Evaporator-Based Potable Water Dispenser (EBPWD) for Long-Duration ECLSS

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UCDAVIS
MECHANICAL AND AEROSPACE ENGINEERING

HuLC
HUMAN LANDER CHALLENGE

Agenda

Introduction

- Background
- Problem Statement
- Proposal Solution

Technology Concept & Approach

- System Requirements
- System Overview
- System Architecture

Conceptual Engineering Design and Analysis

- Heating and Cooling Design
- Structural and Mechanical Design
- Decontamination
- Controls and Electrical

Technical Management

- Risk Assessment and Mitigation
- Project Timeline
- Budget Estimate
- Conclusion and Future Work

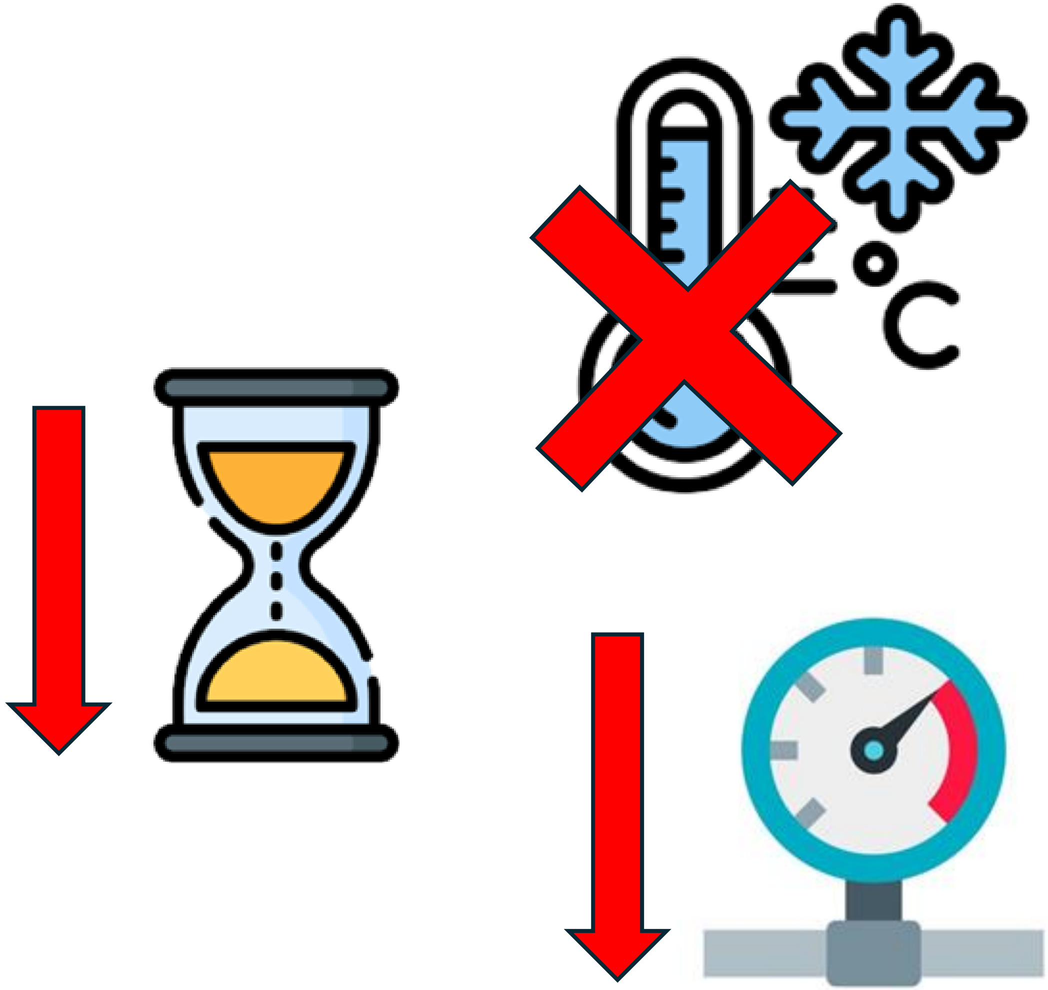
Introduction: Background

- First developed in the 1960s-1970s for the Gemini and Apollo program
- Provides safe drinking water for in-space applications in efforts to advance NASA ECLSS systems
- Gone through multiple iterations and aboard multiple spacecraft (e.g., ISS, Space Shuttle missions)

Introduction: Motivation

Issues that hindered previous PWD performances include:

- Inaccurate dispense volume
- Longevity, not made for long-duration missions
- Pressure losses throughout the system
- Inability to chill below ambient



Introduction: Proposal Solution

The EBPWD aims to address the shortcomings of previous dispenser iterations:

Objective 1: Design, analyze, and test a water dispensing system that has the capability of cooling water with an evaporator

Objective 2: Identify and address pain points of previous dispenser iterations

Objective 3: Develop a system that prioritizes closed-loop architecture for long-duration missions.

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System Requirements

Verification of these requirements will be accomplished through one of four methods:

- Inspection will be conducted through visual examination
  - a.) Drawings and CAD model/assemblies
- Analysis
  - a.) Hand calculations
  - b.) Computer simulations
- Demonstration and testing
  - a.) Model systems and subsystem performance under simulated environmental conditions

Req. ID	Requirements	Rationale	Parent Req.	Child Req.	Verification Method	Req. Met?
MG-1	Enhance life support functionality through safer water delivery while considering the integrated nature of ECLSS within future exploration architectures.	Mission Goal	-	All	Analysis	Met
PM-1	The system shall have targeted use within 5 to 8 years, or be ready between March 1, 2031 and March 1, 2034.	Customer Constraint (Schedule)	MG-1	-	Analysis	Met
PM-2	The system shall be designed for a crew of 4 for cislunar, lunar, and/or Martian environments as applicable.	Customer Constraint	SLS-SPEC-159	MR-5.2, MR-4	Analysis	Met
PM-3	The system shall be designed for deployment on or implementation within NASA/commercial HLS lunar surface or Mars transit assets.	Customer Constraint	MG-1	MR-1, MR-3	Analysis	Met
PM-4	The budget for the system development shall not exceed $11500 USD.	System Constraint (Budget)	MG-1	-	Analysis	Met
MR-1	The system shall have minimal barriers to NASA adoption (e.g., low mass, small size, low power, etc.).	Customer Constraint	MG-1	MR-1.1, MR-1.2, MR-1.3	Analysis	Met

