Impact of Biofilms on the Design and Operation of ISS Life Support Systems

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Layne Carter was hired by NASA in 1988 after receiving a B.S. degree in Chemical Engineering from Oklahoma State University. He also received a M.S. degree in Environmental Engineering from the University of Alabama in Huntsville. During his 28 years at NASA, Mr. Carter has worked on the development, design, delivery and operation of the ISS Water Recovery System (WRS), which includes the Water Processor Assembly (WPA) and Urine Processor Assembly (UPA). His current role is the ISS Water Subsystem Manager, for which he is responsible for the ongoing operation of the water management and WRS on ISS. In addition, he is the co-Lead for NASA's Advanced Exploration Systems (AES) Wastewater Processing and Water Management team, which has the responsibility for developing the technologies to be used for NASA's future manned missions.

Biofilm growth has been an ongoing issue for US and Russian water systems on the International Space Station, and is a critical issue for exploration missions in which water systems must be designed to accommodate dormant periods of up to one year. On ISS, Russian condensate plumbing has previously clogged with biomass, requiring condensate plumbing to now be regularly replaced. In the US Segment, the release of biofilm from the Water Processor waste tank has clogged a solenoid valve downstream of the tank, resulting in the costly replacement of the inlet separator and process pump. Subsequent management of the biofilm in the waste tank involves restrictions on tank cycles to limit the release of biomass and an additional filter to protect downstream components. Engineering personnel are now evaluating concepts to better manage the biomass, including the use of microbial inhibitors and UV LEDs. Though current ISS operations could likely be sustained for the duration of ISS, a more effective method must be developed for managing the growth and release of biomass in future exploration vehicles. Biofilm management for future missions is complicated by the requirement to accommodate extended periods of dormancy during which time the water system will be stagnant. The current approach under consideration is to flush the waste water with product water to reduce the organic content followed by use of microbial inhibitors or UV. However, other concepts may also be developed based on ongoing research.

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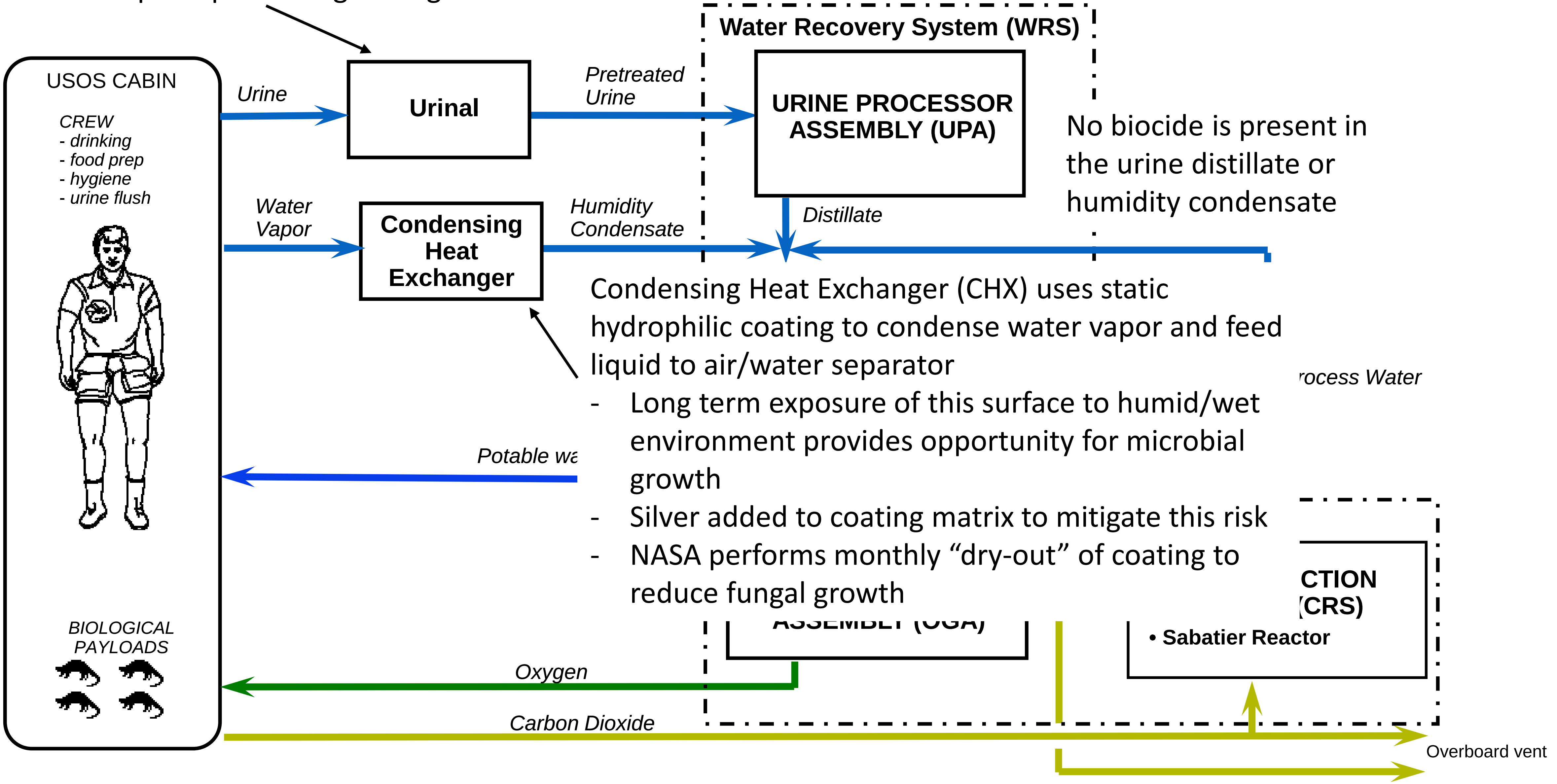
Introduction

- The ISS provides a habitable laboratory environment for 6 crew
- Water resupply from earth is minimized by recycling crew latent (from Condensing Heat Exchanger) and urine
- Biofilm is a specific concern because it can form a solid material that obstructs flow path or tighter clearances (more likely in microgravity)
- The systems primarily susceptible to microbial growth and biofilm are Water Recovery & Management (WRM), the Internal Thermal Control System (ITCS), and the Extravehicular Mobility Unit (EMU)
  - EMU will not be discussed in this presentation
- The WRM and ITCS system design implements various measures to maintain microbial control
  - Concern is with biofilm that obstructs system function, not microbial growth
  - Exception is potable water, where microbial population must be controlled to crew health limits

ery System

Oxidant and inorganic acid are added during urine collection to maintain microbial control and decrease pH for subsequent processing through UPA

