Development Specification for the Portable Life Support System (PLSS) Thermal Loop Pump

Engineering Directorate
Crew and Thermal Systems Division

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National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, Texas 77058

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REVISIONS			
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TABLE OF CONTENTS

Section **Page**

TABLE OF FIGURES

Figure **Page**

TABLE OF TABLES

Table **Page**

1.0 INTRODUCTION

1.1 SCOPE

The AEMU Thermal Loop Pump Development Specification establishes the requirements for design, performance, and testing of the Water Pump as part of the Thermal System of the Advanced Portable Life Support System (PLSS).

1.2 CONVENTIONS AND NOTATIONS

1.2.1 RATIONALE

A rationale statement is included for each requirement. The purpose of the rationale statement is to indicate why the requirement is needed, the basis for its inclusion in a requirements document, and to provide context and examples to stakeholders. It is important to note that a rationale is not binding, and it only provides supporting information. In the event there is an inconsistency between the requirement and the rationale, the requirement is binding and takes precedence.

1.2.2 NOMENCLATURE

Each requirement contained in this development specification is denoted by a unique identifier [R.PUMP.423.XXX] that transcends traditional paragraph numbering to keep requirements traceability more clear and achievable.

0XX-1XX – Functional Requirements
2XX – Interface Requirements
3XX – Firmware Requirements
4XX – Environmental Requirements
5XX – Design and Construction Requirements

1.3 RESPONSIBILITY AND CHANGE AUTHORITY

The responsibility for the development and management of the Thermal Loop Pump Development Specification lies with the Space Suit and Survival Systems Branch within the Crew and Thermal Systems Division (CTSD).

2.0 DOCUMENTS

The documents listed in this section represent the documents that have been identified either in part or in whole within this document.

2.1 APPLICABLE DOCUMENTS

The applicable documents are documents that have been explicitly identified within requirements statements (i.e., “shall” statements) and invoked as technical requirements for implementation. Each requirement statement identifies the applicable subsections of a document unless it has been deemed appropriate to invoke the entire document.

JPR 5322.1 Rev H	Contamination Control Requirements Manual
IPC J-STD-001ES Dec-2010	Space Applications Electronic Hardware Addendum to J-STD-011E Requirements for Soldered Electrical and Electronic Assemblies
MIL-STD-1580 Rev B Jan-2003	Department of Defense Test Method Standard Destructive Physical Analysis for Electronic, Electromagnetic, and Electromechanical Parts
MIL-STD-750-1 Oct-2013	Department of Defense Test Method Standard, Test Methods for Semi-Conductor Devices
MIL-STD-810G Oct-2008	Department of Defense Test Method Standard, Environmental Engineering Considerations and Laboratory Tests
NASA-STD-6016A 11/30/2016	Standard Materials and Processes Requirements for Spacecraft

NASA-STD-8739.4 Mar-2011	Crimping, Interconnecting Cables, Harnesses, and Wiring
SLN13102468 Rev NC	Source Control Drawing, Pump Assembly
SSP 30237 Rev R Jan-2007	Space Station Electromagnetic Emission and Susceptibility Requirements
SSP 30312 Rev H Nov-1999	Electrical, Electronic, and Electromechanical and Mechanical Parts Management and Implementation Plan for Space Station Program
SSP 30423 Rev H Jan-2000	Space Station Approved Electrical, Electronic, and Electromechanical Parts List

2.2 REFERENCE DOCUMENTS

Documents that are identified but are not invoked within requirements statements are listed below.

JSC-63309	Recommendations for Exploration Spacecraft Internal Atmospheres
MIL-STD-130 Rev N Nov-2012	Department of Defense Standard Practice Identification Marking of U.S. Military Property
NASA-STD-6002 Rev D June-2008	Applying Data Matrix Identification Symbols on Aerospace Parts

3.0 DEFINITIONS

STP	Standard Temperature and Pressure (STP) The STP reference for all mass-referenced volumetric flows discussed here-in shall be that as defined by the National Institute of Standards and Technology (NIST) Pressure = 1 atm = 14.676 psia = 101.325kPa Temperature =0C = 273.15K =32F
Cavitation	In Positive Displacement pumps, cavitation will be defined as the pump inlet absolute pressure at the point where there is a loss of 5% of the original flow.
Delta Pressure	Pressure difference between the inlet of the pump and the outlet of the pump. DP = Poutlet minus Pinlet.
Differential Pressure	Pressure difference between the inside wetted part of the pump and the outside non-wetted part of the pump
Motor Power	Motor power as measured by a power analyzer between the controller and the motor.
Initial Build	Prior to final assembly and acceptance testing.
Thermal Loop Pump	Refers to PMP-422, PMP-423, PMP-500 in PLSS 2.5 schematic
IVA	Intra-Vehicular Activity – pre-EVA activity
EVA	Extra-Vehicular Activity

4.0 THERMAL LOOP PUMPS

This section contains the technical design and performance requirements.

4.1 FUNCTIONAL OVERVIEW

This specification is focused on a single pump design that is used in three different locations within the PLSS:

- PMP-423 - Primary Thermal Loop Pump
- PMP-422 - Secondary Thermal Loop Pump
- PMP-500 - Auxiliary Thermal Loop Pump

The primary function of the AEMU Thermal Loop Pump is to circulate water through a given closed loop to facilitate heat transport and transfer. For example, the Primary Thermal Loop Pump circulates water in the Thermal Control Loop:

1. Provides flow through Liquid Cooling Garment to remove heat generated by the suited subject.
2. Provides flow through the Ventilation Loop Heat Exchanger (HX-340) to condition the oxygen in the Oxygen Ventilation Loop.
3. Provides flow through conductively coupled thermal loop lines within the PLSS to selectively remove waste heat from other PLSS components such as the various avionics boxes.
4. Provides flow through a Spacesuit Water Membrane Evaporator (HX-440) to reject heat absorbed from the rest of the loop.

It is envisioned that the Thermal Loop Pump is a positive displacement pump that provides a repeatable volume of flow against a given range of back-pressures provided by the various applications. The intention is to operate the pump at a fixed speed for the given application. The primary system is made up of two identical and redundant pumps of which only one is in operation at given time. The Auxiliary Loop Pump is an identical pump design to the primary pumps but is operated at half the flow rate. Inlet positive pressure to the pumps is provided by the upstream Flexible Supply Assembly (FSA-431 and FSA-531) which are physically located inside the suit volume and pressurized by suit pressure. An integrated relief valve, placed in parallel to the pump's inlet and outlet protects the pump and loop from over-pressurization. An integrated course filter is placed upstream of the pump's inlet to provide filtration and prevent potential debris from damaging the pump.

4.2 PERFORMANCE REQUIREMENTS

4.2.1 LIFE

4.2.1.1 [R.PUMP.423.001] OPERATIONAL LIFE

The Thermal Loop Pump shall have an operating life of at least 4000[(1)] hours and 10,000 On/Off Cycles.

Rationale: Hours based 100 EVAs at 8 hours per EVA and 2 hours pre/post-EVA functional time for prebreathe and other activities with a scatter factor of 4. On/Off cycles are based on the expected cycling of a pump for preflight acceptance, IVA and EVA activities.