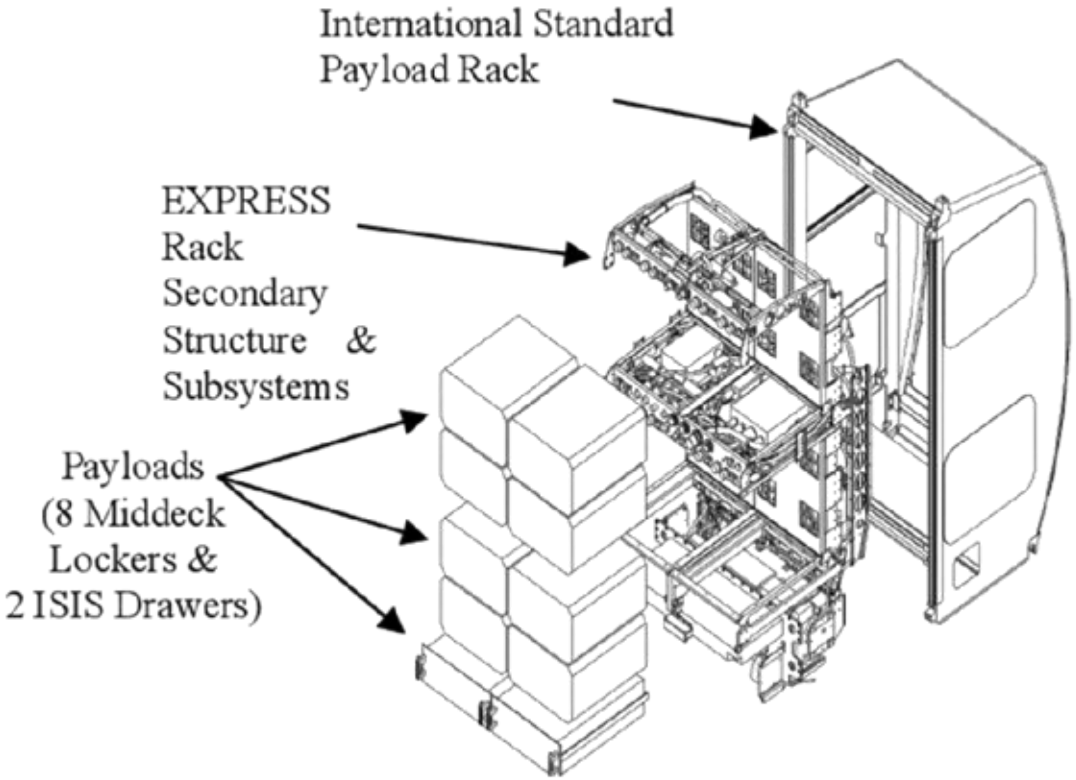
MR-1.1	The system shall not exceed a total mass of 15 kg.	System Constraint	MR-1	-	Analysis, Inspection	In Progress
MR-1.2	The system shall not exceed 0.47 m x 0.28 m x 0.55 m in stowed configuration.	Size of Space Shuttle Middeck Lockers and previous potable water dispensers designs.	MR-1	-	Analysis, Inspection	In Progress
MR-1.3	During operation, the system shall receive no more than 28 Vdc of power.	Power draw from EXPRESS Rack 6 of current ISS Potable Water Dispenser	MR-1	-	Analysis, Test	In Progress
MR-2	The system shall add no additional risks posed to crew.	Customer Constraint	MG-1	MR-2.1	Analysis	Met
MR-2.1	The system's microbial water quality limit shall be less than or equal to 50 CFU/mL for potable water.7,8	System Constraint	MR-2	-	Test	Not Met
MR-3	The system shall have the ability to survive launch loads.	Customer Constraint	MG-1	-	Analysis, Test	In Progress
MR-4	The system must have a mission operational life of 30-days for lunar surface missions, or 1200-days for Mars missions	Customer Constraint	MG-1	-	Analysis	Met

MR-5	The system shall be able to safely and efficiently deliver temperature-controlled water for astronauts' food and beverage needs, emphasizing ergonomics and throughput while minimizing waste and cleaning requirements.	Customer Constraint	MG-1	MR-5.1, MR-5.2	Test	Not Met
MR-5.1	Water shall be dispensed at 25 mL increments.7,8	On the ISS, water is dispensed in fixed increments to properly hydrate food and beverages without overflow, while aligning with preparation instructions and meal schedule constraints.	MR-5, NASA-STD-3001	-	Test	Not Met
MR-5.2	For hydration, the dispenser shall provide a minimum of 2.5 L (84.5 fl oz) per crewmember per day.7,8	System Constraint	MR-5, NASA-STD-3001	-	Test	Not Met
MR-6	The system shall be able to withstand environmental effects such as corrosion.	System Constraint	MG-1	-	Inspection	Not Met

System Overview

Dispenser Logistics – Initial Set Up

- Water is pressure fed from water supply (22.5 psig and 22.5 °C)
- Powered via 28 Vdc auxiliary output □ connect to ISS EXPRESS Rack 6
    - a.) Provides up to 2000 watts & 20 amps