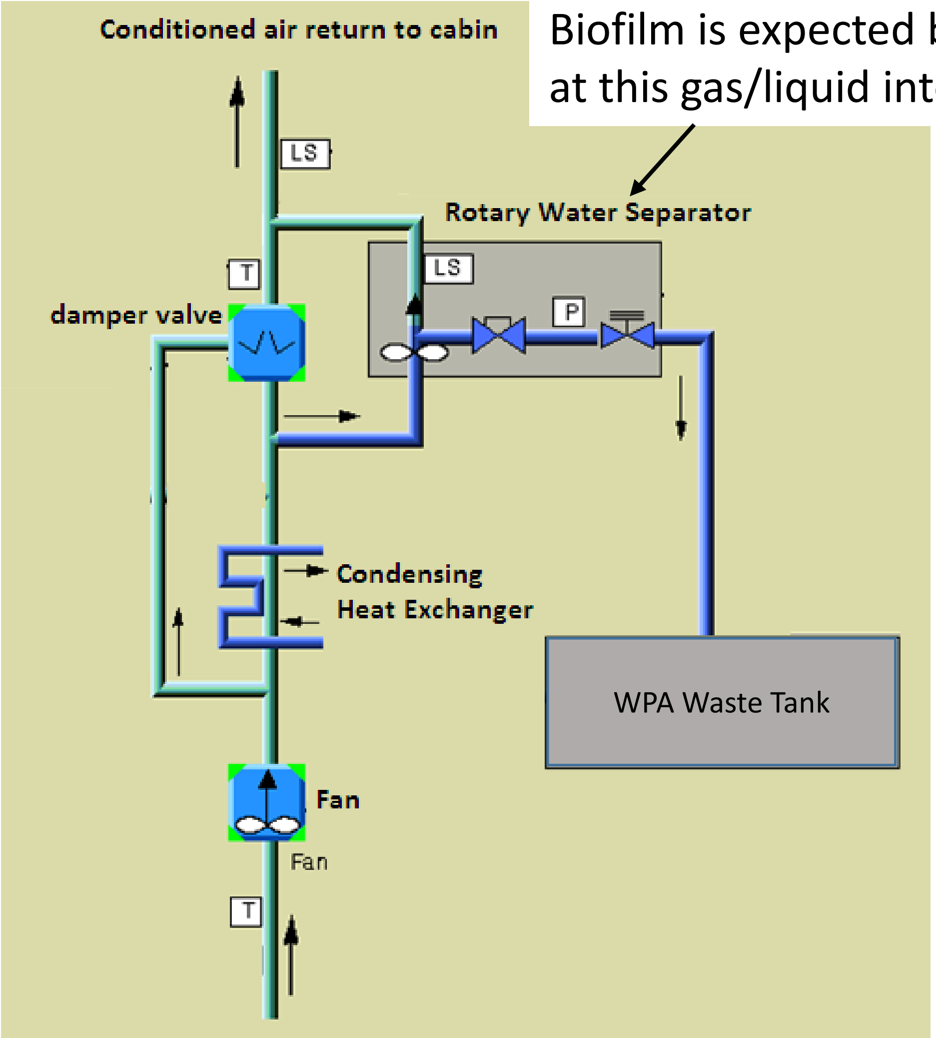


No biocide is present in the urine distillate or humidity condensate

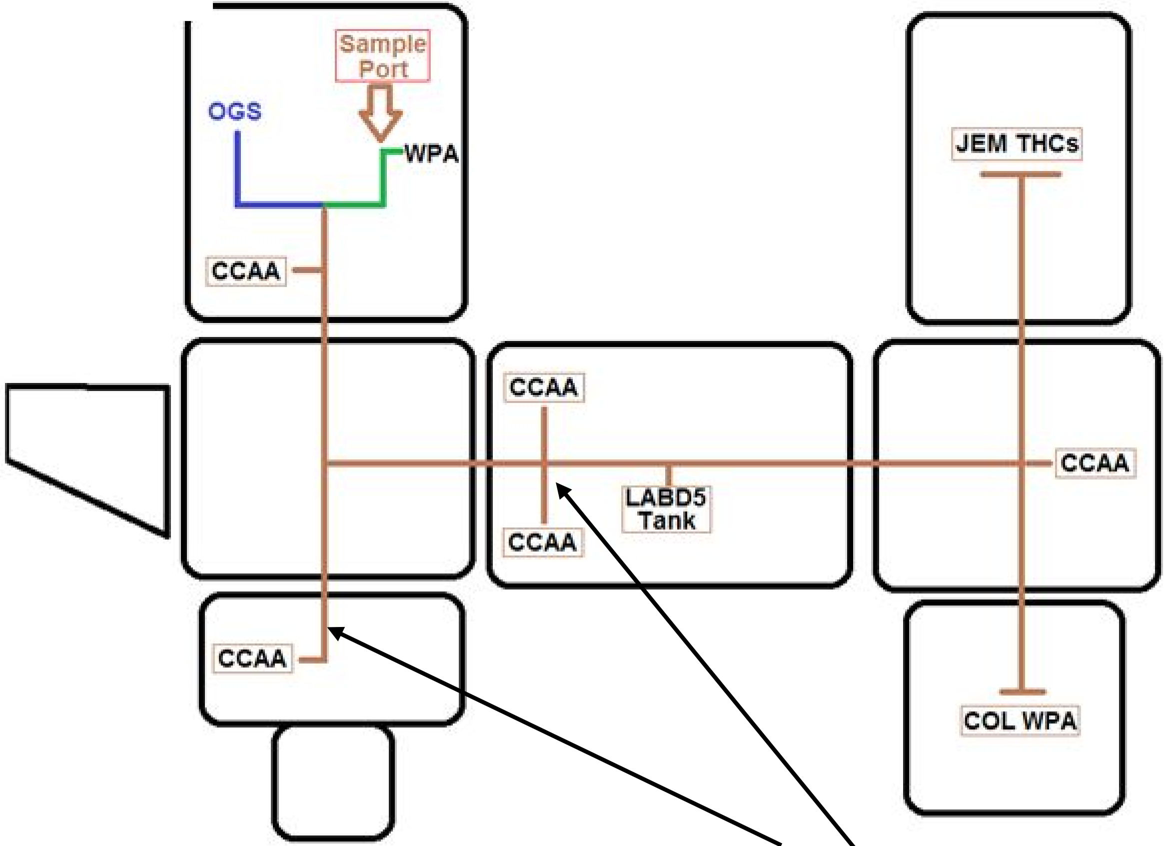
Condensing Heat Exchanger (CHX) uses static hydrophilic coating to condense water vapor and feed liquid to air/water separator

- Long term exposure of this surface to humid/wet environment provides opportunity for microbial growth
- Silver added to coating matrix to mitigate this risk
- NASA performs monthly “dry-out” of coating to reduce fungal growth

Common Cabin Air Assembly (CCAA)

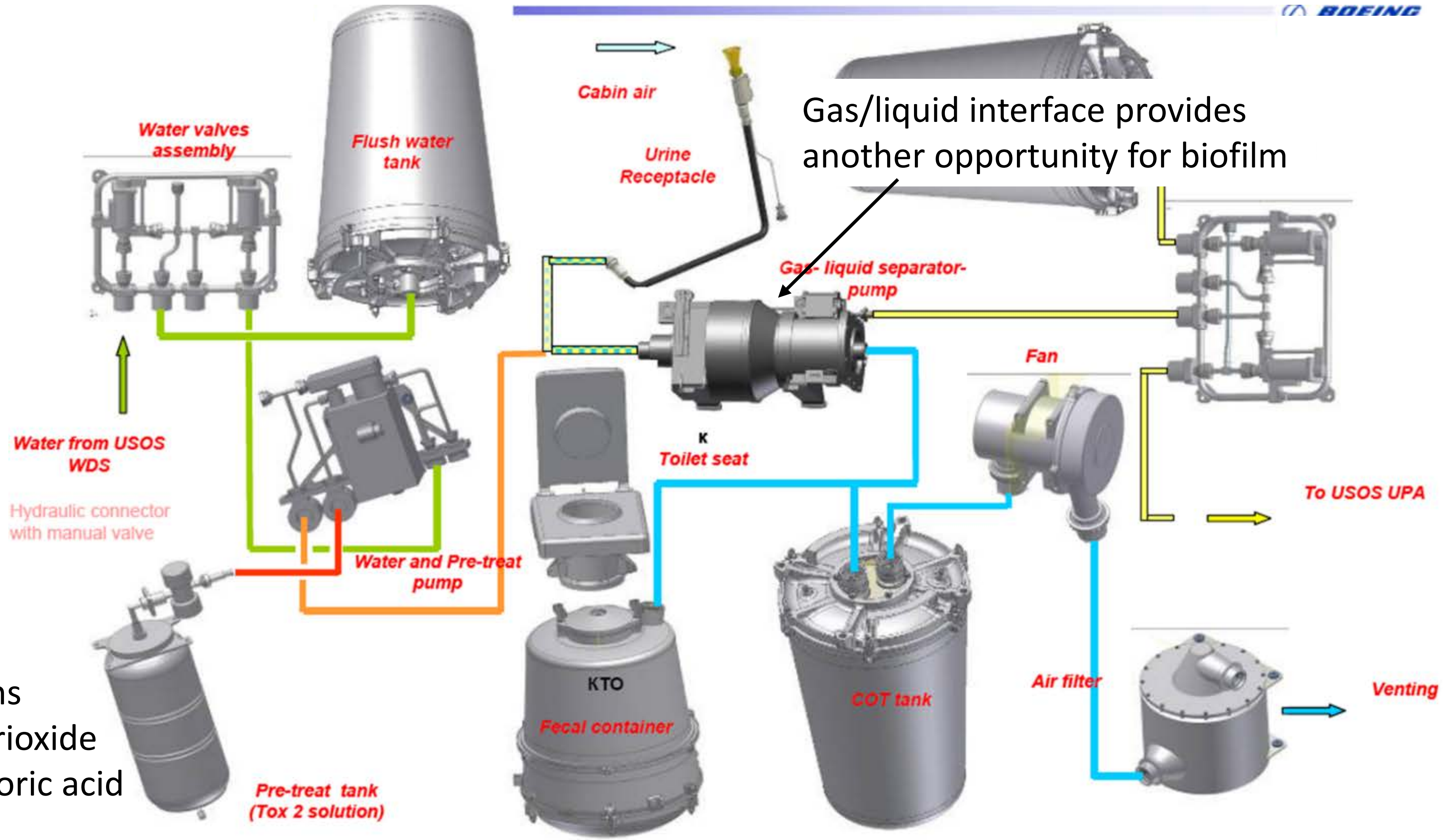


Biofilm is expected beginning at this gas/liquid interface



Numerous dead legs in plumbing provide opportunity for biofilm

Waste and Hygiene Compartment (Urinal)



Gas/liquid interface provides another opportunity for biofilm

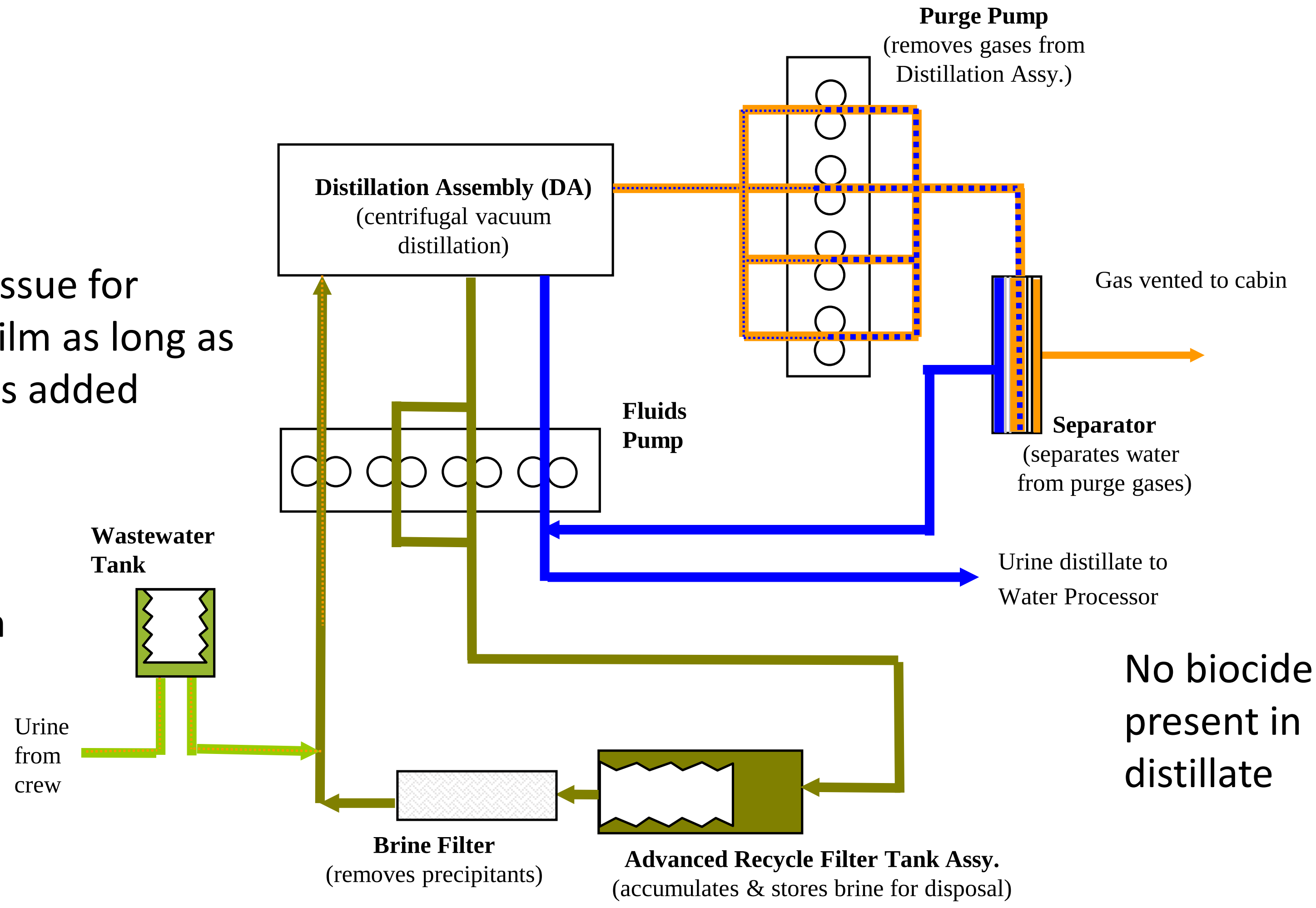
Tank contains chromium trioxide and phosphoric acid

