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

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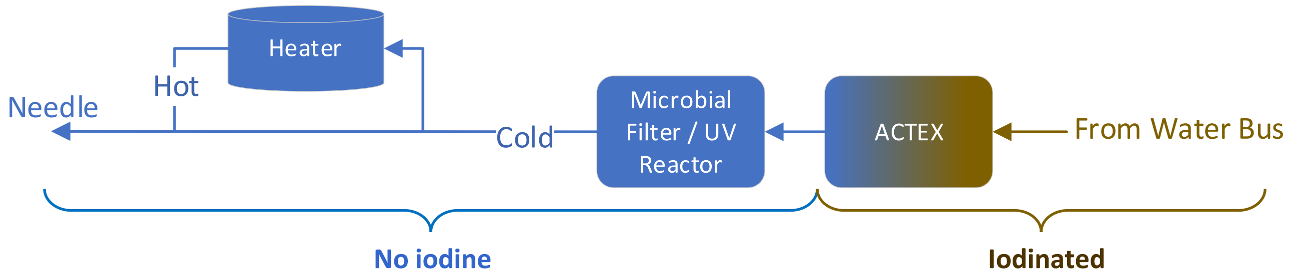
Agenda

1. Introduction
2. Background
3. Strategy
4. Challenges of Iodine Removal from Hot Water
5. Path to a Solution
6. Preliminary Trade Study
7. Conclusions and Plan Forward

Introduction

- **ISS Potable Water Dispenser (PWD) and Exploration PWD (xPWD) use biocidal iodine for protection against microbial growth in the potable lines**
  - Iodine is not safe for crew consumption at its biocidal levels, so it must be removed before dispensed.
  - Current (x)PWD design removes iodine before the heater, leaving wetted segments without biocide

Current (x)PWD Config. (Simplified)

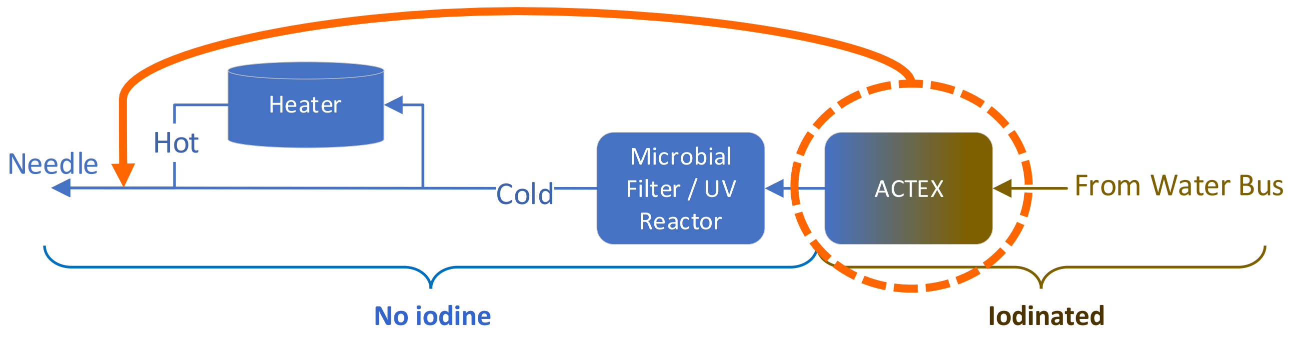


- **This segment without biocide is a concern for microbial growth to NESC, especially coming in and out of dormancy**
  - Exploration missions → dormant periods
  - ISS (x)PWD have not been proven for success during dormancy

Introduction

- **In 2021, the NASA Engineering and Safety Center (NESC) published a report aimed at identifying and prioritizing biocide solutions for future missions to ensure robust microbial control coming in and out of dormancy**
  - NESC proposed 33 options, including iodine, silver, chlorine, and bromine-based biocide solutions.
- **The top-ranked architecture was iodine as a biocide, with a design change to the PWD to achieve iodine removal at or closer to needle**
  - NESC also indicated that the current removal media may perform less effectively in hot water than at ambient temperatures