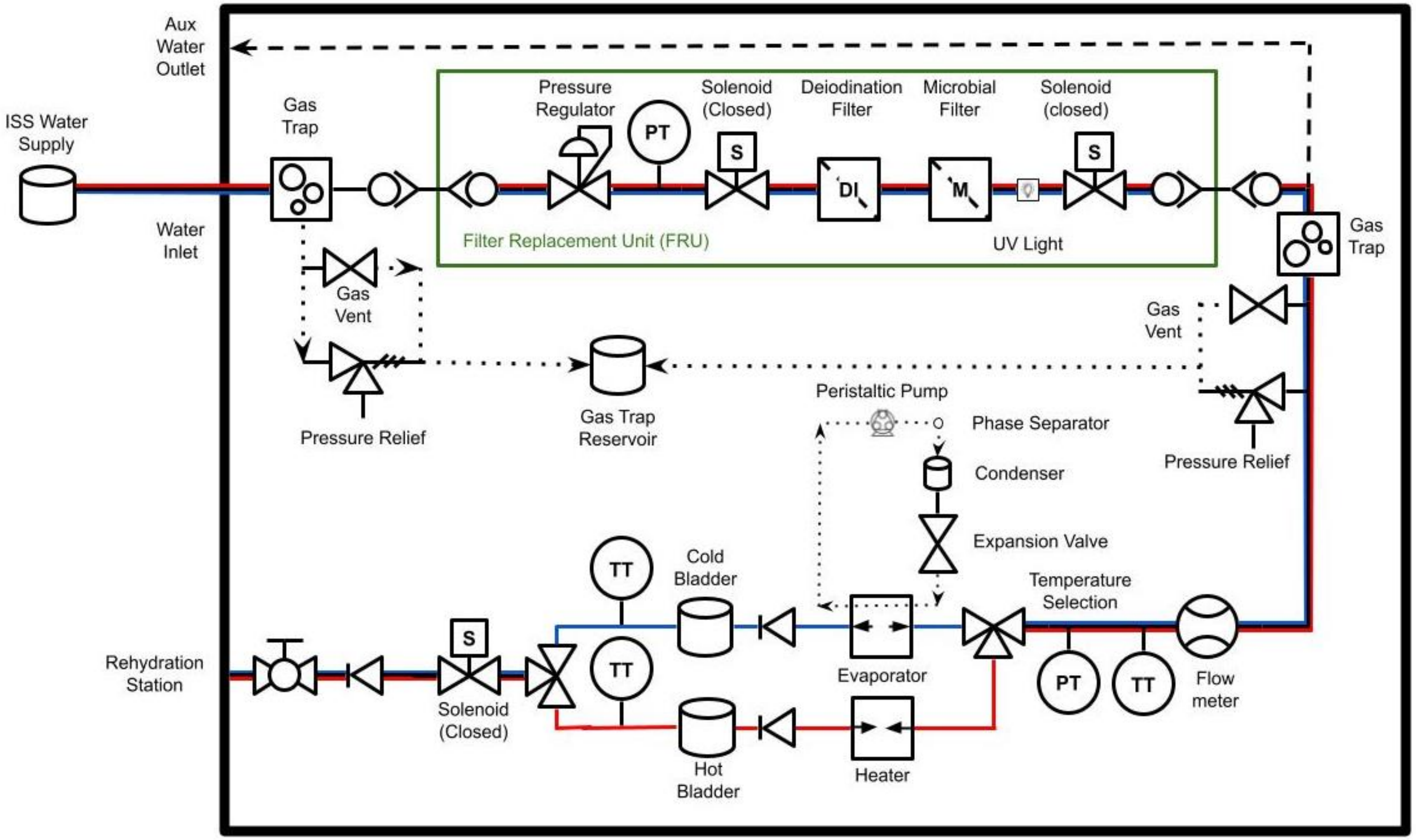


Exploded view of an International Standard Payload Rack and EXPRESS Rack sub-components. Reprinted from Allen & Garneau (2024).

System Architecture

EBPWD P&ID-Subsystem

- ⬛ Structural and Mechanical Design
- 🟩 Filter Replacement Unit (FRU)
- 🟥🟦 Heating and Cooling Design
- ☐ Controls and Electrical



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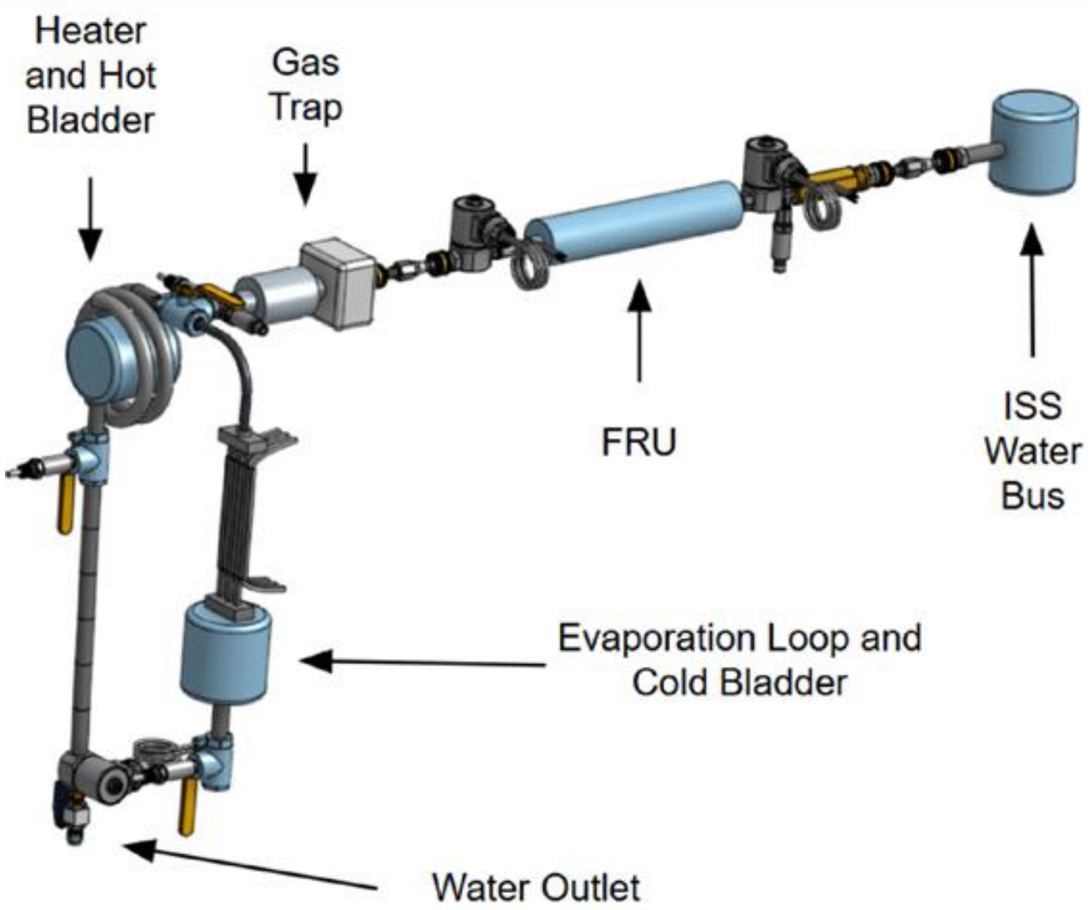
Heating and Cooling Design

The EBPWD thermal design is divided into two primary subsystems

Heating Subsystem:
- Provides potable water at temperatures running between 68°C (155°F) and 79°C (175°F)

Cooling Subsystem:
- Provides water at temperatures below ambient ≤16°C (60°F)
- Utilizes cooling loop with R134a



Heating Subsystem

Heating Subsystem operates as follows:

Water directed from water supply → **The water is routed through heater tubes/coils** → **Heat Transfer Occurs: heater coils → water** → **Water collect inside the bladder** → **Bladder is compressed at constant rate** → **Water dispensed**

Cooling Subsystem

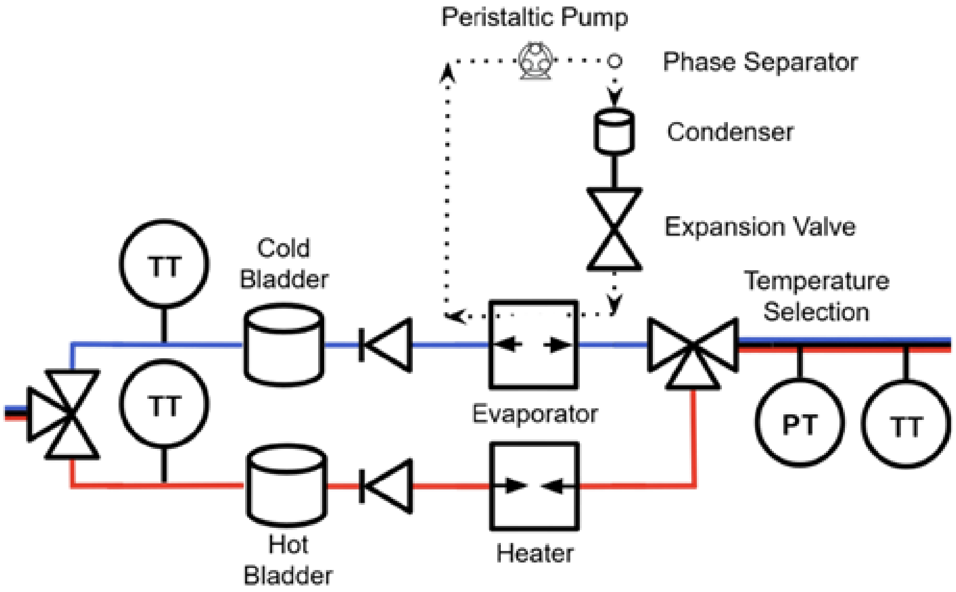
Cooling Subsystem operates as follows:

- Water directed from water supply
- The water is pushed through selected square microchannel
- Every other channel: peristaltic pump circulates R134a
- Heat transfer occurs within closed loop
- Chilled water collects within bladder
- Bladder compresses, water is dispensed

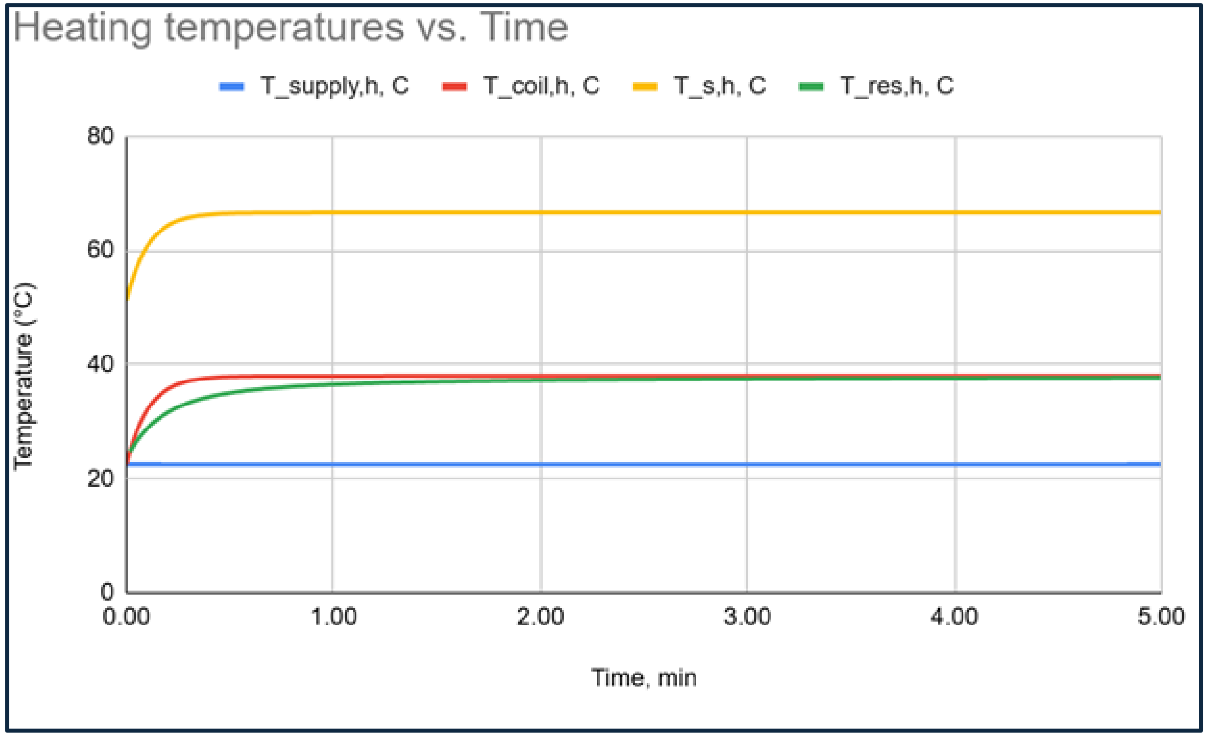
Cooling and Heating Design

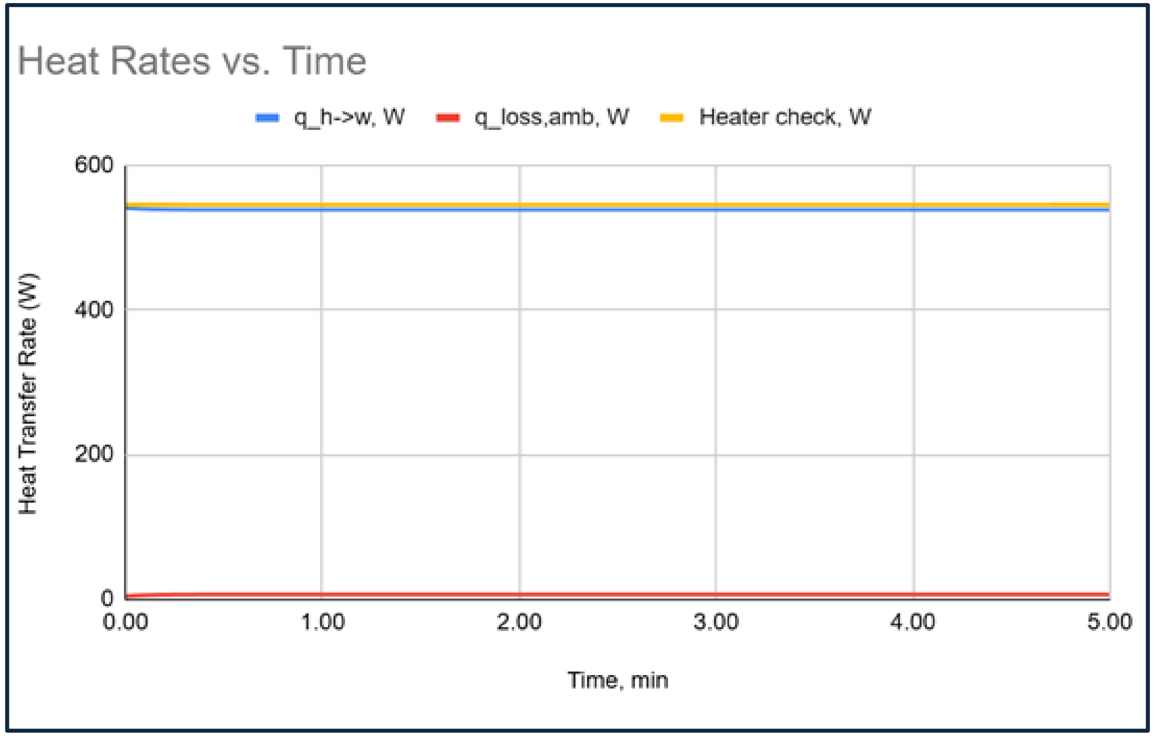
Cooling and Heating subsystem Calculators:

- Volumetric flow rate assumed 500 mL/min
- Intended as a preliminary sizing tool
  Ex: sizing variables-heating tube length
- Tracks the temperature in the heated/cooled section, avg temp of water in the bladder (heated/cooled)