Sulfuric acid is used in the Russian segment

Urine Processor Simplified Schematic

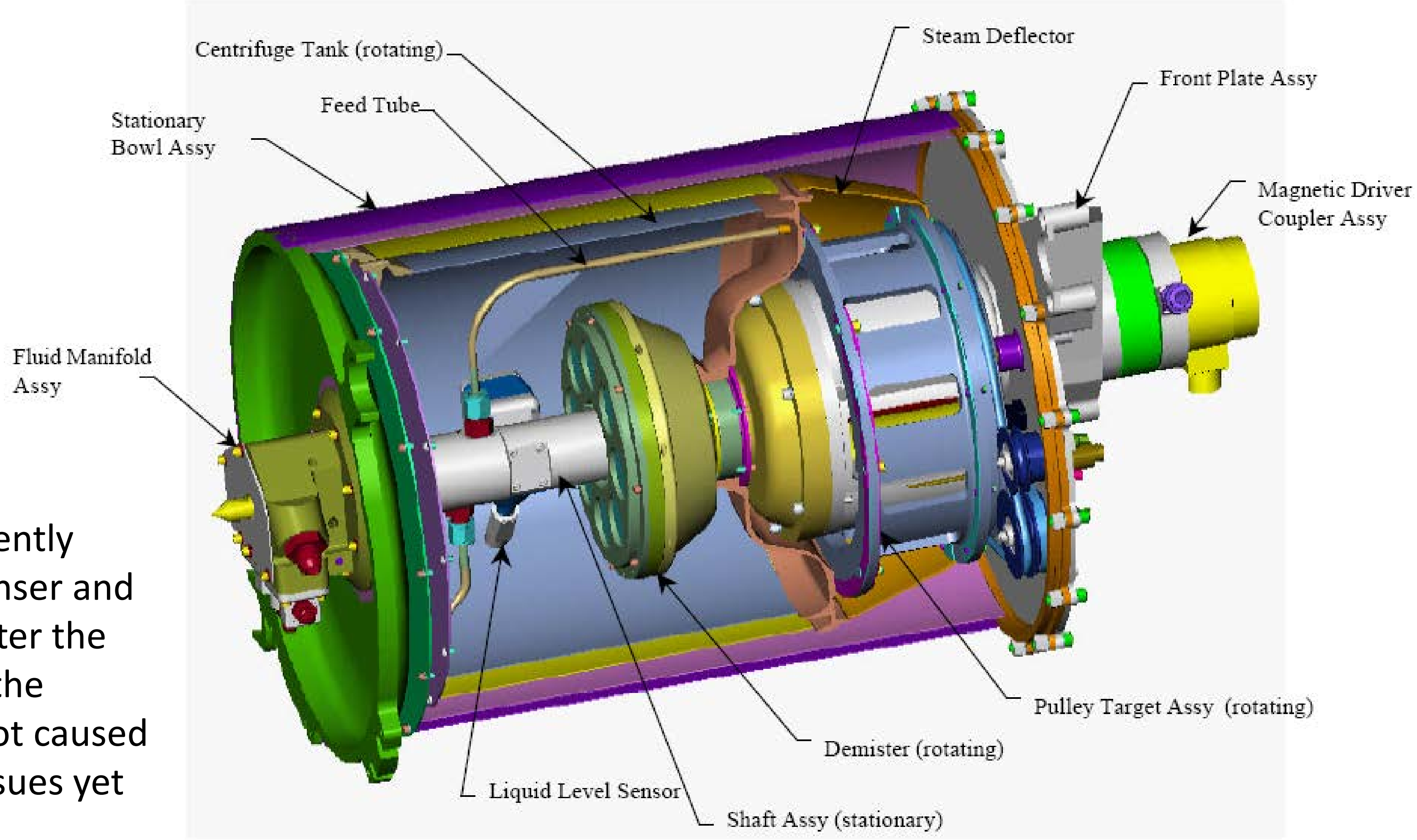
Brine is typically not an issue for microbial growth or biofilm as long as sufficient pretreatment is added

