of 4.1-8.1 psid for EVA conditions. The Secondary Oxygen Regulator Controller, CON-250 is commanded directly by the SOR_SET switch on the DCU. The SOR_SET is a ganged set of 2 DPDT switches that provide 4 discrete IO lines toggled by the crewmember selection of “OFF” or “ON” enabling the input commanding and logic to tolerate multiple discrete bit-flips without issuance of a false positioning command. When the SOR_SET is set to “ON”, the CON-250 commutates the actuator on the 2nd stage regulator to set the output pressure to 3.5-3.7 psid via a stored step count which is continuously checked against the linear position sensor that is physically integrated with the drive shaft in order to validate positioning of the load spring. The CON-250 and SOR_SET commanding works independently of the CON-150 or other controllers in the PLSS as well as the CWS. When the POR can no longer maintain the set pressure in the 4.1-8.4 psid range and the pressure drops to ~3.7 psid, the SOR, which has been sitting in lock-up waiting to regulate since the depress sequence will begin to regulate and hold the suit pressure at 3.5-3.7 psid. The outlet of the regulator is fed directly into the oxygen ventilation loop just upstream of the interface pad between the PLSS and HUT hatch where it, in short order, is routed to the helmet inlet in the PGS. The SOV includes an RTD measuring wall temperature to improve the determination of available oxygen mass during usage. The SOR includes inlet, interstage, and outlet pressure transducers to assess the health of the regulators and provide feedback to the regulator controller, CON-250. The motor phase currents are also monitored by the controller to validate in-family performance throughout life of operations. The CON-250 monitors all of the sensors attached to the regulator, commutates the linear actuator to set the pressure, accepts commands for the pressure set-point directly via physical switch throws on the DCU, locally identifies and reacts to faults within the controller, and sends telemetry back to the Caution and Warning System (CWS) for further fault detection and computation.

2.4 OXYGEN VENTILATION LOOP

The oxygen ventilation loop provides for CO2 washout, humidity control, trace contaminant removal, and PGS inlet gas temperature control. To accomplish this, a centrifugal fan is utilized to move the loop at flowrates variable between 3-8 acfm with nominal set-points between 4.5-6 acfm; the goal of the integration with the redesigned Zsuit HUT/helmet is to lower the flowrate required for the ISS EMU SSA (Apollo A7LB helmet) at 6 acfm to something closer to 4.5 acfm in order to save fan power and reduce the PLSS volume/mass. In following the schematic return from the Liquid Cooling and Ventilation Garment (LCVG) extremities, the ventilation flow is returned through the TCC-360 cartridge which includes a fine particulate filter and activated charcoal trace contaminant scrubber. The final selection of the particular scrubber design will be influenced by multiple options presently being pursued under SBIR and assessment of applicability of products such as Ammonasorb II for Barnebey Sutcliffe (a phosphoric acid wash-coated activated charcoal capable of adsorbing NH3 as well as a wide range of trace contaminants). From the TCC-360, ventilation gas flows through the hatch feed-through to the PLSS interface pad and into an inlet header for the fan tree which includes the RV-348 Secondary Positive Pressure Relief Valve (SPPRV) and returns from both of the multi-gas sensors. The RV-348 is provides 2-fault tolerance to over-pressure failures from failed regulators and single fault tolerance to over-pressure failures due to RV-346 failure during airlock depress. Under nominal operations, the ventilation gas then flows into the FN-323, Primary Fan which applies work to move the gas through the ventilation loop discharging the gas through an outlet check valve (CKV-325). Under a primary fan or other functional loss failure, the FN-324 Secondary Fan may be activated. FN-324 is identical to FN-323 for commonality but through-out its life as a cold-spare unit will see much lower operating hours. When either fan is on and moving ventilation loop gas through its outlet check valve, the check valve on the opposing fan is checked and prevents back-flow. From the outlet of the fan manifold, the suit return multi-gas sensor (GS-300) uses the fan head-rise to sample a small stream ~150sccm of the gas to determine the CO2 and H2O content before it enters the GX-380, Rapid Cycle Amine (RCA) swing-bed. The RCA uses a special formulation of amines referred to as SA9T implemented in a two-bed thermally interconnected system in which one bed adsorbs CO2/H2O from the ventilation loop accepting gas from the fan outlet and the other bed desorbs CO2/H2O to vacuum. When the CO2 readings from the helmet inlet gas sensor (GS-322) reaches a determined value depending on the chosen algorithm (3mmHg for PLSS 2.0), the Ventilation Loop Controller, CON-350 commutates a rotary stepper actuator with integrated Rotary Variable Differential Transformer (RVDT) to position a rotary ball valve stack first to an equalization position in which the both beds are isolated from both vacuum and the ventilation. At this point the desorbing bed that is regenerated is equalized with the adsorbing bed that is saturating at about half of the suit pressure (~2.2 psia during an EVA at 4.3 psia). The valve is then moved to complete the bed swing connecting the regenerated bed to the ventilation loop and the saturated bed to the vacuum source in order to begin the next half-cycle. For PLSS 2.0 using a CON-350 prototype, the cycle time was reduced to <3 seconds with the equalization time <1 second. Under conditions in which the gas sensor (GS-322) has failed, CON-350 will revert to a conservative time-based cycle which is designed to remove enough CO2 for a high metabolic rate. During the bed-transition operation, the CON-350 positions the beds via step counting on the rotary actuator with position checks from the RVDT and should the checks fail, the CON-350 can then position the bed via hard stop at the end of travel. From the RCA outlet, the ventilation gas travels to the HX-340 ventilation loop sensible heat exchanger where heat added by the fan and RCA is removed and cool dry gas exits where the ventilation loop temperature sensor (TS-320) senses the gas temperature headed to the PGS inlet. The heat exchanger is designed as a linear flow element allowing a small mass flow meter attached to the HX-340 to measure the mass flow rate for the ventilation loop with the volumetric flow calculation determined by the CWS using the suit pressure calculated from the DP-114 or DP-214. For conversion to the open loop flow configuration, the RCA may be in the OFF position permitting no flow through the component or the outlet check valves on the fans will preclude the reverse flow. Just before the gas reaches the PLSS interface pad to hatch interface, a pitot probe (PP-391) pulls a small stream of gas (~150 sccm) through a sample line with a filter and orifice back to the helmet inlet gas sensor (GS-322) which then quantifies the species of H2O and CO2; the sample gas is then returned to the inlet of the fan using the pressure drop across the spacesuit to drive the flow. The clean, dry, low humidity, low CO2 gas is fed into the PGS and onto the oro-nasal region of the crew member. At this point, the crew inspires the inlet gas and expires gas with elevated CO2 and humidity which is washed downward by the inlet gas flow and eventually out to the extremities where it is picked up and recirculated through the system. The CON-350 is controlled directly by the crew via mechanical switches located on the DCU. The RCA_SW offers three positions, CO2 – OFF – TM. In the OFF position, the rotary ball valve is parked precluding flow through either bed and isolating both beds from each other and from either the ventilation loop or vacuum manifold. In the CO2 position, the CON-350 monitors the GS-322 and performs a bed half-cycle when the CO2 value reaches a trip limit. In the TM position, the CON-350 maintains a counter and performs a bed half cycle on a fixed time interval. The FAN_SW offers three positions: PRI – OFF – SEC. For the OFF position, the controller does not commutate fan motors and sits in quiescent mode monitoring the attached sensors and sending telemetry. In PRI, the CON-350 commutates the primary fan motor at a fixed speed. In SEC, the CON-350 commutates the secondary fan motor at a fixed speed. The power for the primary vs secondary fans are fed from independent power feeds from the main PLSS power bus, each with independent current limiters in the CWS. The CON-350 is capable of operating regardless of the operation of other controllers.

Additional components located on the PGS include the Positive Pressure Relief Valve (PPRV) and Suit Purge Valve (SPV). The PPRV protects the suit and oxygen ventilation loop from over-pressurization in the event that either the POR or SOR fail open; it would also protect the suit during an airlock depress where the ambient pressure decrease is faster than the combined suit leakage, RCA ullage loss, and metabolic consumption. The SPV enables a nominal function for denitrogenation purge that occurs at the beginning of every EVA as the suit environment is transitioned from a mixed gas to a single gas oxygen environment. The SPV also enables the redundant life support function of the secondary oxygen loop in which the valve is actuated to enable the open loop purge mode needed; the SPV would offer the 30 minute abort time at the higher flow rate. The helmet purge valve will offer the lower purge flow capable of the longer abort time when accompanied by the Auxiliary Thermal Control Loop (ATCL).