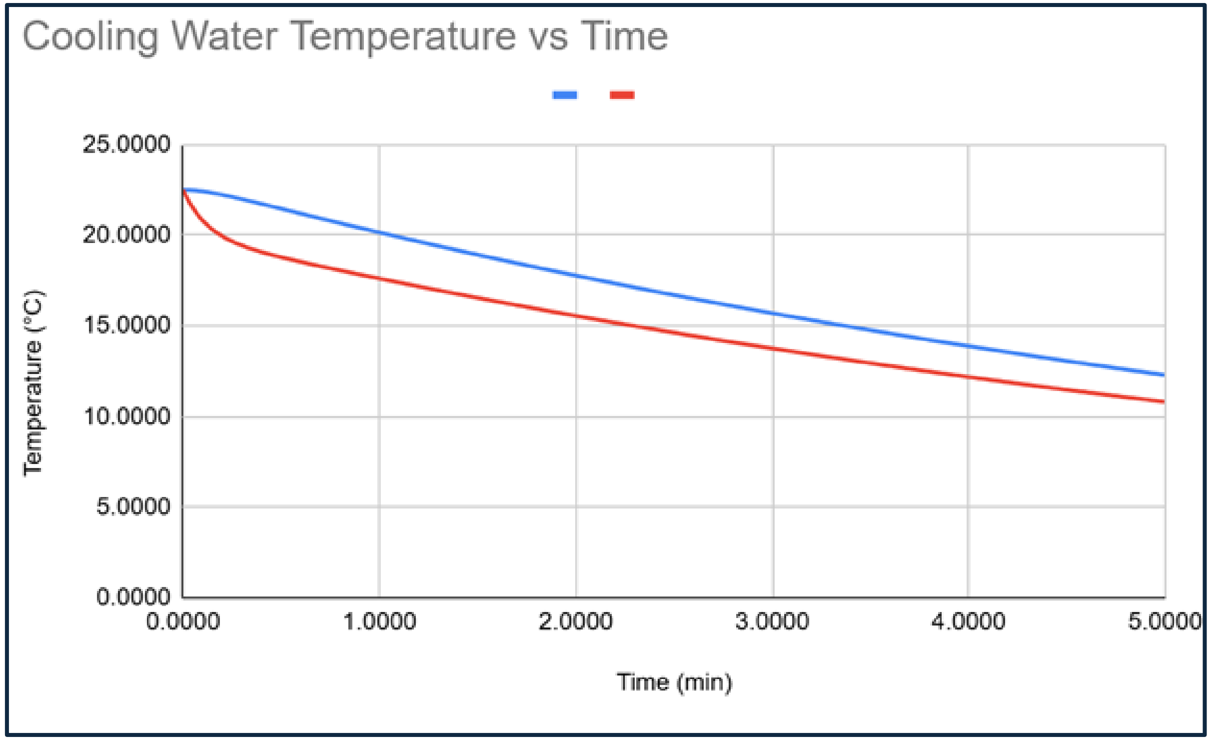


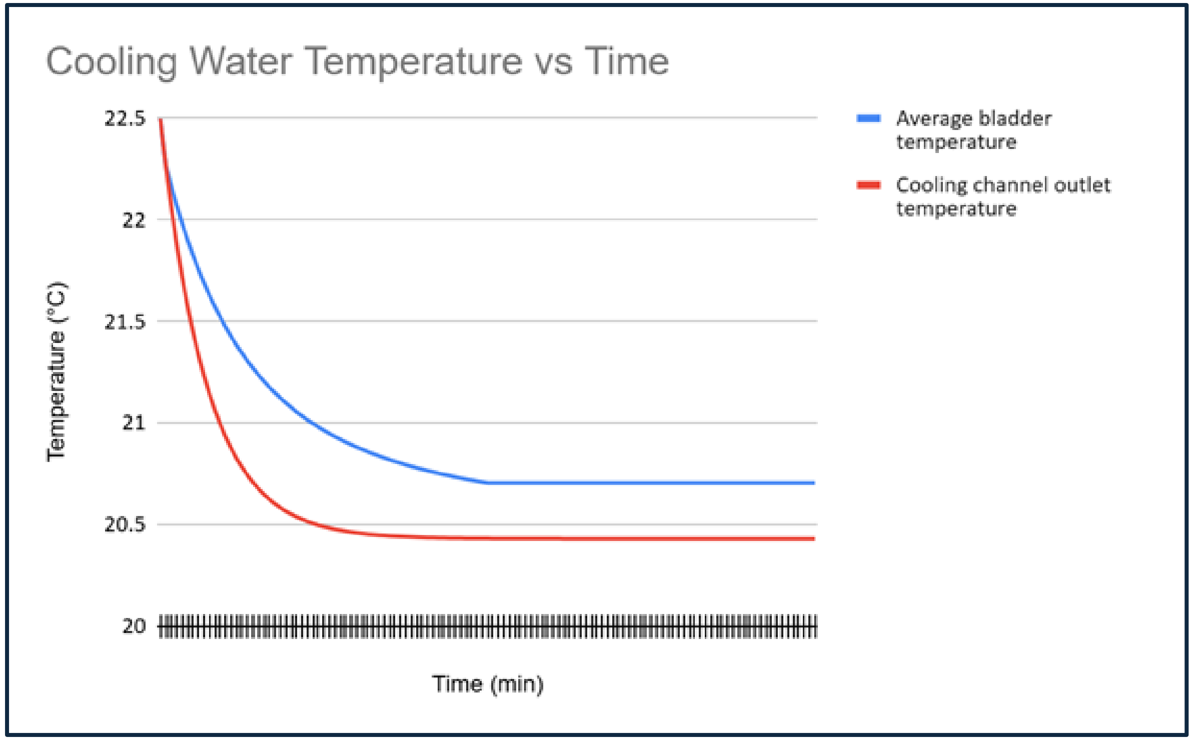
Heating Calculator
Result





Cooling Calculator
Result





Structural and Mechanical Design

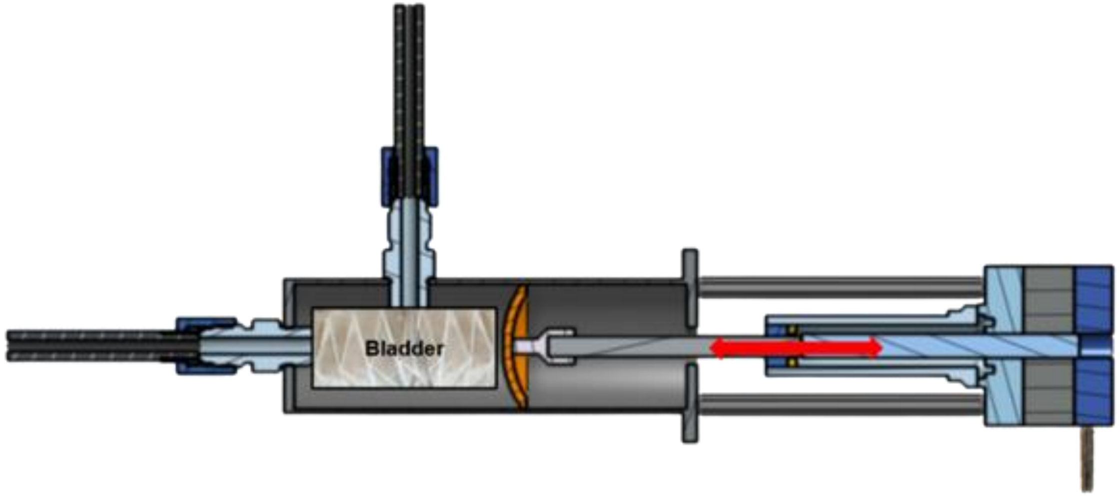
Cooling and Heating subsystem Calculators:

- Designed to fit within two stacked ISS Shuttle Middeck lockers
- Internal volume of 4.06 cubic feet: 23.00" height, a width of 18.50" & 21.50" in depth
- Mass is approximately 15 kg

