ISS Water Recovery System, Vapor Compression Distillation Process in Microgravity

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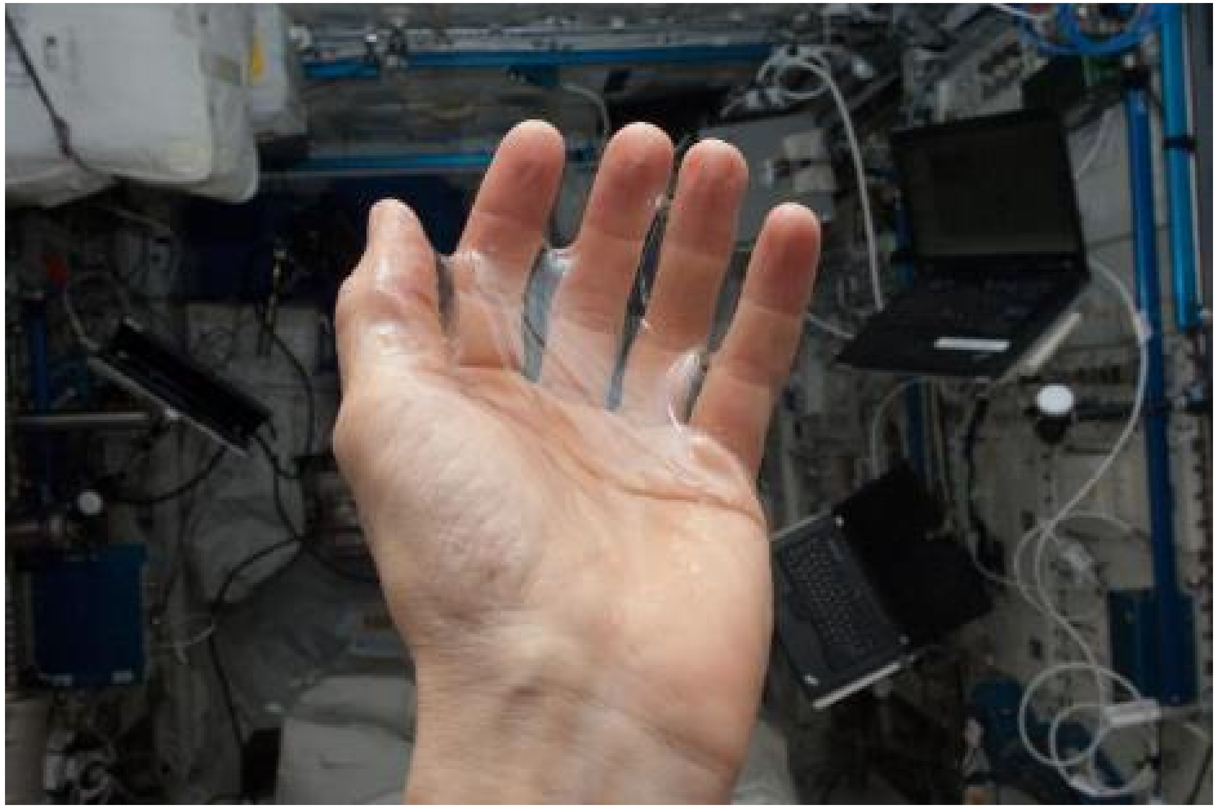
Outline

- Microgravity Considerations
- Water Recovery System Architecture
- UPA Overview
- Partial Gravity Urine Recovery
- Fluid Physics Challenges

Introduction

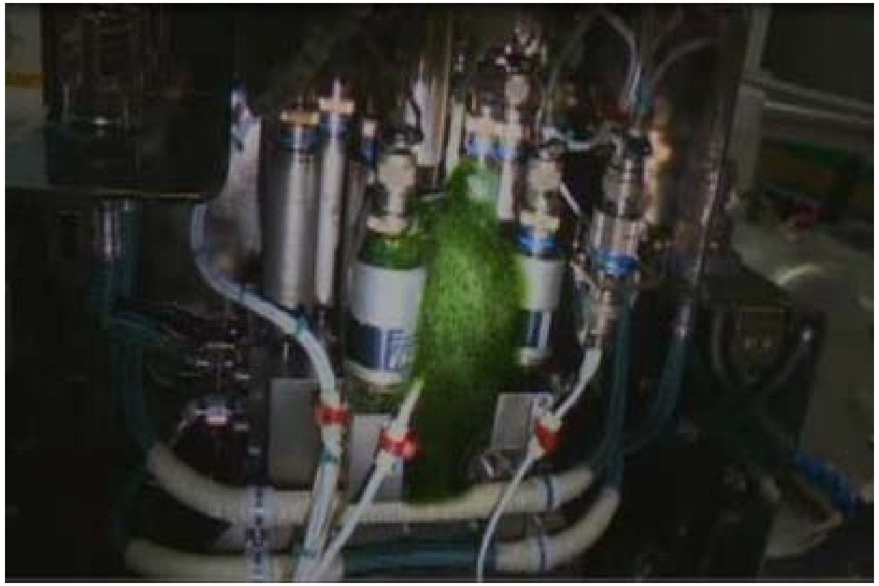
- Water treatment processes in microgravity are challenged with multi-phase fluid flow
- Gas/liquid fluid flow occurs during waste water collection (urine, condensate, Sabatier product water) and during the treatment process as required (urine distillation, catalytic oxidation with gaseous oxygen)
- Gas/liquid fluid flow has typically not been an issue on ISS due to appropriate design solutions
  - Rotary or passive separators
  - Potentially higher pressure drop in microgravity will be evaluated with the GRC Packed Bed Reactor Experiment (PBRE)
- Solids in the liquid phase have also not been an issue as long as the system is properly designed (i.e., filtration)
- Primary issue with fluid physics has been with *unexpected* multi-phase flow
  - Solids (e.g., precipitation, biomass, catalyst fines) in the absence of gravity will tend to fail systems
  - Free gas will also impact system function if not properly managed (by occluding filters or adsorbent/IX media, or lodging in tanks)

Fluids in μG

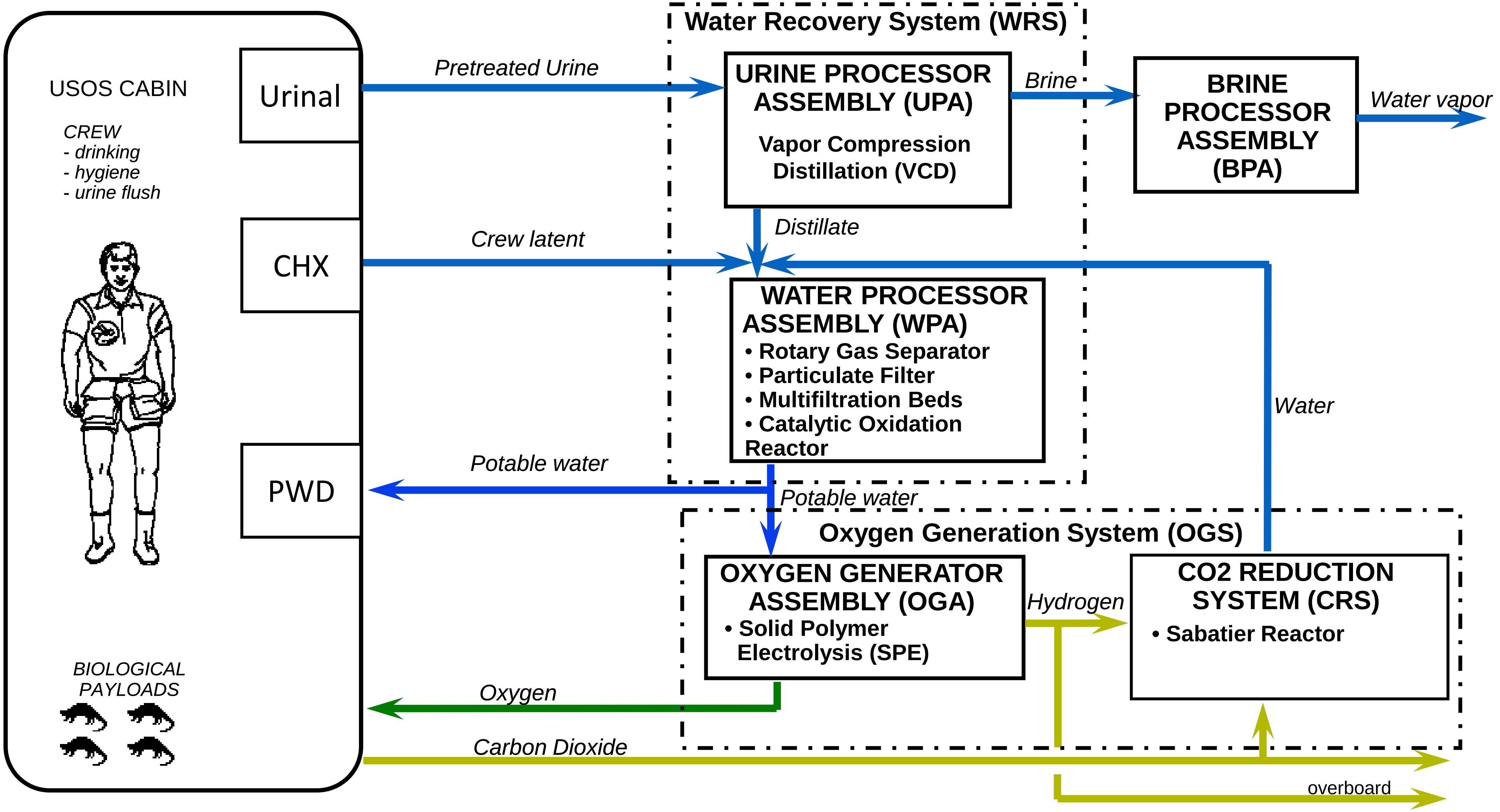


- The behavior of liquids on board an orbiting spacecraft is primarily driven by surface tension effects
- In microgravity, the net sum of inertial forces acting on the liquid balance to almost zero so capillary forces dominate