2.5 THERMAL CONTROL LOOP

The thermal control loop performs primary thermal control for the suited crewmember and the PLSS. The loop is designed and sized to accommodate metabolic waste heat, electronics waste heat, and environmental heat leak in hot environments with the maximum rejection design point of 810W. To accomplish this, the loop includes a Feedwater Supply Assembly (FSA) which utilizes the suit ventilation loop pressure to compress the compliant bladder which then pressurizes the thermal loop fluid to approximately the same pressure as the ventilation loop (slightly less given work performed on the bladder). This enables redundant pressurization for the thermal loop as the Primary Oxygen Regulator (POR) or the Secondary Oxygen Regulator (SOR), can pressurize the thermal loop meaning that a loss of the primary oxygen supply does not necessitate an open-loop abort as the secondary is capable of enabling the thermal loop operation. Water usage from the FSA is tracked by the Caution and Warning System (CWS-650) via utilization computed from the Spacesuit Water Membrane Evaporator (SWME). Should an external leakage occur which renders the utilization calculation invalid, a secondary leakage detection method using staged check valves is employed to offers a pressure drop signature at the input to the thermal loop pump (PT-432) with ~ 1 lb of feedwater remaining to enable an orderly termination on primary resources. Once the fluid has been pressurized by the FSA, it travels out of the PGS and into the PLSS where the LCVG outlet temperature sensor (TS-400) measures the water temperature via an insertion style RTD. Next, the fluid contacts the thermal control loop pressure sensor (PT-432) which measures the absolute loop pressure just prior to the pump inlet. The pump (PMP-423) moves the entire loop via an external gear positive displacement pump powered by a Brushless Direct Current (BLDC) motor running at a speed set by the thermal loop controller (CON-450). The nominal thermal loop flow is 200pph which is maintained throughout IVA and EVA operations. A cold-spare secondary pump (PMP-422) provides the ability to continue EVA operations or make an orderly termination in the event of a primary pump failure. It is independently switched from the pump switch (PUMP_SW) on the Display and Control Unit (DCU-685), fed by a redundant power line and current limiter from the CWS-650, and commutated by a redundant BLDC controller in the CON-450. With the implementation of a positive displacement pump with high efficiency, the pump design is capable of generating higher pressures under a dead-head condition than can be tolerated by the other components in the thermal loop. As a result, a dual-bypass relief valve (RV-424) is placed across the pump outlet to inlet. In the event that a restricted flow fault condition occurs, the bypass relief valve will open at ~15 psid to limit the overall pressure experienced by the other thermal loop components. From the pump outlet, the thermal loop fluid is pushed through the liquid side of the ventilation loop heat exchanger (HX-340); as noted in the ventilation loop section, this heat exchanger provides sensible cooling of the helmet inlet gas as well as integrated ventilation loop flow measurement. From the HX-340 outlet, the thermal loop fluid moves out of the PLSS through the S-5 port, through the hatch on the Z-HUT, through the integrated water lines in the HUT, and into the DCU-685 common quick disconnect (QD-686). For operations in which the Service and Cooling Umbilical (SCU-801) is present and mated, the thermal loop fluid moves out towards the vehicle heat exchanger to enable vehicle supplied cooling. That fluid returns to QD-686 where it is then routed back through the Z-HUT and then the finest filter in the thermal loop (F-448) before re-entering the PLSS at port, S-4. For operations in which the SCU-801 is not present, the QD-686 connects the vehicle interface inlet/outlet ports in a bypass and then returns the fluid back through the Z-HUT and then the finest filter in the thermal loop (F-448) before re-entering the PLSS at port, S-4. Upon returning to the PLSS, the fluid is routed to the SWME (HX-440) inlet which includes an absolute pressure sensor (DP-425A) and an RTD insertion probe temperature sensor (TS-441). As the fluid flows through the inner diameter of the ~28000 hollow-fibers, the back-pressure on the outside of the fibers is maintained via a stepper actuator controlled back-pressure valve such that the desired outlet temperature observed from the SWME is achieved. The exhaust water vapor is then rejected through the back-pressure valve to space vacuum. The latent cooling from the evaporation of a small portion of the thermal loop fluid then cools the remaining fluid passing through the SWME. Any gas entrained in the fluid is also removed at this point as it readily passes through the membrane and out to space vacuum. This enables the system to be primed and wetted from dry, to remove incidental bubbles that could be introduced with mating/demating of loop QDs, and bubbles that could evolve from dissolved gases coming out of solution during reduced pressure operations. As the fluid leaves the SWME (HX-440) it immediately contacts an RTD insertion probe temperature sensor (TS-439) and an absolute pressure sensor (DP-425B). The outlet temperature sensor (TS-439) is used to control the SWME back-pressure position to achieve the 50°F (10°C) set-point for the outlet water temperature. The two temperature sensors (TS-441 and TS-439) are used along with other parameters such as the thermal loop flow-rate to compute the heat rejection of the SWME and its associated water utilization. The two pressure sensors are used to determine the pressure drop across the SWME which is then used to determine the thermal loop flow along with competing computations from the positive displacement pump. From the SWME outlet instruments, the fluid enters the Thermal Control Valve (TCV-421) which is a linear actuator based spool valve which either directs all flow through the LCVG, around the LCVG via a bypass, or some ratio in-between with a resolution of ~8000 steps. The TCV-421 position is manually controlled by the TCL_SET knob located on the DCU-685; it may also be controlled in an automated sense by the Auto-Cooling Control (ACC) algorithm running in the CON-450 if the TCL_SET is placed in ACC mode. At this point, the CON-450 computes a local metabolic rate based on the thermal loop heat balance, adjusts for ambient heat leak by measuring the values of the TMG temperatures (TS-442, TS-443, TS-444, TS-445) and considers a comfort bias factor, then positioning the TCV-421 as dictated by the control algorithm outputs to maintain crew comfort. The crew can over-ride this method at any time by manually positioning the TCL_SET to a given set-point. From the TCV outlet the fluid flows either back to the pump inlet on a bypass leg or into the Z-HUT via P-5, through the hatch lines, to the Water Line Vent Tube Assembly, and ultimately to the Liquid Cooling and Ventilation Garment (LCVG) where the water effects heat removal from the skin of the crew member. An inadvertent outcome of this approach is that, as the water temperature is reduced during periods of high metabolic activity to enable greater heat transfer to the water with a limited skin temperature range, the water tubes across the LCVG enclosed in the Pressure Garment form a shell and tube condensing heat exchanger in which all moisture pressure with a dewpoint above the water temperature condenses onto the LCVG. The increased moisture present increases the overall heat transfer coefficient for the LCVG (UA) which enables increased heat rejection from the crew member. Upon subsequent low metabolic rate activity periods with warmer water temperatures in the LCVG, the ventilation loop slowly removes the condensed moisture via the RCA (GX-380). On the LCVG outlet/PLSS thermal loop return line the FSA-431 provides make-up feedwater and sets the pressure for the loop based on the suit ventilation loop pressure as described earlier.

2.6 AUXILIARY THERMAL CONTROL LOOP (ATCL)

The Auxiliary Thermal Control Loop (ATCL) provides redundancy for the primary thermal control loop life support functions but at diminished capability designed to support an EVA abort to the vehicle safe haven for 60 minutes. The system sits idle with a dedicated auxiliary thermal loop controller (CON-550) monitoring instruments for health status determination during the EVA while operating on the primary system. When the crew determines that the primary loop has been lost and wishes to engage the ATCL, the ATCL_SW is set to “ON” which signals to the

CON-550 to turn on the auxiliary thermal control loop pump and to open the back-pressure valve on the auxiliary evaporator (HX-540); the operation of these devices is powered independently from the primary systems using a dedicated battery, the ATCL battery (BATT-590). This battery is constructed from the same battery modules that make up the primary and accessory batteries but is dedicated to the ATCL alone. The auxiliary thermal control loop consists of a small Feedwater Supply Assembly (FSA) of similar construction to the primary FSA but sized for the reduced duration of 60 minutes. The fluid loop is fully redundant to the primary thermal loop in order to eliminate the single point failure of thermal control loop fluid leakage disabling both the primary and redundant functions. The pressurized fluid travels from the auxiliary FSA (FSA-531) through the Z-HUT hatch lines, through the P-6 port at the PLSS/HUT interface pad, to the pump inlet pressure sensor (PT-532). The PT-532 monitors the inlet pressure to the pump to detect the depletion of the FSA-531 and determine if PMP-500 is operating in the cavitation pressure range. The auxiliary thermal loop pump (PMP-500) moves the fluid via a positive displacement pump (same design as the PMP-423/PMP-422) with a lower speed set-point to achieve a nominal 100 pph flowrate and a reduced overall operating life requirement. With the implementation of a positive displacement pump with high efficiency, the pump design is capable of generating higher pressures under a dead-head condition than can be tolerated by the other components in the ATCL. As a result, a dual-bypass relief valve (RV-524) is placed across the pump outlet to inlet; this is the same component as the RV-424 but in a different location within the PLSS. In the event that a restricted flow fault condition occurs, the bypass relief valve will open at ~15 psid to limit the overall pressure experienced by the other loop components. From the pump outlet, the ATCL fluid is moved to the inlet of the auxiliary evaporator (HX-540) also known as the Mini-Membrane Evaporator (Mini-ME). This component borrows heavily from commonality with the primary components using the same hollow-fiber module that is used in the SWME (HX-440); the SWME uses three of these modules. The stepper actuator back-pressure valve is also the same as that used on the primary system. The operation of the evaporator, is however, much simpler in that it is either ON or OFF and does not perform thermostatic control functions like the SWME. The HX-540 operates in a topping capacity to control heat storage for 60 minutes below 300 BTU in a neutral thermal environment with the low flow open loop ventilation flow from the helmet mounted purge valve (~1.7 pph). Like the SWME, the HX-540 directly cools the ATCL fluid flowing through its ~9300 hollow-fibers and also degasses the ATCL by directly removed entrained gas. The cooled ATCL fluid moving from the outlet of the HX-540 encounters the TS-501 RTD insertion probe thermal sensor which monitors the fluid temperature leaving the unit; as stated, this sensor does not feed a thermostatic control loop but is present instead to enable a functional checkout of the system at the start of each EVA. Since the HX-540 is wetted and sitting dormant under nominal operations, the TS-502 RTD insertion probe style temperature sensor is placed into the core of the hollow-fiber bundle as a direct verification that the fibers have not frozen precluding proper function. This could occur should the back-pressure valve on the HX-540 fail to close or leak during the EVA sequence with the ATCL fluid stagnant in the hollow-fibers. From the TS-502 temperature sensor the ATCL fluid moves from the PLSS into the Z-HUT via the P-7 port and once inside the hatch volume enters the F-548 ACTL filter, the finest filter in the ATCL and one that is serviceable with access to the hatch cover. After the F-548 filters particulate from the ATCL fluid, it moves into a dedicated core torso run of tubing on the LCVG. This core torso minimizes the impact of the incorporation of the ATCL while providing the maximum effective cooling for this function. The ATCL fluid, moving through the LCVG core torso run pickups up waste heat from the crewmember's core and transports it at ~100pph. Leaving of the LCVG outlet, the loop returns to the dedicated Feedwater Supply Assembly (FSA-531).

2.7 VACUUM MANIFOLDS

With the removal of requirements for support of SuitPort, the vacuum manifold requirements have simplified. In order to enable the vacuum access required by the Rapid Cycle Amine (RCA, GX-380) to desorb the adsorbed CO2 and H2O, the vacuum manifold provides a ~1in line from the GX-380 rotary ball valve location within the PLSS and transfers it to the back-plate where it is routed to an accessible location on the front of the suit (near DCU QD). For the airlock IVA configuration, a vacuum access jumper would be connected to the manifold to enable the RCA to desorb while the suit ambient was at cabin pressure. For the EVA configuration, the port would be open and enable desorption to available space vacuum. A pressure sensor, PT-1001 is included on the manifold line to enable the Caution and Warning System (CWS) to monitor the status of the manifold for the purposes of ensuring that proper operating conditions exist for the RCA.

2.8 POWER

The PLSS includes three different battery assemblies composed of differing parallel configurations of a single common battery module arranged in an 8S configuration using LG MJ1 18650 which yields a 24-34VDC output rail with scalable capacity.