Structural and Mechanical Design

Compressible Bladder:

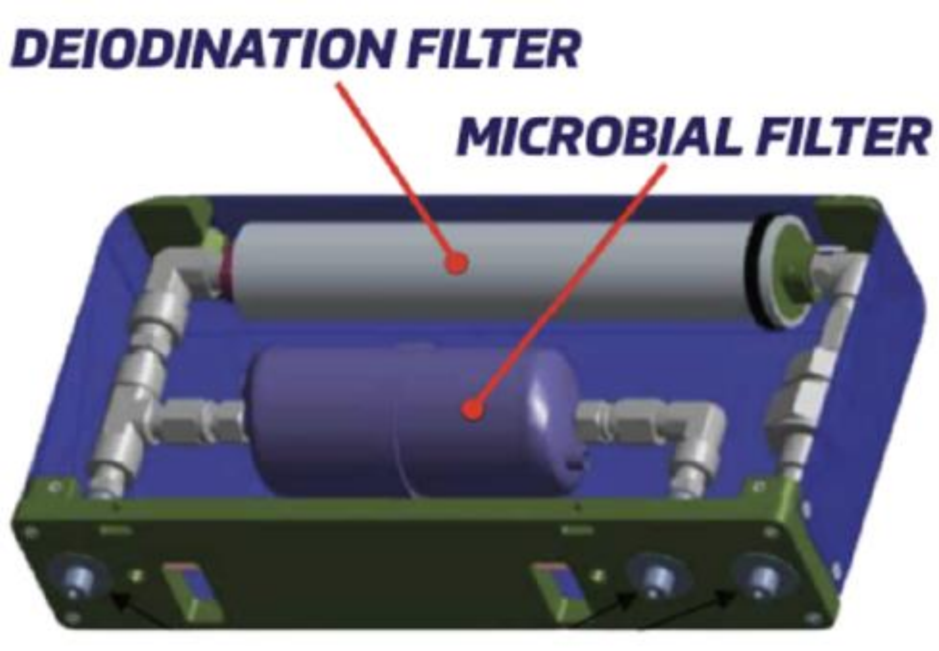
- Utilizes Linear electric motor to compress the flexible bladder
- Dispenses stored water at a constant rate
- Bladder geometry will be designed to appropriately push the water completely out



Decontamination

Filter Replacement Unit:

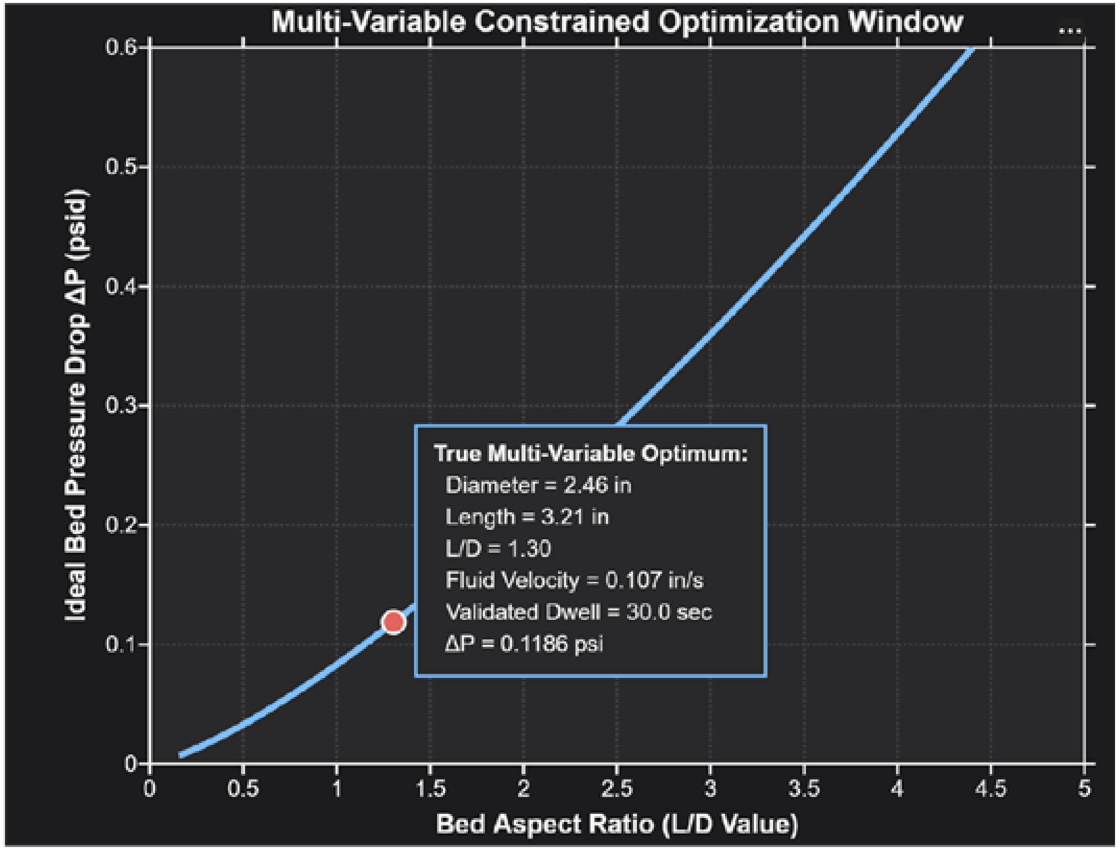
- Responsible for filtering safe drinking water
- Houses two filters in series: deiodination filter & microbial filter
- Water safety requirements:
  a.) Iodine concentration < 0.2 ppm
  b.) Microbial count < 50 CFU/mL



Decontamination

Resin Bed Simulation:

- Provides optimized geometry for resin bed
- Sets the foundation for future work with sizing the ACTEX
- Meets calculated filter requirements:
  a.) water dwell time 30 seconds
- Lowest possible pressure drop



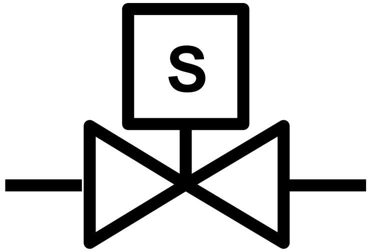
True Multi-Variable Optimum:
Diameter = 2.46 in
Length = 3.21 in
L/D = 1.30
Fluid Velocity = 0.107 in/s
Validated Dwell = 30.0 sec
ΔP = 0.1186 psi

Controls and Electronics

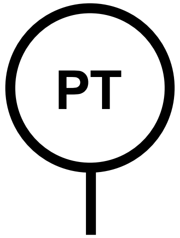
Electronics Outline:

- System safety and redundancy
    a.) internal volume control watchdog timer
- Manage EBPWD: processes environmental telemetry and user inputs
- Provides active monitoring of the water in the EBPWD
    a.) Electronics mounted behind interface
    b.) input via sensors
    c.) output → actuates the system’s solenoid valves and interface panel

