Hot Water, Cold Reality: Feasibility Assessment of Iodine Removal in Heated Spacecraft Potable Water Systems

Mary Lou Nadeau[1]
Aerodyne Industries, Houston, TX, 77058

Rogelio Garcia Fernandez[2] and Jaione Romero Mangado[3]
Amentum Technology Inc., Houston, TX, 77058

Michael Callahan[4]
NASA Johnson Space Center, Houston, TX, 77058

The current eXploration Potable Water Dispenser (xPWD) design removes iodine upstream of the heated leg due to concerns with the Activated Carbon and Ion Exchange (ACTEX) functionality in hot water, leaving the downstream volume without residual biocide. The NESC determined that this non-iodinated volume is a concern for microbial growth during exploration missions and proposed 33 biocide architecture options for future missions that could address this concern. The top-ranked architecture out of the report was Option 1: moving the iodine removal media as close to the dispensing needle as possible to minimize the wetted components without biocide in the xPWD. Three main challenges were identified with this proposed configuration. First, the hot water at 175 ± 25 °F is a concern for the potential physical degradation of the ion exchange resin and lowered adsorption capacity in activated carbon. Second, moving the ACTEX or alternative sorption media closer to the dispense needle increases the unheated volume downstream of the heater, challenging the ability for dispensed water to meet temperature requirements. Finally, bubbles evolved from dissolved gas coming out of solution in the heater could clog or reduce the efficiency of the sorption media. To address the first challenge, more thermally robust ion exchange resins were identified and adsorption capacity tests were planned and will be discussed in a companion ICES paper (ICES-2026-5). To address the dispense temperature concerns, allowable bed size and architectural configuration changes are proposed. The value of adding phase separators to remove bubbles and potential implementation schemes are discussed. These findings support the development of potable water systems resilient to microbial risks during long-duration space missions.

Acronyms and Nomenclature

ACTEX	=	Activated Carbon and Ion Exchange Bed
ECLSS	=	Environmental Control and Life Support System
HOP	=	Hydrogen-Bonded Organic Polymers
iHOP	=	Ionic Hydrogen-Bonded Organic Polymers
ISS	=	International Space Station
IX	=	Ion Exchange
MCV	=	Microbial Control Valve
NESC	=	NASA Engineering and Safety Center
PWD	=	Potable Water Dispenser
SOA	=	State of the Art
UV	=	Ultraviolet

[1] Modeling and Simulation Chemical Engineer, JETS II Contract, 2224 Bay Area Blvd, JE-5EA.
[2] Life Support Systems Test Engineer, JETS II Contract, 2224 Bay Area Blvd, JE-3EA.
[3] Water Technology Dev. Project Manager, JETS II Contract, 2101 E NASA Pkwy, EC3/JETS.
[4] Water Technology Lead, Crew and Thermal Systems Division, 2101 E NASA Pkwy, EC3.

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WPA = Water Processor Assembly
xEMU = Exploration Extravehicular Mobility Unit
xEVA = Exploration Extravehicular Activity
xPWD = Exploration Potable Water Dispenser

I. Introduction

FUTURE long-duration missions to the moon and Mars will require potable water systems that remain safe during extended uncrewed periods. Unlike the International Space Station (ISS), where continuous crew presence and high water throughput reduce microbial risks, future habitats may remain dormant for months or years. Dormancy introduces a significant challenge: preventing microbial growth in ultrapure water systems, which can persist even under nutrient-poor conditions.

Currently, iodine is used as a biocide in the ISS water systems at 1–4 mg/L, imparted by an iodinated resin in the Water Processor Assembly (WPA) and removed by the Activated Carbon and Ion Exchange (ACTEX) bed in the Potable Water Dispenser (PWD) before crew consumption. NASA standards limit iodine to <0.2 mg/L due to health concerns, requiring its removal prior to use [1]. In the Exploration Potable Water Dispenser (xPWD), iodine removal occurs upstream of the heater due to concerns with the ACTEX performance in hot water, leaving the downstream volume without residual biocide. Despite the temperature being likely high enough for thermal disinfection, the NASA Engineering and Safety Center (NESC) identified that this non-iodinated volume is a concern for microbial growth during exploration missions [2] due to the expected periods of dormancy in which the lines would likely remain wetted and have the potential for microbial proliferation.

To address this, the NESC evaluated 33 biocide architecture options. The top-ranked concept, Option 1, relocates iodine removal media downstream of the heater, near the dispense point, minimizing wetted components without biocide. However, this approach raises key questions: Can the ACTEX or alternative media function effectively in hot water? Will increased downstream volume allow for dispense temperature requirements to be met? How will bubbles from dissolved gases affect performance? This paper summarizes a feasibility assessment of these challenges and explores potential solutions, including thermally robust media and configurational modifications.

A. Current PWD and xPWD

A simplified schematic of the current ISS Potable Water Dispenser (PWD) is provided in Figure 1. The system has been in continuous operation on orbit since 2009 [3]. Iodine removal is accomplished by the Activated Carbon and Ion Exchange (ACTEX) filter assembly, which consists of an in-line packed bed containing activated carbon and ion exchange resin. The activated carbon adsorbs the molecular iodine (I_2) and the ion exchange resin removes the ionic species of iodine. The ACTEX is designed to reduce total iodine (in the form of molecular iodine (I_2) and iodide (I^-)) from 6.0 mg/L to 0.2 mg/L [4].

Each unit is replaced after processing approximately 4320 lbm of water [5]. Assuming a nominal PWD consumption rate of 2.5 L per crewmember per day and a six-person crew, this corresponds to roughly four months of operational life. For future missions with a four-person crew, the same throughput would extend the lifetime to approximately six months. Downstream of the ACTEX, a microbial filter provides redundant microbial control and protects the system from potential back-contamination through the dispensing needle. This component is a 0.2-micron filter constructed with Nylon media and a polypropylene housing. While long-term compatibility testing between iodine solutions and these materials has not been conducted at Johnson Space Center, the microbial filter has been observed to adsorb iodine [6]. To minimize any risk of mechanical degradation associated with material interactions, the microbial filter is positioned downstream of the ACTEX.

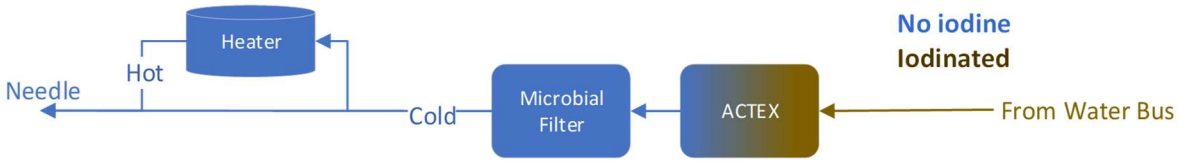

Figure 1. ISS PWD Simplified Schematic

Operational experience with the PWD directly informed the development of the eXploration Potable Water Dispenser (xPWD), whose schematic is shown in Figure 2. Design updates include the elimination of dead legs within the fluid path and the replacement of the 0.2-micron microbial filter with a flow-through ultraviolet (UV) reactor to

provide redundant microbial control. Since its deployment in 2023, the xPWD has consistently operated within microbial specifications.