Battery	Description	Nominal Voltage (VDC)	Location	Configuration	Capacity(1) (Wh)	Load Criticality
BATT-590	Auxiliary Thermal Control Loop Battery	29.1	Inside PLSS volume	8S – 1P	95	Crit 1S
BATT-690	Primary PLSS Battery	29.1	Underside of PLSS backplate and PLSS volume	8S – 8P	756	Crit 1R
BATT-790	Accessory Battery	29.1	Inside PLSS volume	8S – 2P	189	Crit 3

2.8.1 BATT-590 – Auxiliary Thermal Control Loop Battery

This is a 1S criticality battery that serves to provide power for the Auxiliary Thermal Control Loop (ATCL) in order to provide cooling to the crew upon failure of primary systems such that an EVA abort time of up to an hour can be supported. This battery will be tested via OCV evaluation followed by a brief (~2-5 min) load test at the beginning of each EVA, then maintained in standby awaiting actuation of the switch on the DCU (ATCL_SW) by the crewmember should an emergency EVA abort or terminate be required due to the failure of a primary life support function. As that switch is closed, the battery will then source power to actuate the HX-540 Mini-Membrane Evaporator (Mini-ME) and PMP-500 Auxiliary Thermal Control Loop pump; these two components will then cool and circulate the cooled water through dedicated loops on the torso of the Liquid Cooling and Ventilation Garment (LCVG) in order to prevent the crew from exceeding permissible heat storage limits during the retreat back to the safe haven such as the airlock.

2.8.2 BATT-690 – PLSS Primary Battery

The PLSS Primary battery (BATT-690) is responsible for feeding power to high criticality loads such as the PLSS fans, pumps, actuators, sensor, controllers, radio, and DCU. It is important to note here that PLSS 2.0 was designed with the ability to use the current EMU AgZn and LLB batteries as a project cost/schedule risk mitigation. For PLSS 2.5, the package challenges were significant enough that the luxury of carrying the EMU battery as a back-up plan has not been possible so it was dropped as a backup option. Initially the use of a Battery Management System and then Battery Monitoring System (BMS) was evaluated for the common battery module approach but did not add any appreciable risk mitigation while driving volume, mass, power, and cost due to the need to replicate the BMS intelligence across multiple battery modules (14 total at the time, now down to 11 modules for all three battery assemblies). EM-PEM-15-0009 obtained concurrence on the interpretation of the Crewed Space Vehicle Battery Safety Requirements, JSC-20793, Rev C from EP Battery Safety and the NESC. Under this agreement, the BMS was not required and the use of top/bottom fusing and a smart charger with charge port on the PLSS traded well for the architecture. As described in the table above, the BATT-690 includes 8 parallel (8P) battery modules that are 8S. This has the benefit of maintain the 28V rail when a battery in a module is lost as its failure mode and the action of the top and bottom fusing isolates the module from the rest of the rail. At that point, the 28VDC rail remains available to all of the PLSS components with the loss of ~1hr of EVA time, meaning that it is conceivable to perform a 5hr EVA with the loss of 3 battery modules although the likelihood of that occurring is implausible given the anticipated failure rates of the batteries themselves followed by the likelihood that an EVA would be continued under such circumstances.

2.8.3 BATT-790 – PLSS Accessory Battery

The PLSS accessory battery, BATT-790 is responsible for powering Crit 3 loads such as the helmet camera, heated gloves, informatics, helmet lights, aux data port, dosimeter, and storage similar to that of the Rechargeable EVA Battery Assembly (REBA) on the ISS EMU Program. BATT-790, consists of Qty 2 common battery modules of the same design as those used in BATT-690.

2.8.4 CHGR-840 – PLSS Battery Smart Charger

With the implementation of passive battery modules, the health status and hazard controls for the Lithium Ion chemistry are implemented in the “smart” charger. The PLSS implements a single Mighty Mouse 805 85 pin charge port connector which directly and independently accesses each battery module to provide a dedicated recharge current and monitor an integrated thermal sensor, full string voltage, and mid-string voltage while charging. The charge profile will be a constant current-constant voltage (CC-CV) profile to trickle cut-off. Additional screening functions will be included to verify battery health during pre-charge and charge operations.

2.9 CONTROLLERS/CAUTION AND WARNING SYSTEM (CWS)

The PLSS operates with distributed controllers that are responsible for low-level functions such as motor commutation and sensor monitoring with internal telemetry streamed to the Caution and Warning System (CWS-650). Some of the functions performed by the respective controllers are discussed in the relevant sections but for summary purposes, the list of controllers is as follows:

- CON-150 – Primary Oxygen Regulator Controller
    - Commutates the linear actuator that sets the pressure output for the POR
    - Excites and monitors attached instruments (TS-110, PT-112, PT-115, PT-116, DP-114, PRV-113E)
    - Excites and reads the command input from the DCU, POR_SET
    - Provides an optically isolated watchdog trigger fail bit to the CWS
    - Connects to the CWS directly streaming telemetry over a half-duplex Low Voltage Differential Signaling (LVDS) communications interface
- CON-250 – Secondary Oxygen Regulator Controller
    - Commutates the linear actuator that sets the pressure output for the SOR
    - Excites and monitors attached instruments (TS-211, PT-215, PT-216, DP-214, PRV-213E)
    - Excites and reads the command input from the DCU, SOR_SET
    - Provides an optically isolated watchdog trigger fail bit to the CWS
    - Connects to the CWS directly streaming telemetry over a half-duplex Low Voltage Differential Signaling (LVDS) communications interface
- CON-350 – Oxygen Ventilation Loop Controller
    - Commutates the rotary stepper actuator positioning the GX-380 bed between A, B, equalize, and lock-up positions
    - Commutates the primary fan BLDC motor with HED position feed-back
    - Commutates the secondary fan BLDC motor with HED position feed-back and a dedicated, isolated power input from the CWS
    - Excites and monitors attached instruments (GX-380F, PT-1001, DP-321, TS-320, FN-323D, FN-324D)
    - Provides power to the attached multi-gas sensors (GS-322 and GS-300) then reads the RS-485 full-duplex output telemetry stream (this was set due to commonality with the ISS EMU IRCO2 sensor replacement effort)
    - Excites and reads the command inputs from the DCU, FAN_SW and RCA_SW
    - Provides an optically isolated watchdog trigger fail bit to the CWS
    - Connects to the CWS directly streaming telemetry over a half-duplex Low Voltage Differential Signaling (LVDS) communications interface
- CON-450 – Thermal Loop Controller
    - Commutates the linear actuator positioning the TCV-421, Thermal Control Valve
    - Commutates the linear actuator positioning the HX-440, SWME back-pressure valve
    - Commutates the primary pump BLDC motor with HED position feed-back
    - Commutates the secondary pump BLDC motor with HED position feed-back and a dedicated, isolated power input from the CWS

  - Excites and monitors attached instruments (TS-441, TS-439, DP-425A, DP-425B, PT-432, TS-400, TS-442, TS-443, TS-444, TS-445, TCV-421C, HX-440D, PMP-423D, PMP-422D)
  - Excites and reads the command inputs from the DCU, PUMP_SW, TCL_SET, and SCU_MATE
  - Provides an optically isolated watchdog trigger fail bit to the CWS
  - Connects to the CWS directly streaming telemetry over a half-duplex Low Voltage Differential Signaling (LVDS) communications interface
- CON-550 – Auxiliary Thermal Control Loop (ATCL) Controller
  - Commutates the linear actuator positioning the HX-540, back-pressure valve
  - Commutates the pump BLDC motor with HED position feed-back
  - Accepts a dedicated BATT-590 power input for the actuator and pump loads with ORing for the monitoring functions.
  - Excites and monitors attached instruments (TS-501, TS-502, HX-540D, PMP-500D, PT-532)
  - Excites and reads the command inputs from the DCU, ATCL_SW
  - Provides an optically isolated watchdog trigger fail bit to the CWS
  - Connects to the CWS directly streaming telemetry over a half-duplex Low Voltage Differential Signaling (LVDS) communications interface

Much like what is done in a modern car, the controllers are distributed such that they accept a single battery or vehicle supplied power rail, in this case, at ~28VDC. The controllers, as a result, are more modular as the interface to the PLSS is simplified to power, LVDS communications, and a few discretes but does not involve monitoring or managing a series of power rails such as 12V, 5V, 3.3V, etc since the controllers can make whatever is required to perform the functions on their side of the interface. The controllers are also physically located near the actuators being driven and near the sensors being excited and monitored as an ORU-able part of the system. The controllers have isolated command inputs from the DCU-685 which each controller excites and which the inputs return to that same controller. This means that should a controller fail or should the DCU display fail, that the other controllers will continue to operate and respond from the DCU switches.

The Caution and Warning System (CWS-650) much like its ISS EMU namesake, is a monitoring system not a control system. The CWS receives telemetry from all of the attached controllers, converts the raw counts to engineering units for PLSS instruments, packages the telemetry for downlink over UHF and through an isolated diagnostics port, computes consumables valves selecting the limiting consumable to determine EVA time, computes states and state transition logic, computes augmented parameters for system health/error checking, computes fault detection logic, generates messages for the DCU, generates tones for the radio to internal audio interface, communicates the messages to the DCU for display to the crew, accepts switch inputs from the crew via the DCU (CWS_SW, PWR_SW) to operate soft-menus for manipulation of the software, switches power between SCU supplied vehicle power and internal battery (BATT-690), provides power distribution and current limiting to attached loads within the PLSS, directly monitors internal health sensors, monitors the BATT-690 voltage/current, then provides automated sequences such as leakage checks, purge timers, and prebreathe profile clocks.

2.10 RADIO/ANTENNA

The EV-701, Radio is powered by a current limited primary power bus feed from the CWS-650. It accepts telemetry from the CWS and then makes a TDMA connection to the Space to Space Communications System (SSCS), specifically the Space to Space Station Radio (SSSR) to enable communications with other spacesuits EVA and to transfer suit telemetry to the vehicle and ground. The Space to Space Advanced EMU Radio (SSAER) as the EV-701 is often termed, is a functional redesign of the Space to Space EMU Radio (SSER) currently flying on the ISS EMU. It seeks to implement the functions performed by the SSER but in an FPGA that is reconfigurable and capable of supporting future exploration needs with UHF communications. It also seeks to implement radio redundancy throughout taking what has been implemented in the SSER and further improving upon it for redundancy.

The antenna is intended to be a patch-style antenna with one located on each side of the PLSS main structure. Each antenna would be directly tied to one of the dual-redundant UHF radios within the EV-701 assembly.

2.11 DISPLAY AND CONTROL UNIT (DCU-685)

The DCU is attached to the anterior of the ZHUT and serves as the main crew interface for control of the PLSS. The DCU performs the following functions:

- Provides the suit side of the common QD connection of vehicle services: oxygen, thermal loop/aux thermal loop, power, communications, data
- Provides thermal and auxiliary thermal loop fluids interface to the SSA HUT
- Provides the critical message display to the crew
- Provides physical controls for critical functions that are directly tied to the PLSS controllers
- Provides a physical suit pressure gauge reading with clear visibility to the crew
- Provides connections from the HUT to the suit purge valve for hand access (either hand) with visible verification
- Provides control of power supply switching or transfer between vehicle and on-board power
- Provides an automated checkout connection to enable remote commanding of switch positions

3.0 XPLSS OPERATIONS DESCRIPTION

The intention of the PLSS Operations Description is to define behavior of the PLSS in conjunction with the larger xEMU System while interfacing with various vehicle configurations. This is not intended to replace the xEMU Operations Concept Document, but rather to provide a more detailed description of how the PLSS is expected to operate in context of the xEMU Operations Concept for the purpose of requirements development and PLSS design.