4.2.1.2 [R.PUMP.423.002] USEFUL LIFE

The Thermal Loop Pump shall have a useful life of 15 years minimum without refurbishment assuming that the usage rate does not exceed operational life (Para 4.2.1.1).

Rationale: This provides a tracking clock from the time wetted service is started.

4.2.1.3 [R.PUMP.423.003] SHELF LIFE

The Thermal Loop Pump shall have a shelf-life of 15 years minimum.

Rationale: This allows for program logistics flexibility without recertification.

4.2.1.4 [R.PUMP.423.004] LIMITED LIFE

As a goal, the Thermal Loop Pump should have no limited life items falling short of the specified operating, useful, or shelf life.

Rationale: The goal is to have no limited life hardware; this is a goal given that state of the art hardware design and manufacturing often limits the implementation of the entire system to less than the full useful life. For example, the need for relief valves or regulators to be operated every X days to mitigate stiction or other issues associated with long term inactivity.

4.2.2 [R.PUMP.423.005] INTERCHANGEABILITY

The Thermal Loop Pump shall be interchangeable between the Primary and Auxiliary Water Cooling loops.

Rationale: Pump design including pump head, pump motor, electrical interface and form factor is expected to be identical for both water loop pumps.

4.2.3 FLOW AND PRESSURE

4.2.3.1 [R.PUMP.423.006] PRIMARY LOOP DESIGN POINT (PMP-423/PMP-422)

The Thermal Loop Pump shall be designed to flow a minimum of 200 pph of water at a maximum loop pressure drop of 6 psid at 50 F.

Rationale: The anticipated nominal flow rate during EVA is 200 pph and highest expected (nominal) pressure drop is 6 psid.

4.2.3.2 [R.PUMP.423.007] AUXILIARY LOOP DESIGN POINT (PMP-500)

The Thermal Loop Pump shall be designed to flow a minimum of 100 pph of water at a at a maximum loop pressure drop of 3.1 psid at 50 F.

Rationale: The anticipated nominal flow rate is 100 pph and highest expected pressure drop is 5 psid.

4.2.3.3 [R.PUMP.423.008] FLOW RANGE

The Thermal Loop Pump shall be able to flow between 70 pph – 220 pph.

Rational: The Primary and Auxiliary pumps will have a flow range allowance for their respective nominal operation but will be designed per [R.PUMP.423.006] and [R.PUMP.423.007].

4.2.3.4 [R.PUMP.423.009] MINIMUM OPERATING PRESSURE-CAVITATION RESISTANCE

The Thermal Loop Pump shall not cavitate at or above a pump inlet pressure of 2.0 psia at the design point defined by [R.PUMP.423.006].

Rationale: This lower pressure permits the operation of the ventilation loop at SOR regulation band 3.7-3.9 psid while allowing the pressure decay in the FSA for the purposes of low level detection. Schematically the pump inlet pressure is based on PT-432 which is located at about 2 inches from the pump inlet fitting at a diameter of 0.33 inches. In Positive Displacement pumps, cavitation will be defined inlet absolute pressure where there is a loss of 5% of the original flow.

4.2.3.5 [R.PUMP.423.010] SUCTION LIFT

Thermal Loop Pump shall have lift capability of water from a height of 20 inches against at a maximum loop pressure drop of 10 psid and a set flow rate of 200 pph.

Rationale: With an unprimed and air tight system, the pump should be able to pull water from a height of 20 inches. In operation, the pump will need provide enough suction lift to pull water from the FSA without the help of external pressure.

4.2.3.6 [R.PUMP.423.011] PRESSURE SCHEDULE

Thermal Loop Pump operating pressures shall be as follows:

Operating Pressure	Pump Differential Pressure (Internal-Wetted to External-Non-wetted volumes) kPa (diff) [psid]
Maximum Design Pressure (MDP) (1)	241 [35]
Structural Pressure (1.1 x MDP)	265 [38.5]
Proof Pressure (1.5 x MDP)	362 [52.5]
Ultimate Pressure (2.5 x MDP)(3)	603 [87.5]
Collapse Pressure(2)	-103 [-15]

Rationale:

(1) The MDP for the Thermal Control Loop is based on an external environment vacuum condition and a pump head of 10 psid with a fully recharged FSA where the supply water is ~ 15 psig over an IVA cabin pressure of 14.7 psia. Considering the pump inlet pressure conditions takes in to account the losses of the SCU, TCV and SWME (~5 psi loss), the max outlet pressure will be 35 psid. The SWME hollow-fibers need to be maintained below 35 psid to mitigate weeping across the membrane walls.

(2) The collapse pressure is pressure at which a negatively or externally loaded pressure vessel will collapse on itself. This is mainly useful for ensuring that helium leakage testing can be performed on a component or system at lab ambient pressure.

(3) This satisfies Table 3.3.1-1 (Minimum Factors of Safety for Pressure) Sub para 3.D (Actuating cylinders, valve, etc.) in SSP 30559, ISS Structural Design and Verification Requirements.

4.2.4 POWER AND MOTOR

4.2.4.1 [R.PUMP.423.012] INPUT POWER/VOLTAGE

The Thermal Loop Pump shall have a maximum allowable electrical motor power consumption per Table 4.2-1.

Design Point	Max Power Consumption (watts)	Voltage
R.PUMP.423.006	5 watts	22-34 VDC
R.PUMP.423.007	2.5 watts	22-34 VDC

Table 4.2-1- Maximum Allowable Pump Power

Rationale: Imbedded in the requirement is motor efficiency and volumetric efficiency to meet the power, flow and delta pressure at the design point. For verification purposes the pump power input will be determined by the total Phase power as measured by a power analyzer such as a Yokogawa Power Analyzer.

4.2.4.2 [R.PUMP.423.013] MOTOR CONFIGURATION

The Thermal Loop Pump motor should be a wye motor configuration.

4.2.4.3 [R.PUMP.423.014] RESERVED

4.2.4.4 [R.PUMP.423.015] HALL EFFECT DEVICE OUTPUT

The Thermal Loop Pump shall utilize Hall Effect Device with a digital square output of 0-5 VDC.

Rationale: CON-450 will utilize HED feedback to control the pump speed and compute RPM.

4.2.4.5 [R.PUMP.423.016] HALL EFFECT DEVICE EXCITATION

The Thermal Loop Pump's Hall Effect Device shall be excited by 4.5 to 5.5 VDC with current draw less than 10mA.

Rationale: This excitation will be provided by (CON-450 Thermal Loop Controller or CON-550 Auxiliary Thermal Loop Controller) therefore the HEDs should be designed to use this excitation.

4.2.5 OPERATING FLUID

4.2.5.1 [R.PUMP.423.017] FEEDWATER

The Thermal Loop Pump shall be compatible and operate using water per JSC-SPEC-C-20D, Grade B.

4.2.5.2 [R.PUMP.423.018] CONTAMINATED FEEDWATER

The Thermal Loop Pump shall be compatible and operate using water per JSC-SPEC-C-20D, Grade A with the added contaminants totaling the amounts dictated in Table **4.2-2**.