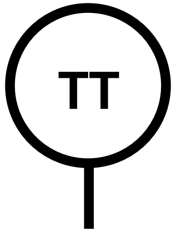
Solenoid Valve



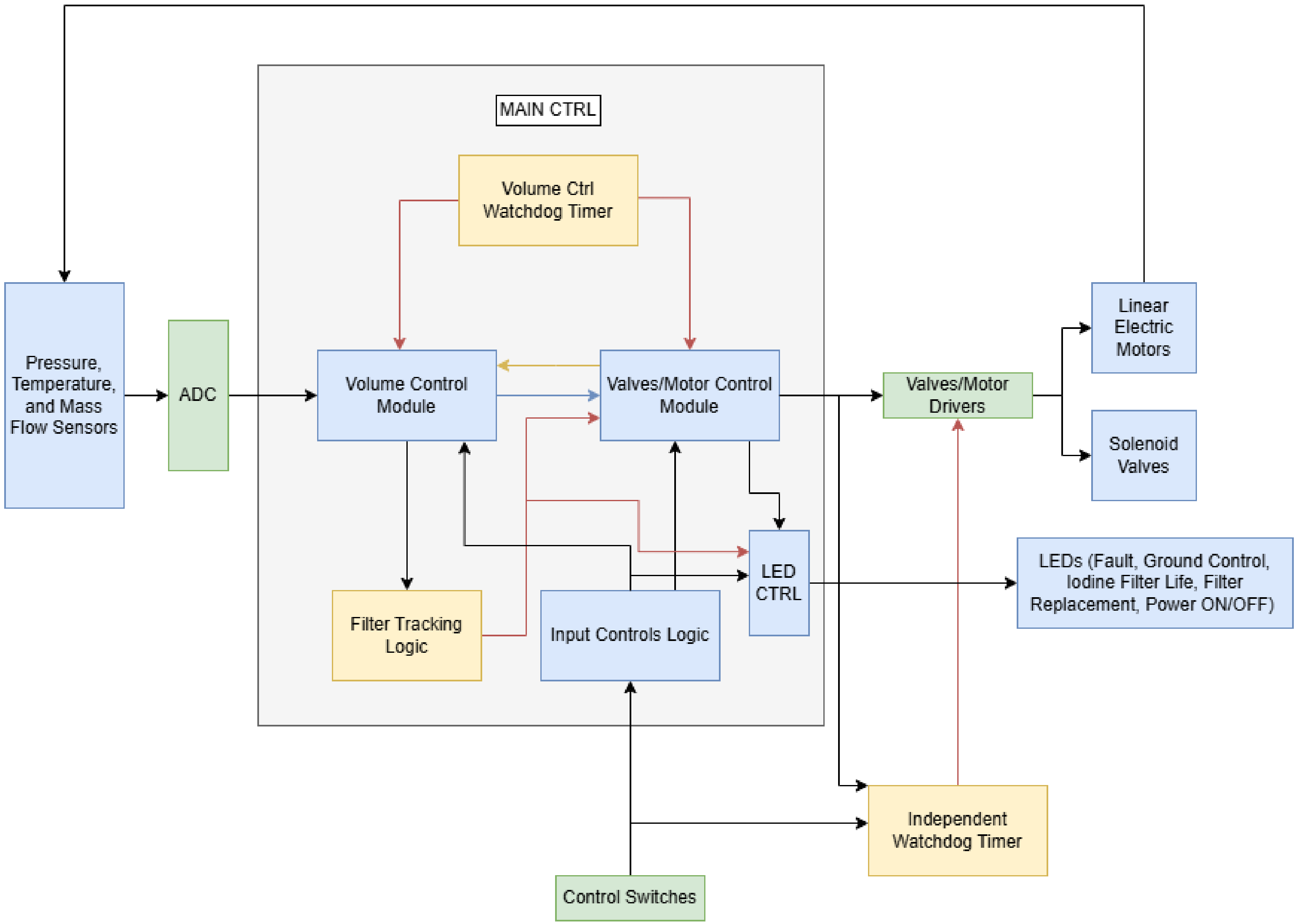
Pressure Transducer



Temperature Transducer



Flow Control Electronics Diagram



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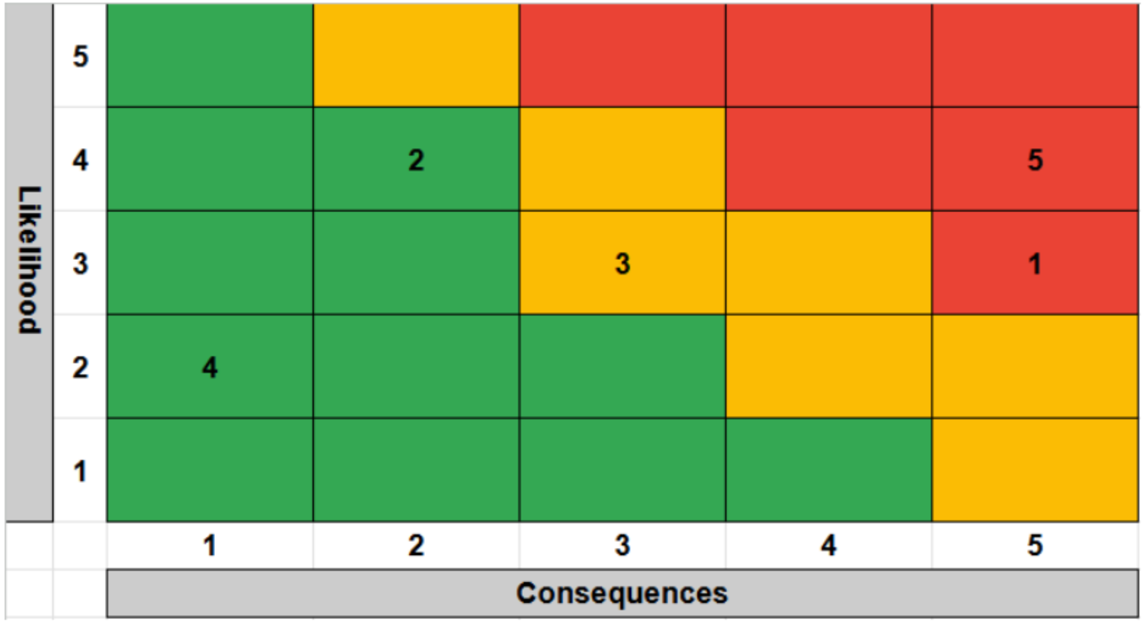
Risk Assessment & Mitigation

<u>The matrix compiles 5 relevant critical risks to determine likelihood and consequences</u>

1) Biofilm development under stagnant conditions
2) Inaccurate dispense volume
3) Inaccurate outlet temperature
4) Inaccurate dispense flow rate
5) Unknown science behind fluid behavior in microgravity