3.1 SUITPORT CONFIGURATION

DELETED

The suit port configuration was removed from xPLSS requirements and is no longer being pursued.

3.2 AIRLOCK CONFIGURATION

Given that the pre-launch processing, pre-launch stowage, and post-return destow operations are dependent on the details of the Program and vehicle architecture needs, these areas are not considered at this point. Rather, the focus of this behavioral description is spent on the preEVA, EVA, and postEVA operations details. This section focusses on the airlock style of vehicle to suit interface with special consideration for the airlock interface style presently available on the International Space Station (ISS).

3.2.1 ASSUMPTIONS

Cabin pressure = 14.7 +0.5/-0 psia
Cabin mixture = 21% O2 balance N2

3.2.2 PLSS TO PGS MATE/DEMATE OPERATIONS

Depending on the particular launch configuration, logistical needs for suit sizing, or IFM operations, the PLSS may be removed from or installed onto the PGS.

For cost savings related to launch adapter development, it is expected that the PLSS will be launched to ISS in the SEMU Launch Adapter in an M03 bag. This will be separate from the DCU and HUT as the SEMU stack-up for the suit is too large to fit.

3.2.2.1 PLSS TO PGS MATING

PLSS Assembly

1. Destow the PLSS and remove protective cover from the PLSS interface pad
2. Clear the TMG from the mating interfaces
3. Mount the PLSS into the EDDA
4. Open the hatch and remove the protective cover
5. Verify/disconnect the Water Line Vent Tube Assembly (WLVTA)
6. Verify/disconnect the comm/biomed connector
7. Depin the hatch from the HUT
8. Take hatch, and engage the two lower mushroom bolt/trailer hitches onto the PLSS
9. Hatch can be rocked out from the PLSS at the top by ~10 deg
10. Mate the HUT interface pigtail connector to the hatch
11. Inspect and make sure that no FOD is present at the hatch to PLSS interface pad
12. Rock the hatch back into the PLSS interface pad and start the 4 captive fasteners
13. Torque the four fasteners to XX in-lbs
14. Hang the PGS onto the hatch and re-pin the hinges
15. Open the hatch (swing the suit out)

16. Mate the comm/biomed connector
17. Mate the WLVTA if needed connection
18. Reinstall the hatch protective cover
19. Close the hatch (swing the suit back)
20. Close the TMG around the PLSS/HUT Interface

DCU Assembly

1. Destow the DCU and remove the protective cover from the HUT interface pad
2. Inspect the DCU and HUT sides of the interface and ensure that no FOD is present
3. Mate the DCU to the HUT and start the four captive fasteners
4. Torque the 4 captive fasteners to XX in-lbs
5. Open the HUT TMG to enable line routing to the PLSS.
6. Remove the connector caps and mate the DCU to PLSS electrical harness

NOTE: If this is to be performed in the ISS Equipment Lock as assumed, position the HEPA filtered air hose such that core flow is encompassing the oxygen connections at the PLSS backplate.

7. Carefully remove the PLSS side connector cap on the primary oxygen loop connection.

NOTE: This may vent a small amount of oxygen depending on the leakage of the regulator check valve. We may have to add steps and a tool to vent this line before mating if we want to protect for leakage from the check valve on the regulator assembly. ISS EMU depressurizes the tankage as a precaution; that is another option but will come with complications as venting both charged tanks on two suits will dump 7-8 lbs of oxygen into the airlock and take 30+ minutes at maximum regulator flowrates especially if there is a desire to get below ullage pressure. We could also look at the implementation of a QD here but it would involve greater complexity, pressure losses, etc to improve an infrequent operation.

8. Remove the connector caps and mate the DCU to PLSS primary high pressure oxygen line to the primary oxygen line connection.
9. Remove the connector caps and mate the DCU to PLSS secondary high pressure oxygen line to the secondary oxygen line connection.
10. Tighten each fitting to snug.
11. Close the HUT TMG gauntlet around the lines and secure.

3.2.3 PREEVA CHECKOUT - MANUAL

This section focusses on the suit functional notional verification sequences to be performed prior to each EVA series and after initial launch/destow. This draft will be updated as the FMEA matures to ensure as many FMs are screened preEVA as possible.

- Power up
  - PWR - BATT
  - Initial power up and Power On Self Test (POST)
- HL comm check
  - Mate SCU-801
  - Configure vehicle comm system
  - Vehicle powered hard-line communications check
- RF comm check
  - Configure vehicle comm for RF check
  - Suit/vehicle RF network radio communications check
  - Deconfigure vehicle comm
- Wireless data check
  - Verify suit data being transmitted over wireless data network
- RCA/Fan function check
  - Assumes that the cabin PPCO2/RH is elevated

  - Close-up suit
  - MSPV - CL
  - Set POR => 0.4 psi
  - FAN – ON
  - RCA – TM
  - Monitor dropping PPCO2 and RH readings
  - Fan – OFF
  - RCA – OFF
- SOR flow and regulation check
  - With suit already closed up and at ~0.4 psid
  - SOR => 3.7 psid
  - Record the time to pressurize the known suit volume to 3.7 psid
- POR flow and regulation check
  - With suit already closed up and at ~3.7 psid
  - POR => 8 psid
  - Record time to pressurize the known suit volume to 8 psid
- Recharge flow check
  - Open vehicle O2 supply
  - Record time for top-off of Primary and Secondary tanks
- Suit leakage check
  - With suit closed and pressurized to 8 psid
  - SOR => OFF
  - POR => OFF
  - Monitor time for pressure decay for 5 minutes
  - MSPV – HI
  - Monitor time for pressure drop to cabin ambient
  - Disconnect AEMU Servicing Umbilical
- Dry LCVG degas/Thermal Loop check
  - Monitor DP-425 and PT-432
  - Connect dry LCVG to suit multiple water connector
  - PUMP – ON
  - TCV – C
    - This should drive the SWME full open where the gas can be purged.
  - Monitor the time required to remove all bubbles via inspection of the LCVG/WLVTA tubing
  - TCV-H
  - PUMP-OFF
- Battery load check
  - The checkout is essentially a battery load check
  - Monitor loaded voltage during the checkout
  - Connect AEMU Servicing Umbilical
  - Bring up vehicle power
  - PWR – SCU
  - Record battery OCV
  - PWR – BATT
  - Shut-down vehicle power
  - PWR - SCU
- Battery recharge check
  - Initiate in-suit battery recharge/top-off
  - Disconnect and stow SCU-801

3.2.4 PREEVA CHECKOUT – AUTOMATIC

This section focusses on the suit functional verification sequences to be performed prior to each EVA series and after initial launch/destow but in an automated fashion. The details of the automated sequences to be performed will be determined by first seeking to screen all criticality1 and 2 FMs in the FMEA followed by a negotiation of risk vs cost for the community.

- Connect automated checkout kit between the suit and the umbilical
- Configure the vehicle supplies and communications
- PWR – ON
- Initiate automated checkout
    - The automated checkout system will manipulate the switched inputs on the DCU via over-rides and manipulate the suit configuration via control valving running an automated sequence of tests
- PWR – OFF
- Disconnect automated checkout kit
- Initiate in-suit battery recharge/top-off
- Disconnect and stow SCU-801

3.2.5 EVA SEQUENCES

This section focusses on the depress, EVA, and repress sequences that would be performed on a given EVA day.

Entry Point/Assumptions:

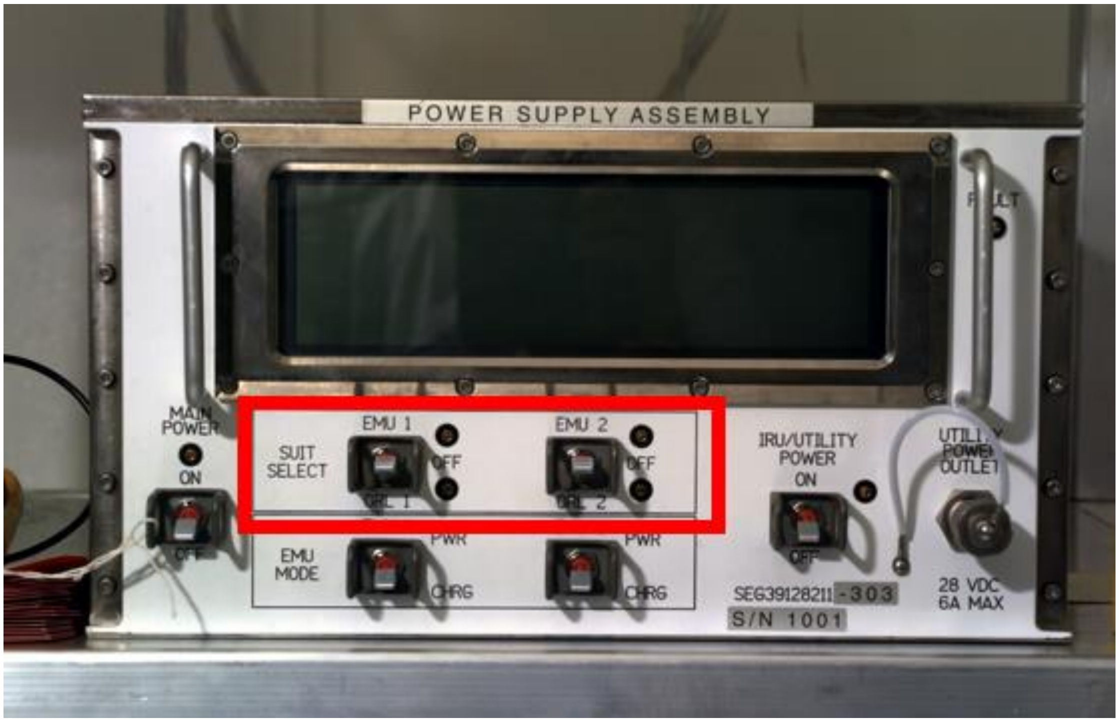
- The xEMUs are mounted on holding fixtures and PLSS is already attached to PGS
    - Could possibly use EMU Don/Doff Assemblies (EDDA) if the PLSS can be packaged into a Shuttle/ISS EMU OML and the suit were not a rear-entry configuration or a means of support for the suit could be devised for the donning.
    - It is presently assumed that the xEMU PGS will be a rear entry configuration and that the suit will either be restrained in the EDDA via the AAP mounts on the PLSS or that a Yoke will be developed to hold the suit from the front
- The SCU is available but not connected.
- Cabin pressure is 14.7 psia but could be 10.2 psia as required for a given prebreathe protocol.
- Airlock configuration is that of ISS with selected modifications to accommodate an xEMU.
- There is a 2-person EV crew with IV crew assistance on equipment lock operations.
- Comm is integrated into the PGS – i.e. no comm cap
- Airlock provides vacuum access for RCA desorb via an umbilical.