Contaminant	Amount (mg/L)
Barium	0.1
Calcium	1.0
Chlorine	5.0
Chromium	0.05
Copper	0.5
Iron	0.2
Lead	0.05
Magnesium	1.0
Manganese	0.05
Nickel	0.05
Nitrate	1.0
Potassium	5.0
Sulfate	5.0
Zinc	0.5
Organics	
Total Acids	0.5
Total Alcohols	0.5
Total Organic Carbon	0.3

Table 4.2-2 **- PLSS Feedwater Contaminants**

Rationale: The table was generated with margin based on the capabilities of the International Space Station Water Processor Assembly (WPA). The potable water requirements specified per SSP 41000, Table LVI convey the Spacecraft Maximum Allowable Concentrations (SMAC) that can be tolerated by a human for long durations whereas the included table seeks to require performance with water that includes contaminants *reasonable to expect a spacecraft to deliver to the PLSS.*

4.2.5.3 [R.PUMP.423.019] Iodine Biocide

The Thermal Loop Pump shall be compatible and able to operate using water with concentrations up to 6 ppm of iodine biocide in the loop.

4.2.5.4 [R.PUMP.423.020] Silver Nitrate Biocide

The Thermal Loop Pump shall be compatible and able to operate using water with concentrations up to 1 ppm of silver biocide in the loop.

4.2.6 [R.PUMP.423.021] Inlet or Supply Temperature

The Thermal Loop Pump shall operate with a water supply temperature of 1.7 °C [35 °F] to 51.7 °C [125 °F].

4.2.7 Leakage

4.2.7.1 [R.PUMP.423.022] External Leakage

The Thermal Loop Pump shall limit external water leakage to 2.36E-04 lb/hr at a differential pressure of 15 psid at the inlet/outlet of the pump in an unpowered state.

4.2.7.2 [R.PUMP.423.023] Reverse Leakage with Pump OFF

The thermal control loop shall limit reverse flow of water at to a maximum of 0.45 kg/h [1 pph] with a differential pressure of 68.9 kPad [10 psid] minimum applied across the pump outlet to pump inlet with the pump motor unpowered.

Rationale: The Primary Thermal Cooling Loop has redundant pumps in parallel but only one is operational at all times which exposes the non-operational pump to the potential of reverse leakage across its outlet and inlet. This leakage should be limited.

4.2.8 Pump and Motor Materials

4.2.8.1 [R.PUMP.423.024] Pump Housing Material

The Thermal Loop Pump shall be constructed of Titanium 6-4 per Ti 6-4 round bar: AMS4928
Ti 6-4 Plate: AMS4911.

Rationale: All components in the Thermal Cooling Loops will be constructed of Titanium 6-4 for weight savings. In addition, to prevent potential galvanic mismatches the pumps will also be constructed of Titanium 6-4.

4.2.9 [R.PUMP.423.025] Mass

The Thermal Loop Pump shall have a mass that is less than .85 kg [1.86 lbs] in flight configuration.

4.2.10 Supplemental Functions

4.2.10.1 [R.PUMP.423.026] Stator Temperature

Thermal Loop Pump shall provide a 1000 Ohm DIN Class A RTD integrated to the motor stator to monitor stator temperatures.

Rationale: Stator temperature can be used to determine motor baseline performance and subsequent degradation.

4.2.11 CONTAMINATION TOLERANCE

4.2.11.1 [R.PUMP.423.027] CLEANLINESS

The Thermal Loop Pump wetted (internal) surfaces shall be initially cleaned to Level 150A and maintained to Level 150 or better per JPR 5322.1.

Rationale: This rating limits the Non-Volatile Residue (NVR) to 1 mg/ft^2 and the particle size distribution below 100 microns. Both of these limits are administrative controls intended to mitigate kindling chain and particle impact ignition mechanisms respectively. For thermal loop pump assembly, lubricants such as Braycote 601 are used to prevent binding or drag on moving parts precluding the ability to maintain an "A" designation for NVR.

4.2.11.2 [R.PUMP.423.028] CONTAMINATION TOLERANCE

The Thermal Loop Pump shall withstand contamination particles up to 250 micron size and meet flow requirements per Para 4.2.3.

Rationale: The inlet filter for the pump is sized at 250 micron with a system filter at 25 micron. The pump may be exposed to the occasional particle between 25 and 250 micron from a mate-demate operation or sourced from the feedwater bladders.

4.3 INTERFACE REQUIREMENTS

4.3.1 [R.PUMP.423.201] OUTER MOLD LINE

The Thermal Loop Pump shall meet the structural interfaces as set by source drawing SLN13102468.

4.3.2 ELECTRICAL INTERFACES

4.3.2.1 [R.PUMP.423.202] ELECTRICAL CONNECTION

The Thermal Loop Pump shall possess an electrical interface port connector and pin out as shown in Table 4.3-1 and SLN13102468.

Pin	Signal Name	Contact
1	MOTOR STATOR TEMP EXC	23
2	HED POWER (+5VDC)	23
3	MOTOR PHASE A	23
4	MOTOR STATOR TEMP RTN	23
5	MOTOR GND (HED PWR RTN)	23
6	HED A OUTPUT	23
7	MOTOR PHASE B	23
8	HED B OUTPUT	23
9	HED C OUTPUT	23
10	MOTOR PHASE C	23
Connector: 805-017-07M9-10EA Mighty Mouse 805 Series from Glenair		
Mating Connector: 805-061-16M9-10SA106 Mighty Mouse 805 Series from Glenair, Cobra Backshell with integrated connector Triple-start ACME thread, ratcheting plug Electroless Nickel Finish		

Table 4.3-1 - J1 Connector

4.3.2.2 [R.PUMP.423.203] ISOLATION

The Thermal Loop Pump internal windings and circuits shall be isolated from the chassis/housing by greater than 2MOhms.

4.3.3 FLUID INTERFACES

4.3.3.1 [R.PUMP.423.204] SEAL REDUNDANCY

The Thermal Loop Pump shall have two seals between any path of the wetted surfaces and non-wetted surfaces.

Rationale: All PLSS components will have two seals to vacuum.

5.0 OPERATIONAL ENVIRONMENTS

5.1 PRESSURE

5.1.1 [R.PUMP.423.401] AMBIENT PRESSURE - OPERATIONAL

The Thermal Loop Pump shall operate in a pressure environment ranging from 0.0 to 105 kPa [0.0 to 15.2 psia].

5.1.2 [R.PUMP.423.402] AMBIENT PRESSURE – NON-OPERATIONAL

The Thermal Loop Pump, as part of the PLSS or at component level in a stowed configuration, shall operate after exposure to a pressure environment ranging from 0.0 to 130 kPa [0.0 to 18.8 psia].

Rationale: This addresses the range of pressure regimes across the potential vehicles with Progress being the driving case on the upper end and vacuum being common to most cargo vehicles. This is not intended to address the wetted areas which already have a pressure rating exceeding this transient but moreover to *address the non-pressurized areas not intended to be pressure vessels such that venting can be appropriately sized while still meeting EMI considerations.*

5.1.3 AMBIENT PRESSURE CHANGE RATE

5.1.3.1 [R.PUMP.423.403] DECREASING - OPERATIONAL

The Thermal Loop Pump shall function during and after an ambient environment pressure drop of -156 torr/min [-3 psi/min] for up to 4.8 minutes.