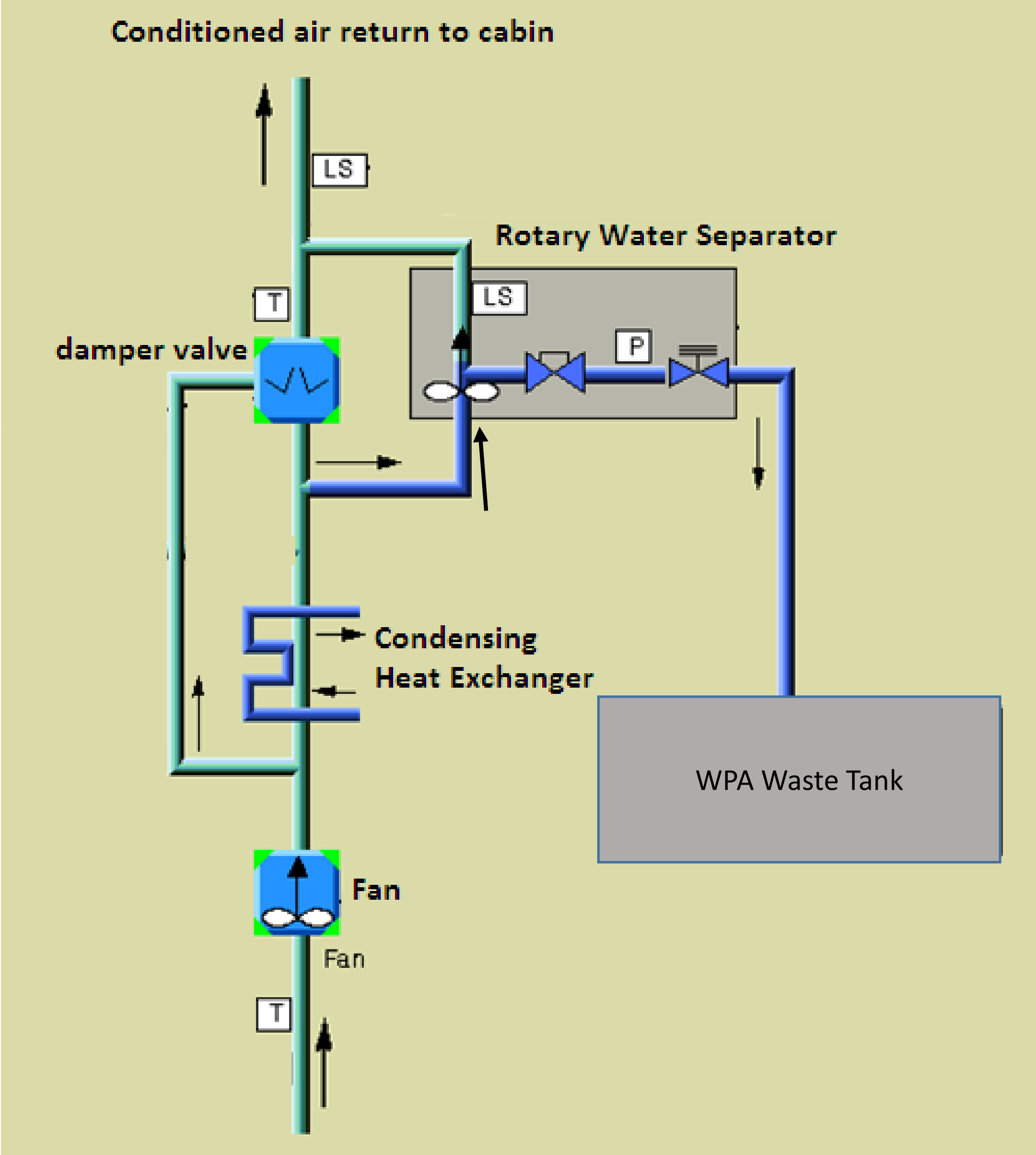
Fluids In μG



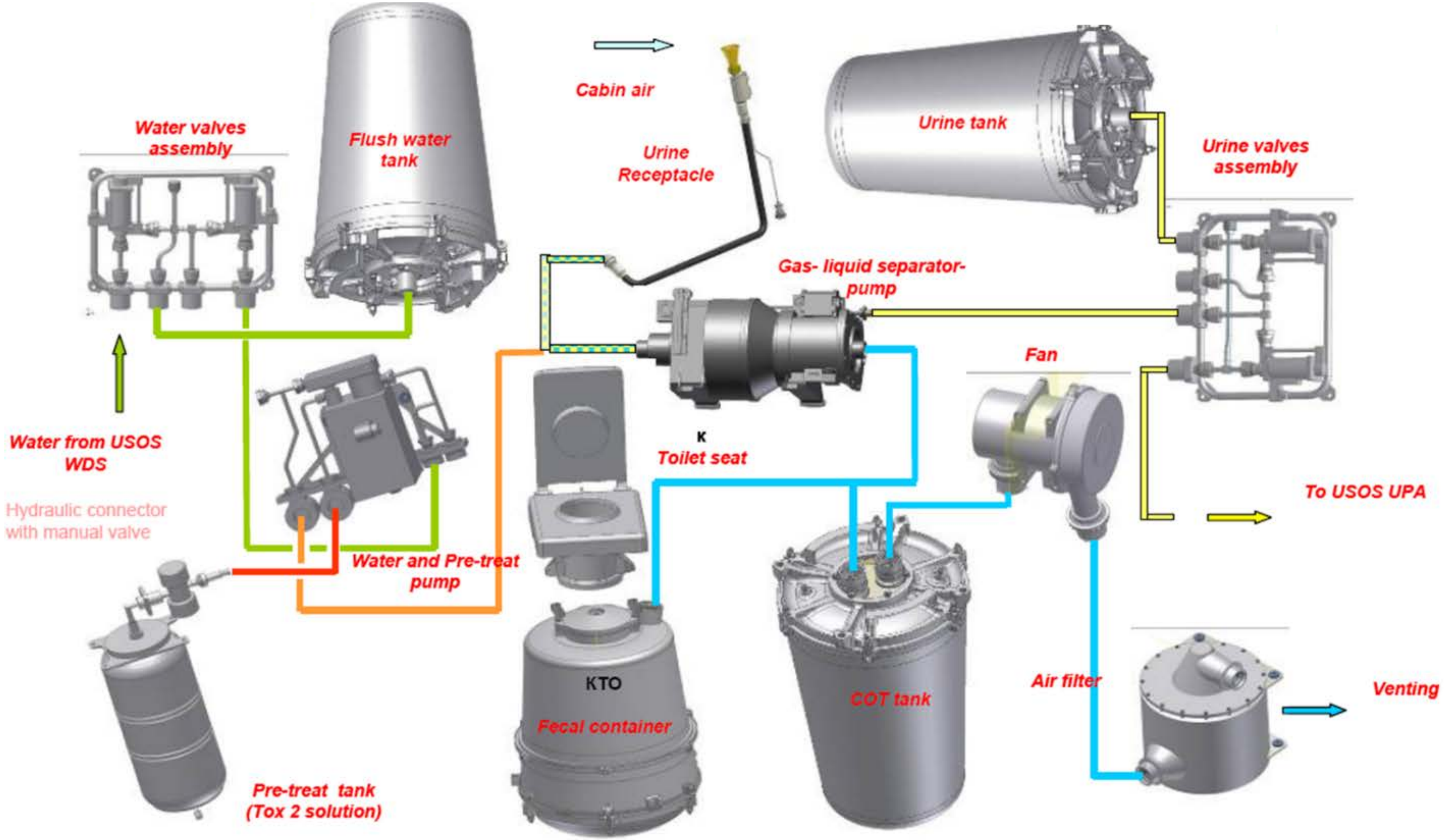
WRS & OGS Architecture Overview



Common Cabin Air Assembly (CCAA)