DCU Switch/PLSS Control	**Position**
PWR_SW (SCU/BATT)	SCU
FAN_SW (PRI/OFF/SEC)	OFF
PUMP_SW (PRI/OFF/SEC)	OFF
POR_SET (0, 0.4, 0.9, 4.3, 6.0, 8.0)	0 (OFF)
SOR_SW (ON/OFF)	OFF
RCA_SW (TM/OFF/CO2)	OFF
SCU_MATE (ON/OFF)	OFF
TCL_SET (OFF, H, 1, …,9,C, ACC)	OFF
ATCL_SW (ON/OFF)	OFF
CWS_SW (PRO/OFF/STAT)	OFF
Multi-position Suit Purge Valve (MSPV)	HI
SOFT SWITCH CONFIGURATIONS	
COMM (HL/PRI/ALT/OFF)	OFF
FREQ (LO/PTT/HI)	PTT
VOL (0-10)	0
INFO	OFF
State	0 (OFF)

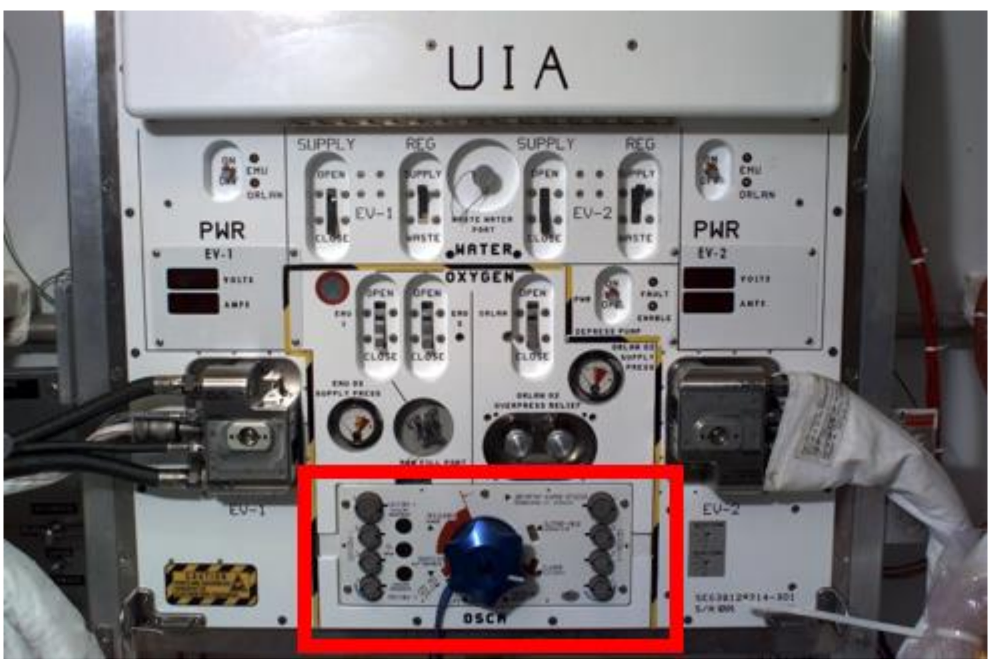
3.2.5.1 SUIT DONNING

1) Verify PWR_SW = SCU
2) On UIA, Verify PWR EV1/2 - OFF
3) Remove DCU cover, and mate the xEMU Servicing and Cooling Umbilical (SCU)
   This closes SCU_MATE but the suit is not yet powered.
4) Remove the protective cover and install the Vacuum access umbilical onto the port on the front of the suit
5) PWR_SW = BATT
   Taking the PLSS PWR-BATT provides power to the CWS-650. With power applied, the CWS will initialize and will provide filtered, current limited, suit power to all of the attached controllers and radio (EV-701) which will also power up in quiescent monitoring mode after an initialization. At this point, the PLSS will be powered and transmitting telemetry but not moving actuators.

   State => 1(Start-up)



6) PSA => MAIN POWER = ON
7) PSA => SUIT SELECT to ORL 1/2
8) Verify voltage on ORL 1/2 is 26.0 – 30.0 VDC
    NOT EMU, Orlan mode provides 28V power needed for xEMU. The EMU mode will provide 18.2VDC which is below the lower operating limit of the PLSS.
9) PSA => EMU MODE => PWR for ORL 1/2



10) UIA => PWR EV 1/2 = ON
11) UIA => Verify Orlan 1/2 LEDS illuminated
12) UIA => Verify display on UIA reads 26.0-30.0 VDC and ~0 A on each channel
13) PWR_SW => SCU

This will transfer power from battery to vehicle power but there should be no restarts or upsets with the transfer.

14) UIA => Verify O2 supply pressure as read via the high pressure O2 supply gauge (location where the OSCA presently resides).
15) UIA => Open the high-pressure oxygen supply valve (located where the OSCA presently resides) to initiate oxygen flow to the SCUs

    With ~2450 psia supply source (exploration will be 2850-3000 psia), the CWS will first have telemetry on the existing tank pressure for both the primary and secondary, then will see a charge rate up to the source pressure. The support team will have to make a judgment about the initial tank pressure given the dwell time and initial pressure at the start of that dwell as to the acceptability of the pressure.
16) UIA => Open the VAC ISO VALVE on each umbilical port
17) Vehicle will configure either the vacuum access pump or Equipment lock vacuum isolation valves to open and provide vacuum to the suit
18) Verify/Open suit hatch

    Human-in-the-loop (HITL) testing with PLSS 2.0 and the Mark III spacesuit prototype demonstrated that the initially high concentrations of NH3 (~6000 ppm est) can be adequately controlled around or below oro-nasal threshold (<3 ppm) by swinging each bed to vacuum with the fan off twice and then running the fan with the hatch open for a 3-5 minutes.
19) RCA_SW => TM

    The RCA switch is thrown on the DCU, which then toggles a set of DIO lines to the CON-350, Ventilation loop controller. The controller then swings the RCA at timed cycle of ~2 minutes. This will swing the RCA and desorb the beds, clearing most of the NH3 before the Fan is switched on in subsequent steps.
20) Wait 8 minutes minimum before proceeding.
21) FAN_SW => SEC

    The fan switch mounted on the DCU is thrown and toggles a set of DIO lines to the CON-350, Ventilation Loop Controller which then, via the BLDC motor controller spins up the fan to a single set-point speed chosen for optimal power consumption at EVA conditions. In this case, the use of the secondary ventilation fan is initiated. CON-350 will spin the fan up, measure current, speed, etc and confirm proper fan operation. The fan will begin circulation of gas in the open ventilation loop purging out residual NH3. This serves as a preEVA checkout of the secondary fan.
22) Don MAG
23) Don Biomed sternal harness
24) Don TCU

    PLSS would like to get rid of these to improve conductivity to skin and allow warmer water temperature in the thermal loop, but listed them as legacy since this hasn't been done yet and may not be possible for microbial control reasons aside from specific thermal comfort issues.
25) Don LCVG
26) FAN_SW => PRI

    The fan switch mounted on the DCU is thrown and toggles a set of DIO lines to the CON-350, Ventilation Loop Controller which then, via the BLDC motor controller spins up the fan to a single set-point speed chosen for optimal power consumption at EVA conditions. In this case, the use of the primary ventilation fan is initiated. CON-350 will spin the fan up, measure current, speed, etc and confirm proper fan operation. The fan will complete circulation of gas in the open ventilation loop purging out residual NH3.
27) Don xEMU via rear-entry hatch
28) Connect LCVG to internal water line vent tube assembly (this includes primary and auxiliary loops as well as the ventilation return tree)

    This would be done part of the way through donning as the crew could still reach the connectors but the hatch would not yet be closed.
29) Connect biomed to internal suit harness
30) Verify/adjust integrated speakers/mics as needed
31) RCA_SW => CO2

    The RCA switch is toggled to "CO2" position where CON-350, then reads the PPCO2 value of GS-322 (helmet inlet) and then swings the beds accordingly. This reduces the frequency of the bed cycling raising the ventilation loop humidity and reducing ventilation loop gas lost.
32) PUMP_SW => PRI

    The Pump switch on the DCU is thrown and toggles a set of DIO lines to CON-450, Thermal Loop Controller which then uses the on-board BLDC motor controller to spin the pump at a fixed speed that *correlates to ~200 pph. The primary pump is selected at this point so that the water loop can be circulated through filter F-448 protecting the secondary pump inlet filter from additional loading should there be a systemic water quality problem with precipitates, etc.*

State => 2(Donning/Doffing A/L)

33) TCL_SET => C

With the TCL_SET => [not OFF] and SCU_MATE = ON, the thermal loop controller (CON-450) sets the HX-440 back-pressure valve to a fixed value of 10% open to enable degassing but does not attempt to control the outlet temperature.

34) Verify cooling in LCVG and no visible leakage from mated connectors

35) TCL_SET => {as needed for comfort}

TCL-SET is defaulted to OFF at the start-up with the HX-440 back-pressure valve closed and the TCV – H or full bypass. CON-350 sees the SCU_MATE-ON and only changes the TCV-421 position to act as a diverter valve function using the vehicle heat exchanger for the cooling source. The TCV-421 position can then be ramped from full flow (TCV – C) at ~200 pph to the LCVG to (TCV-H) ~0 pph to the LCVG in bypass.

36) Check comm

37) Close and lock rear hatch

38) If gloves are not already installed and locked, do so now

39) Verify MSPV - CL

40) POR_SET => 0.4 psid

The multi-position switch on the DCU is manually set by the crew to the 0.4 psid set-point. For PLSS 2.5 this is being accomplished by three mechanical switches connected with a special slider that excite 6 DIO lines connected to CON-150, the Primary Oxygen Regulator (POR) controller which then sets the regulator to the selected set-point. This then begins pressurization of the crew in the suit.