Gas in tank is difficult to remove, and provides starting point for biofilm



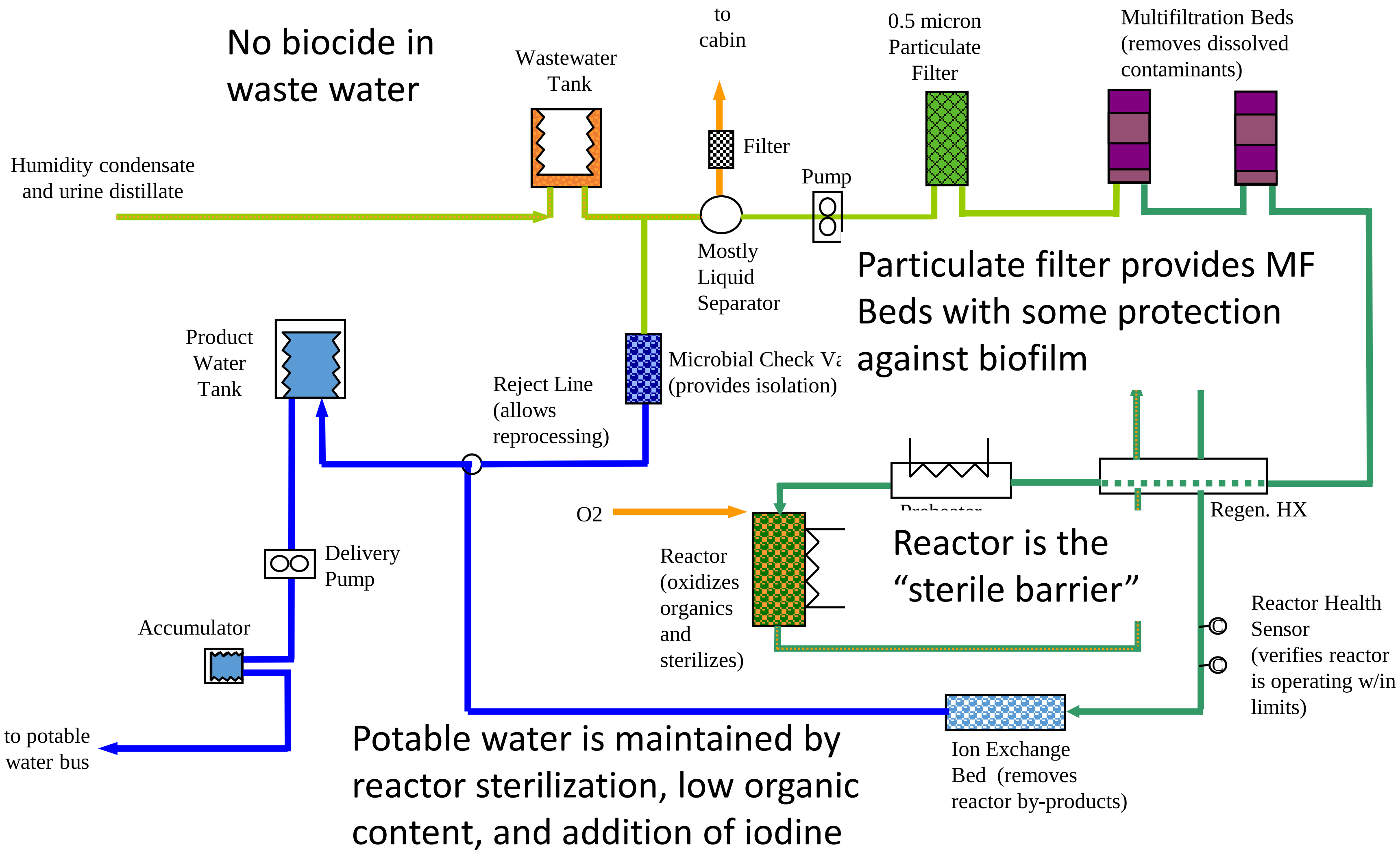
No biocide present in distillate

Cross Section of Distillation Assembly



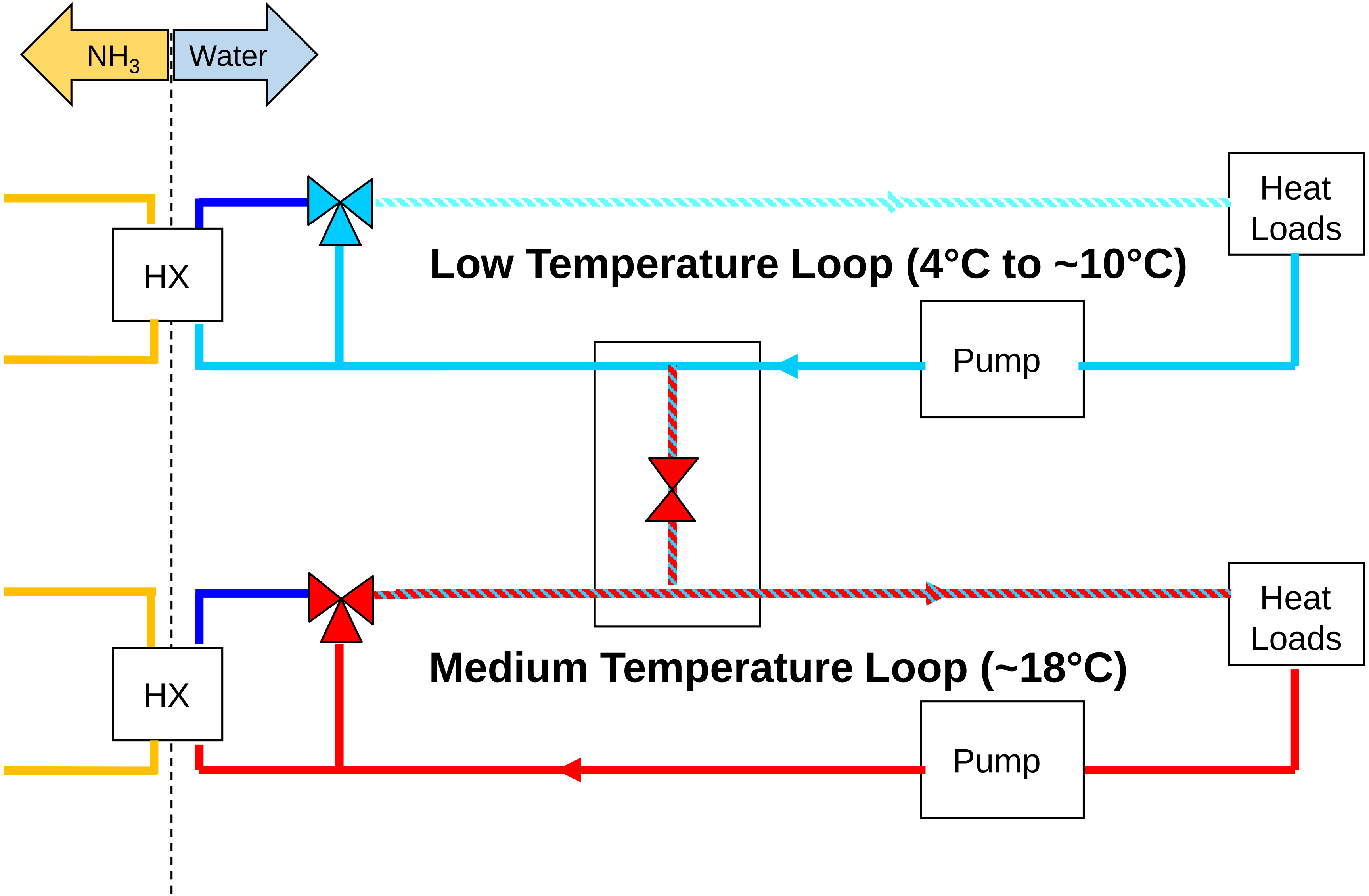
Biomass is consistently seen in the condenser and stationary bowl after the DA is returned to the ground, but has not caused any operational issues yet in the UPA on ISS

Water Processor Simplified Schematic



Lab Internal Thermal Control System (ITCS)

- Water coolant for internal heat loads
  - Rejects heat to external ammonia cooling system
- Lab launched with ~300 CFU/100 ml
- Concern that biofilm could affect the interface Heat exchanger
- Addition of silver
- Switch to ortho phthalaldehyde
- Minimize stagnation

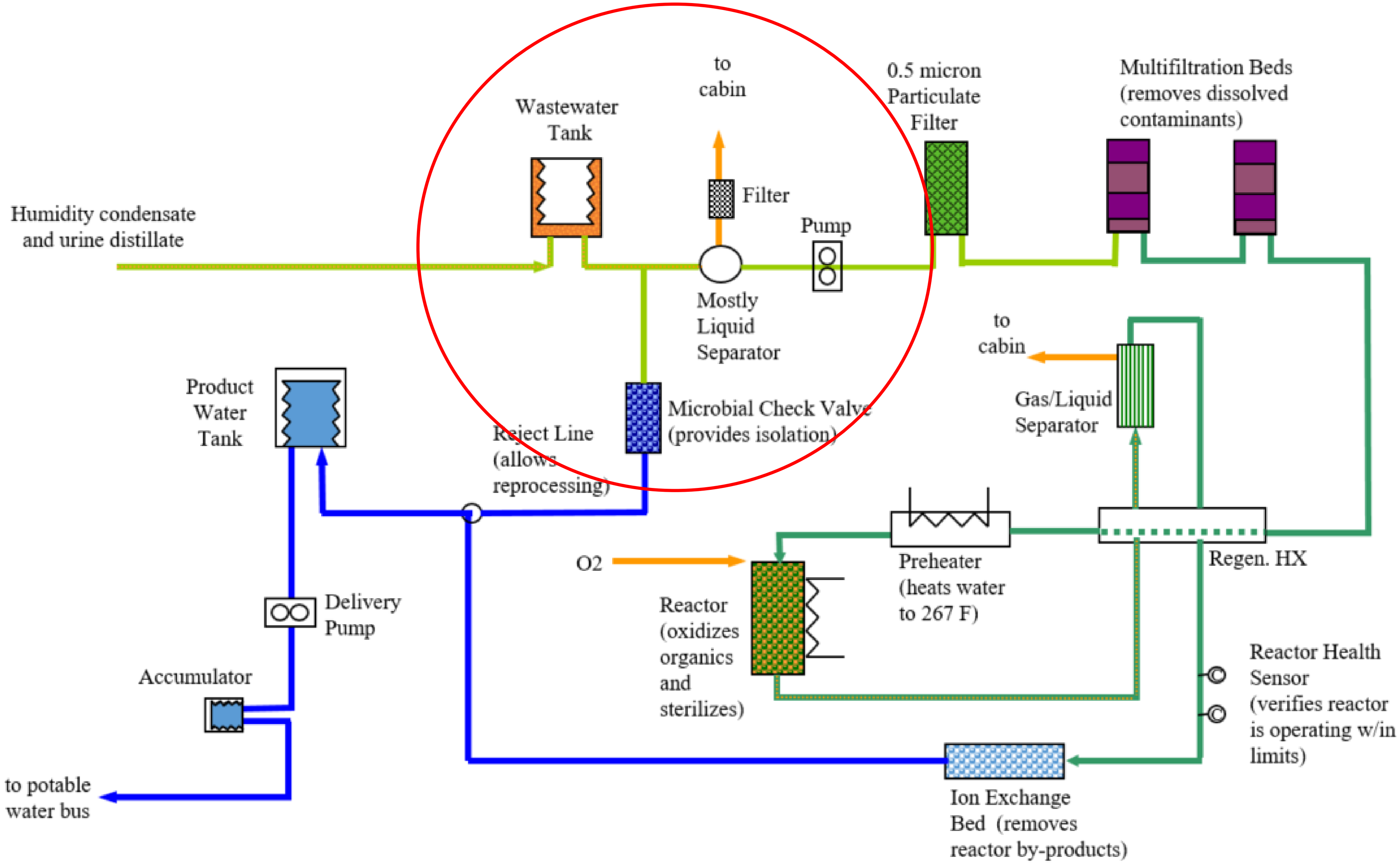


Design Concepts (summary)

- Monthly dry-out to prevent fungal growth on CHX coating
- Oxidant and inorganic acid to maintain microbial control in urine
- No biocide in urine distillate and humidity condensate
- Sterilization, low organic content, and iodine to maintain microbial control in potable water

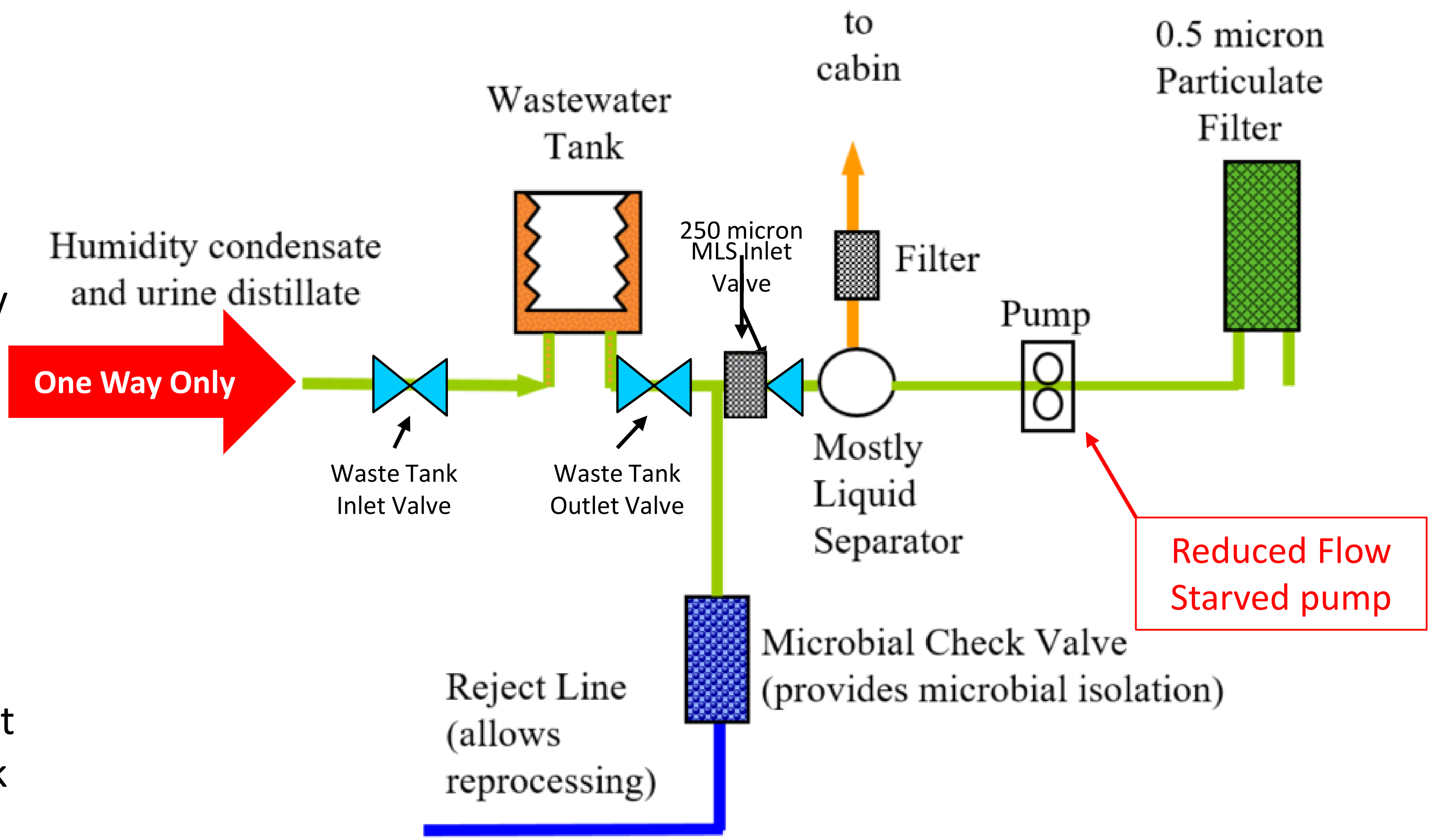
- Biofilms are a concern to the operation of even the best designed Systems
- Understanding and avoiding the risks associated with biofilms reduces maintenance and increases systems efficiency
- Examples:
  - Biofilm in Water Processor waste water components
  - Water Samples
  - Condensate Plumbing
  - Urine pretreatment control