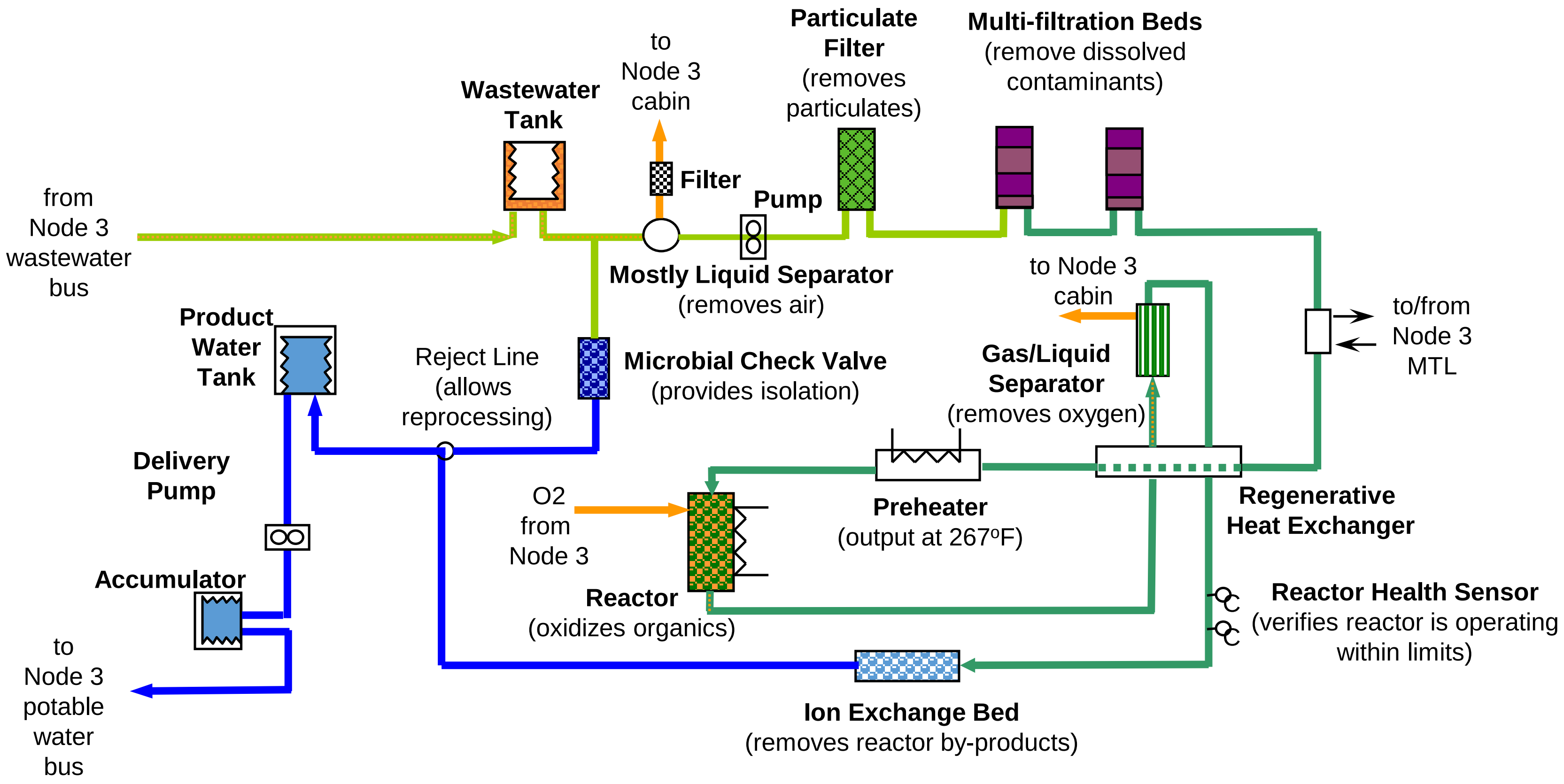
Waste and Hygiene Compartment



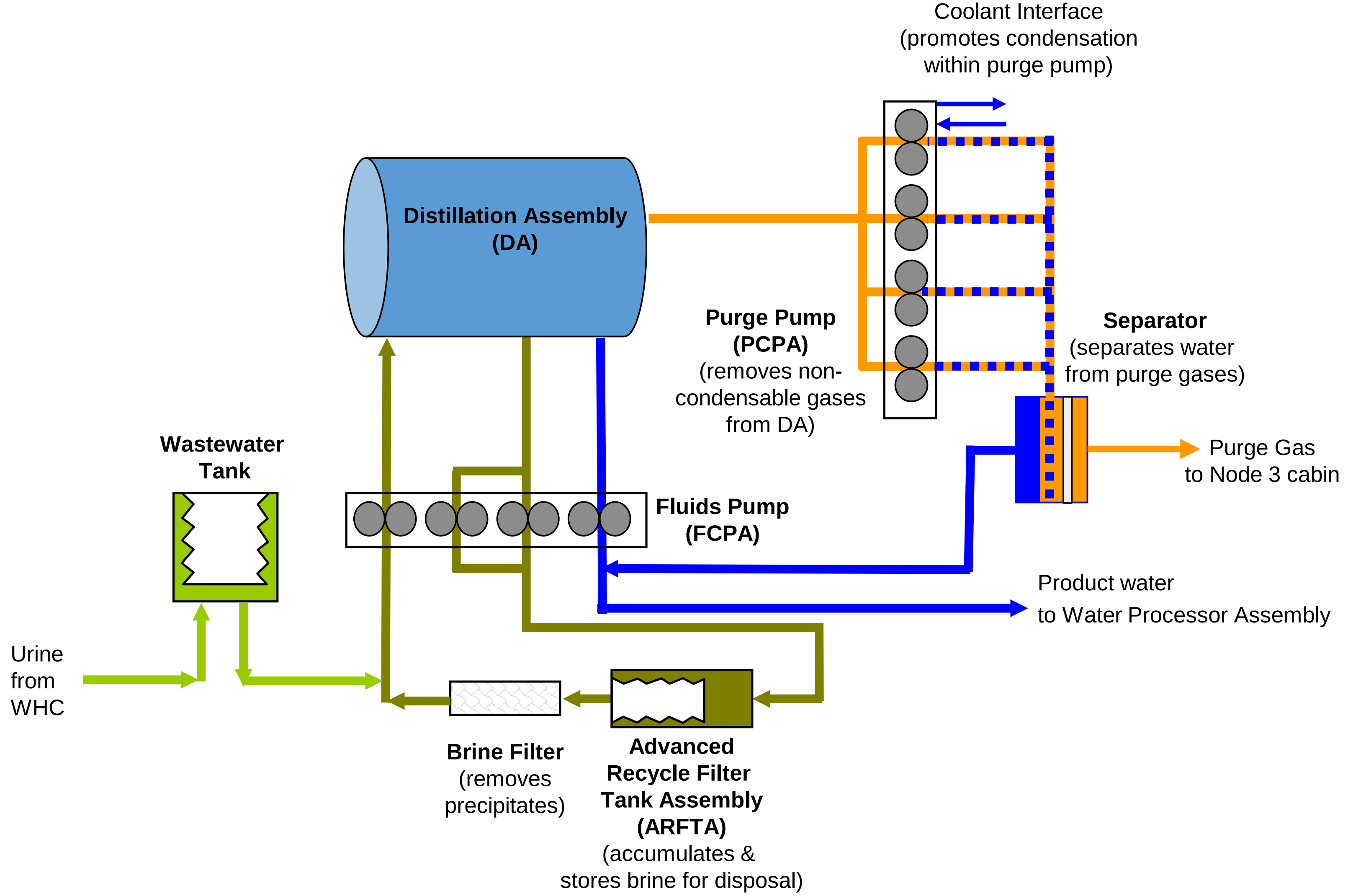
ISS Waste & Hygiene Compartment

ISS Waste & Hygiene Compartment

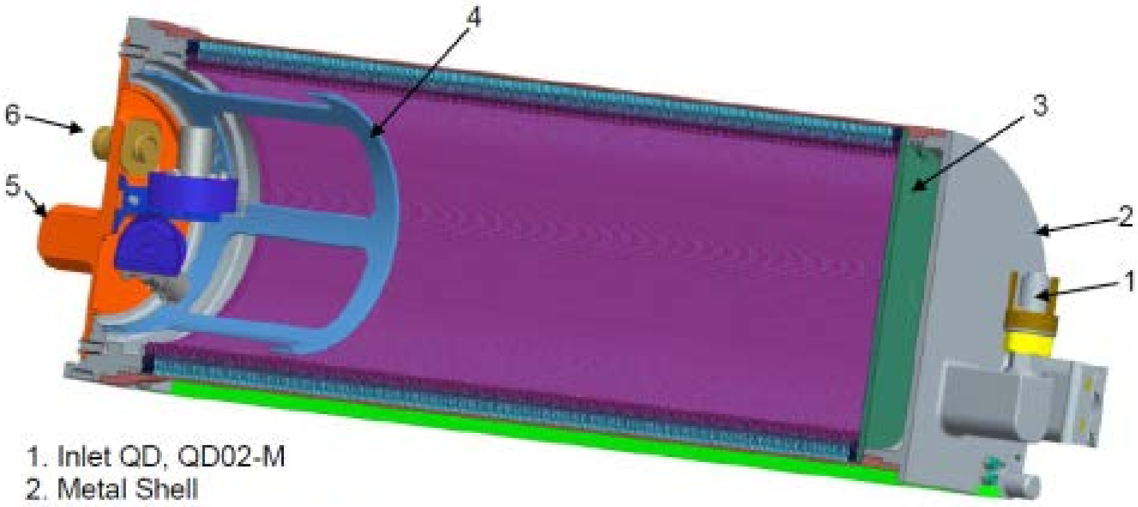
Water Processor Simplified Schematic



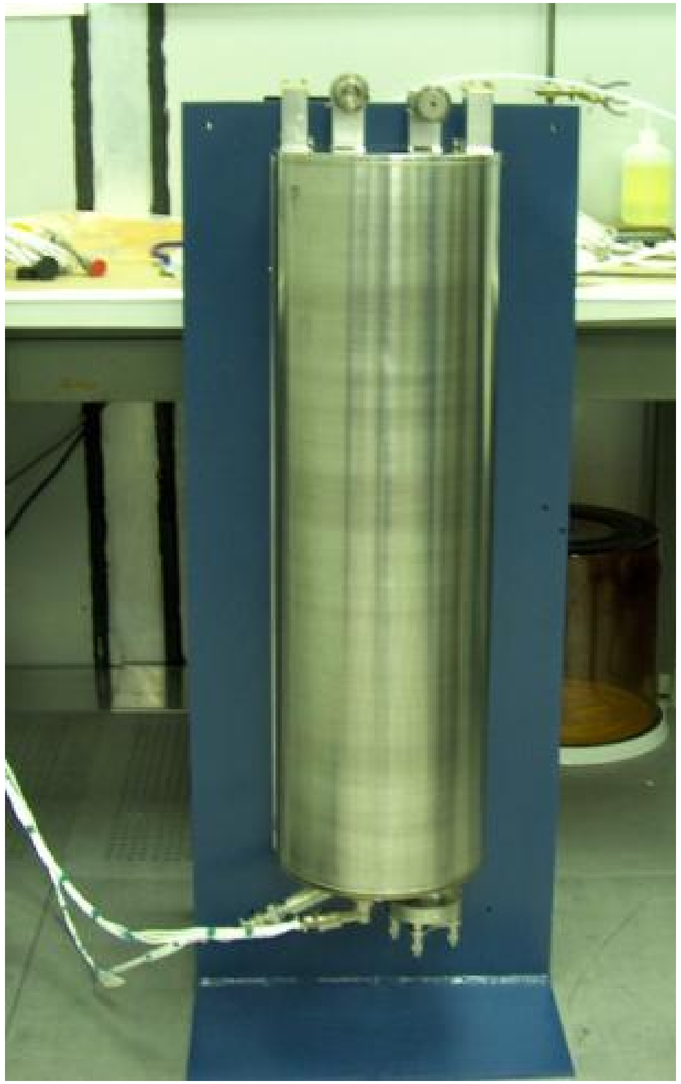
Urine Processor Assembly Simplified Schematic



Wastewater Storage Tank Assembly



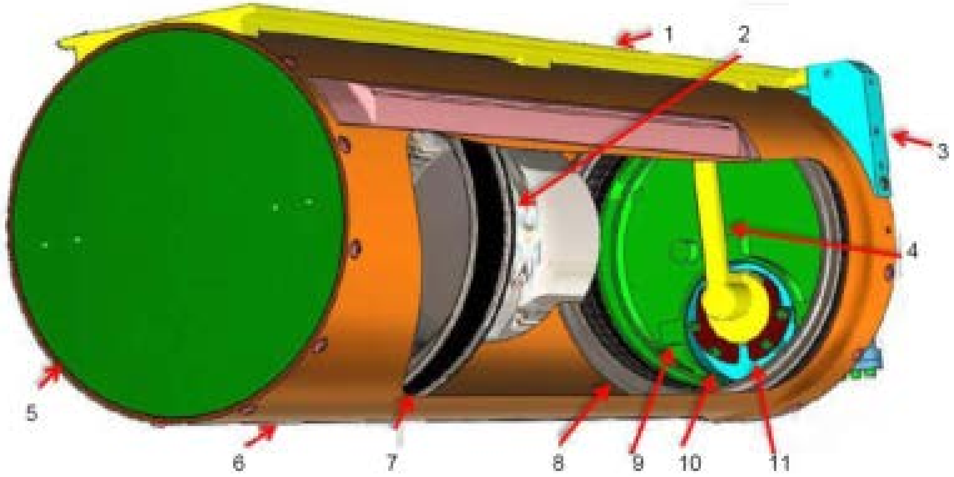
1. Inlet QD, QD02-M