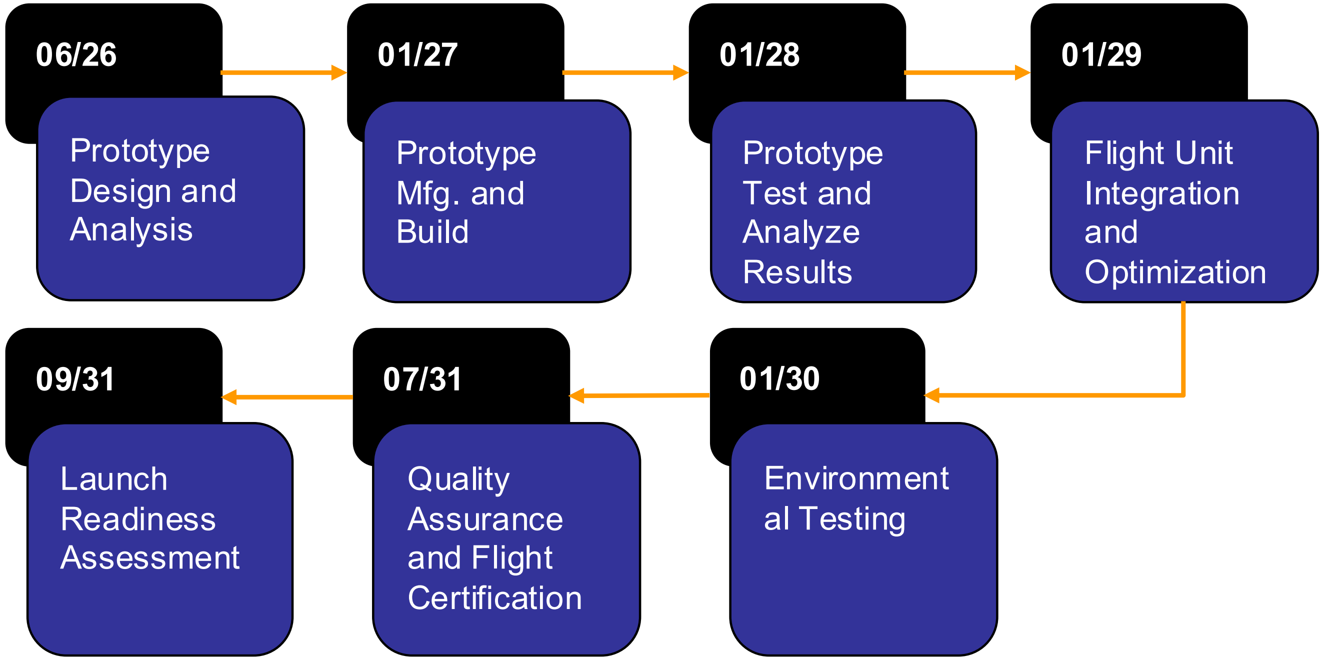


Likelihood					
5	🟩	🟨	🟥	🟥	🟥
4	🟩	🟩 2	🟨	🟥	🟥 5
3	🟩	🟩	🟨 3	🟨	🟥 1
2	🟩 4	🟩	🟩	🟨	🟨
1	🟩	🟩	🟩	🟩	🟨
	1	2	3	4	5
	Consequences				

Project Timeline

Outline

- Project Timeline spans 5 years from January 2026 (TRL 1) to December 2031 (TRL 7)
- The Design Phase spans from January 2026 to December 2026 (raise to TRL 3)
- Manufacturing Phase beginning January 2027 (raise to TRL 4)
- Comprehensive testing plans will be developed by Fall 2026



06/26 Prototype Design and Analysis

01/27 Prototype Mfg. and Build

01/28 Prototype Test and Analyze Results

01/29 Flight Unit Integration and Optimization

01/30 Environmental Testing

07/31 Quality Assurance and Flight Certification

09/31 Launch Readiness Assessment

Budget Estimate

Outline:

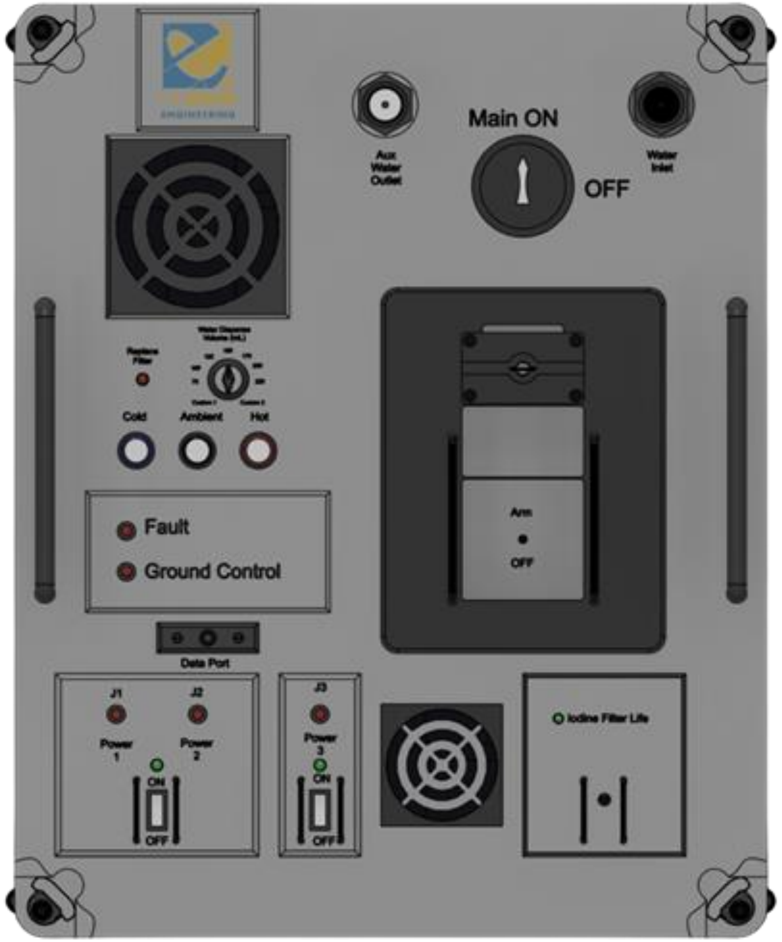
- Total Budget ($11,500)
- Funds will be used to build prototypes and the dispenser ground unit
- Upon completion of the Bill of Materials projected cost will be made using the NASA Project Cost Estimating Capability (PCEC)

Category	Line-Item	Description	Amount ($)
Income	Grant Funding	CaSGC Grant	$2,500.00
	NASA Funding	HuLC Phase 2	$9,000.00
			$11,500.00
Expenses	**Non-Personnel Costs**		
	*Bill of Materials	Cost of Development	$4,504.04
	Travel: Flights, Hotel, Ground Transportation	Transportation to HuLC Forum for 3 Team Members	$5,351.00
	Contingency Reserve	Reserve for unforeseen or unexpected expenses	$1,644.96

Conclusion

Overall:

- Two preliminary sizing tools were developed
  - Tracks water temperature
  - Optimizes resin bed geometry
- CAD model of Dispenser Housing
- Compressible Bladder Assembly
- CAD of EBPWD piping circuit



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Future Work

Next steps:

- Housing and FRU rail system CAD modeling
- Sizing and design of filters and UV Light in the FRU
- Extend longevity of filters for longer duration missions
- High-fidelity simulations for heating and cooling loops in Thermal Desktop
- Develop simulations and hand calculations for flexible bladder compression
- Storage compartment design
- Compacting fluid circuit into internal dispenser housing volume
- Electronic circuit and PCB design for fluid flow control

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NICHOLAS ACADEMIC CENTERS

California Space Grant Consortium

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Thank You!