Current (x)PWD Config. (Simplified) + Proposed Change



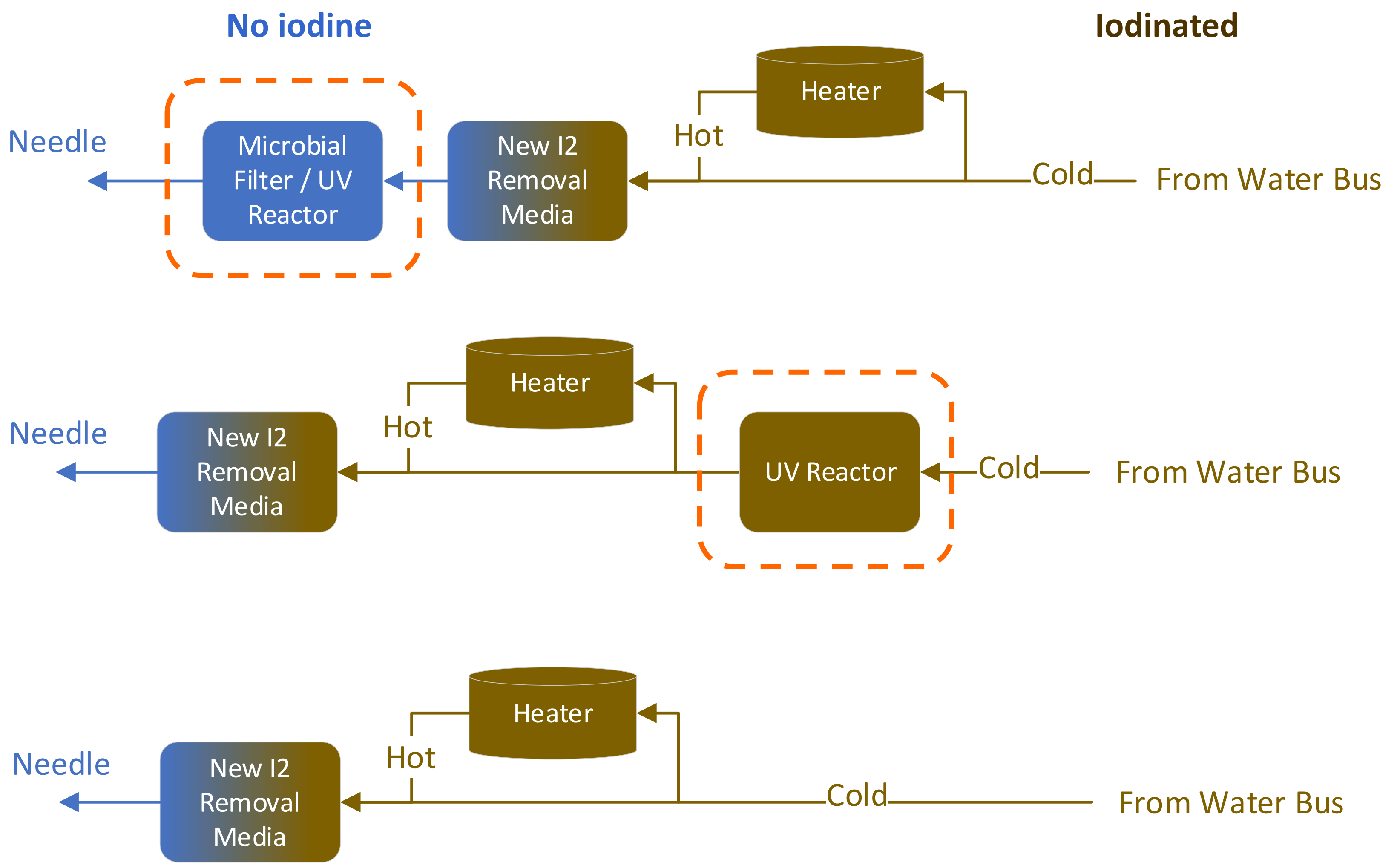
- **The aim of this study is to investigate the feasibility of removing iodine from heated spacecraft potable water systems**