2. Metal Shell
3. End of bellows (sweeper)
4. Stop
5. Quantity Sensors, Q1
6. Pressure Sensor, P17

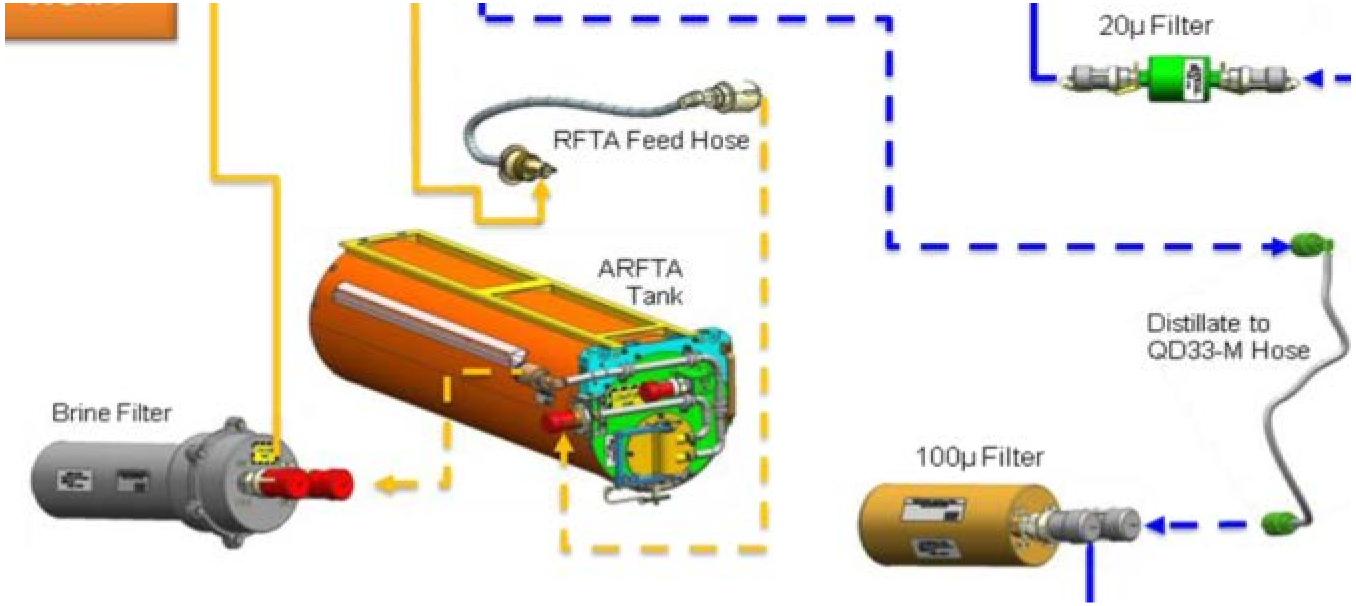


Advanced Recycle Filter Tank

1. Rail (yellow)
2. Sweeper (metallic)
3. Bracket (blue)
4. Manifold (yellow)
5. End Cap (green)
6. Housing (orange)
7. Sweeper Guide (black)
8. Bellows (metallic)
9. Stationary Term/Port Cap (green)
10. Iso Valve (blue)
11. Clip (red)

(majority of bellows removed for clarification)