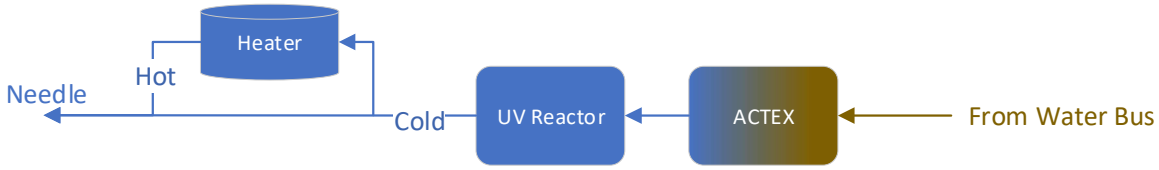

Figure 2. xPWD Simplified Schematic

Option 1 of the NESC assessment recommends relocating the iodine removal bed from its current position upstream of the heater to a location downstream of the heater and closer to the point of use, as shown in Figure 3 and Figure 4. The report further indicates that the existing ACTEX media formulation is not compatible with elevated water temperatures, necessitating the development of an alternative iodine removal medium. In these revised configurations, iodine would remain present throughout the wetted components of the xPWD, which may eliminate the need for a microbial filter or UV reactor for routine microbial control. Nevertheless, the redundant microbial control may be desired to mitigate the risk of back contamination from the point of use [6].

For configurations incorporating the PWD 0.2-micron microbial filter, the filter should be positioned downstream of the iodine removal media (Figure 3), as its materials are likely incompatible with iodine exposure. The UV reactor may be located either downstream (Figure 3) or upstream (Figure 4) of the iodine removal bed; however, if placed upstream, the impact of UV irradiation on iodine's biocidal efficacy must be evaluated.

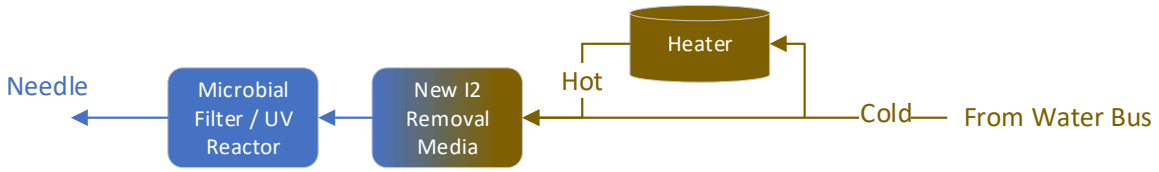

Figure 3. Interpretation of NESC Recommendation with I_2 Removal Media and Microbial Control Downstream of the Heater

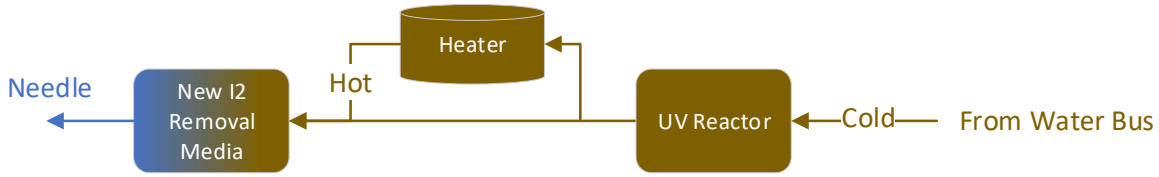

Figure 4. Interpretation of NESC Recommendation with I_2 Removal Media Downstream of the Heater and UV Reactor Upstream of the Heater

To evaluate the feasibility of these configurations, it is first necessary to review the water dispensing requirements summarized in Table 1. Section II B examines the extent to which NESC Option 1 satisfies these requirements without introducing any additional hardware or operational constraints, and Section IV presents potential architectural solutions to address the identified gaps.

Table 1. Potable Water Dispensing Requirements and Standards

Parameter	Requirement / Standard	Reference
Dispense volumes	25 to 250 mL	[6] [7]
Hot dispense temperature	155°F to 175°F	[1]
	150°F to 200°F (actual PWD range)	[6] [7]
Nominal dispense temperature	64°F to 81°F	[1]
Hot water volume	600 mL per meal per crewmember available as hot water	[1]
Remove Iodine	Iodine <0.2 mg/L before crew consumption	[4]
Microbial Control	≤50 CFU/mL bacteria, no detectable coliforms	[3], [5]

B. Study Strategy

The project strategy began with assessing the feasibility of using the current ACTEX bed downstream of the heater without modification. The ACTEX materials' ability to withstand elevated temperature was considered, including whether filter lifetime or iodine removal performance could be degraded when compared to ambient temperature operation. Additionally, the ability of the system to meet dispense temperature requirements if relocating the ACTEX increased the fluid volume downstream of the heater was investigated, as well as whether gas bubbles could interfere with ACTEX operation or reduce iodine removal efficiency. At the same time, the team also began identifying alternative media capable of meeting the performance and compatibility requirements and determining whether system-level configuration changes could support the use of either (a) the existing ACTEX or (b) a more efficient or thermally robust media in the revised configuration.

II. Implications of Moving the ACTEX

To evaluate the first set of considerations in the project strategy, three primary implications of relocating the ACTEX downstream of the heater were identified: (1) the effect of elevated temperature on the performance and lifetime of the removal media, (2) the system's ability to meet dispense temperature requirements with the revised configuration, and (3) the potential for dissolved gases to come out of solution after heating and subsequently affect the ACTEX, microbial filter, or UV reactor. The following section discusses these topics and present the corresponding analysis results.

A. Temperature Effect on Removal Media

The state-of-the-art (SOA) ACTEX consists of an activated carbon bed followed by an ion exchange bed. The activated carbon is not expected to undergo material degradation at the temperatures produced by the (x)PWD heater; however, its adsorption capacity is anticipated to decrease as temperature increases. In contrast, the ion exchange resin, particularly the anion exchange component, is susceptible to thermal degradation above 140 °F [8] so the manufacturer does not recommend its use in hot water applications [9].

1. Temperature Effect on Activated Carbon

Activated carbon is generally considered a thermally robust material and is therefore not expected to degrade at the temperatures present in the heated leg of the (x)PWD. According to the senior product manager for Schunk FU 4652 (S. Guenther, personal communication, April 3, 2025), the material's maximum operating temperature is 130 °C (266 °F) in an oxidizing atmosphere and up to 250 °C (482 °F) in a non-oxidizing atmosphere, which is well above any temperatures anticipated in spacecraft potable water systems. Although the material is stable, its physical adsorption capacity typically decreases with increasing temperature. Indeed, activated carbon beds can be regenerated by heating the media to desorb previously adsorbed species. Despite this well-established behavior for gas-phase adsorption, relatively few studies have examined how temperature influences iodine adsorption from aqueous solution.