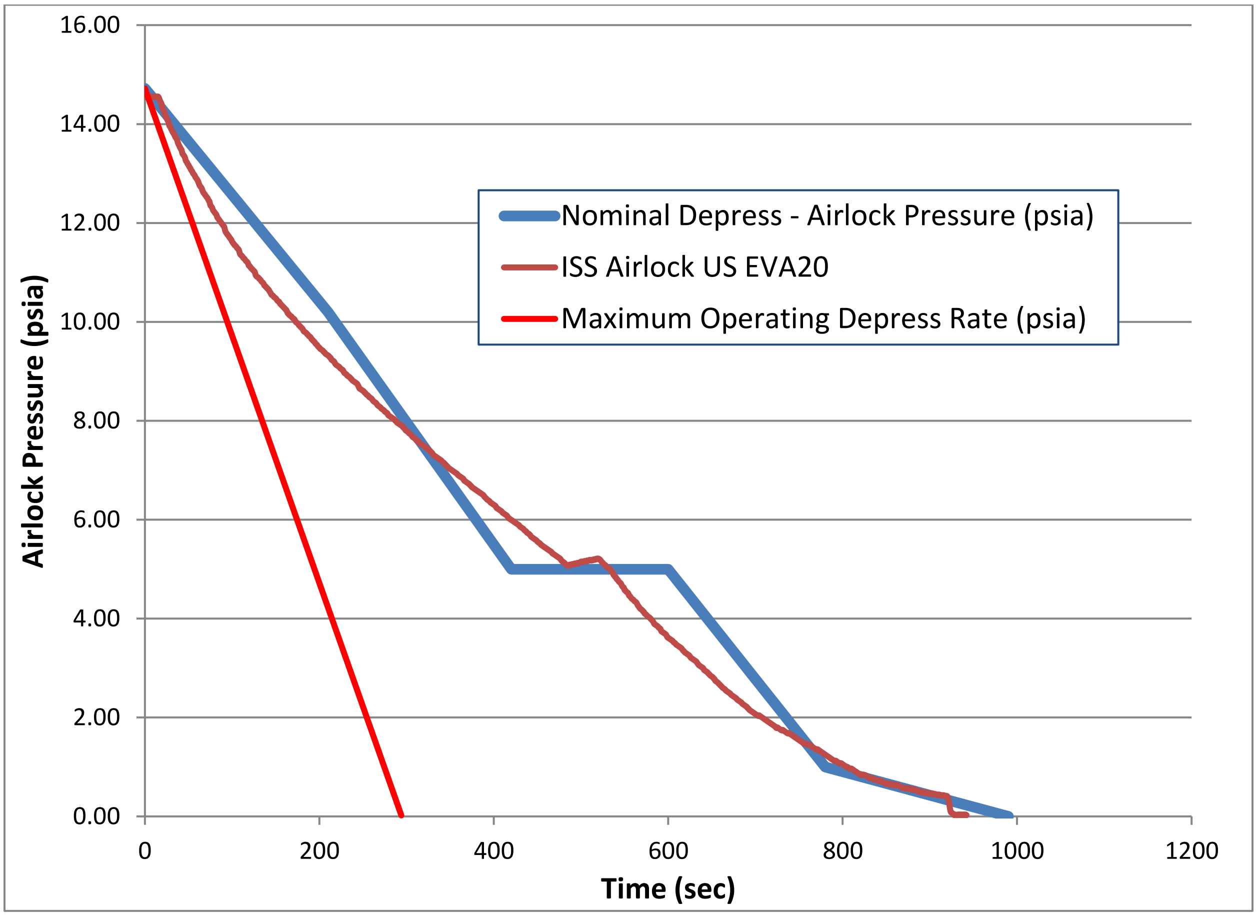


Figure 5-1 - Nominal Airlock Depress Profile

5.1.3.2 [R.PUMP.423.404] DECREASING – NON-OPERATIONAL

The Thermal Loop Pump, in a stowed configuration, shall function after exposure to an ambient environment pressure drop of -6000 torr/min [-116 psi/min] for approximately 7 seconds.

Rationale: The driving requirement is derived from the depress curve of the Progress launch vehicle. This is not intended to address the wetted areas which already have a pressure rating exceeding this transient but moreover to address the non-pressurized areas not intended to be pressure vessels such that venting can be appropriately sized while still meeting EMI considerations.

5.1.3.3 [R.PUMP.423.405] INCREASING - OPERATIONAL

The Thermal Loop Pump shall function during and after an ambient environment pressure increase of 6.9 kPa/sec [1 psi/sec] for 14 seconds.

Rationale: This is analogous to repressing a vacuum chamber from full altitude (10-6 torr) to sea level (14.7 psia) in a 15 second period.

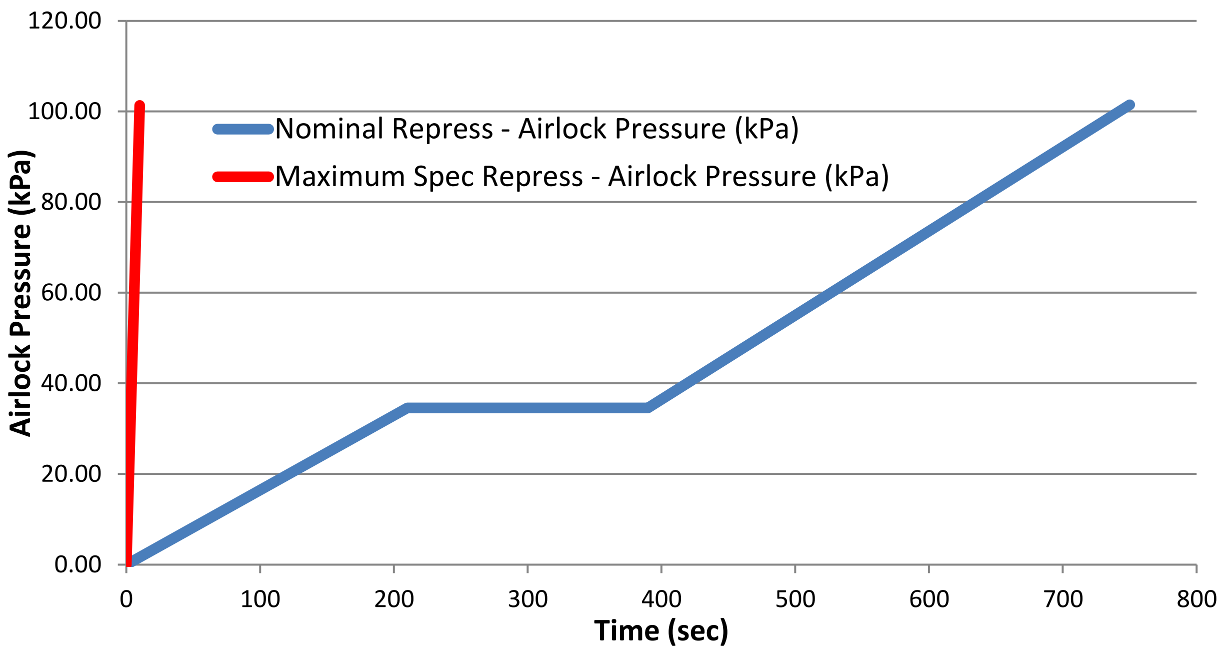


Figure 5-2 - Nominal Airlock Repress Profile

5.2 [R.PUMP.423.406] THERMAL ENVIRONMENT

The Thermal Loop Pump shall operate within an ambient temperature range of 1.7 °C [35 °F] to 51.7 °C [125 °F].