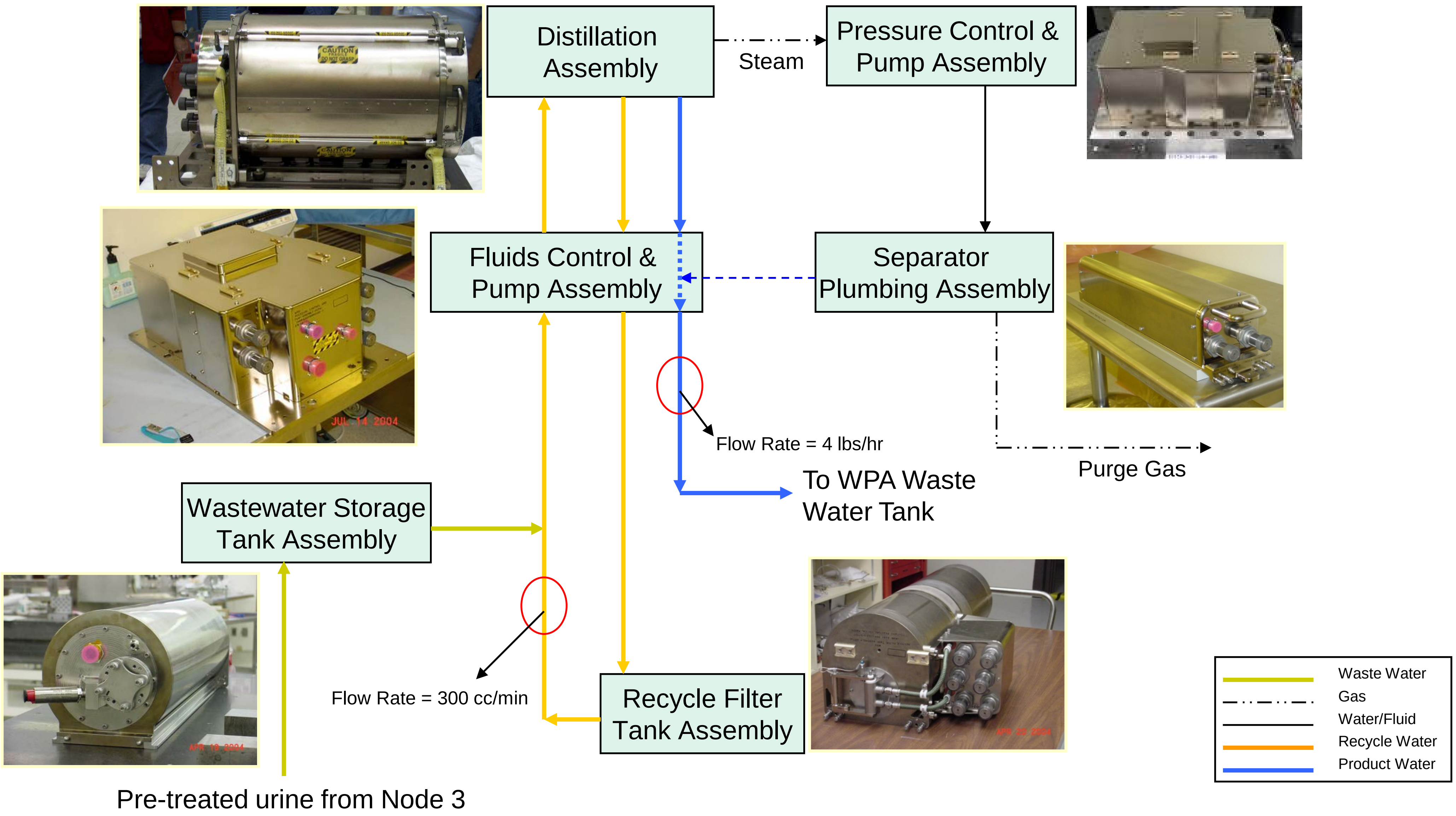


Urine Processor Assembly Overview

- A vapor compression cycle is utilized to distill product water from pretreated urine. A pretreatment formulation is used to stabilize the urine after collection.
- The pretreated urine is concentrated to 75-85% recovery with the resulting brine returned to Earth.
- The process is very energy efficient as the heat of vaporization required for boiling of the pretreated urine at reduced pressure is provided by the condensed product water.
- The UPA is housed inside ISS WRS Rack #2 and is composed of the following components:
  - Distillation Assembly (DA)
  - Fluids Control & Pump Assembly (FCPA)
  - Pressure Control & Pump Assembly (PCPA)
  - Firmware Controller Assembly (FCA)
  - Wastewater Storage Tank Assembly (WSTA)
  - Recycle Filter Tank Assembly (RFTA)
  - Separator Plumbing Assembly (SPA)