Although iodine uptake into activated carbon is typically observed to be governed by physical adsorption, one study reported that chemical adsorption (chemisorption) may dominate for aqueous I_2 on oak crown derived activated carbon [10]. The authors observed an increase in adsorption capacity with increasing temperature, a trend that is only thermodynamically possible for chemisorption, as physical adsorption is inherently exothermic. Because the surface chemistry and functional groups of activated carbon vary significantly with the activation process, some carbons may support chemisorption while others may not. Consequently, benchtop testing is needed to quantify the temperature dependence of aqueous iodine uptake for the Schunk FU (formerly Ambersorb) activated carbon used in the state-of-the-art ACTEX, in order to fully characterize the role of temperature in iodine removal from solution.

Another concern associated with reduced iodine adsorption capacity at elevated temperatures is the scenario illustrated in Figure 5. Near the end of the ACTEX's lifetime, when the bed is approaching its hot temperature capacity, iodine may continue to adsorb slowly at ambient temperature during periods when no hot water is flowing through the bed (e.g., overnight or between uses). Upon reheating, the reduced adsorption capacity at higher temperature could lead to desorption of previously captured iodine, resulting in elevated iodine levels in the dispensed water. To prevent

this outcome, the ACTEX would need to be replaced based on its hot water capacity rather than its ambient temperature capacity.

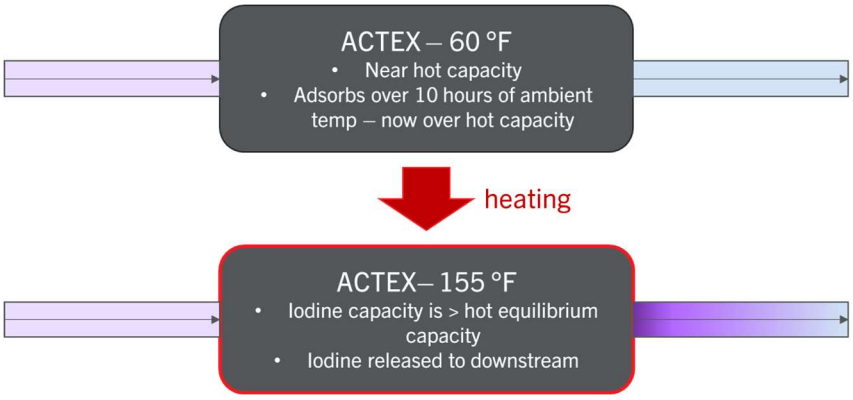

Figure 5. Potential Scenario for Iodine Release

2. Temperature Effect on Ion Exchange Resin

Similar to activated carbon, the equilibrium iodine capacity of ion exchange resins is expected to exhibit temperature sensitivity. However, the more significant concern is the potential for high temperatures to cause physical degradation of the resin. The ion exchange media used in the state-of-the-art ACTEX is Purolite™ UltraClean™ 3600, a mixed bed resin consisting of a Type 1 quaternary ammonium anion exchange resin in the OH^- form and a sulfonic acid cation exchange resin in the H^+ form [9]. Although only the anion exchange component removes ionic iodine species, Packham and coworkers note that, in spacecraft potable water applications, "[p]ure anion exchange resins were avoided because of their known tendency to leach materials (primarily amines) into the product water. With a mixed bed resin, any breakdown products can be removed in-situ by the cation exchange portion of the bed, while the anion exchange component is available for iodide removal" [11].

H^+/OH^- mixed bed resins, such as Purolite™ UltraClean™ 3600, provide total demineralization: iodide is exchanged for OH^-, and the corresponding counterion is exchanged for H^+, producing water as the byproduct. This makes H^+/OH^- mixed beds an advantageous option when operated within the allowable temperature range. At elevated temperatures, however, OH^- form anion exchange resins are susceptible to hydrolysis of their strongly basic functional groups. This degradation pathway converts strongly basic sites to weakly basic sites and can ultimately result in complete loss of the functional group. For example, testing of a strongly basic anion resin in the OH^- form (the same type as UltraClean) showed that exposure to water at 100 °C (212 °F) for 140 hours (5.8 days) led to an approximate 75% reduction in strongly basic sites [8]. Consequently, the maximum recommended operating temperature for UltraClean and many other OH^--form resins is 60 °C (140 °F). Thermal stability is also influenced by factors such as the type and density of cross-linking. More thermally robust resin options are identified and discussed in Section III.B.

3. Temperature Effect on Iodine Speciation in Water

When dissolved in water, molecular iodine (I_2), exists in equilibrium with several aqueous iodine species. The concentration of each specie is a function of the pH, temperature, and total iodine present in the solution. The corresponding equilibrium relationships have been quantified and reported across multiple studies [12], [13]. Figure 6 presents the calculated speciation profile as a function of pH at 25°C and a total ioidine concentration of 2 mg/L, reproduced from Atwater et al. [12]. Among the species present, iodine (I_2), hypoiodous acid (HOI), iodine cation $[H_2OI]^+$ are considered active antimicrobials, while iodide (I^-), iodate (IO_3^-), hypoiodite (OI^-), triiodide (I_3^-), do not have biocidal capability.

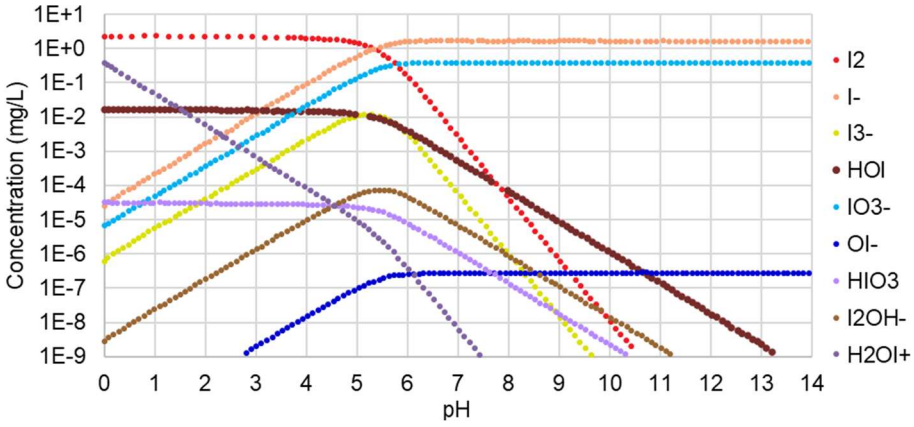

Figure 6. Equilibrium concentration of iodine species at 25°C and total iodine concentration of 2 mg/L. Adapted from Atwater et al. [12].