5.2.1 [R.PUMP.423.407] HUMIDITY

The Thermal Loop Pump shall operate in an environment with Relative Humidity (RH) cycling between 30 ± 10% and 80 ± 10% for ten 24 hr cycles per MIL-STD-810G, Method 507.5, Induced Cycle B3.

Rationale: A cycle is defined as a variation in temperature from 25 ± 5 °C [77 ± 9 °F] and 30 ± 10% RH to 65 ± 5 °C [149 ± 9 °F] and 80 ± 10% RH and back over a 24hr period.

5.2.2 [R.PUMP.423.408] GRAVITATIONAL FIELDS

The Thermal Loop Pump shall operate in the gravitational fields defined in Table 5.2-1 in any orientation.

Environment	Gravity Field (g)
Terrestrial	1
Lunar	0.17
Mars	0.38
LEO	~0

Table 5.2-1 - Gravitational Fields

5.2.3 DYNAMIC AND ACOUSTIC LOADS

Due to the numerous locations and orientations that exist for the pump as implemented in the three different locations within the PLSS, the pump needs to accommodate the provided dynamic loads in any possible orientation.

5.2.3.1 [R.PUMP.423.409] ACCELERATION LOAD FACTORS

The Thermal Loop Pump, as packaged for flight (installed in PLSS or at component level), shall meet requirements after exposure to the accelerations defined in Table 5.2-3Table 5.2-2.

Nx (g)	Ny (g)	Nz (g)	Rx (rad/sec^2)	Ry (rad/sec^2)	Rz (rad/sec^2)
+/- 7.0	+/- 4.0	+/- 4.0	--- (1)	--- (1)	--- (1)

Table 5.2-2 - Design Load Factors for Launch Vehicles

5.2.3.2 [R.PUMP.423.410] ACCELERATION LOAD FACTORS - SURVIVABLE

The Thermal Loop Pump, as packaged for flight (installed in PLSS or at component level), shall remain contained and intact as to not present a hazard during and after exposure to the accelerations defined in Table 5.2-3.

	Nx (g)	Ny (g)	Nz (g)	Rx (rad/sec^2)	Ry (rad/sec^2)	Rz (rad/sec^2)
Launch	+9.0/-7.0	+/- 4.0	+/- 4.0	+/- 13.5	+/- 8.5	+/- 11.5
Landing	+/-10.0	+/-6.6	+/-6.6	---	---	---

Table 5.2-3 - Launch and Landing Survivable Load Factors

5.2.3.3 RANDOM VIBRATION

5.2.3.3.1 [R.PUMP.423.411] RANDOM VIBRATION - OPERATING

The Thermal Loop Pump shall operate during and after exposure to the vibration profile shown in Table 5.2-4 for a minimum of 30 minutes in each axis.

FREQUENCY (Hz)	LEVEL
10 – 40	0.0549 g^2/Hz
40 – 500	-5.49 dB/oct
500	0.0006 g^2/Hz
COMPOSITE	**2.00 grms**
Duration	**30 min**

Table 5.2-4 - Random Vibration Profile - Operating

Rationale:

(1) *The PLSS needs to tolerate transport across terrestrial surfaces as part of a roving vehicle demonstration followed by eventual flight usage on a roving vehicle in the lunar and Martian environments. The selection of time per axis is currently arbitrary given that the final vehicle configurations and operations concepts are not known. The vibration profile is more aggressive than the original MIL-STD-810G, Method 514.6, Category 4, Common Carrier US Truck vibration reference.*

5.2.3.3.2 [R.PUMP.423.412] RANDOM VIBRATION - NON-OPERATING

The Thermal Loop Pump, as packaged for flight[(1)], shall operate after exposure to the vibration profile Table 5.2-5/Figure 5-3 in each orthogonal axis.

FREQUENCY (Hz)	**LEVEL**
20 – 153	0.057 g^2/Hz
153 – 190	+7.67 dB/oct
190 – 250	0.099 g^2/Hz
250 – 750	-1.61 dB/oct
750	0.055 g^2/Hz
750 – 2000	-3.43 dB/oct
2000	0.018 g^2/Hz
COMPOSITE	**9.47 grms**
Duration	**60 sec for 1 launch**

Table 5.2-5 - AEMU Random Vibration Profile (Reference SSP-50835, Table 3.1.1.2.1.2.1-1)