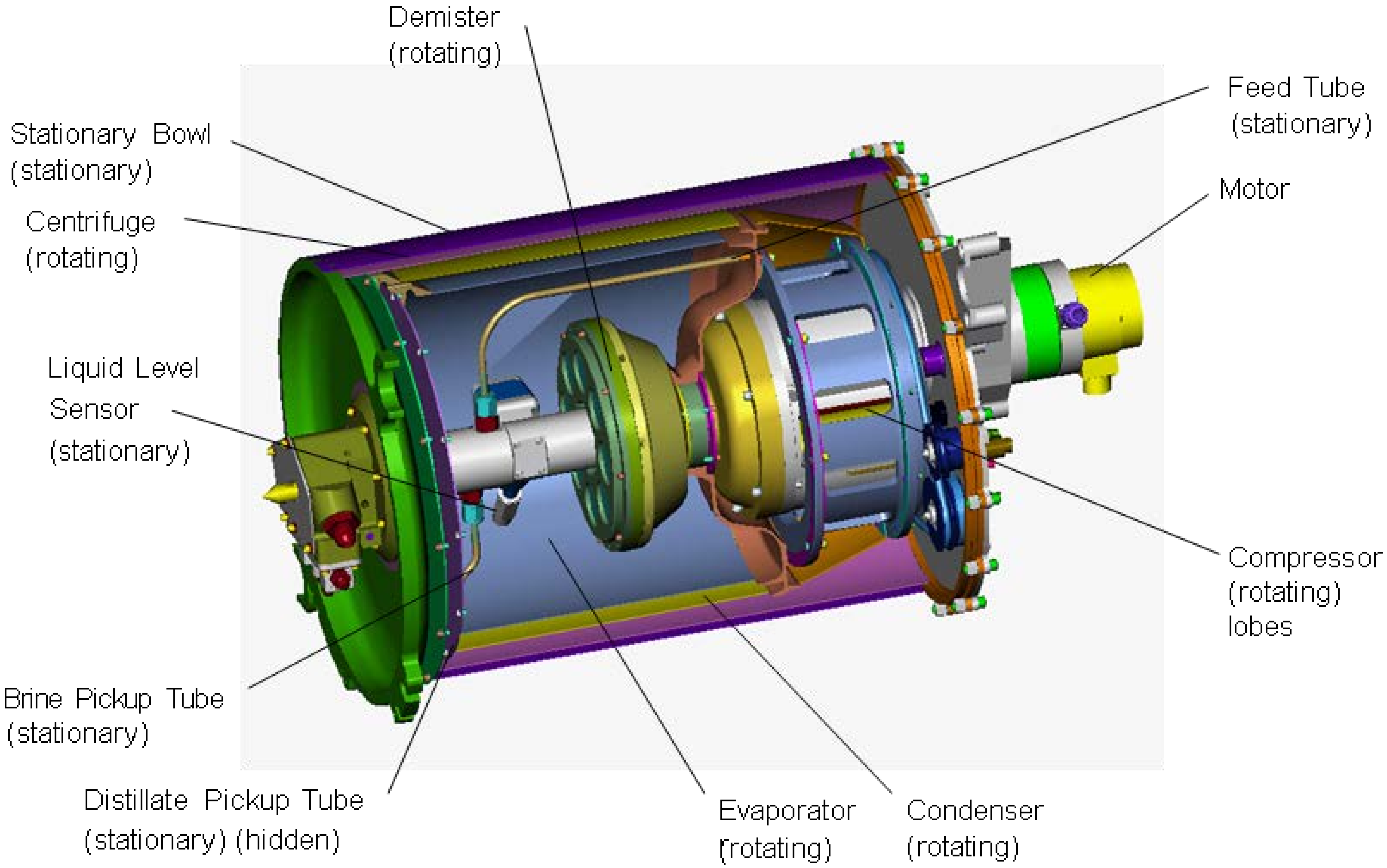
Urine Processor Assembly Overview

Major ORU's and Process Flow



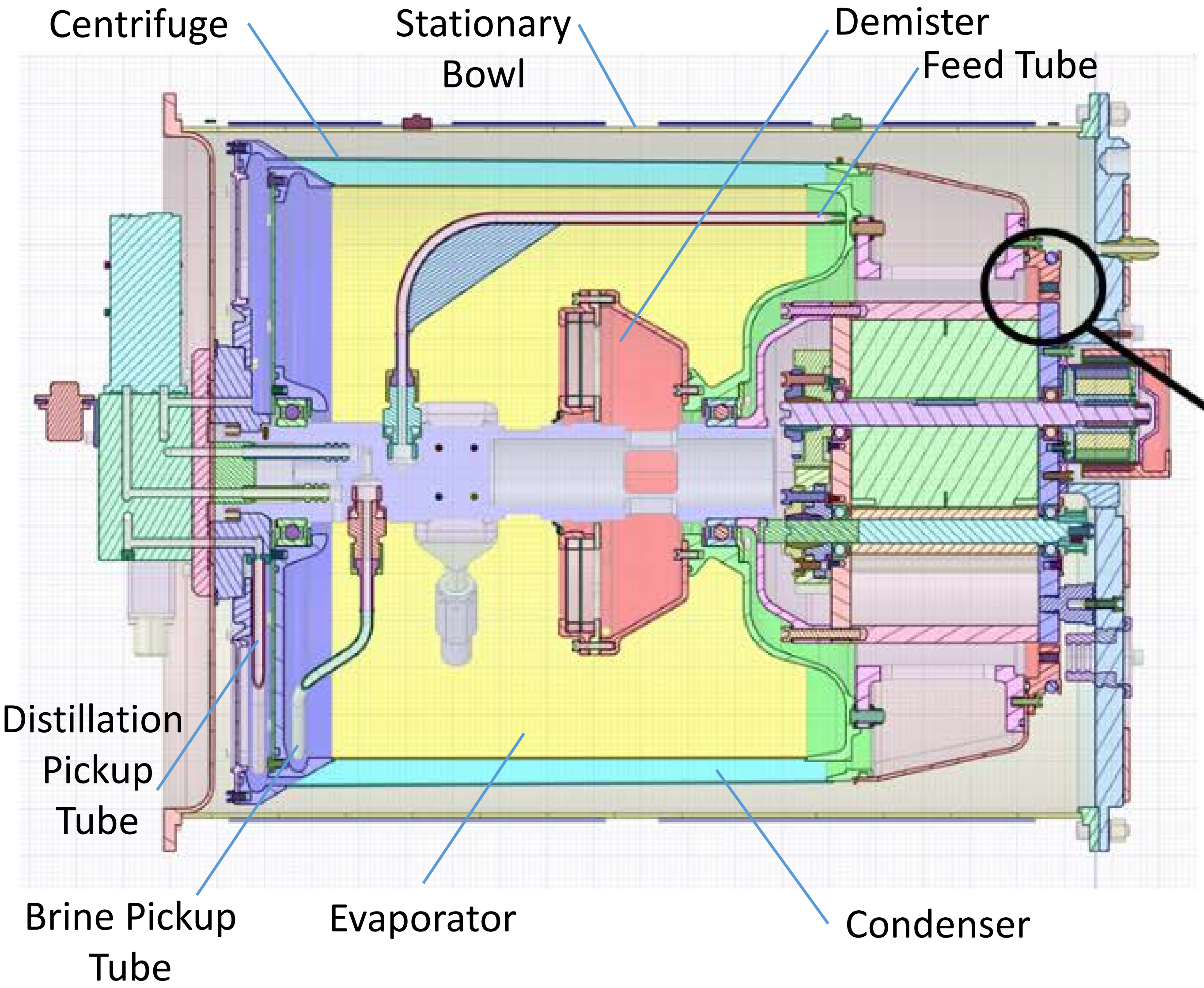
Urine Processor Assembly Overview

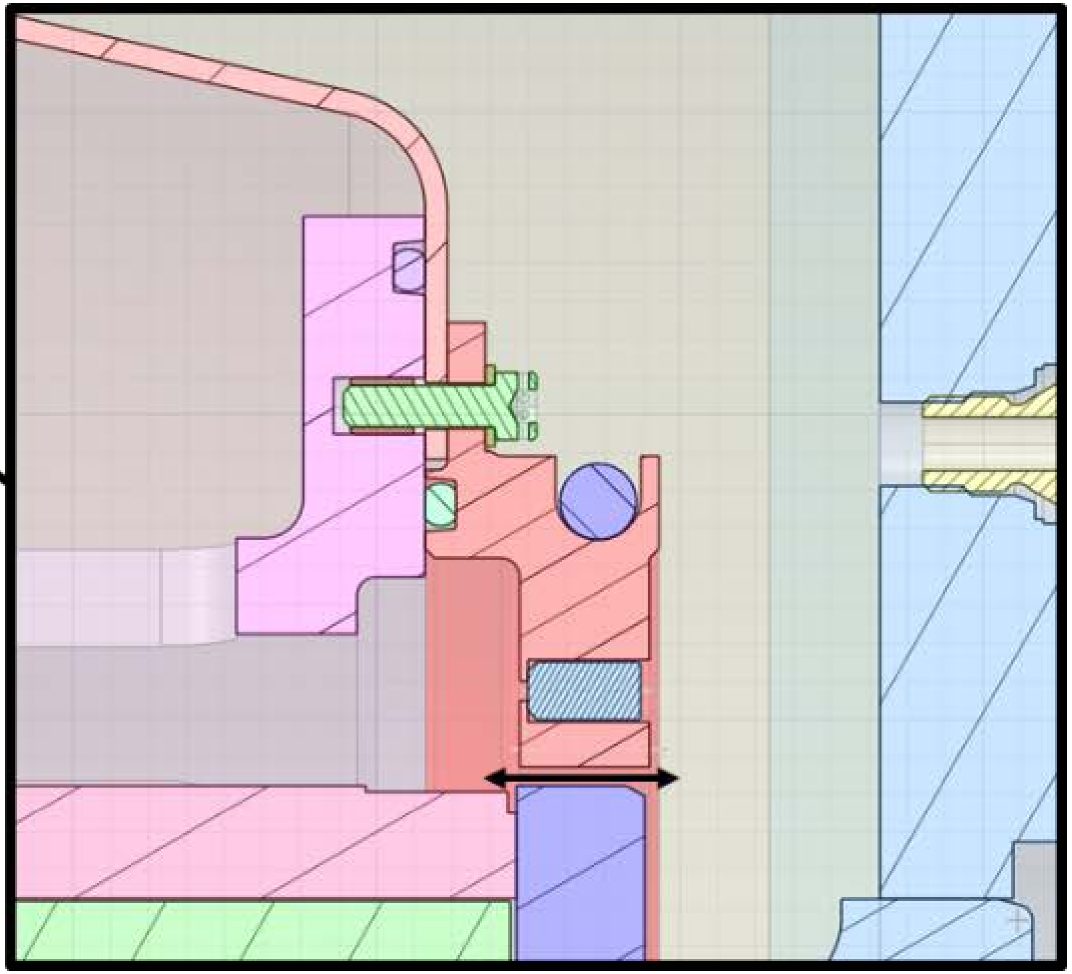
Distillation Assembly Cut-away



Urine Processor Assembly Overview

Distillation Assembly Cross Section

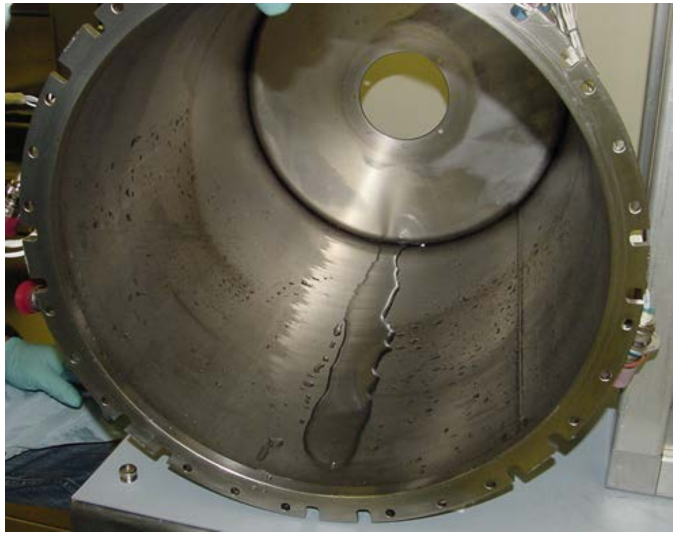




Circumferential gap between the Condenser and Stationary Bowl located near the compressor outlet