Within the pH range typical of spacecraft potable water systems (approximately 5–7, and generally nearer to 5), the dominant iodine species are I_2, I^-, and IO_3^-, with molecular iodine (I_2) being the only form exhibiting antimicrobial activity. A prior modeling effort evaluated these equilibria using Aspen Plus; however, that analysis assumed isothermal operation at 25 °C and therefore did not capture temperature-dependent behavior. In the present work, temperature-dependent equilibrium expressions derived from Burns et al. [13] were incorporated. Figure 7 illustrates the resulting speciation trends for a total iodine concentration of 5 mg/L. At 25 °C, a solution containing 5 mg of I_2 per liter exhibits a pH of approximately 5. As temperature increases, the solution pH decreases due to both iodine equilibria and water hydrolysis. Based on pH effects alone, this shift would be expected to favor I_2 over I^-, which can be seen in Figure 6. However, the temperature dependence of the iodine equilibria dominates, driving the overall speciation strongly toward iodide at elevated temperatures.

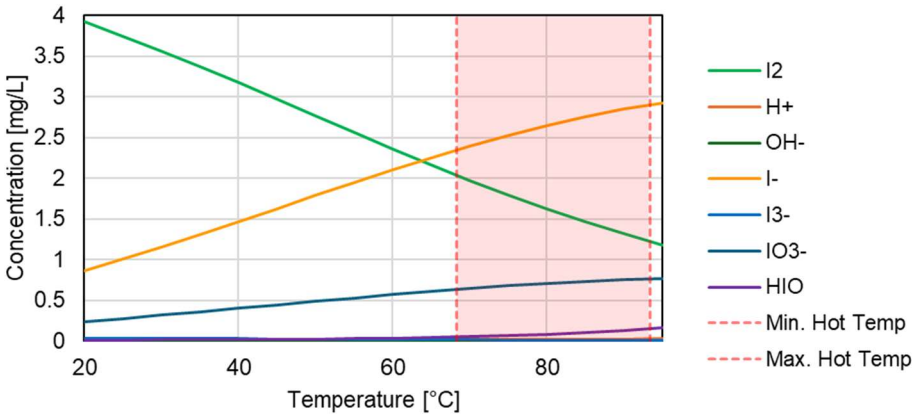

Figure 7. Temperature Effect on Speciation of 5 mg/L Iodine in Water

Because the current ACTEX removes molecular I_2 and iodine ions (I^-, I_3^-, etc.) via two different media, this shift in speciation is a crucial design factor that must be addressed when removing iodine from hot water. For example, if the state-of-the-art ACTEX was used to remove iodine from hot water, the amount of ion exchange resin would likely need to be increased while the amount of activated carbon to adsorb I_2 could potentially be decreased. However, the removal efficiency of iodine from activated carbon and ion exchange resin at elevated temperatures would also need to be considered when deciding the removal media ratio. If the same filter is used to remove iodine from both the hot and ambient streams, this could result in a required oversizing of the bed. If two separate filters are used (one for hot, one for ambient), then two different ratios of adsorbents may be considered for each side.

B. Delivery Temperature

As summarized in Table 1, hot water dispense volumes must reach at least 150 °F to satisfy PWD and xPWD requirements, and at least 155 °F to meet NASA standards. The PWD and xPWD heater coils control the water temperature to 175 ± 25 °F, ensuring temperatures at the heater outlet are within requirements. After leaving the heater, however, the water passes through a short unheated section of tubing before reaching the dispense needle. In the current (x)PWD configurations this downstream volume is intentionally minimized, limiting heat loss. Relocating the iodine removal media downstream of the heater would increase this wetted volume and raise the likelihood that a hot dispense fails to meet its minimum temperature requirement. Conversely, an ambient dispense immediately following a hot dispense could exceed its allowable maximum temperature.

The wetted volume of the ACTEX has not been precisely measured or modeled because it depends on the void fraction of the media and the internal hardware such as spacers and a spring. Random loose packing of uniform spheres generally yields void fractions of 0.40–0.41, while the densest ordered packing of spheres approaches 0.2595 [14]. Because both the carbon and resin are compressed during assembly, a void fraction below 0.4 is reasonable. The presence of a compression spring, which allows unrestricted flow around it, further complicates the estimate. Based on these considerations, the ACTEX wetted volume is expected to fall between 50 and 170 mL, though this range carries significant uncertainty and warrants further characterization.

Additional downstream volume is contributed by the UV filter (47 mL) in the xPWD and the microbial filter (approximately 300–470 mL) in the PWD. Although redundant microbial control may be required in order to prevent back-contamination from the point-of-use, this secondary barrier could potentially be located upstream of the heater. This configuration would reduce the downstream volume and mitigate temperature mixing concerns while still providing the required microbial protection.

To maintain compliance with dispense temperature requirements, the volume of the iodine removal media and associated plumbing should be minimized. Alternatively, system-level modifications, such as incorporating separate

hot and ambient iodine removal beds, adding recirculation, or applying heated overwraps to downstream components, could ensure temperature control regardless of media volume. These options are examined further in Section IV. If such configuration changes are not implemented, the dispense temperature will remain sensitive to the total downstream volume.

C. Bubbles

Another concern associated with relocating the iodine-removal bed downstream of the heater is the potential for bubble formation. The product water leaving the catalytic reactor in the WPA on the ISS contains dissolved oxygen near its saturation limit after passing through the gas–liquid separator. As shown in Figure 8, oxygen solubility decreases substantially as temperature increases, dropping by roughly a factor of three between room temperature and 190 °F. This reduction in solubility means that dissolved oxygen may come out of solution in the heated section of the (x)PWD, leading to bubble formation.

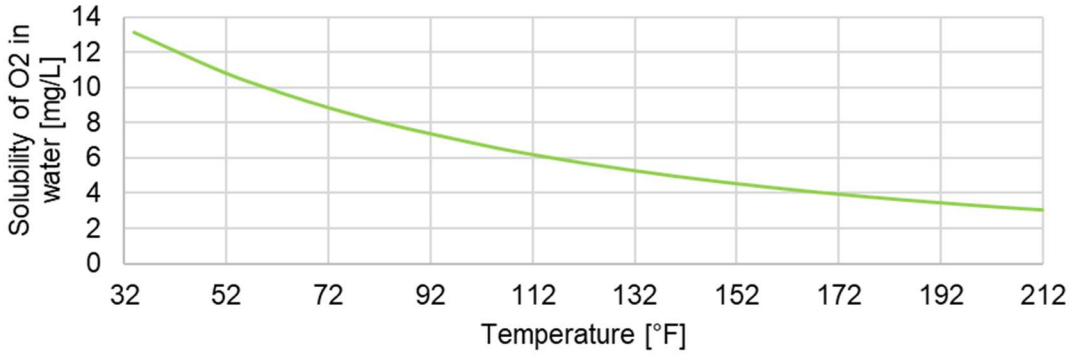

Figure 8. O_2 Solubility in Water, Partial Pressure of O_2 = 0.2 atm

A preliminary calculation was carried out to estimate the amount of dissolved oxygen that could come out of solution in the heated leg of the xPWD. Oxygen solubility depends on both temperature and the partial pressure of oxygen in the associated vapor phase. As illustrated in Figure 9, oxygen dissolves into the WPA catalytic reactor effluent on the ISS under elevated pressure and temperature. The stream then cools and passes through the Gas-Liquid Separator (GLS), where it is assumed to equilibrate with cabin air. Although the GLS outer shell is maintained at approximately 200 °F, the temperature of the product water is expected to fall between this value and the cabin air temperature.