Possible Interpretations of the Proposed Solution

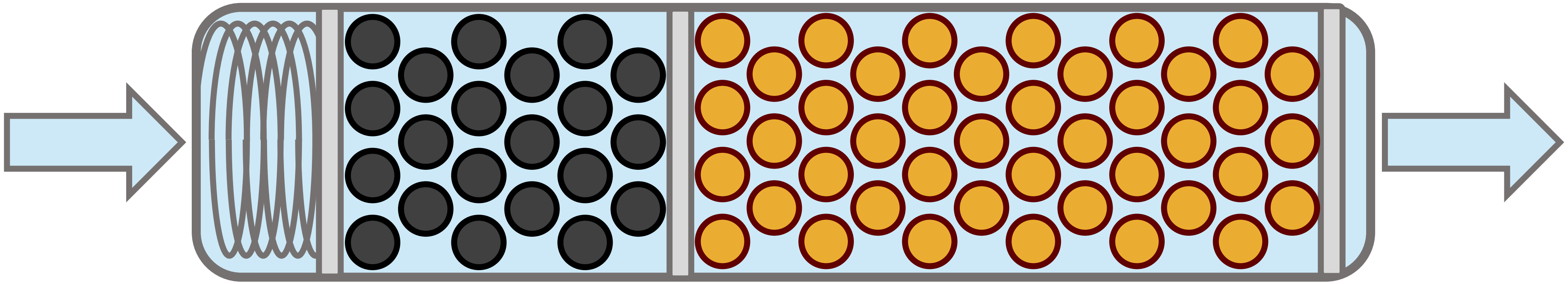
Microbial control downstream of iodine removal

Microbial control upstream of iodine removal (UV only)

No additional microbial control



State of the Art: Activated Carbon and Ion Exchange (ACTEX)



Activated Carbon
- Adsorbs the molecular iodine (I_2)

Ion Exchange Resin
- Removes the ionic species

Together, reduce $I_2 + I^-$ from 6 mg/L to <0.2 mg/L

Spacecraft Potable Water Requirements

Parameter	Requirement	Reference
Dispense volumes	25 to >500 mL in 25 mL increments	ISS PWD
	25 to 250 mL in 25 mL increments	NASA-STD-3001
Hot dispense temperature	155°F to 175°F	NASA-STD-3001
	150 to 200 °F	ISS PWD
Nominal dispense temperature	64°F to 81°F	NASA-STD-3001
Hot water volume	600 mL per meal per crewmember available as Hot Water	NASA-STD-3001
Remove Iodine	Iodine <0.2 mg/L before crew consumption	Human Integration Design Handbook (HIDH), ISS PWD
Microbial Control	≤50 CFU/mL bacteria, no detectable coliforms	ISS PWD

Strategy

Investigate: Can the State of the Art (SOA) ACTEX be used downstream of the heater as-is?