Water Processor Inlet Issues



Water Processor Inlet Issues

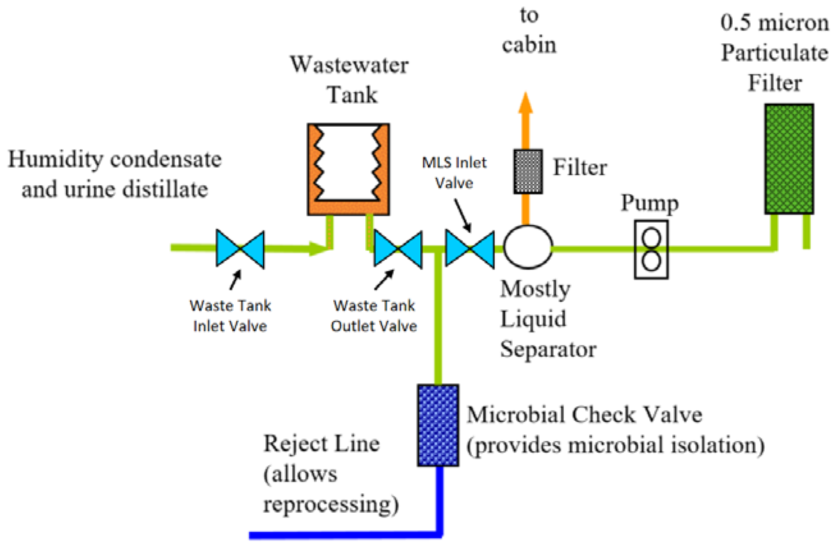
- In late 2009, NASA personnel observed a decrease in the flow of waste water from the waste tank to the Mostly Liquid Separator (MLS)
- Analysis of the problem indicated an obstruction in the plumbing that ultimately required replacement of the Pump/Separator ORU
- Ground investigation determined the inlet solenoid valve to the MLS was obstructed with a biofilm
- Further analysis of the issue concluded that biofilm was accumulating in the waste tank and periodically released downstream
    - Likely exacerbated by nominal tank operations at the time



MLS Inlet Valve

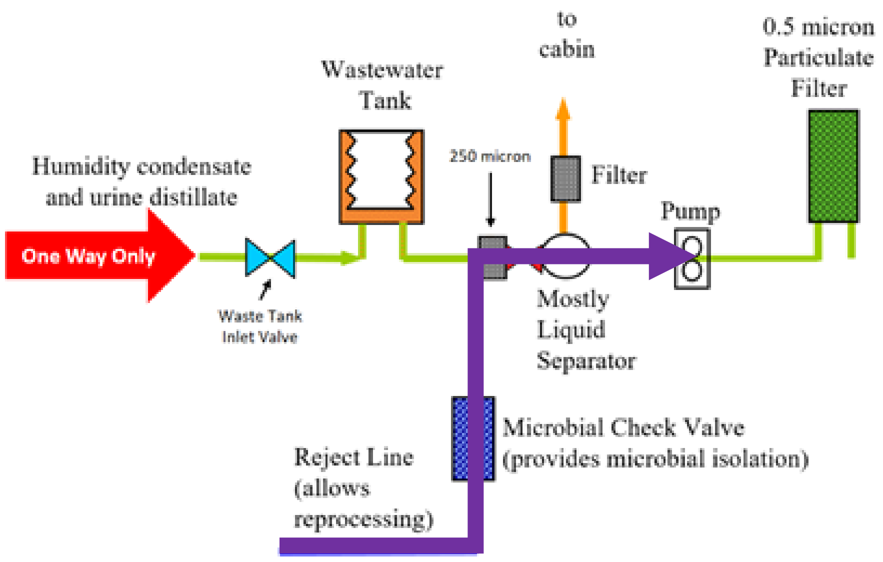
Fungal isolates were *Acremonium* and *Penicillium* species

Bacterial isolates are typically *Ralstonia, Wautersia* and *Burkholderia* species



Operational and Design Modifications

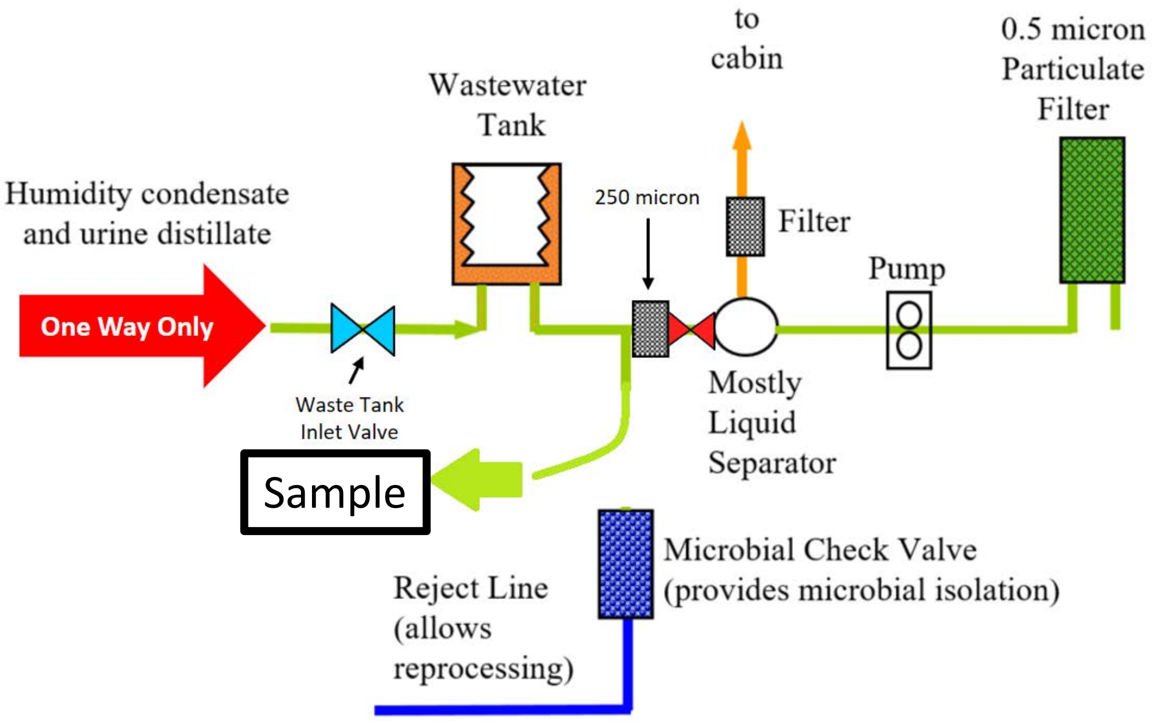
- Multiple modifications were implemented to address the failure of the MLS inlet solenoid valve
  - Tank Cycling
    - To reduce the release of biomass from the waste tank, controls have been implemented that require the tank to be “fully” cycled each month. This prevents the quantity of biofilm that can accumulate on the bellows, while also reducing the quantity that can be released at any given time.
  - 250 micron filter
    - installed downstream of the waste tank to protect the clearances in the solenoid valve. This filter typically requires annual replacement
  - Regular flushing
    - At the completion of each process cycle, iodinated water from the product line is recirculated to the MLS. This insures the solenoid valve and MLS is flushed with iodinated water prior to any extended standby period.