Depending on the local temperature and partial pressure of oxygen (pO_2), the concentration of dissolved oxygen in the liquid phase, [O_2] varies. Some representative values are listed in Table 2.

Table 2. Predicted Concentration of Dissolved Oxygen as a Function of Temperature and Pressure

Temperature [°F]	Gauge Pressure [psig]	Vapor Phase O_2 Mole Fraction [-]	pO_2 [atm]	Dissolved O_2 [mg/L]
200	0	0.21	0.21	3.5
125	0	0.21	0.21	5.9
63	0	0.21	0.21	10.1
63	3	0.21	0.25	12.2
63	30	0.21	0.64	27.2

After leaving the GLS, the product water containing roughly between 3 and 27 mg/L of dissolved oxygen enters the (x)PWD heater, where the solubility range drops to approximately 3 to 5 mg/L. In the most extreme case, this reduction corresponds to a 23.7 mg/L loss in solubility, which could produce bubbles occupying up to about 2.6 percent of the fluid volume at 200 °F and 0 psig. The effect of bubbles on the ACTEX performance was evaluated in a study at Johnson Space Center during the original PWD testing phase and these results can be made available upon request to NASA internal contacts. Ultimately, repeat and long-duration testing will be required in order to

determine the effect of bubles on ACTEX performance over the lifetime of the filter. Combined with the ion exchange resin's temperature limit of 140 °F (60 °C), these concerns supported the decision that the ACTEX would remain upstream of the PWD heater.

The current state-of-the-art microbial filter cannot tolerate bubbles because of its very small 0.2-micron pore size. In contrast, the xPWD design replaces this filter with a UV reactor, and the hardware team does not anticipate any bubble-related issues for that component.

III. Potential Solutions

This section presents potential solutions to the challenges identified in Section II.

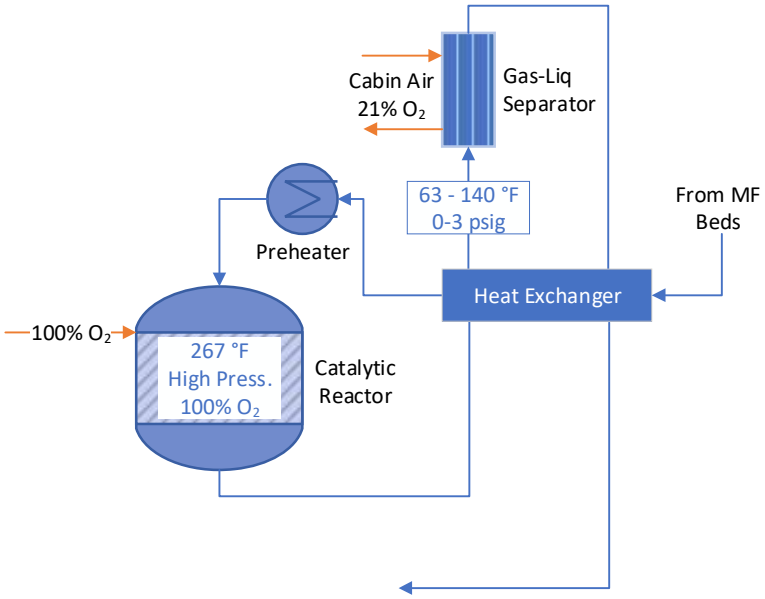

Figure 9. Simplified Partial WPA Schematic

A. Iodine Equilibrium Capacity Testing

Because the iodine removal capacity of the current media is expected to decline at temperatures in the hot side of the PWD, equilibrium capacity testing at 90 °C has been initiated and will continue into 2026. This testing is described in a companion ICES paper, ICES-2026-5. In parallel, a literature review of advanced media with potentially higher iodine and iodide capacity at elevated temperatures has also begun and will continue through 2026.

B. Thermally Robust Media

Because the current ion exchange resin degrades at temperatures above 60 °C (140 °F), the team procured several commercially available alternatives with higher thermal limits. Most of these were anion exchange resins in the chloride (Cl^-) form, which are generally more thermally stable than hydroxide (OH^-) forms and can tolerate temperatures up to 100 °C (212 °F). However, Cl^- resins release chloride into the product water, which may be undesirable. Pairing them with a cation exchange resin in the Na^+ form would produce salt as the exchange byproduct, but that raises potential palatability concerns. Activated carbon is not expected to experience physical degradation at 90 °C. The more thermally robust resins are discussed further in ICES-2026-5.

The manufacturer's characterization of resin lifetime is based on industrial use, where resins operate continuously and experience very high throughputs. In the (x)PWD, the number of wetted hours at elevated temperature will depend on how the bed is integrated into the dispensing system. Because thermal degradation occurs gradually, resin lifetime will be evaluated and verified before flight. It remains possible that the current ion exchange resin could operate in heated segments but would require more frequent replacement. Likewise, although the newly procured Cl^- form anion exchange resins are rated to 100 °C (212 °F), the vendor notes that operation above 60–70 °C (140–158 °F) may shorten their service life.

The EC3 Water Technology Development Group is also collaborating with Professor Chenfeng Ke's team at Washington University in St. Louis, whose work in chemical synthesis has produced new materials with strong affinity for iodine species in water. Their Hydrogen-Bonded Organic Polymers (HOPs) and their ionic derivatives (iHOPs) show high iodine uptake capacity and appear to maintain performance at elevated temperatures [15]. These materials will be included in the test matrix to assess their suitability as advanced iodine removal media. Alongside the commercially available high temperature resins and the WashU iHOP materials, a broader literature review of additional advanced iodine removal media has begun and will be reported in future proceedings.

C. Delivery Temperature

This section evaluates potential sizes of the iodine removal media that could meet the hot dispense temperature constraint. If a mass of hot water, m_{hot}, at temperature T_{hot} is mixed with a mass of cooler water, m_{cold}, at temperature T_{cold}, the resulting mixture temperature T_{mix} can be determined by equating the heat lost by the hot water to the heat gained by the cold water (Eq. 1). Rearranging this relationship yields Eq. 2 for solving T_{mix}.

$$m_{hot}\, c_p\, (T_{hot} - T_{mix}) = m_{cold}\, c_p\, (T_{mix} - T_{cold}) \quad \text{Eq. 1}$$

$$T_{mix} = \frac{m_{hot} T_{hot} + m_{cold} T_{cold}}{m_{hot} + m_{cold}} \quad \text{Eq. 2}$$

Here, c_p represents the heat capacity of water. The mass of the cold water, m_{cold}, is calculated as the wetted volume of the components downstream of the heater multiplied by the water density at the cold temperature, ρ_{cold}. Figure 10 shows the relevant control volumes. The dispense volume, $V_{dispense}$, is assumed to begin with the cooler downstream water, with the remaining volume supplied by the heater, as expressed in Eq. 3.

$$V_{dispense} = V_{cold} + V_{hot} = \rho_{cold} * m_{cold} + \rho_{hot} * m_{hot} \quad \text{Eq. 3}$$