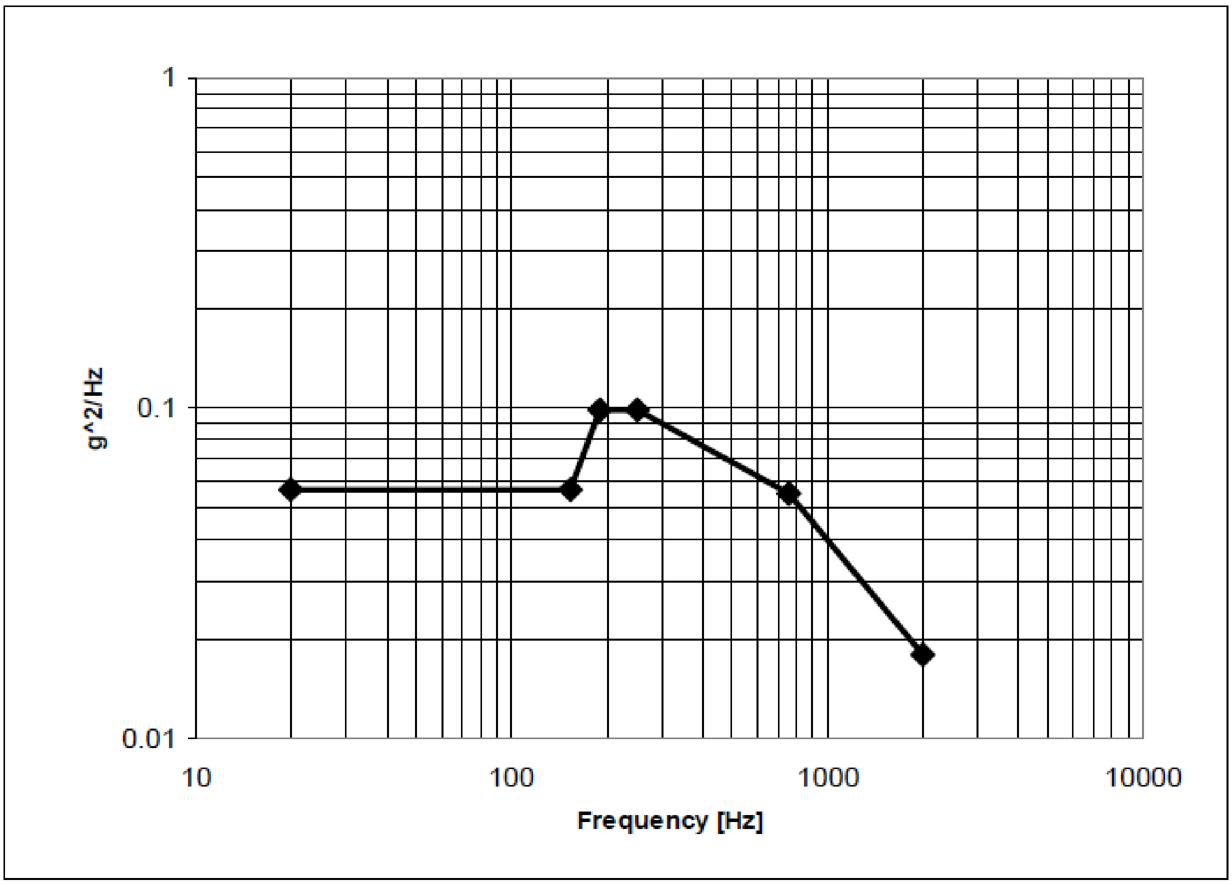


Figure 5-3 - AEMU Random Vibration Profile (Reference SSP-50835, Figure 3.1.1.2.1.2.1-1)

Rationale:

(1) The flight package for the PLSS has not yet been defined but is assumed to be a "soft-stow" approach similar to the EMU Launch Enclosure used for the ISS EMU. This excitation would exist at the package interface. This would be the same approach if the pump was flown at component level as well.

5.2.4 [R.PUMP.423.422] Acceptance Vibration

The PLSS Thermal Loop Pump shall operate during and after exposure to the vibration spectrum (Figure 5-4) for 1 minute in each axis. Operate in this context shall encompass a continuity check or verification of function of all circuits during the vibration.

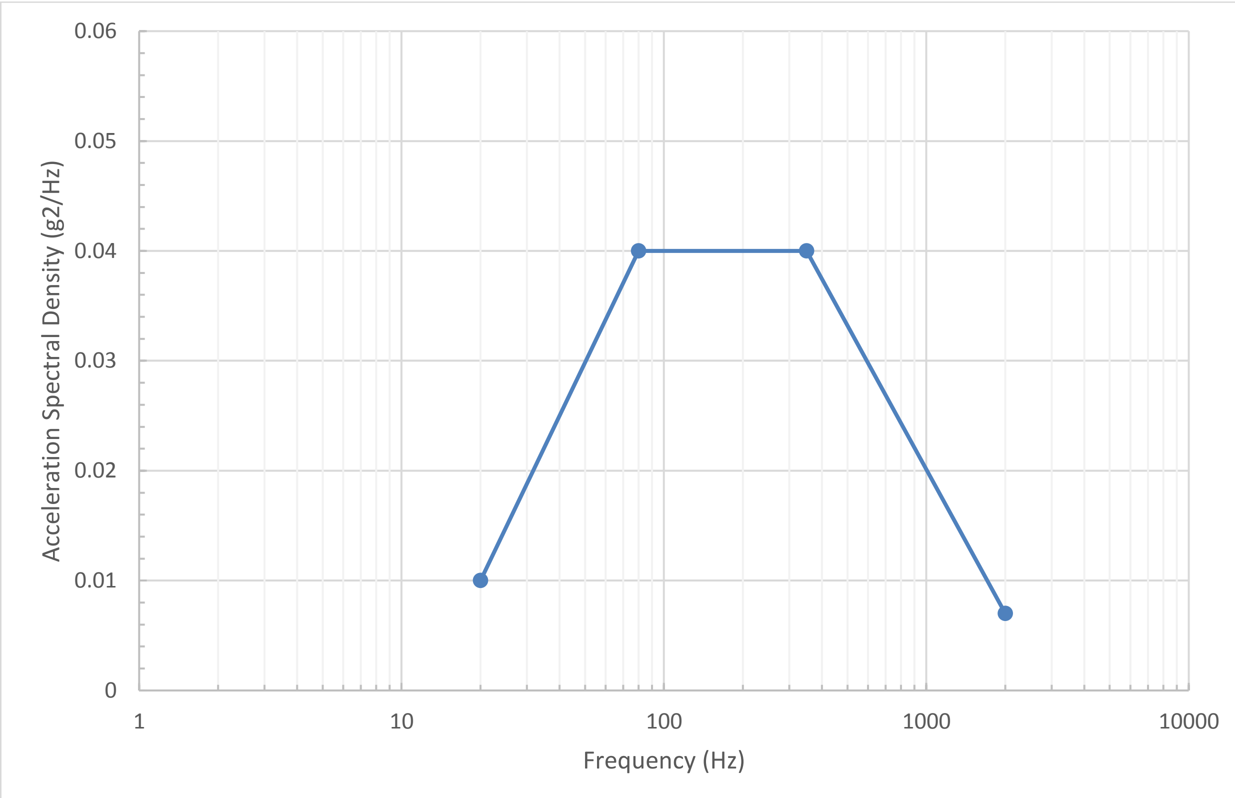


Figure 5-4 - Acceptance Vibration Spectrum

5.2.5 [R.PUMP.423.413] DC Magnetic Field

The Thermal Loop Pump shall operate during and after exposure to a DC Magnetic Field of 250 Gauss at a distance of 64mm [2.5 inches] from the outer mold line of the motor in any direction.

5.2.6 [R.PUMP.423.414] Electromagnetic Emission and Susceptibility

The Thermal Loop Pump shall limit emissions and operate in the presence of the radiated electromagnetic environment as defined in SSP 30237 per sections RE02, RS02, and RS03.

Rationale: The CON-450/CON-550 controllers will address conducted emissions and susceptibility.

5.2.7 [R.PUMP.423.415] Salt Fog

The Thermal Loop Pump, as packaged for flight, shall operate after exposure to a salt fog environment as defined by MIL-STD-810G, Method 509.5 with a NaCl concentration of 1% by weight for a period of 30 days.

5.2.8 [R.PUMP.423.416] Fungus

The Thermal Loop Pump, as packaged for flight, shall operate after exposure to fungus as defined in MIL-STD-810G, Method 508.6.

5.2.9 [R.PUMP.423.417] OZONE

The Thermal Loop Pump, as packaged for flight, shall meet all performance requirements after exposure to environmental ozone at concentrations of 3 to 6 parts per 100 million at sea level to a maximum of 100 parts per 100 million during air transportation at an altitude of 35,000 feet for upto 30 days total exposure duration.

5.2.10 [R.PUMP.423.418] IONIZING RADIATION

The Thermal Loop Pump shall meet requirements while operating in an ionizing radiation environment with attributes as defined in Table 5.2-6.

Component	Non-Destructive SEE/SEFI(2) Rates	Destructive SEE(3) (MeV-cm²/mg)	Total Dose Rad (Si)(1)	NOTE
Pump PMP-423 PMP-422 PMP-500	$\leq 10^{-2}$/2000hrs	≥ 60	13325	

Table 5.2-6 - Radiation Environment Requirements

5.2.11 [R.PUMP.423.419] ATOMIC OXYGEN

The Thermal Loop Pump shall operate with an exposure of 4.4 x 10^{19} particles/cm2-day over the duration of the operational life.