State => 5 (IVA A/L)

DCU Switch/PLSS Control	**Position**
PWR_SW (SCU/BATT)	SCU
FAN_SW (PRI/OFF/SEC)	PRI
PUMP_SW (PRI/OFF/SEC)	PRI
POR_SET (0, 0.4, 0.9, 4.3, 6.0, 8.0)	0.4
SOR_SW (ON/OFF)	OFF
RCA_SW (TM/OFF/CO2)	CO2
SCU_MATE (ON/OFF)	ON
TCL_SET (OFF, H, 1, …,9,C, ACC)	A/R
ATCL_SW (ON/OFF)	OFF
CWS_SW (PRO/OFF/STAT)	OFF
Multi-position Suit Purge Valve (MSPV)	CL
SOFT SWITCH CONFIGURATIONS	
COMM (HL/PRI/ALT/OFF)	HL
FREQ (LO/PTT/HI)	PTT
VOL (0-10)	A/R
State	5 (IVA A/L)

3.2.5.2 LEAKAGE CHECK

State => 5 (IVA A/L)

Suit should be closed and, in this case, already pressurized to 0.4 psid.

1) SOR_SW => ON

The DCU switch is thrown which toggles two IO lines to the CON-250 controller setting the SOR to the 3.5-3.7 psid set-point. The suit pressure will then rise from 0.4 psid to 3.7 psid and hold in a requisite *amount of time to verify the regulator is properly functioning. When pressurization exceeds the POR_SET, the POR will go into lock-up and the SOR will begin regulating the ventilation loop.*

2) Verify suit pressure is stable at 3.6 +/- 0.1 psid.
3) POR_SET => 4.3 psid

   This pressure can be altered to perform the leakage check at whatever the intended EVA pressure is to be; 8 psi for example. In this case, the crew selects the 4.3 psid set-point on the DCU and CON-150 responds by setting the POR to the appropriate pressure. If the pressure is altered, the CWS will adapt the pass/fail criteria applicable to the selected pressure as well as to the ambient pressure.
4) SOR_SW => OFF

   The DCU switch is thrown which toggles the IO lines to the CON-250 controller setting the SOR to 0 psid and driving the unit into lock-up. This will isolate the secondary oxygen supply. With the SCU mated, the vehicle high pressure oxygen supply is constantly topping off the primary and secondary oxygen supplies before EVA start.
5) Manipulate the CWS_SW through the menus and select the leakage sequence
   a) When prompted, RCA_SW => TM

      The bed will swing immediately and start swinging the bed every 2 minutes after that.
   b) When prompted, RCA_SW => CO2
   c) When prompted, POR_SET => 0.4 psid

      The CWS logic will instruct the crew to set RCA=>TM, allow a bed swing and then back to RCA=>CO2. The system will then wait for 10 seconds to stabilize the suit pressure and have the crew take the POR_SET => 0.4 psid. Once the regulator has begun moving to the lower set-pressure, the CWS will begin the pressure decay leakage check timer. The time will be based on the allowable leakage rate, suit free volume, calculated Qmet (Delta PPCO2), as well as the selected POR_SET pressure. Once the time has elapsed, the CWS will issue a message along with the decayed pressure. If the leakage decay is acceptable, then the leak check will be complete. If not, it may need to be repeated after depressing the suit and checking sealing surfaces.
6) PUMP_SW => SEC

   The Pump switch on the DCU is thrown and toggles a set of DIO lines to CON-450, Thermal Loop Controller which then uses the on-board BLDC motor controller to spin the pump at a fixed speed that correlates to ~200 pph. The secondary pump is selected at this point in order to get preEVA run-time and verification accomplished. The primary pump has pushed the entire loop through filter (F-448) multiple times to reduce the chances of loading the secondary pump inlet filter.
7) Upon leakage check complete proceed to Suit Purge and Prebreathe

   State => 5 (IVA A/L)

3.2.5.3 PURGE-PREBREATHE

State => 5 (IVA A/L)

1) CWS_SW => Select Purge Timer Function

   Follow through menus to select appropriate purge. Then proceed.
2) MSPV => HI

   The CWS will start a timer when the Psuit (DP-114 or DP-214) drops > 0.5 psid or the crew could make a menu selection to tell the CWS when they opened the MSPV. The CWS will count down on the selected time and issue a "PURGE COMPLETE, CL PURGE VALVE" message. The time will be based on the worst-case gas quality from the vehicle, lowest purge valve flowrate, largest suit free volume, and least efficient purge efficiency demonstrated or analyzed as part of certification. This is what is done on ISS EMU.

3) MSPV => CL
4) Verify/Set POR_SET => 0.4 psid

   POR_SET switch is set by the crew to 0.4 psid and CON-150 sets the POR to the appropriate set pressure.
5) The prebreathe requirements will vary based on the selected protocol being used, associated R-value, and the designated EVA operating pressure.

Protocol	In-Suit	10.2 (12 hr)	10.2 (24 hr)	Exercise
Mask prebreathe time	None	1 hour	1 hour	80 minutes
In-suit prebreathe time	4 hours	75 minutes	40 minutes	1 hour
Ops Overview *(Details of EVA Prebreathe protocols are in the Aeromed Flight Rule #B13-107)*	Breathe O_2 in-suit for 4 hours while cabin is at 14.7, go out the door.	Breathe O_2 on mask while depressing cabin to 10.2, wait 12 hours before in-suit prebreathe, go out the door.	Breathe O_2 on mask while depressing cabin to 10.2, wait 24 hours before in-suit prebreathe, go out the door.	Exercise on bike for 10 min. at beginning of mask prebreathe, depress airlock to 10.2, breathe in-suit for 1 hour, go out the door.

Table 3-1 - ISS EMU Prebreathe Protocols for 4.3 psia EVA Pressure

3.2.5.4 DEPRESS

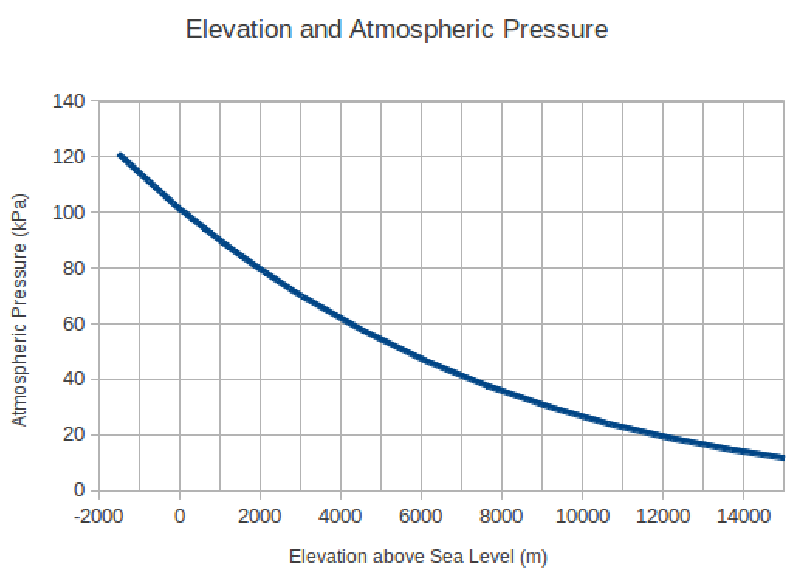
<u>Assumptions:</u>

- This assumes that the vacuum access for the RCA is available to both suits in the Crewlock, not just the Equipment Lock on ISS or any other airlock based vehicle.
- IVA hatch is closed and locked

State => 5 (IVA A/L)

1) PUMP_SW => PRI
   The Pump switch on the DCU is thrown and toggles a set of DIO lines to CON-450, Thermal Loop Controller which then uses the on-board BLDC motor controller to spin the pump at a fixed speed that correlates to ~200 pph. After check-out of the secondary pump, the primary pump is configured prior to depress operations. Given programmatic risk posture, it is possible that the secondary pump could be used through this sequence should the primary pump have failed.
2) UIA – DEPRESS PUMP PWR SW = ON
3) CrewLock – DEPRESS PUMP MANUAL ISOLATION VALVE = OPEN
   The xEMU PPRV is set ~8.6 psid and may crack depending on the depress rate and starting pressure. The CWS detects the airlock depress via PT-116 decreasing.
   State => 8 (Depress 1)
   The CWS will monitor PT-116 and when it drops below 6 psia, will switch to
   State => 9 (Depress 2)
   This will result in DCU messages and a tone to the crew to let them know they are approaching 5 psia on the airlock depress although the PT-116 pressure will also be displayed on the DCU during the depress cycle starting at State 8 (Depress 1).
4) When Crew-lock at 5 psia, Crewlock - DEPRESS PUMP MANUAL ISOLATION VALVE = CLOSED
5) MSPV – LO
   a) Allow suit pressure (DP-114/DP-214) to drop to 5-6 psid
      This performs a preEVA flow verification of the low setting of the purge valve and lowers the suit pressure for a leakage check.

6) MSPV- CL
7) Manipulate the CWS_SW through the menus and select the leakage sequence
    a) When prompted, RCA_SW => TM
       The bed will swing immediately.
    b) When prompted, RCA_SW => CO2
       The CWS logic will instruct the crew to set RCA=>TM, allow a bed swing and then back to RCA=>CO2. The system will then wait for 10 seconds to stabilize the suit pressure, then the CWS will begin the pressure decay leakage check timer. The time will be based on the allowable leakage rate, suit free volume, calculated Qmet (Delta PPCO2), as well as the selected suit pressure. Once the time has elapsed, the CWS will issue a message along with the decayed pressure.
    c) When complete, CWS => LEAK CHK COMPLETE, RATE <X.X psi/min
8) SOR_SW => ON
9) POR_SET => 4.3 psid
10) Crewmember check through Suit Status on display to verify no warnings and all consumables and functions nominal
11) Ground will get these via telemetry and may want Crew to read-off display to verify they match
12) Resume depress to vacuum at no greater than 10000 ft/min
13) CrewLock – DEPRESS PUMP MANUAL ISOLATION VALVE = OPEN



The CWS detects the airlock depress via PT-116 decreasing. When PT-116 < 4 psia, it transitions to
State => 10 (Depress 3)
This is approaching the uninhabitable ambient environment. The CWS will continue to monitor PT-116 and when it drops below 1 psia, it will transition to
State => 11 (Depress 4)
The CWS will monitor PT-116 < 0.5 psia and SOR-ON or TS-439 < 60F or PT-432 < 8.4 psia and then transition to
State => 12 (EVA)