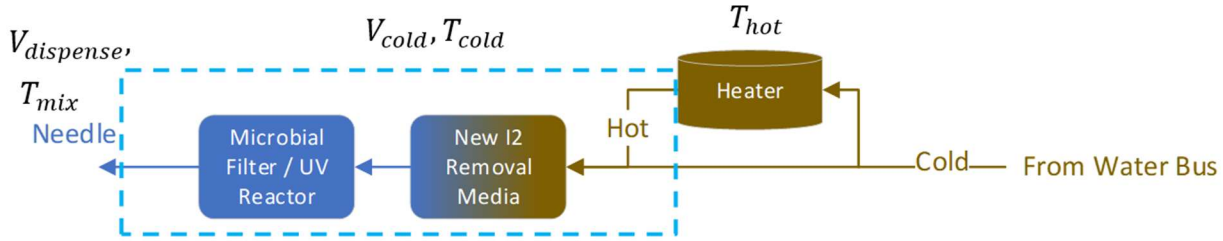

Figure 10. Temperature Dispense Modeling Variables on the NESC-Proposed Configuration

In terms of volumes, the mixed dispense temperature can be calculated by rearranging Eq. 2 and Eq. 3 which yields Eq. 4 below.

$$T_{mix} = \frac{(V_{dispense} - V_{cold})\rho_{hot} T_{hot} + V_{cold} * \rho_{cold} * T_{cold}}{(V_{dispense} - V_{cold})\rho_{hot} + V_{cold} * \rho_{cold}} \quad \text{Eq. 4}$$

Although crew rarely select a single 25 mL hot dispense volume, it represents the bounding case because it is the most challenging scenario for meeting the temperature requirement. The intersection of the required T_{mix} and the calculated T_{mix} for a given volume downstream of the heater is shown in Figure 11.

According to Figure 11, the downstream volume required to support a 25 mL hot dispense above 155 °F is estimated to be between 8 and 13.7 mL. This calculation does not include conductive heat transfer between the downstream water and the heater outlet, nor other thermal interactions within the system. For hot dispense volumes, such heat transfer would raise the delivered temperature and therefore increase the allowable wetted volume downstream of the heater. A more detailed thermal model would provide a more accurate estimate of the permissible downstream volume for the NESC Option 1 proposed configuration.

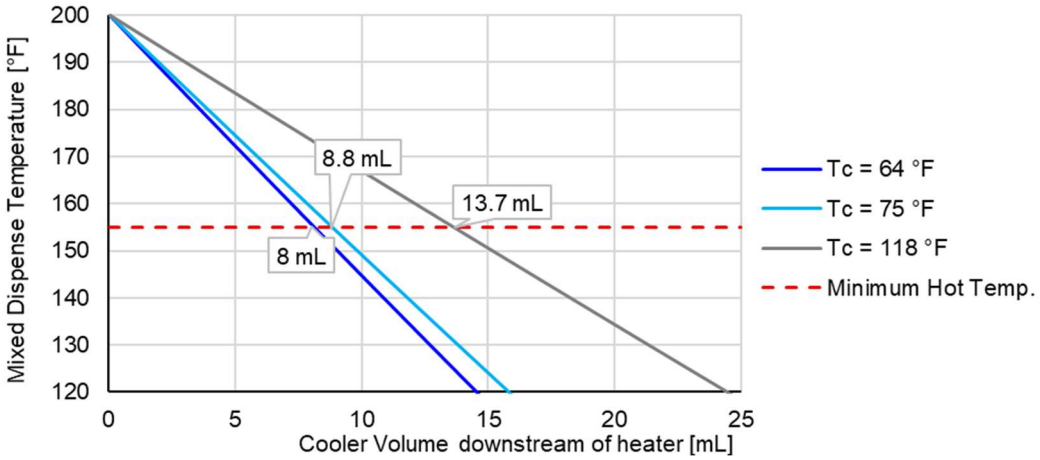

Figure 11. Temperature of a 25 mL Dispense, Assuming Water Temperature Out of Heater = 200 °F

In practice, crew members use hot water primarily for rehydrating meals and preparing hot beverages, typically dispensing more than 200 mL. Table 3 summarizes the maximum downstream volumes that satisfy a 150 °F dispense requirement for various combinations of dispense volume, heater temperature, and cold side temperature.

Table 3. Downstream volume required to meet a 150 °F dispense temperature requirement

Dispense volume [mL]	T_{hot} [°F]	T_{cold} [°F]	T_{req} [°F]	Maximum V_{cold} to meet hot Temp Reqt. [mL]
25	165	64	150	4
25	165	81	150	4
25	175	64	150	6
25	175	81	150	7
25	195	64	150	8
25	195	81	150	10
200	165	64	150	29
200	165	81	150	35
200	175	64	150	44
200	175	81	150	52
200	195	64	150	67
200	195	81	150	77
250	165	64	150	36
250	165	81	150	44
250	175	64	150	55
250	175	81	150	65
250	195	64	150	84
250	195	81	150	97

Based on this conservative analysis, it would be challenging for any iodine-removal media to be compact enough to reside downstream of the heater while still meeting the hot dispense temperature requirement for a 25 mL dispense. A more detailed thermal model that incorporates transient heating from the heater to downstream components could yield more realistic limits on allowable downstream wetted volume. For larger dispense volumes, the NESC Option 1 proposed configuration becomes more feasible, though it would still likely require a reduction in media size relative to the SOA ACTEX. For instance, achieving a 250 mL hot dispense with an average heater outlet temperature of 175 °F and a downstream water temperature of 64 °F would require the downstream wetted volume to remain below 55 mL. If the downstream water temperature were elevated to 81 °F, potentially due to heat transfer from the heater, the allowable volume would increase to 65 mL. As noted earlier, the current ACTEX's wetted volume has not been directly measured but is estimated to fall between 50 and 170 mL. Section 4 discusses configurational approaches that could enable iodine removal media of any size to satisfy the hot dispense temperature requirement.

D. Bubbles

As noted in Section 2.C, bubbles may form upon heating the product water and pass through the iodine removal media. The first step is to determine whether bubbly flow is acceptable to the program, provided that pressure drop limits and iodine removal performance can still be met. If bubbly flow is deemed acceptable, repeat testing should be conducted to confirm acceptable pressure drop through the state-of-the-art (SOA) ACTEX media. Additional long-duration iodine removal tests under representative flow conditions would also be required. If these tests demonstrate acceptable performance, dedicated gas–liquid separation may not be necessary. Any new iodine removal media would need to be evaluated under bubbly flow conditions to ensure that it does not become obstructed and that iodine removal performance is not degraded.

If bubbly flow is not acceptable, then either a gas–liquid separation method must be incorporated, or the system architecture must shift toward an approach that avoids iodine removal from hot water. Several degassing strategies could be considered. The gas–liquid separator currently used on station is one potential option, and other commercial or developmental separation technologies may also be suitable.