Rationale: Since the PLSS does not have a prolonged exposure under nominal operations with airlock-based LEO missions, the short-term daily ram fluence value for ISS is applied.

5.2.12 [R.PUMP.423.420] ATMOSPHERIC COMPOSITION

The Thermal Loop Pump shall meet requirements while operating in an ambient environment with an oxygen concentration up to 26.5% with the balance composed of nitrogen, metabolic products (CO2 and H2O), and trace gases.

Rationale: The 26.5% value is derived from the upper bound published in JSC-63309, Recommendations for Exploration Spacecraft Internal Atmospheres and exceeds the maximum value permitted in SSP 50835 of 24.1%.

5.3 INDUCED ENVIRONMENTAL CONTRIBUTIONS

5.3.1 [R.PUMP.423.421] NOISE LIMITS

The Thermal Loop Pump shall limit noise generation as described in Table 5.3-1 as measured 0.76 m [2.5 ft] from the Pump Outer Mold Line (OML).

Case	**Operating Conditions**	**Typical Duration for Airlock Operations**	**Frequency Band (Hz)**	**SPL (dB)**
IVA	Pressure = 14.7 psia	2 hours	NC-60	---

	Ambient Temperature = 80F			
[redacted]			16	90
			31.5	85
			63	77
			125	71
			250	66
			500	63
			1000	60
			2000	59
			4000	58
			8000	57

Table 5.3-1 - Generated Noise for IVA Operations

6.0 DESIGN AND CONSTRUCTION

6.1.1 [R.PUMP.423.501] WETTED MATERIALS

The Thermal Loop Pump shall select materials that are considered inert in high purity water or obtain special permission from NASA based on data related to compatibility with the ISS EMU Sublimator.

6.1.2 OUT-GASSING/OFF-GASSING

6.1.2.1 [R.PUMP.423.502] TOXIC OFF-GASSING

The Thermal Loop Pump shall meet the requirements of [MPR 45]/ [MPR 46] of NASA-STD-6016A.

6.1.2.2 [R.PUMP. 423.503] VACUUM STABILITY

The Thermal Loop Pump outer surfaces and vented cavities that will be exposed to the vacuum environment shall be rated as vacuum compatible per [MPR 95] of NASA-STD-6016A.

6.1.3 [R.PUMP. 423.504] CRIMPING, INTERCONNECTING CABLES, HARNESS, AND WIRING

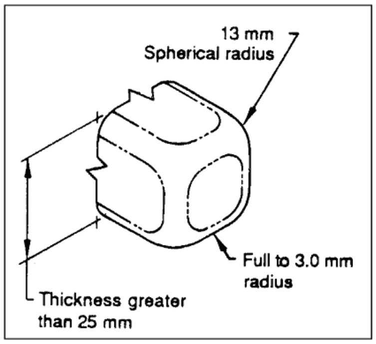
The Thermal Loop Pump internal harnessing shall comply with NASA-STD-8739.4, Crimping, Interconnecting Cables, Harnesses, and Wiring.

6.1.4 [R.PUMP. 423.505] SOLDERED ELECTRICAL AND ELECTRONIC ASSEMBLIES

The Thermal Loop Pump soldered electrical and electronic assemblies shall adhere to IPC J-STD-001ES, Space Applications Electronic Hardware Addendum to J-STD-011E Requirements for Soldered Electrical and Electronic Assemblies with exception of Chapter 10.

6.1.5 [R.PUMP. 423.506] EXPOSED BURRS/SHARP EDGES

The Thermal Loop Pump shall comply with the limits established in Table 7.1-1 for exposed edges that are accessible during nominal operation or planned intromission maintenance.

Material Thickness, t	Minimum Corner	Minimum Edge Radius	Figure
t > 1 in (t > 25 mm)	0.5 in (13 mm (spherical))	0.125 in (3.0 mm).	

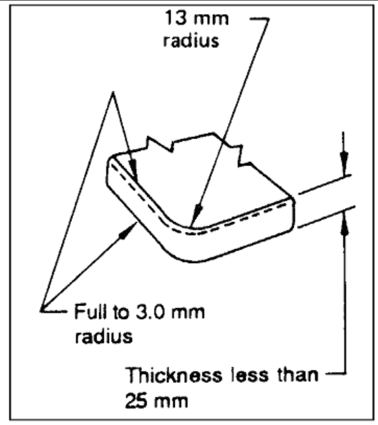
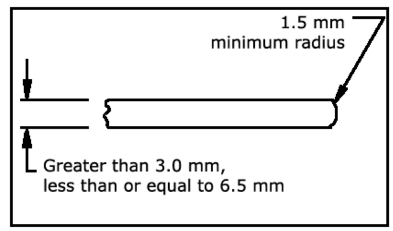
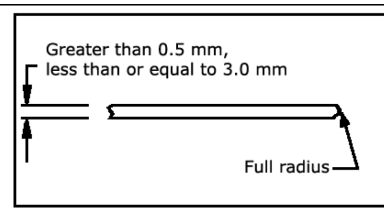
Material Thickness, t	Minimum Corner	Minimum Edge Radius	Figure
0.25 in. < t ≤ 1 in. (6.5 mm < t ≤ 25 mm)	0.5 in. (13 mm)	0.125 in. (3.0 mm)	
0.125 in. < t ≤ 0.25 in. (3.0 mm < t ≤ 6.5 mm)	0.25 in. (6.5 mm)	0.06 in. (1.5 mm)	
0.02 in. < t ≤ 0.125 in. (0.5 mm < t < 3.0 mm)	0.25 in. (6.5 mm)	Full radius	

Table 5.3-1 - Exposed Corners and Edge Requirements

6.2 [R.PUMP. 423.507] ELECTRONIC, ELECTRICAL, AND ELECTROMECHANICAL (EEE) PARTS

The Thermal Loop Pump shall implement design using Grade 1 or 2 EEE parts from the NASA Parts Selection List (NPSL) or SSP 30423, Space Station Approved Electrical, Electronic, and Electromechanical Parts List where possible or obtain approval to use via Non Standard Parts Approval Request (NSPAR).

6.2.1 [R.PUMP. 423.508] PARTS DERATING

The Thermal Loop Pump shall be designed with electrical and thermal derating as defined in SSP 30312, Electrical, Electronic, and Electromechanical and Mechanical Parts Management and Implementation Plan for Space Station Program.

Rationale: The AEMU Project has not yet defined a EEE parts plan but it is expected that using already approved hardware will be more cost effective where added capability, reduced SWaP, or other advantages do not necessitate selection of unapproved parts that carry risk and cost burden.

6.2.2 [R.PUMP. 423.509] DESTRUCTIVE PHYSICAL ANALYSIS (DPA)

The Thermal Loop Pump, for flight production, shall screen all non-approved or Grade 2 EEE parts per MIL-STD-1580.

Rationale: This is intended to enable increased reliability of the components used in the controller by physical screening of parts that do not have proven supply chains.