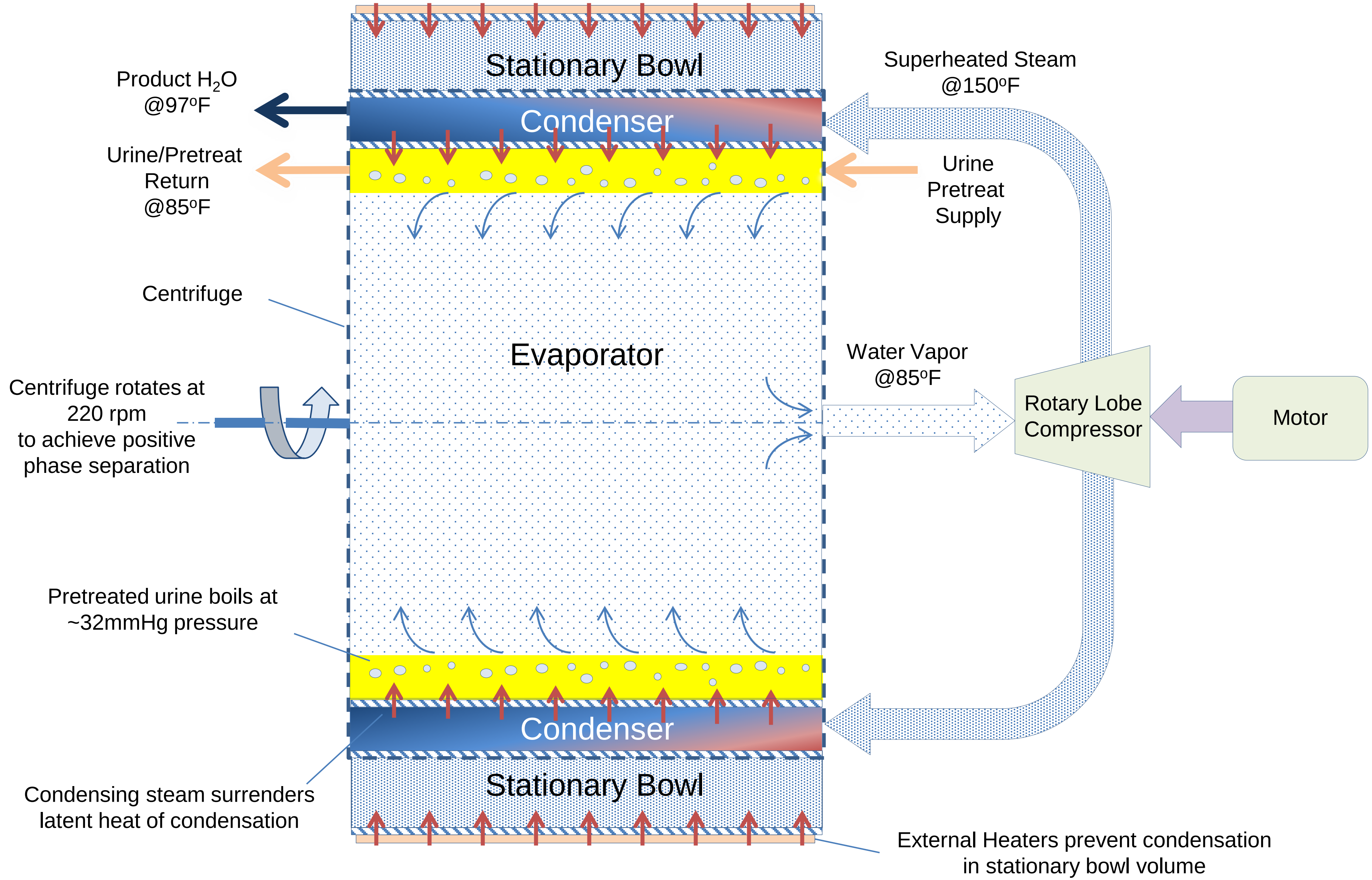
Urine Processor Assembly Overview

Inside the Distillation Assembly



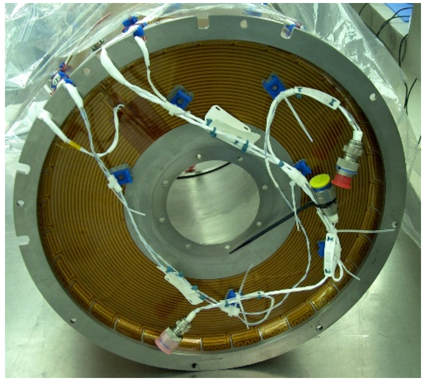
Urine Processor Assembly Overview

Distillation Assembly Operation



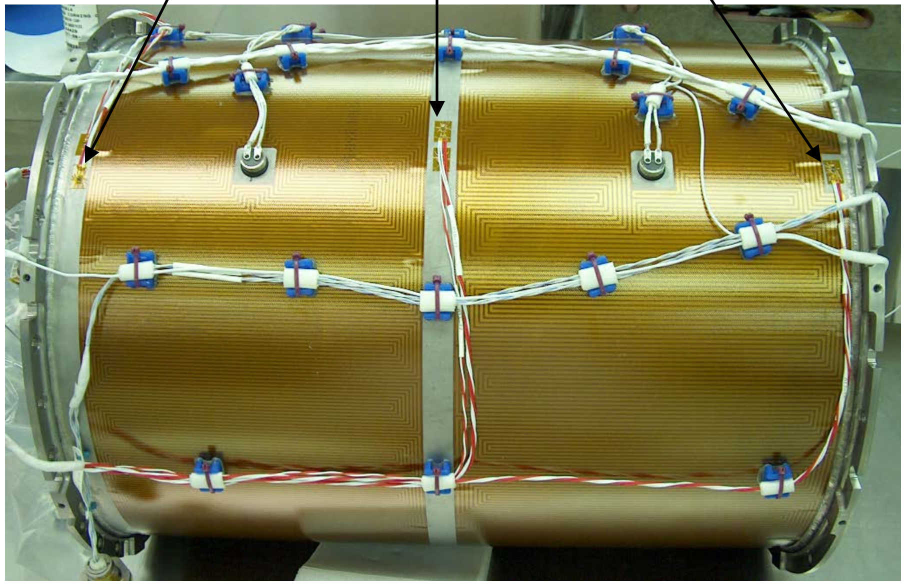
Urine Processor Assembly Overview
Distillation Assembly Stationary Bowl Heaters

Front

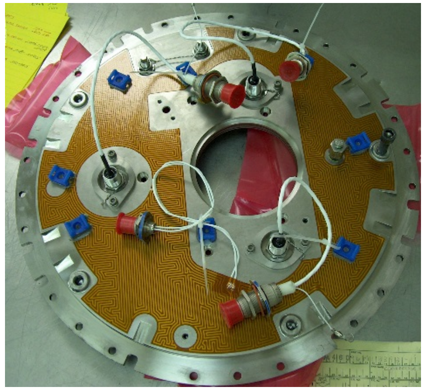


RTDs (Resistance Temperature Device)

T5 T6 T7



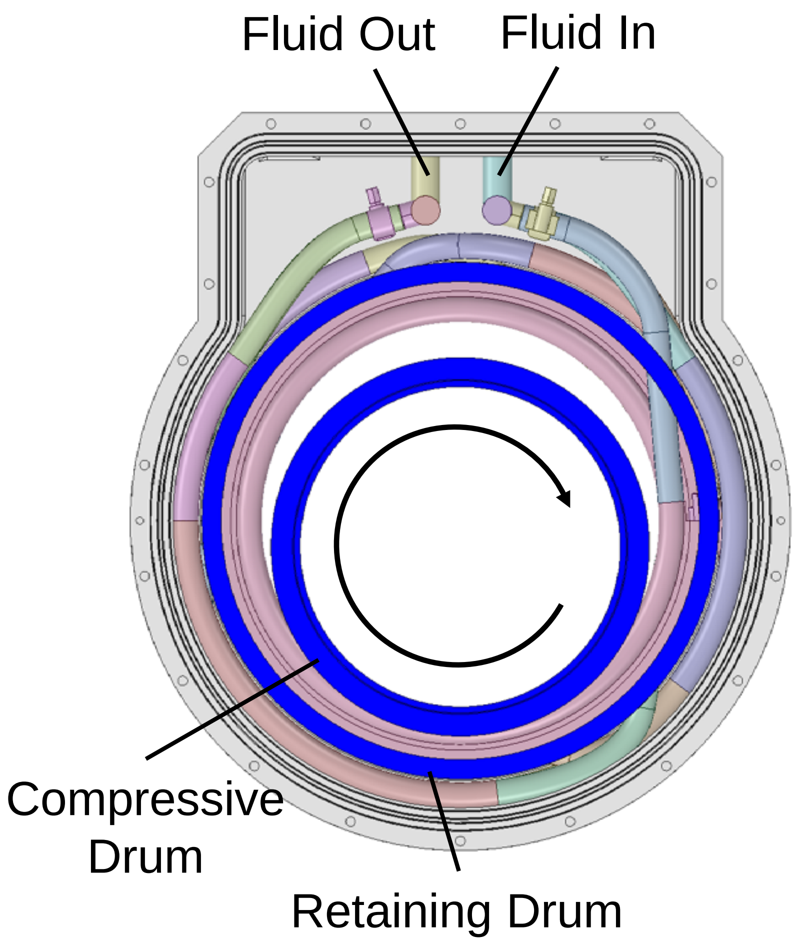
Back

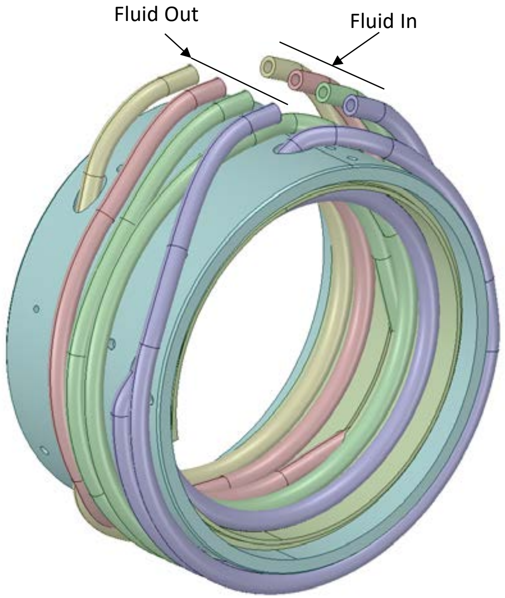


- 4 heaters surround the stationary bowl
- RTD-T5 controls 2 front heaters
- RTD-T6 controls 2 rear heaters
- On Temp = 128ºF
Off Temp = 132ºF

Urine Processor Assembly Overview

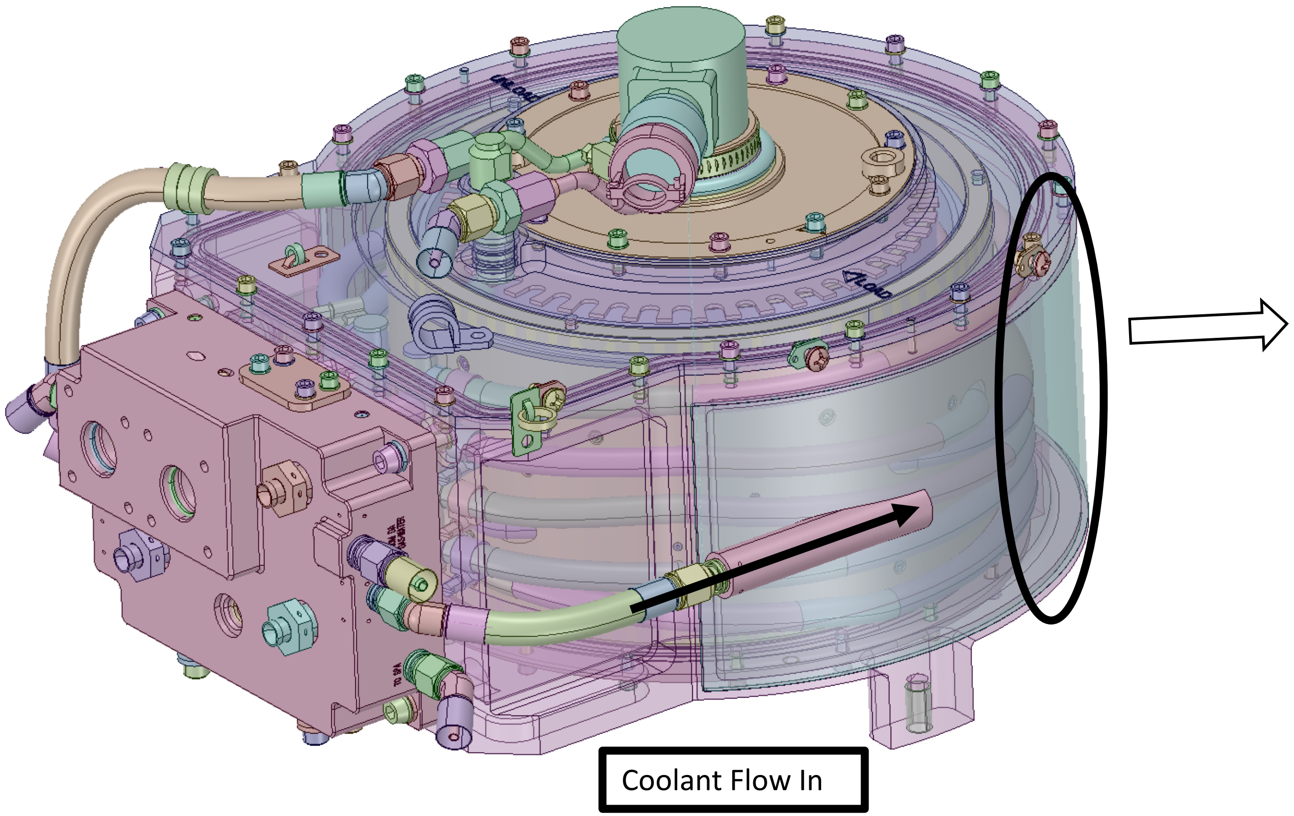
Inside the Pressure Control Pump Assembly