IV. Preliminary Trade Study – Alternative Configurations

To address the challenges of meeting delivery temperature and managing bubbles, several alternative configurations are considered. One option for improving hot dispense performance is to add a second leg to the PWD, directing hot dispense volumes through one ACTEX and ambient dispense volumes through the other, as shown in Figure 12. This arrangement prevents the temperature of one dispense from influencing the next for both hot and ambient water. However, on the hot side, the first dispense may still fall short of the temperature requirement because the wetted volume downstream of the heater would have cooled to room temperature.

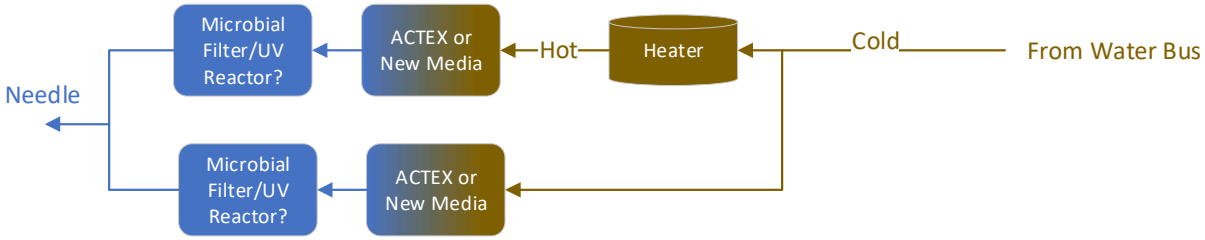

Figure 12. Alt. Config. 1: Separate Hot and Ambient Legs

The PWD and xPWD heaters consist of coils of pipe wrapped with heating tape. To ensure that the first hot dispense meets the required temperature, similar heaters could be applied to the components and fluid lines located downstream of the main heater, as illustrated in Figure 13. With adequate insulation, this approach would keep the hot side warm without influencing the ambient side. However, it would increase the system's power demand and, if the iodine removal media is sensitive to elevated temperatures, could shorten its operational lifetime.

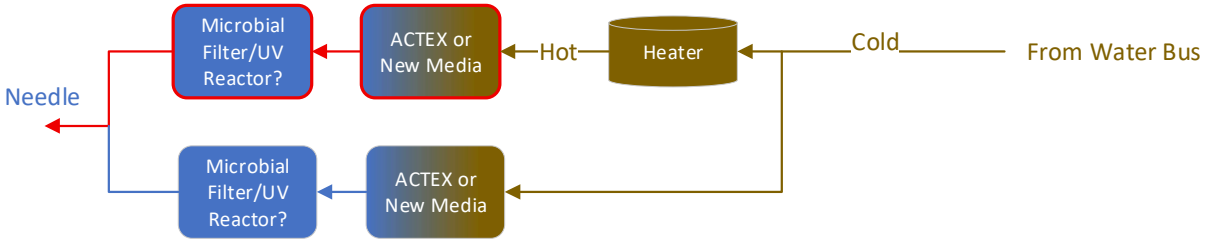

Figure 13. Alt. Config. 2: Separate Hot and Ambient Legs + Heater Wrap

If wrapping the downstream components with heaters is not feasible, another option is to recirculate the hot side through the heater until the downstream temperature reaches the required dispense temperature. However, recirculating water downstream of the ACTEX (Schematic 3A, Figure 14) would increase the non-iodinated volume of the PWD, which runs counter to the objectives of this project. Therefore, for recirculation to be a viable approach, an additional microbial control valve (MCV) should be installed downstream of the ACTEX, as shown in Schematic 3B in Figure 15.

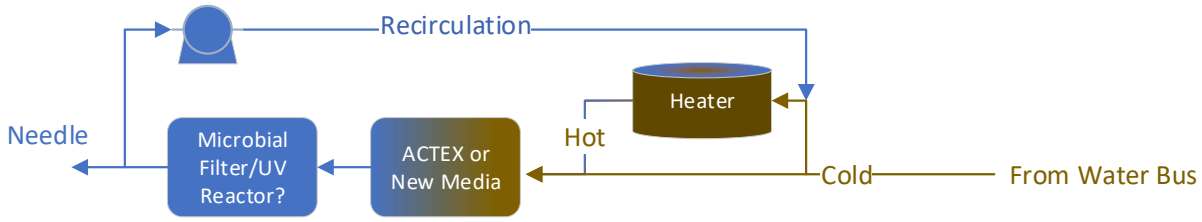

Figure 14. Alt. Config. 3A: Recirculation

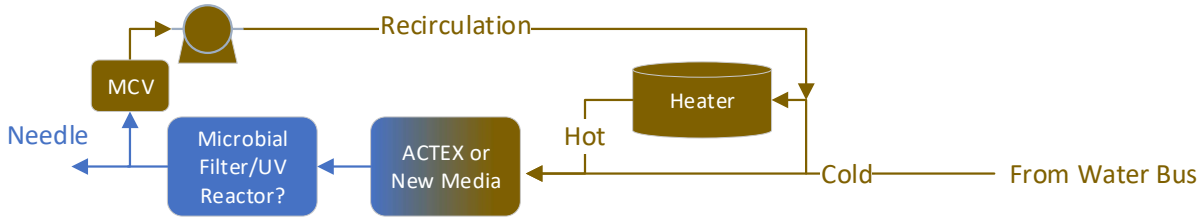

Figure 15. Alt. Config. 3B: Recirculation + Reiodination

Schematic 3B (Figure 15) would increase consumable use and reduce the lifetime of the ACTEX or new media, since it would remove more iodine per dispense than it would without the additional MCV. Both Schematic 3A and Schematic 3B would also likely fail to meet ambient dispense temperature requirements if an ambient dispense occurs immediately after a hot dispense. To address this, an additional leg could be incorporated into the recirculation arrangement, as shown in Alternative Configuration 4 (Figure 16), assuming that re-iodinating the recirculated hot stream is required to minimize the non-iodinated portions of the potable water system.

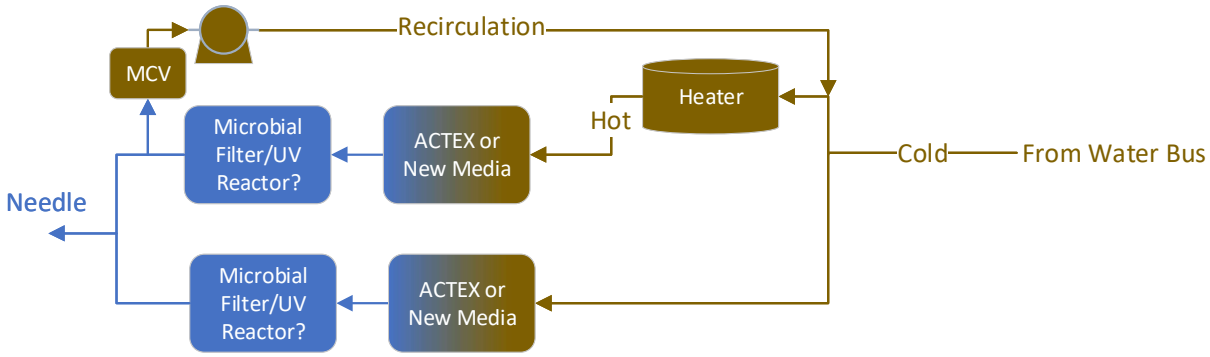

Figure 16. Alt. Config. 4: Separate Lines + Recirculation + Reiodination

Up to this point, none of the schematics provide protection against bubbles entering the iodine removal media, microbial filter, or UV reactor. One option is to add a gas–liquid separator after the heater, which could be incorporated into Alternative Configurations 1, 2, 3, and 4 (Figure 18), as well as the NESC Option 1 proposed configuration (Figure 17).