14) When Crewlock reaches 3.0 psia, EV HATCH MPEV = OPEN
15) When Crewlock reaches 1.5 psia
    a) Crewlock - DEPRESS PUMP MANUAL ISOLATION VALVE = CLOSED
    b) UIA - DEPRESS PUMP PWR SW = OFF
16) When PT-116 or vehicle airlock pressure <.5 psia
    a) EV Hatch – open and stow
    b) EV Hatch – MPEV = CLOSED
17) CWS_SW soft menu verifications/settings
    a) COMM => PRI

b) FREQ => LOW
c) COMM VOL => As required

18) Perform communications check with EV crew, IV crew, and ground
19) Adjust volume as required
20) POR_SET => EVA pressure {4.3, 6.2, 8.2 psid}
    If running the nominal 4.3psid EVA pressure, then this is just a check, otherwise, this is a setting change.
21) TCL_SET => H
    Preparation for Auxiliary Thermal Control Loop check. With the SCU_MATE = ON, this will set TCV-421 to full bypass, while it continues to degas the thermal loop with HX-440 at 10% open. At vacuum the thermal loop will begin to drop in temperature based on the additional heat rejection from the SWME at vacuum conditions.
22) ATCL_SW => ON
    The ATCL switch is thrown and toggles a set of IO lines to CON-550 control circuits which then begins commutation of PMP-500 at a set speed and simultaneously opens the back-pressure valve on HX-540 to a single preset value.
    Monitor TS-501 to see a drop in temperature, crew will detect cooling in the torso of the LCVG, verify PT-532 inlet pressure, verify position sensor on HX-540, verify battery loaded voltage, verify hollow fiber bundle temperature drop, etc.
    This process will take 2-5 minutes.
23) ATCL_SW => OFF
    The auxiliary thermal control loop has completed check-out, return to EVA configuration. This will depower CON-550 commutation/actuation circuitry stopping the pump and closing the HX-540 valve.
24) TCL_SET => {as required}
25) UIA => Take the VACUUM ISOLATION VALVE EV1/2 = CLOSED
26) Disconnect RCA vacuum access umbilical and stow
27) Verify/Set RCA => CO2
    The crew sets this manually on the DCU via the RCA switch and CON-350 then begins monitoring the GS-322 output and swinging the RCA based on set value.
28) PWR => BATT
    This is the historical starting point for the EVA. This transitions PLSS power from umbilical supplied power to internal battery power from BATT-690. The informatics power depending on the suit configuration will either be on via a signal from the CWS precipitated by an algorithm or by soft menu selection.
29) UIA => PWR EV 1/2 = OFF
30) UIA => Verify Orlan 1/2 LEDS not-illuminated
31) Disconnect the SCU from the DCU, reinstall protective DCU cover, and stow SCU in pouch
    This sets SCU_MATE = OFF, which will toggle a set of DIO lines to CON-450, Thermal Loop Controller. The controller will then set the HX-440 back-pressure valve and TCV-421 as directed by the crew via the TCL_SET located on the DCU. HX-440 will now begin to control the heat rejection from the system.
32) Crewlock - DEPRESS PUMP MANUAL ISOLATION VALVE = CLOSED
33) Crewmember check through Suit Status on display to verify no warnings and all consumables and functions nominal
34) Ground will get these via telemetry and may want Crew to read-off display to verify they match
35) TCL_SET => {as required}
    Crew may select Auto Cooling Control (ACC) by setting the TCL_SET = ACC which is one détente beyond FULL COLD. In this configuration, the CON-450 Thermal Loop Controller will calculate the metabolic rate and environmental heat leakage, then determine an appropriate setting for the TCV-421 to maintain comfort.
36) Set suit visors as required
37) Egress airlock

State => 12 (EVA)

DCU Switch/PLSS Control	**Position**
PWR_SW (SCU/BATT)	BATT
FAN_SW (PRI/OFF/SEC)	PRI
PUMP_SW (PRI/OFF/SEC)	PRI
POR_SET (0, 0.4, 0.9, 4.3, 6.0, 8.0)	4.3
SOR_SW (ON/OFF)	ON
RCA_SW (TM/OFF/CO2)	CO2
SCU_MATE (ON/OFF)	OFF
TCL_SET (OFF, H, 1, …,9,C, ACC)	A/R
ATCL_SW (ON/OFF)	OFF
CWS_SW (PRO/OFF/STAT)	OFF
Multi-position Suit Purge Valve (MSPV)	CL
SOFT SWITCH CONFIGURATIONS	
COMM (HL/PRI/ALT/OFF)	PRI
FREQ (LO/PTT/HI)	LO
VOL (0-10)	A/R
INFO	ON
State	12 (EVA)

3.2.5.5 EVA

This section is quasi-static with respect suit configuration as the suit should be invisible to the crew and not the subject of the EVA. That said, the suit does have the capability to allow for functions such as zero or reduced prebreathe where-by the crew via some yet to be determined protocol, would be able to dial down the POR set pressure from a given starting point, such as 8.0 psid down, in increments as necessary, to a set-pressure as low as 4.1 psid per the current specifications.

3.2.5.5.1 VACUUM FEEDWATER RECHARGE

This operation could be required in the event that the environment was warm/hot, metabolic rate was high, SWME water utilization efficiency was diminished, or the planned EVA time was in excess to design constraints.

1) IV crew configure the vehicle feedwater supply in recharge mode (8 psid over cabin pressure = 22.7 psia)
   This could be as high as 15 psid over cabin pressure if the xEMU was using the IRU on ISS.
2) EV crew remove the protective cover on the DCU and mate the SCU to the DCU
   This will set SCU_MATE = ON which toggles an input DIO line to thermal loop controller, CON-450. This will then result in use of the TCL_SET to control the TCV position only as the HX-440 back-pressure valve will move to a 10% open position for degassing.
3) Set TCL_SET => {as required}
4) Monitor PT-432 until stable and > 20.7 psia
   The actual termination criteria will result from detailed analysis and test of the PT-432 location vs the input pressure from the ECLSS system. The FSA-431/FSA-531 will be topped-off at the same time and will cause a drop in the inlet pressure at PT-432.
5) IV terminate recharge operations
6) EV demate the SCU from the DCU, then reinstall the protective cover
   This will set SCU_MATE = OFF which toggle an input DIO line to thermal loop controller, CON-450. This will then result in use of the TCL_SET to control the TCV position and set the closed loop control on the SWME outlet temperature.

7) Set TCL_SET => {as required}
8) IV crew deconfigure the vehicle feedwater supply

3.2.5.5.2 PRIMARY/SECONDARY OXYGEN RECHARGE/TOP-OFF

This operation could be required in the event that the suit leakage is higher than nominal (but not so high as to cause EVA abort), the EVA duration is longer than nominal, or the metabolic rate is higher than nominal.

1) Check O2 supply open and adequate pressure to SCU
2) EV crew open protective cover on DCU and mate the SCU to the DCU
   This will set SCU_MATE = ON which toggles an input DIO line to thermal loop controller, CON-450. This will then result in use of the TCL_SET to control the TCV position only as the HX-440 back-pressure valve will move to a 10% open position for degassing.
3) Set TCL_SET => {as required}
4) Monitor PT-112 until stable and > 2400 psia
   This value can be changed based on what is needed for the top-off and what is provided by the vehicle.
5) EV demate the SCU from the DCU the reinstall the protective cover
6) Set TCL_SET => {as required}

3.2.5.6 REPRESS

State => 12 (EVA)

DCU Switch/PLSS Control	**Position**
PWR_SW (SCU/BATT)	BATT
FAN_SW (PRI/OFF/SEC)	PRI
PUMP_SW (PRI/OFF/SEC)	PRI
POR_SET (0, 0.4, 0.9, 4.3, 6.0, 8.0)	4.3 {6.0, 8.0}
SOR_SW (ON/OFF)	ON
RCA_SW (TM/OFF/CO2)	CO2
SCU_MATE (ON/OFF)	OFF
TCL_SET (OFF, H, 1, …,9,C, ACC)	A/R
ATCL_SW (ON/OFF)	OFF
CWS_SW (PRO/OFF/STAT)	OFF
Multi-position Suit Purge Valve (MSPV)	CL
SOFT SWITCH CONFIGURATIONS	
COMM (HL/PRI/ALT/OFF)	PRI
FREQ (LO/PTT/HI)	LO
VOL (0-10)	A/R
INFO	ON
State	12 (EVA)

1) Ingress airlock
2) Verify EV hatch closed and locked
3) Remove the SCU from the protective pouch
4) Open and secure the DCU protective cover, then mate the SCU to the DCU
   CON-450 will sense the change in the SCU_MATE = ON and the SWME will revert to degas mode with no temperature output control. Primary and secondary O2 tanks will begin recharge immediately upon SCU connection.

5) UIA => Verify O2 supply pressure as read via the high pressure O2 supply gauge (location where the OSCA presently resides)
6) UIA => Verify/Open the high-pressure oxygen supply valve (located where the OSCA presently resides) to initiate oxygen flow to the SCUs

   With ~2450 psia supply source (exploration will be 2850-3000 psia), the CWS will first have telemetry on the existing tank pressure for both the primary and secondary, then will see a charge rate up to the source pressure. The support team will have to make a judgment about the initial tank pressure given the dwell time and initial pressure at the start of that dwell as to the acceptability of the pressure.
7) UIA => PWR EV1/2 SWITCH = ON
8) UIA => Verify EV1/2 ORL LEDs illuminated
9) UIA => Verify EV1/2 Display = 26.0-30.0 VDC

   The CWS will sense voltage is present on the SCU supply source and issue a message to SET PWR SCU since power is present.
10) PWR_SW = SCU
11) Set TCL_SET => {as required}
12) COMM => HL
13) Remove vacuum access umbilical cover and connect the umbilical to the RCA vacuum access port
14) UIA => VACUUM ISOLATION VALVE EV 1/2 = OPEN
15) Repress to 5 psia at no greater than 10000 ft/min
    a) EV Hatch – Verify MPEV = CLOSED
    b) IV Hatch – EQUALIZATION VALVE – Throttle OFF to NORM as required to control the repress rate

       CWS will monitor PT-116 and when increasing, transition to

       State => 13 (Repress 1)

       This will set PT-116 as the default display on the DCU. As PT-116 > 4 psia, it will transition to

       State => 14 (Repress 2)

       The CWS will issue a tone and DCU display to let the crew know that they are approaching 5 psia or whatever the vehicle needs to airlock integrity leakage check prior to complete repress.
16) When Crewlock at 5 psia, IV Hatch – EQUALIZATION VALVE = OFF
17) Perform an airlock leakage check
18) Verify Glove Heaters = OFF
19) Verify Gloves are clean
20) SOR_SW => OFF

    The crew physically flips the SOR_SET switch on the DCU which then toggles two DIO lines to the CON-250; the SOR controller then sets the SOR to shut-off or lockup.