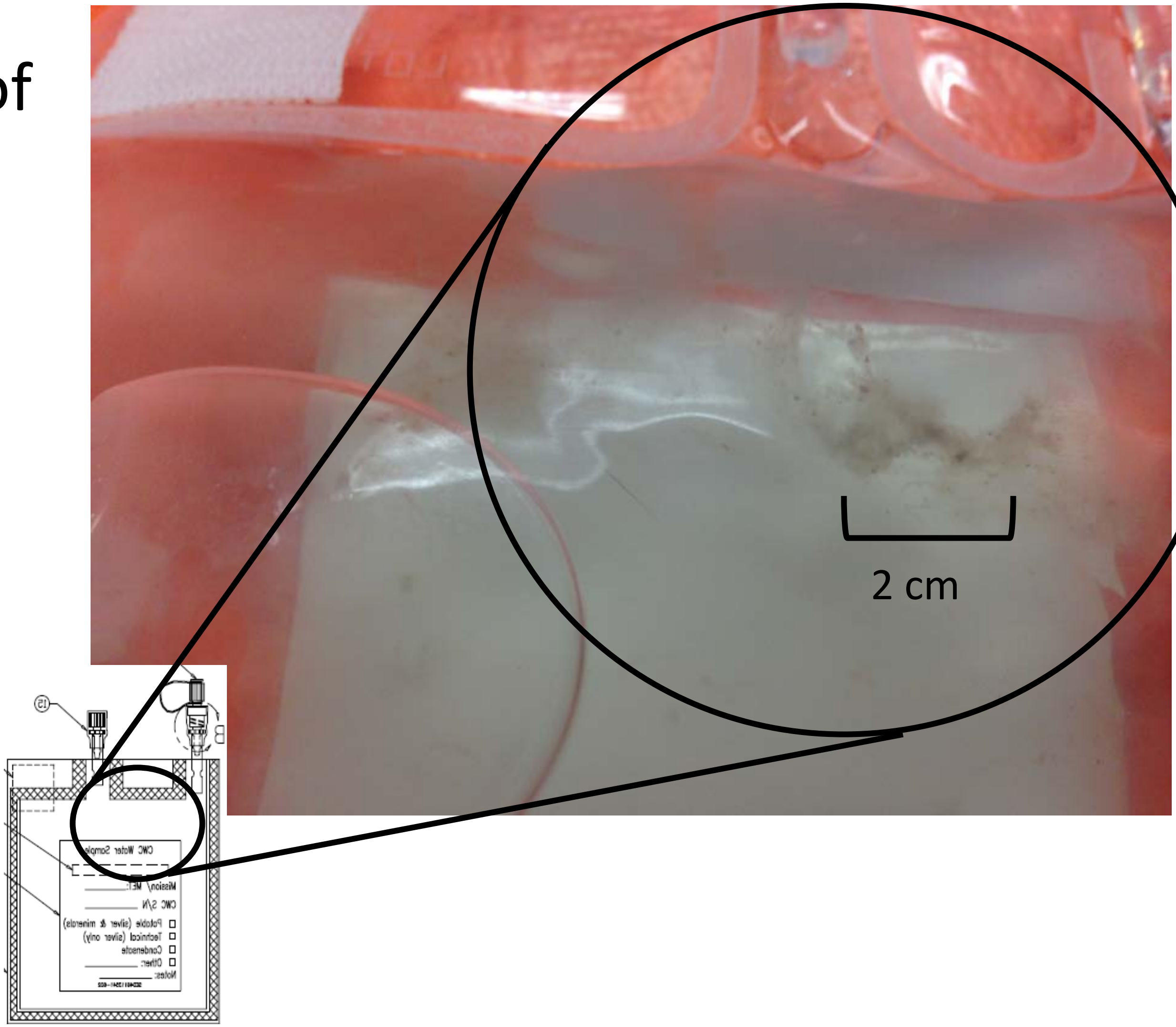


Software update to flush with iodine

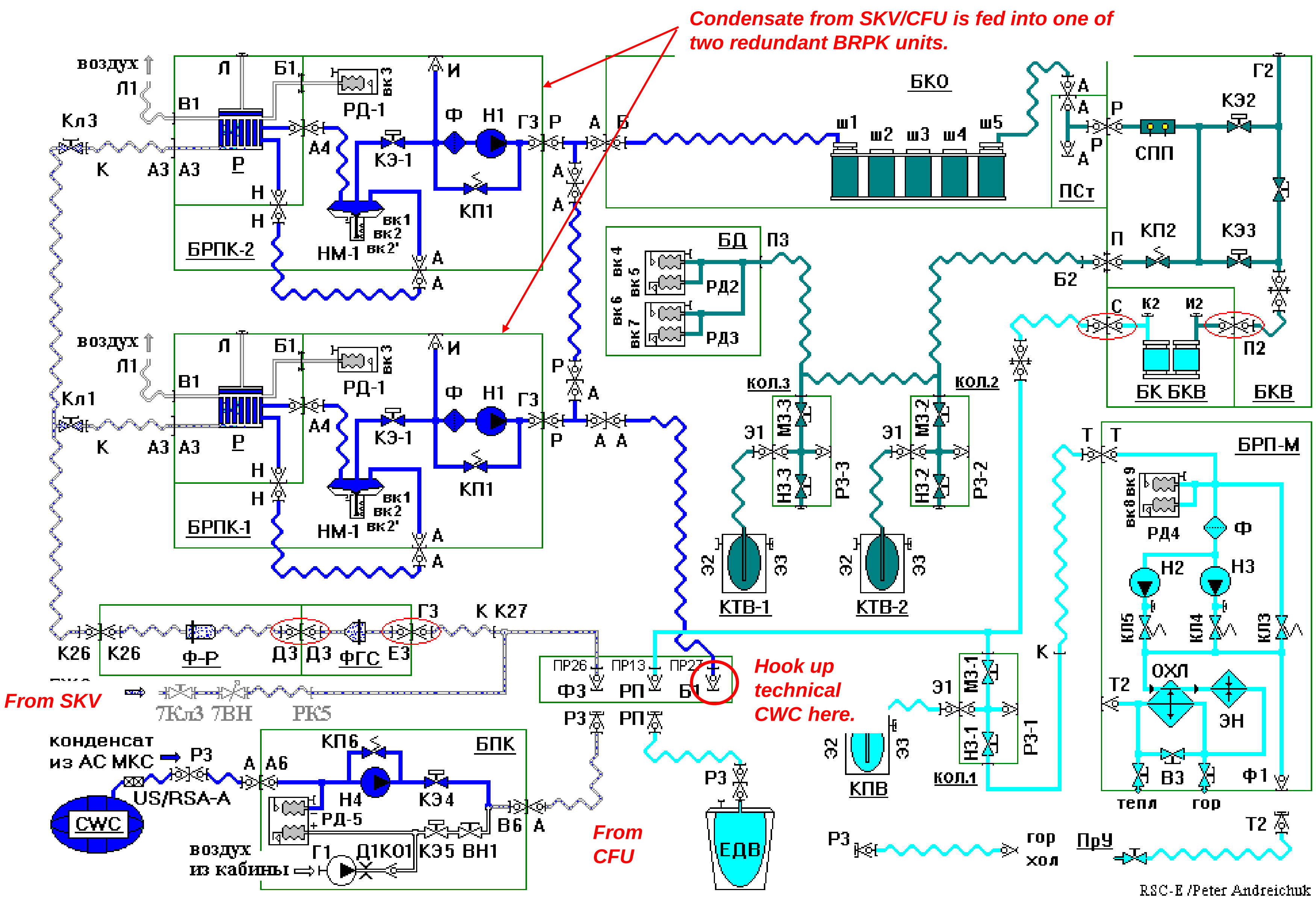
Waste Water Tank Sample

- Quarterly samples monitor the health of the waste water
- Quantity of biomass in samples has decreased since implementing controls





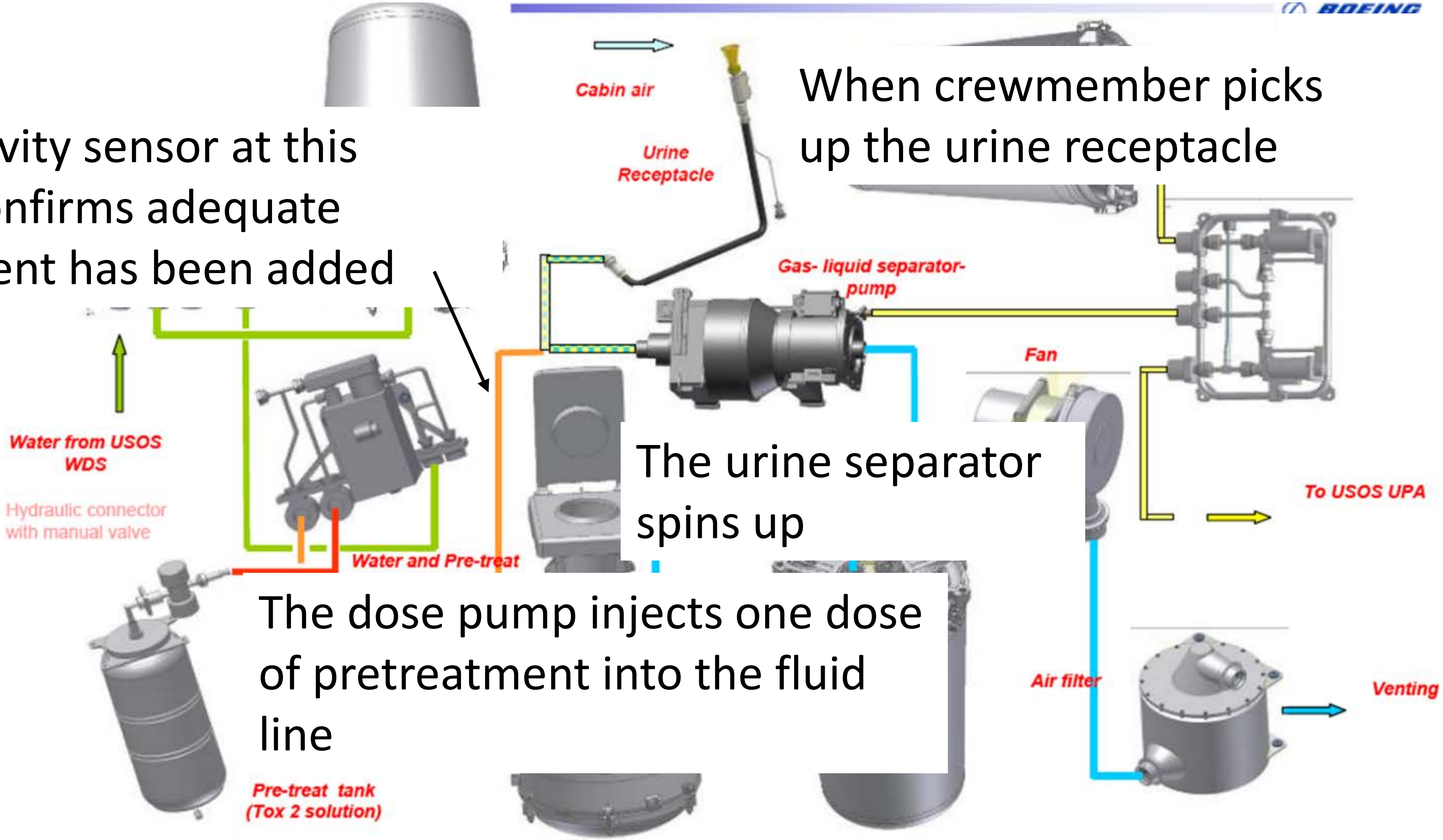
Biofilm in Russian Condensate Plumbing



Russian Segment

- Mitigation activities:
  - Where viable, replaced hoses with those that can be visually inspected
  - Now implement scheduled replacement of hoses
  - All waste water transferred to the Russian processor is filtered to 20 micron