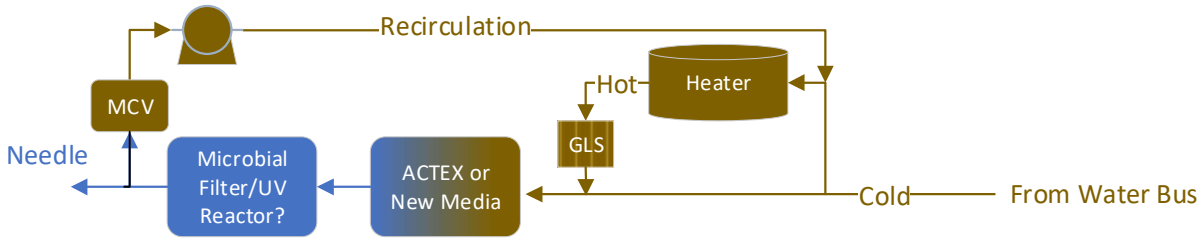

Figure 17. NESC Option 1 Proposed Config. + GLS

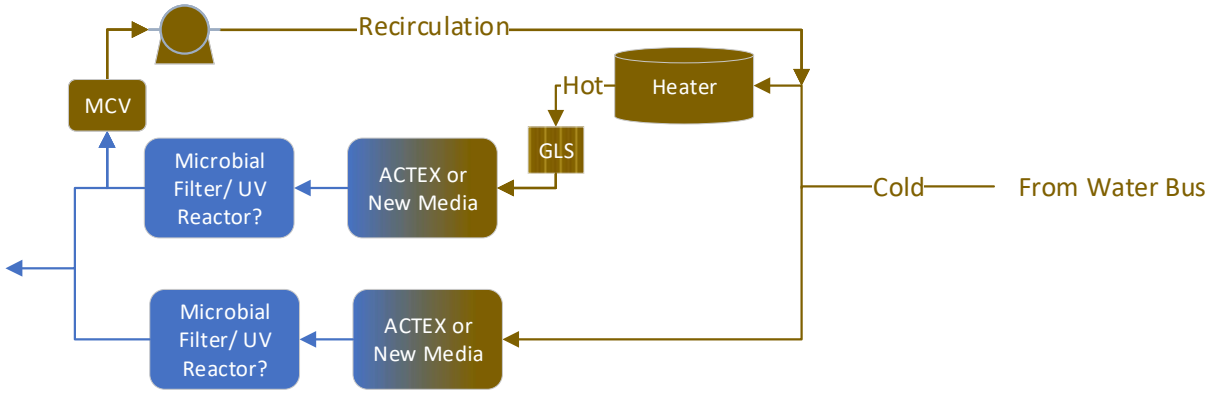

Figure 18. Alt. Config. 4 + GLS

Table 4 compares the four options that satisfy the NESC Option 1 objective of reducing the non-iodinated volume in the (x)PWD across six evaluation criteria. First, whether the configuration is likely to meet the ambient and hot dispense temperature requirements is assessed. Then, whether the configuration would impact the power demand, built-in mass, consumable mass, and risk bubbles in the ACTEX is assessed. In the table, green indicates a favorable outcome, red indicates an unfavorable outcome, and yellow signifies that additional information is required to assess favorability. For instance, Alt. Config. 1 is rated favorably for ambient dispense temperature and power demand because it is expected to meet the ambient temperature requirement and does not increase the power load of the (x)PWD. It is rated unfavorably for hot dispense temperature, built-in mass, and bubble risk, as there is a risk hot temperature requirement may not be achieved, additional plumbing increases system mass, and bubbles may pose a risk to the ACTEX. The consumable mass assessment remains uncertain because, although two ACTEX or new media units would need to be installed, each would remove less iodine per day and therefore might not require replacement as often as the single-line configuration currently used in the xPWD.

Table 4. Comparing Alternative Configurations

Alt. Config.	Description	Ambient Dispense Temp	Hot Dispense Temp	Power Demand	Built-In Mass	Consumable Mass	Bubbles to ACTEX
0	NESC Proposed Option 1						
1	Separate Lines						
2	Separate Lines + Heating Wrap						
3B	Recirculation + Re-iodination						
4	Separate Lines + Recirculation + Re-iodination						

The team recommends evaluating the proposed configurations with respect to mass, power, volume, and their ability to meet system requirements. The placement of the UV reactor should also be reviewed to determine whether UV exposure could negatively impact the biocide, and the compatibility of iodine with the reactor's materials should be assessed. In parallel, the team recommends investigating more robust and efficient iodine removal media for use in hot water, as outlined in Section III.B.

V. Conclusion

To address the concern that the non-iodinated leg downstream of the ACTEX in the current xPWD is a risk for microbial growth in exploration missions, the NESC brought forward 33 options to mitigate that risk. This report

discusses the feasibility assessment conducted to address Option 1: moving the ACTEX or new removal media as close to the dispensing needle as possible. This assessment identified three primary challenges: media performance at elevated temperature, the ability to meet dispense temperature requirements, and the impact of bubbles on iodine removal.

To address challenge 1, benchtop tests were initiated to understand how temperature affects the SOA materials' adsorption capacity and check for physical degradation due to temperature. Commercially available resins with temperature limits compatible with the hot water leg of the xPWD were procured and are slated for testing next fiscal year. If the FY26 literature search reveals promising advanced adsorbents, they will be procured and added to the test matrix.

Next, to address challenge 2, simple thermal modeling results suggested that for a 25 mL dispense, the allowable downstream volume must remain below 4–10 mL depending on heater and downstream temperatures. Larger dispense volumes (e.g., 250 mL) allow more practical downstream volumes of 36–97 mL even under conservative assumptions. If a more efficient iodine removal media is identified, and/or more refined thermal modeling shows better margin, then simply moving the iodine removal bed to as close to the needle as possible could be an acceptable solution. However, FY25 analyses indicate that implementing Option 1 will likely require a combination of solutions, so the alternative configurations described in Section 4.0 will be traded in parallel with media testing and development.

Ultimately, the team found that a smaller ACTEX (or new media) will likely be required to implement NESC's proposed configuration for Option 1 from the Biocide Assessment that meets all system requirements without additional modification. In FY26, the team will continue assessing the SOA and newly identified media and trading configuration solutions.

Acknowledgments

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