WARNING
IF DCS SYMPTOMS ARE PRESENT, MAINTAIN POR_SET AT EV PRESSURE

21) POR_SET => 0.4 psid

    The crew manually commands via the POR_SET DCU switch, CON-150 to a set pressure of 0.4 psid and it then sets the POR to the appropriate pressure.
22) Resume repress to cabin pressure at no greater than 10000 ft/min
    a) IV Hatch – EQUALIZATION VALVE – Throttle OFF to NORM as required to control the repress rate
23) When Crewlock pressure is within 0.5 psid of cabin pressure, IV Hatch – EQUALIZATION VALVE = OFF
24) Open hatch and ingress Equipment lock
25) Once at cabin pressure, begin doffing sequence

State => 14 (Repress 2)

3.2.5.7 SUIT DOFFING

DCU Switch/PLSS Control	**Position**
PWR_SW (SCU/BATT)	SCU
FAN_SW (PRI/OFF/SEC)	PRI
PUMP_SW (PRI/OFF/SEC)	PRI
POR_SET (0, 0.4, 0.9, 4.3, 6.0, 8.0)	0.4
SOR_SW (ON/OFF)	OFF
RCA_SW (TM/OFF/CO2)	CO2
SCU_MATE (ON/OFF)	ON
TCL_SET (OFF, H, 1, …,9,C, ACC)	A/R
ATCL_SW (ON/OFF)	OFF
CWS_SW (PRO/OFF/STAT)	OFF
Multi-position Suit Purge Valve (MSPV)	CL
SOFT SWITCH CONFIGURATIONS	
COMM (HL/PRI/ALT/OFF)	HL
FREQ (LO/PTT/HI)	PTT
VOL (0-10)	A/R
INFO	OFF
State	14 (Repress 2)

State => 14 (Repress 2)

1) Remove EVA tools as required
2) Engage the xEMU into the EDDA
3) CWS_SW => Set INFO = OFF

WARNING
IF DCS SYMPTOMS ARE OR WERE PRESENT, CONTACT MCC VIA PMC

4) POR_SET => 0 (OFF)
   The crew manually commands via the POR_SET DCU switch, CON-150 to a set pressure of 0 psid and it then sets the POR to the appropriate pressure, which in this case is lockup.
5) MSPV => HI
   This depresses the suit to enable doffing.
6) When Suit P is < 0.5 psid, remove a glove to fully depress the suit, then remove both gloves.
7) PUMP_SW => OFF
8) TCL_SET => OFF
   This sets TCV-421 to bypass and closes the back-pressure on HX-440.
9) Open hatch and begin to doff the suit.
10) Lean out and disconnect the LCVG WLVTA and biomed
11) Fully doff the suit
12) Doff LCVG
13) Doff TCU
14) Doff MAG and dispose
15) Doff Biomed sternal harness
16) FAN_SW => OFF
17) RCA_SW => OFF
   The DCU fan switch toggles a set of IO lines to the CON-350 controller which tells the on-board BLDC motor controller to disable the drive. The RCA switch then toggles a set of I/O lines to the CON-350 controller which then responds by moving the RCA valve into a 90/270 park position which isolates both beds and then disables the drive/actuator.
18) CWS_SW => COMM = OFF

State => 14 (Repress 2)
The suit power will need to be cycled for the state to reset to state 2.

DCU Switch/PLSS Control	**Position**
PWR_SW (SCU/BATT)	SCU
FAN_SW (PRI/OFF/SEC)	OFF
PUMP_SW (PRI/OFF/SEC)	OFF
POR_SET (0, 0.4, 0.9, 4.3, 6.0, 8.0)	0 {OFF}
SOR_SW (ON/OFF)	OFF
RCA_SW (TM/OFF/CO2)	OFF
SCU_MATE (ON/OFF)	ON
TCL_SET (OFF, H, 1, …,9,C, ACC)	OFF
ATCL_SW (ON/OFF)	OFF
CWS_SW (PRO/OFF/STAT)	OFF
Multi-position Suit Purge Valve (MSPV)	CL
SOFT SWITCH CONFIGURATIONS	
COMM (HL/PRI/ALT/OFF)	OFF
FREQ (LO/PTT/HI)	PTT
VOL (0-10)	A/R
INFO	OFF
State	14 (Repress 2)

3.2.6 POSTEVA SERVICING

Primary/Secondary O2 servicing

1) Check O2 supply open and adequate pressure to SCU
2) Verify/Mate the SCU to the DCU and lock
3) Verify O2 recharge by checking Primary and Secondary O2 Pressures > 2800 psia
   The recharge should have occurred during repress after umbilical reconnect. However, a longer top-off can be achieved that enables the POV/SOV to cool down and the SCU to make-up the gas, hence achieving a greater charge density.

Primary/Auxiliary Feedwater Deservicing

If water deservice is required, configure vehicle side for a water dump from the servicing umbilical.

1) Close suit hatch and gloves.
2) Verify MSPV => CL
3) POR_SET => 8.2 psid
4) PUMP => PRI
   This is an important step given that leaving the pump off would force back-flow through the system, back-flowing F-448. Use of the primary pump was chosen to minimize run-time on the pump and inlet filter on the secondary pump.
5) Monitor PT-432 > 24.4 psia (14.7 psia cabin)
   When the pump inlet pressure drops into this range, cavitation is anticipated and the dump less ullage and < 1 lbs of water is complete.
6) PUMP => OFF
7) POR_SET => 0 psid {OFF}
8) MSPV => LO
   Vent suit pressure to ambient. Leave in this configuration for stowage to prevent suit pressurization in the event of regulator leakage

Water Servicing

1) Configure the vehicle feedwater supply in recharge mode (8 psid over cabin pressure = 22.7 psia)
   This could be as high as 15 psid over cabin pressure if the AEMU was using the IRU on ISS.
2) Verify/Mate the SCU to the DCU and lock
3) Monitor PT-432 until stable and > 20.7 psia
   The actual termination criteria will result from detailed analysis and test of the PT-432 location vs the input pressure from the ECLSS system. The FSA-431/FSA-531 will be topped-off at the same time and will cause a drop in the inlet pressure at PT-432.
4) Record how much feedwater was supplied to the suit
   This will include topping off FSA-531 as well should it have been used.
5) Deconfigure the vehicle feedwater supply

Suit Cleaning

1) Clean the softgoods as required by the PGS team.

Battery Recharge

1) Verify/Mate the SCU to the DCU and lock
2) Verify/Configure the vehicle power supply to provide 28V to the SCU
3) PWR => SCU
   In PWR – OFF, the PLSS is isolated from the external inputs. Taking the PLSS PWR-SCU both enables power up of the PLSS from vehicle supplied power but also enables the power-up of the battery BMS which will then make battery power available a few seconds later. With power applied, the CWS will initialize and will provide filtered, current limited, suit power to all of the attached controllers which will also power up in quiescent monitoring mode after an initialization. At this point, the PLSS will be powered and transmitting telemetry but not moving actuators.
   State => 1(Start-up)
4) Configure vehicle battery charger to initiate charge on a selected battery
   a) BATT-690 – Primary PLSS Battery
   b) BATT-790 – Accessory Battery
   c) BATT-590 – Auxiliary PLSS Battery
   The battery charge lines run from the vehicle battery charger, down the SCU, through the DCU/CWS, and back to the attached battery. Each battery string possesses a BMS that is sensing for charge voltage on the charge input connection and will then configure the BMS into charge mode upon that voltage being sensed. The CC/CV charger will then monitor the output suit telemetry which provides charge information on the battery being charged and will then adjust the source current according to the number of strings active and attached to the charger. The charger will run at a specified constant current to a voltage limit dictated by the specifics of the battery chemistry and cell manufacturer, then will hold at the limit until the current drops below a specified threshold that is also a function of the chemistry and manufacturer. As the charger provides a set current that is then split across the battery packs given their internal impedance, each BMS is monitoring the current through the pack and transmitting that along with other telemetry to the CWS which can compute the overall capacity input into the battery assembly. Each modular BMS will isolate the battery string as it reaches the charge cut-off voltage such that all battery packs can reach charge cut-off even with an initial imbalance.
5) The charger can then automatically serially charge or simultaneously charge all three battery assemblies in the PLSS.
6) Deconfigure the vehicle battery charger.
7) PWR => OFF
8) Deconfigure the vehicle power supply
9) Demate and stow the SCU.

AEMU Stowage

1) Disconnect RCA vacuum access umbilical
2) Check/Verify vehicle power supply - OFF
3) Check/PWR => OFF
4) Disconnect and stow the SCU.
5) Reinstall the gloves, close the hatch
6) MSPV - LO

4.0 ACRONYMS AND ABBREVIATIONS

AEMU	Advanced Extra-vehicular Mobility Unit
ALSA	Astronaut Life Support Assembly
BITE	Built-In Test Equipment
BLDC	Brushless DC
CAMRAS	CO2 And Moisture Removal Amine Swingbed
CFD	Computational Fluid Dynamics
CTSD	Crew and Thermal Systems Division
CWCS	Caution Warning and Control System
CxP	Constellation Program
DAQ	Data-AcQuisition
DCS	DeCompression Sickness
EMU	Extravehicular Mobility Unit
EV	Extra-Vehicular
EVA	Extravehicular Activity
FMEA	Failure Mode and Effects Analysis
FSA	Feedwater Supply Assembly
GOX	Gaseous Oxygen
GSE	Ground Support Equipment
HSIR	Human Systems Integration Requirements
HUT	Hard Upper Torso
HX	Heat Exchanger
ISS	International Space Station
IV	Intra-Vehicular
IVA	Intra-Vehicular Activity
JSC	Johnson Space Center
LCVG	Liquid Cooling and Ventilation Garment
LEO	Low Earth Orbit
MBB	Make Before Break
MEMS	Micro Electro Mechanical System
MEOP	Maximum Expected Operating Pressure
Mini-ME	Mini-Membrane Evaporator
MSPV	Multi-position Suit Purge Valve
NASA	National Aeronautics and Space Administration
NPRV	Negative Pressure Relief Valve
NVR	Non-Volatile Residue
OPS	Oxygen Purge System
PAS	Power Avionics and Software
PLSS	Portable Life Support System or Portable Life Support Subsystem
POR	Primary Oxygen Regulator
POV	Primary Oxygen Vessel
PPRV	Positive Pressure Relief Valve
QD	Quick Disconnect
RCA	Rapid Cycle Amine
RH	Relative Humidity
RTD	Resistance Temperature Device
SIP	Suitport Interface Plate
SOA	Secondary Oxygen Assembly
SOP	Secondary Oxygen Pack
SOR	Secondary Oxygen Regulator
SOV	Secondary Oxygen Vessel
SSA	Space Suit Assembly
SWME	Suit Water Membrane Evaporator

TCC	Trace Contaminant Control
TCV	Thermal Control Valve
UTC	Universal Time Code
WLVTA	Water Line Vent Tube Assembly

5.0 REFERENCES

NASA. (2015, Aug). Development Specification for the Advanced EMU (AEMU) Portable Life Support System (PLSS). Houston, TX: NASA.