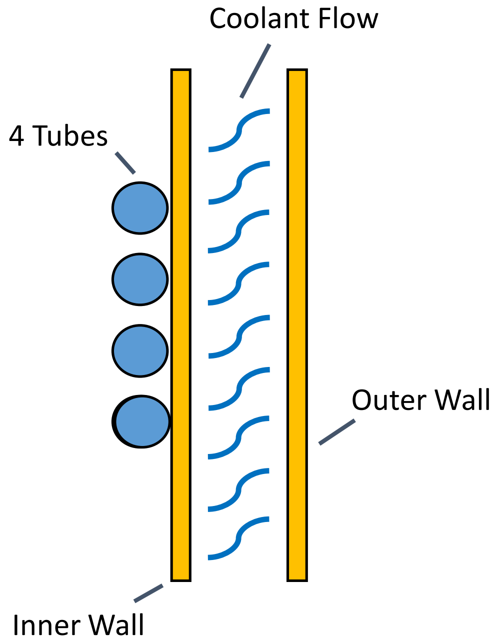




Urine Processor Assembly Overview

Pressure Control Pump Assembly Cooling Jacket

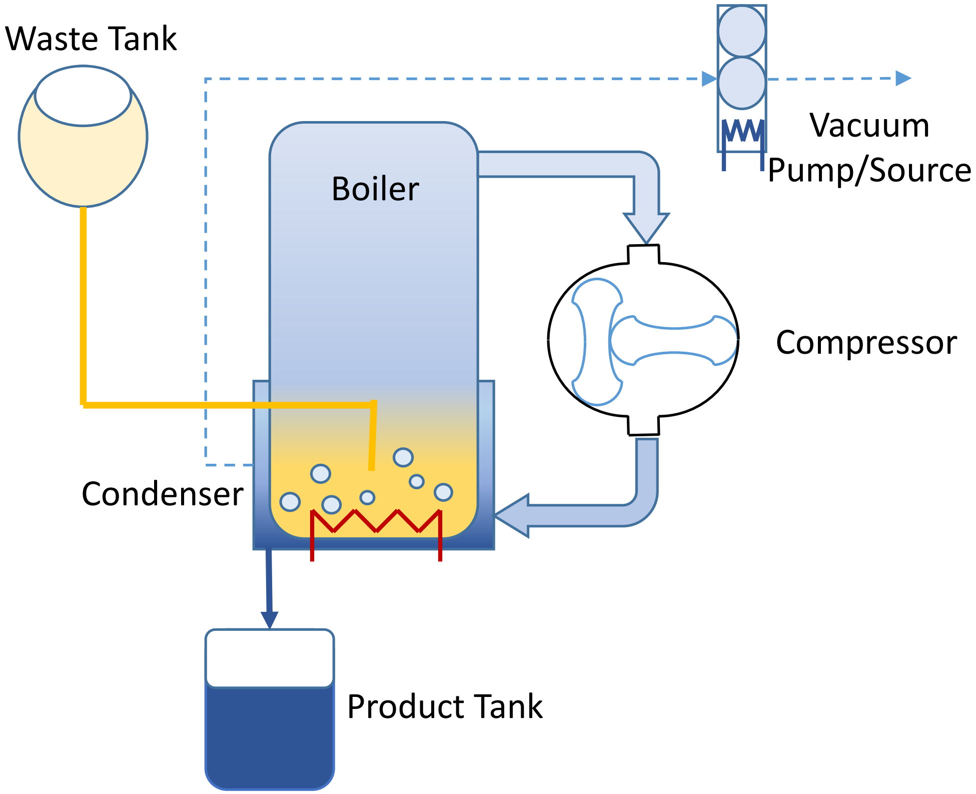




- ISS MTL Coolant flows through a jacket in the PCPA enclosure
  - Allows for additional condensation of the water vapor, which increases the pumping efficiency of the PCPA

Partial G Urine Recovery for Lunar/Planetary Surface

Notional Concept



- A notional vapor compression distillation concept for lunar or planetary surface operation is presented.
- Pretreated urine is introduced into the boiler volume via gravity and the pressurized feed of the waste tank.
- As the urine is distilled, phase separation occurs naturally under the influence of gravity and steam is drawn of the boiler where it is compressed and introduced into the condenser.
- Operating at a ΔT of 10-15 ^{o}F, the heat of vaporization is recovered from the steam to boil the pretreated urine.
- Liquid condensate collected in the bottom of the condenser is gravity fed into a collection tank.
- A vacuum pump or source is needed to periodically draw non-condensable gases out of the condenser volume.
- A contingency heater is added if needed to drive off the last bit of water at very high solids concentrations.

Partial G Urine Recovery for Lunar/Planetary Surface

Fluid Physics Challenges

- Concentrated urine near solubility limits results in an elevated boiling point. Vapor compression alone may not be sufficient to drive the recovery of water beyond 95%.
- Higher operating temperatures result in lower ammonia solubility in water and perhaps increased evolution of ammonia gas.
- The process for solids separation after nearly 100% water recovery is TBD.
- A mild concern exists over a lack of knowledge about the physics of boiling urine under partial gravity conditions.
- Operating in a gravitational field may provide design opportunities for buoyancy driven movement of waste or product streams.

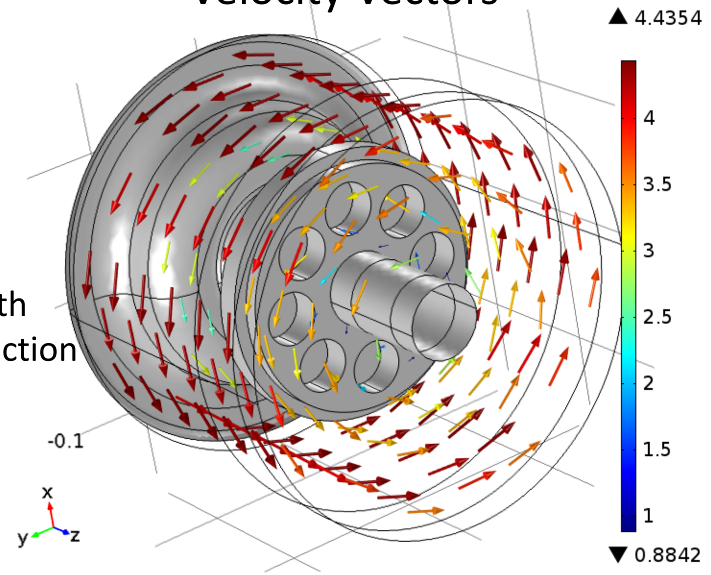
Urine Processor Assembly

Fluid Physics Challenges for Exploration

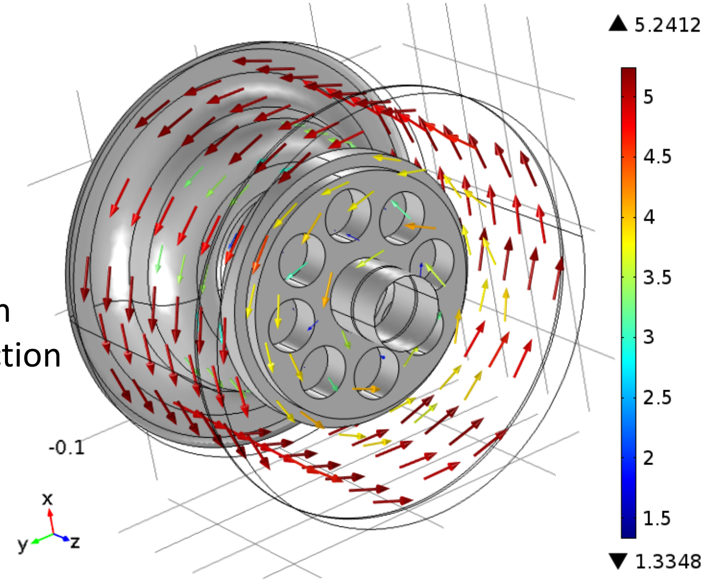
- Downsizing the next generation UPA for exploration missions in microgravity environments (i.e. Mars Transit, Gateway, etc.) is a priority.
  - Current UPA runs on a 25% duty cycle to meet ISS needs.
- Changes to the DA diameter or rotational speed may have unexpected consequences relative to boiling or condensation. Only changes in centrifuge length have been considered.
  - DA condenser fluid physics is complex. Test correlated predictive modeling of boiling and condensation is needed to optimize the next generation UPA.
- Elimination of stationary bowl heaters may provide substantial benefit.
  - Current system is energy efficient with a COP of approximately 4.0 (based on the latent energy of the product stream) but stationary bowl heaters consume 40-50% of the total process power.

Velocity Vectors

2” length reduction



3.75” length reduction



Backup

Overview

Average Human Metabolic Balance (lb/person-day)

Input		Output
Oxygen 1.84		2.20 Carbon Dioxide
Drinking Water 3.56		3.31 Urine
Water in Food 2.54		5.02 Perspiration/ Respiration
Food Prep Water 1.67		0.20 H2O in Feces
Food Solids 1.36		0.24 Solids
Total 10.97		10.97 Total