Waste and Hygiene Compartment (Urinal)



A conductivity sensor at this location confirms adequate pretreatment has been added

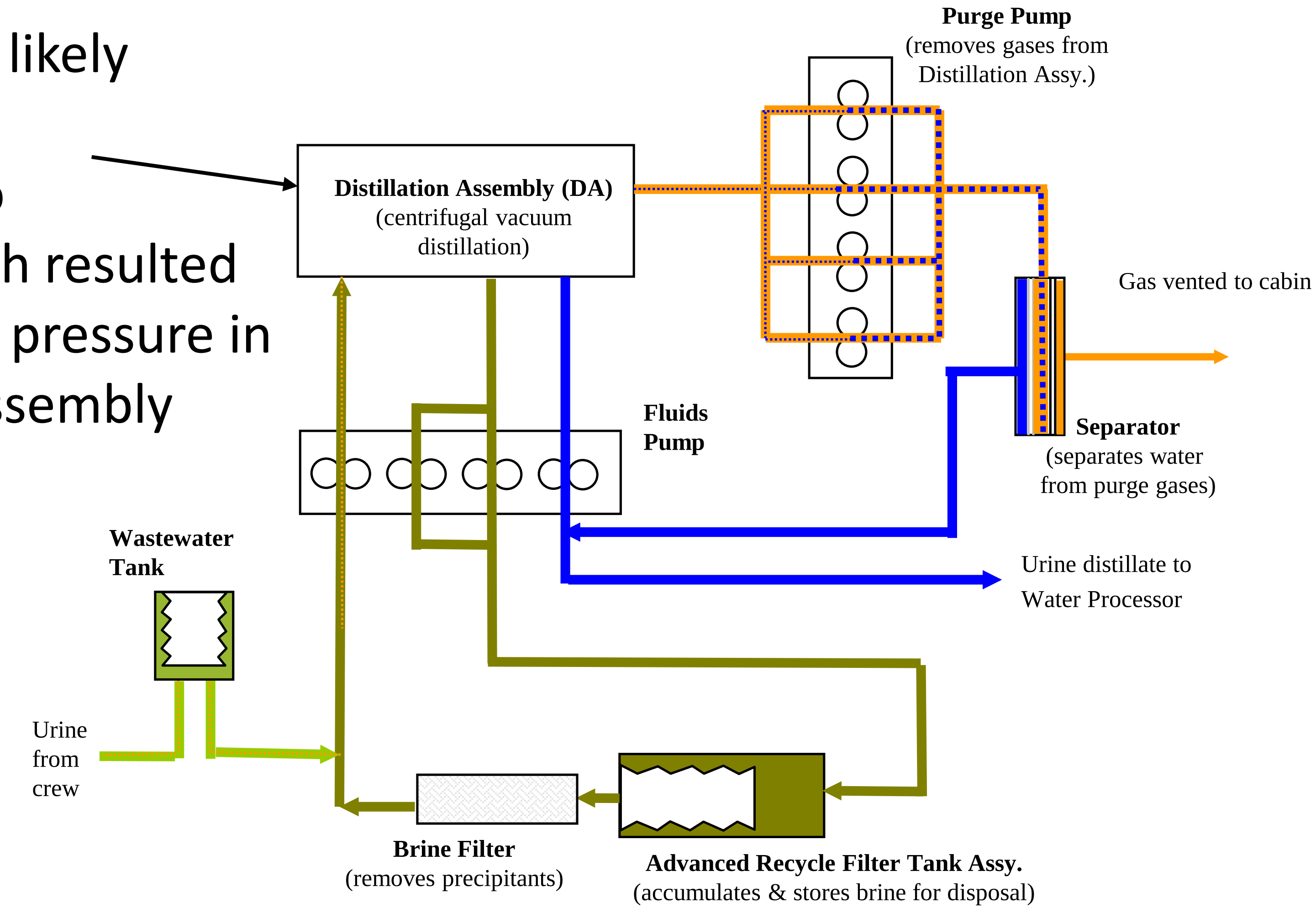
When crewmember picks up the urine receptacle

The urine separator spins up

The dose pump injects one dose of pretreatment into the fluid line

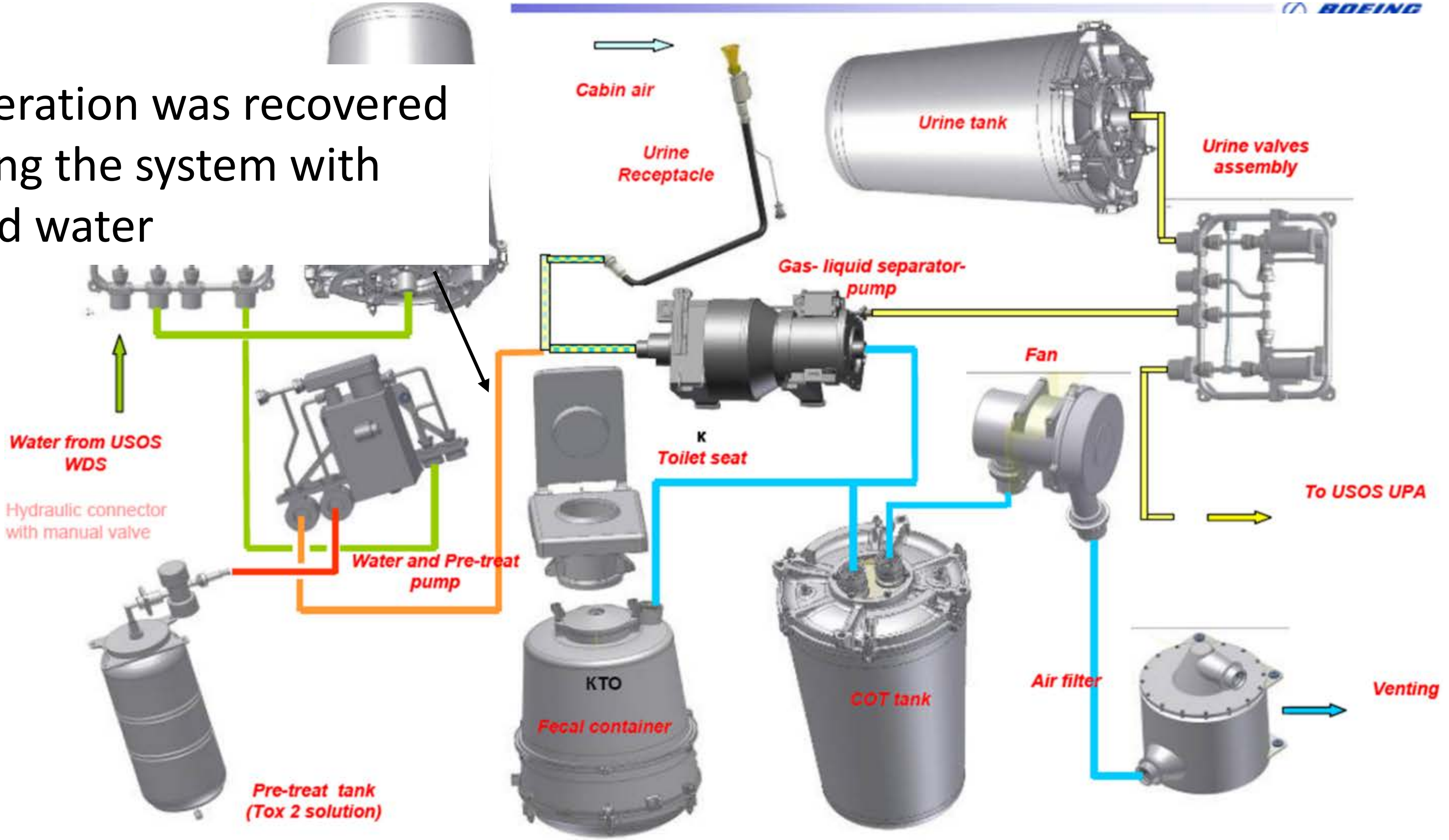
Urine Processor Simplified Schematic

Microbial growth likely resulted in urea decomposition to ammonium, which resulted in higher vacuum pressure in the Distillation Assembly



Waste and Hygiene Compartment (Urinal)