6.2.3 [R.PUMP. 423.510] ELECTROSTATIC DISCHARGE DESIGN

The Thermal Loop Pump, when tested in an unpowered state per MIL-STD-750-1, Method 1020.4 across the case or any external pin, shall meet Class 3A or better. If the component does not achieve the "insensitive" classification, it shall be labeled per MIL-STD-1686C in a clearly visible location.

Rationale: This assumes the Human Body Model (HBM) and is necessary given charges that may be accumulated during ground processing and handling. It is assumed that the system being maintained is unpowered and the crew will be wearing a ground strap when doing the work but since they will not be able to verify the ground connection, this protection is necessary. Class 3A or better meets the ISS requirements stating that no damage will occur below 4000V.

6.3 [R.PUMP. 423.511] IDENTIFICATION

The Thermal Loop Pump shall be labeled with name, part number, dash number, and serial number in letters at least .080in high on the side of the motor housing.

Rationale: This satisfies the requirements of NASA-STD-6002 and MIL-STD-130 which are intended to provide proper marking and identification of hardware.

7.0 APPLICABILITY AND VERIFICATION MATRIX

The following are descriptors for the manner in which the requirement will be met:

- Applicability – App column
  - This column denotes that the applicability of the requirement.
    - A – Applicable
    - N – Not Applicable
    - E – Exception
      - Provide rationale in the comments with respect to the exception.
- Method
  - This set of columns addresses the verification method being used to satisfy the requirement. Denote with an “X” and/or a test paragraph number for the Test Method section.
  - A – Analysis
    - This method covers analysis or analysis with reference to test data.
  - I – Inspection
    - This is by inspection of the drawings, models, etc and is also referred to as “review of design.”
  - T – Test
    - This is a specific test that is performed on the hardware. There are two sub-columns to enable the reference to the use of the test for qualification and/or acceptance.
  - S – Similarity
    - This enables reference to an existing configuration with similar design, performance, etc.
- Verification Documentation
  - This is the location which can, for the certification, house the TPS, test report, engineering memo, etc references for the closure of the certification line item.

Requirement	Description	App	Method					Verification Documentation	Comment
			A	I	T		S		
					Qualification	Acceptance			
[R.PUMP.423.001]	Operational Life	A	X		X				
[R.PUMP.423.002]	Useful Life	A	X						
[R.PUMP.423.003]	Shelf Life	A	X						
[R.PUMP.423.004]	Limited Life	A	X						
[R.PUMP.423.005]	Interchangeability	A	X	X					
[R.PUMP.423.006]	Primary Loop Design Point	A			X	X			
[R.PUMP.423.007]	Auxiliary Loop Design Point	A			X	X			
[R.PUMP.423.008]	Flow Range	A			X	X			
[R.PUMP.423.009]	Minimum Operating Pressure – Cavitation Resistance	A			X	X			

Requirement	Description	App	Method					Verification Documentation	Comment
			A	I	T		S		
					Qualification	Acceptance			
[R.PUMP.423.010]	Suction Lift	A			X	X			
[R.PUMP.423.011]	Pressure Schedule	A	X		X	X			
[R.PUMP.423.012]	Input Power/Voltage	A			X	X			
[R.PUMP.423.013]	Motor Configuration	A		X					
[R.PUMP.423.014]	Motor Can	A		X					
[R.PUMP.423.015]	Hall Effect Device Output	A	X		X	X			
[R.PUMP.423.016]	Hall Effect Device Excitation	A	X		X	X			
[R.PUMP.423.017]	Feedwater	A	X		X				
[R.PUMP.423.018]	Contamination Feedwater	A	X		X				
[R.PUMP.423.019]	Iodine Biocide	A	X		X				
[R.PUMP.423.020]	Silver Nitrate Biocide	A	X		X				
[R.PUMP.423.021]	Inlet or Supply Temperature	A	X		X				
[R.PUMP.423.022]	External Leakage	A			X	X			
[R.PUMP.423.023]	Reverse Leakage with Pump OFF	A			X	X			
[R.PUMP.423.024]	Pump Housing Material	A		X					
[R.PUMP.423.025]	Mass	A			X	X			
[R.PUMP.423.026]	Stator Temperature	A		X					
[R.PUMP.423.027]	Cleanliness	A			X	X			
[R.PUMP.423.028]	Contamination Tolerance	A			X				
[R.PUMP.423.201]	Outer Mold Line	A		X					
[R.PUMP.423.202]	Electrical Connection	A		X					
[R.PUMP.423.203]	Isolation	A			X	X			
[R.PUMP.423.204]	Seal Redundancy	A		X	X				
[R.PUMP.423.401]	Ambient Pressure - Operational	A			X	P			
[R.PUMP.423.402]	Ambient Pressure – Non-Operational	A			X				
[R.PUMP.423.403]	Decreasing - Operational	A			X				
[R.PUMP.423.404]	Decreasing – Non-Operational	A			X				
[R.PUMP.423.405]	Increasing - Operational	A			X				
[R.PUMP.423.406]	Thermal Environment	A			X				
[R.PUMP.423.407]	Humidity	A			X				
[R.PUMP.423.408]	Gravitational Fields	A			X				
[R.PUMP.423.409]	Acceleration Load Factors	A			X				

Requirement	Description	App	Method					Verification Documentation	Comment
			A	I	T		S		
					Qualification	Acceptance			
[R.PUMP.423.410]	Acceleration Load Factors - Survivable	A			X				
[R.PUMP.423.411]	Random Vibration - Operating	A			X				
[R.PUMP.423.412]	Random Vibration – Non-Operating	A			X				
[R.PUMP.423.422]	Acceptance Vibration	A				X			
[R.PUMP.423.413]	DC Magnetic Field	A			X				
[R.PUMP.423.414]	Electromagnetic Emission and Susceptibility	A			X				
[R.PUMP.423.415]	Salt Fog	A	X						
[R.PUMP.423.416]	Fungus	A	X						
[R.PUMP.423.417]	Ozone	A	X						
[R.PUMP.423.418]	Ionizing Radiation	A	X		X				
[R.PUMP.423.419]	Atomic Oxygen	A	X		X				
[R.PUMP.423.420]	Atmospheric Composition	A	X		X				
[R.PUMP.423.421]	Noise Limits	A	X		X				
[R.PUMP.423.501]	Wetted Materials	A	X						
[R.PUMP.423.502]	Toxic Off-Gassing	A	X		X				
[R.PUMP.423.503]	Vacuum Stability	A	X		X				
[R.PUMP.423.504]	Crimping, Interconnecting Cables, Harness, and Wiring	A		X					
[R.PUMP.423.505]	Soldered Electrical and Electronic Assemblies	A		X					
[R.PUMP.423.506]	Exposed Burrs/Sharp Edges	A		X					
[R.PUMP.423.507]	Electronic, Electrical, and Electromechanical (EEE) Parts	A	X	X					
[R.PUMP.423.508]	Parts Derating	A	X	X					
[R.PUMP.423.509]	Destructive Physical Analysis (DPA)	A		X					
[R.PUMP.423.510]	Electrostatic Discharge Design	A	X		X				
[R.PUMP.423.511]	Identification	A		X					