Urinal operation was recovered by shocking the system with pretreated water

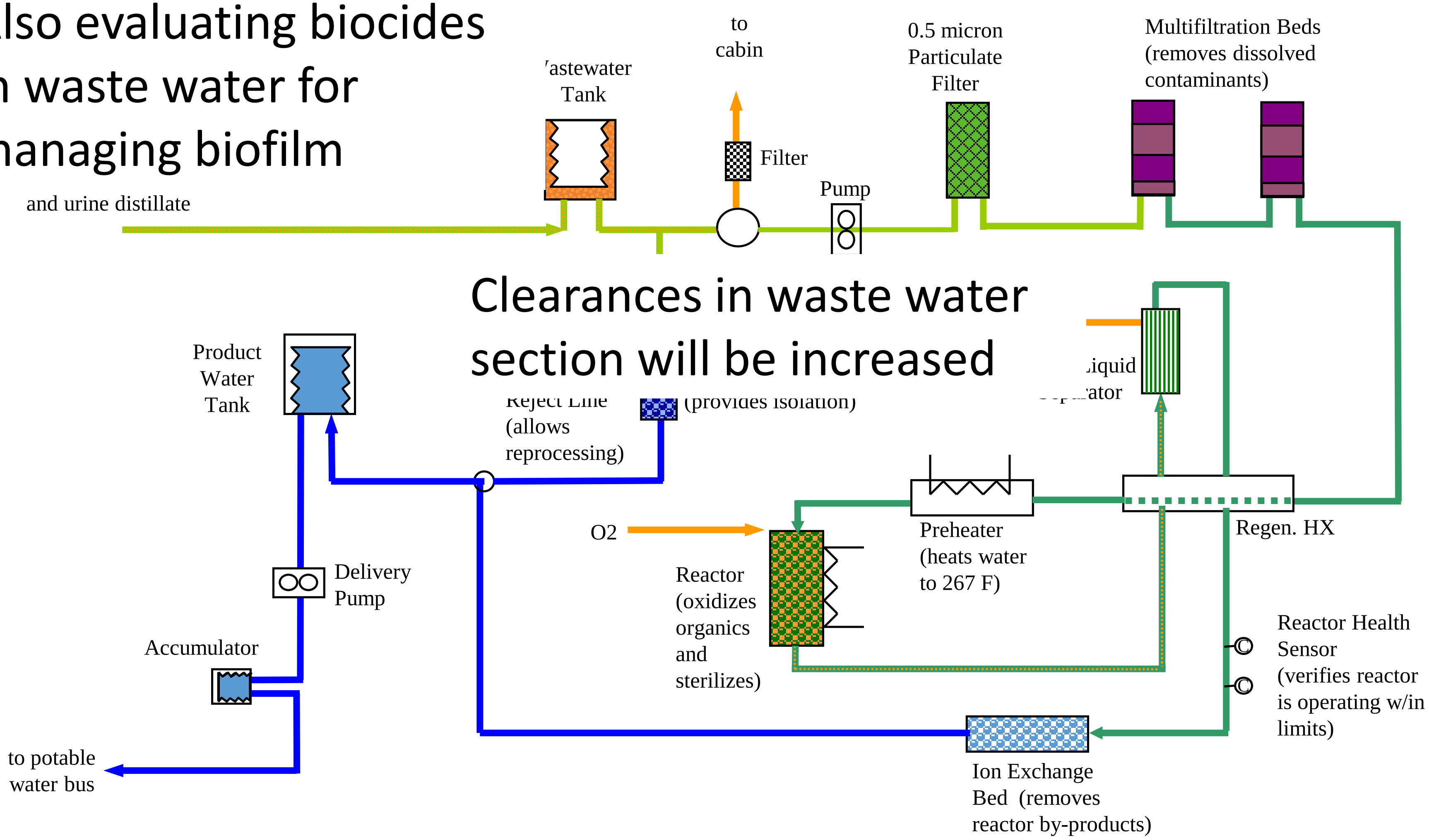


Concepts to be Implemented in Future Systems

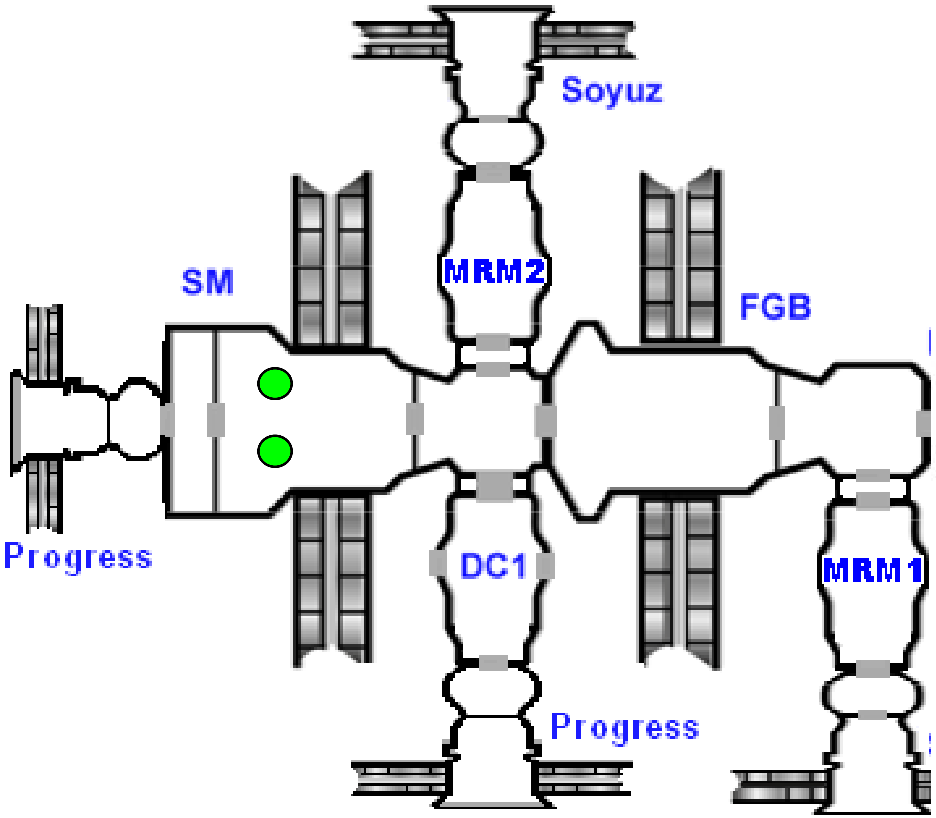
Water Processor Simplified Schematic

Also evaluating biocides in waste water for managing biofilm

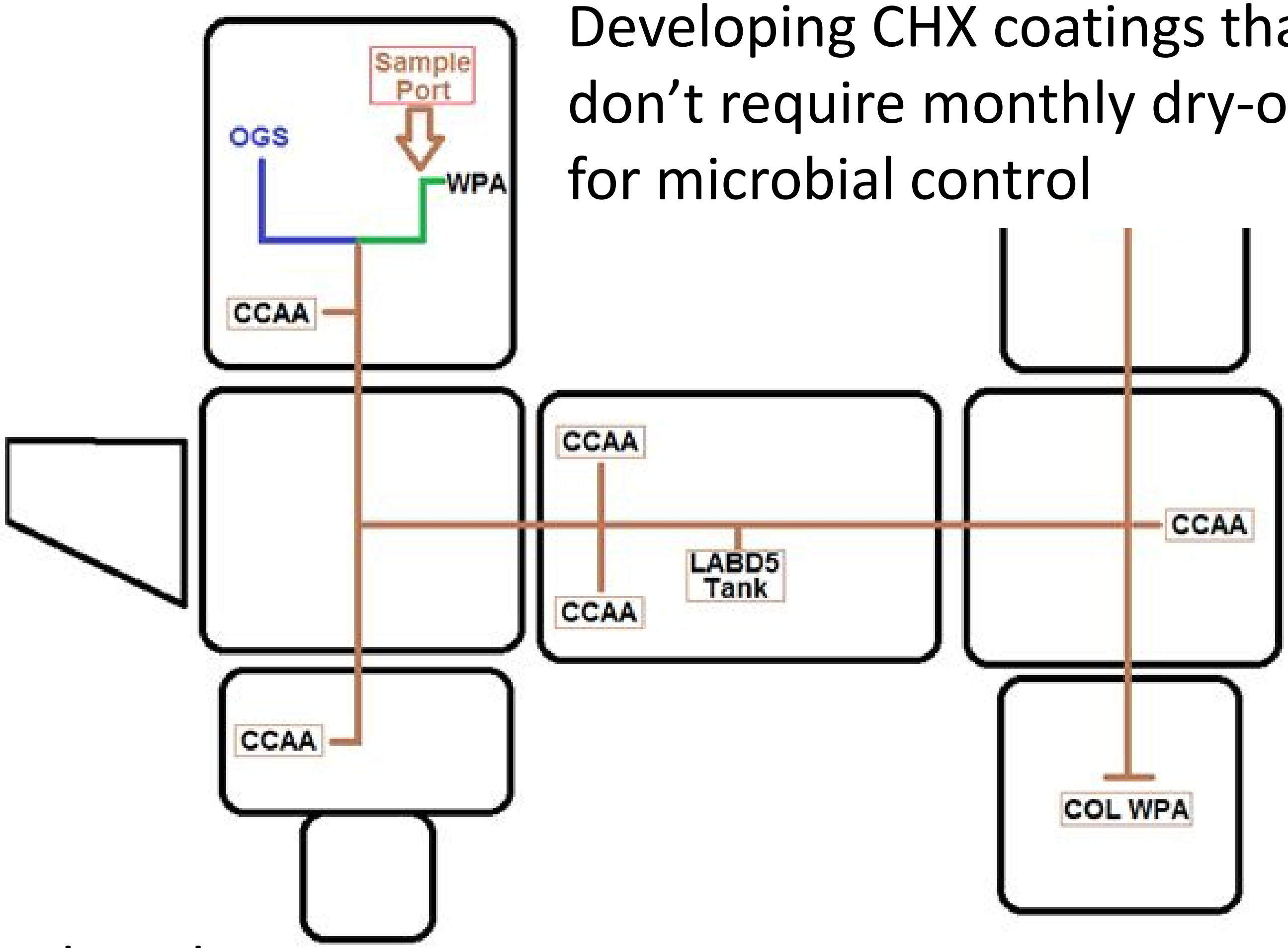
Clearances in waste water section will be increased



Humidity and Water Management on ISS



Reduce plumbing length



Developing CHX coatings that don't require monthly dry-out for microbial control

Eliminate deadlegs

Dormancy

- For missions beyond ISS (e.g., Mars), periods of dormancy will be required in which the water systems are not used for approximately one year
- Stagnant water systems are highly susceptible to biofilm growth, and it is unlikely the current system would be operational after one year of dormancy
- Options for dormancy include “drain and dry”, maintain in recirculation mode, or flush with biocidal water prior to dormancy (potentially coupled with periodic UV treatment)

Summary

- Biofilms have been effectively managed on ISS when proper controls are in place (urine, condensing heat exchanger coating, potable water)
- The Water Processor waste tank is a good example of the potential ramifications of biofilm if left unchecked
- Rigorous design solutions are now being developed to insure the reliability of future water systems