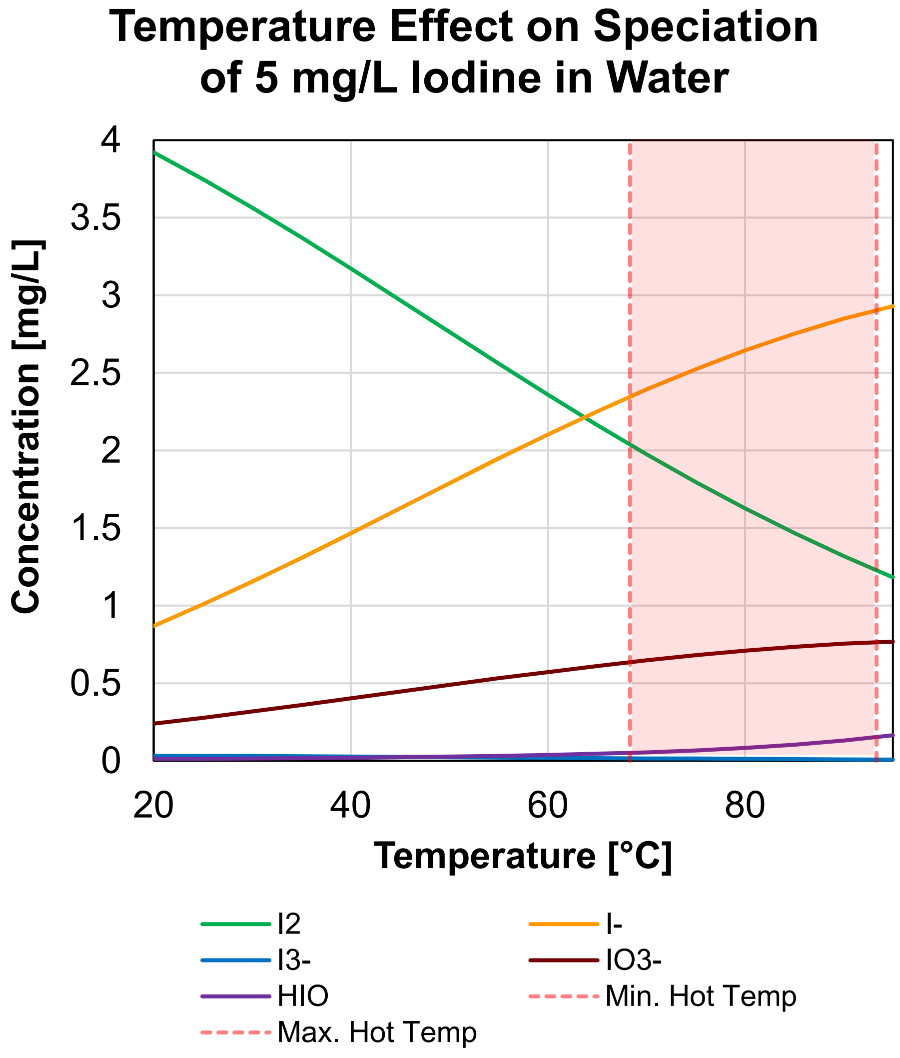
Anticipating challenges, simultaneously identify:

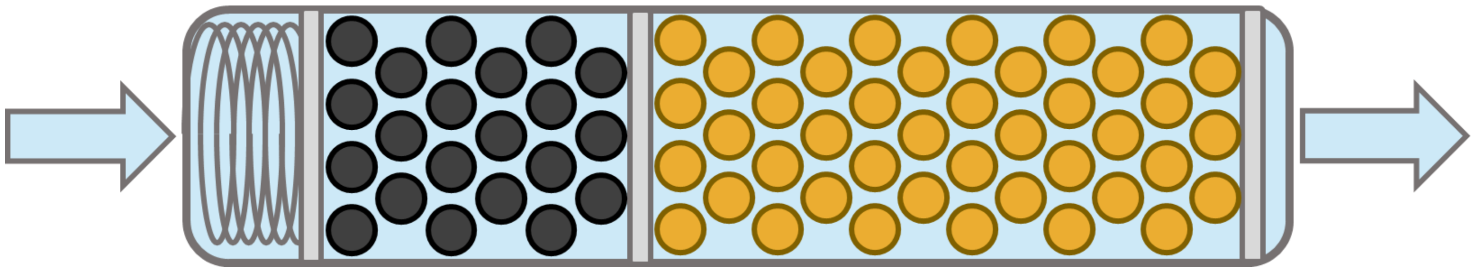
- Potential alternative media
- Potential system-level configuration changes support either:
  - A) Existing ACTEX
  - B) More efficient or thermally robust media

Challenges of Removing Iodine from Hot Water

- Temperature Effect on Removal Media
- Bubbles
- Delivery Temperature

Temperature Effect on State-of-the-Art Materials





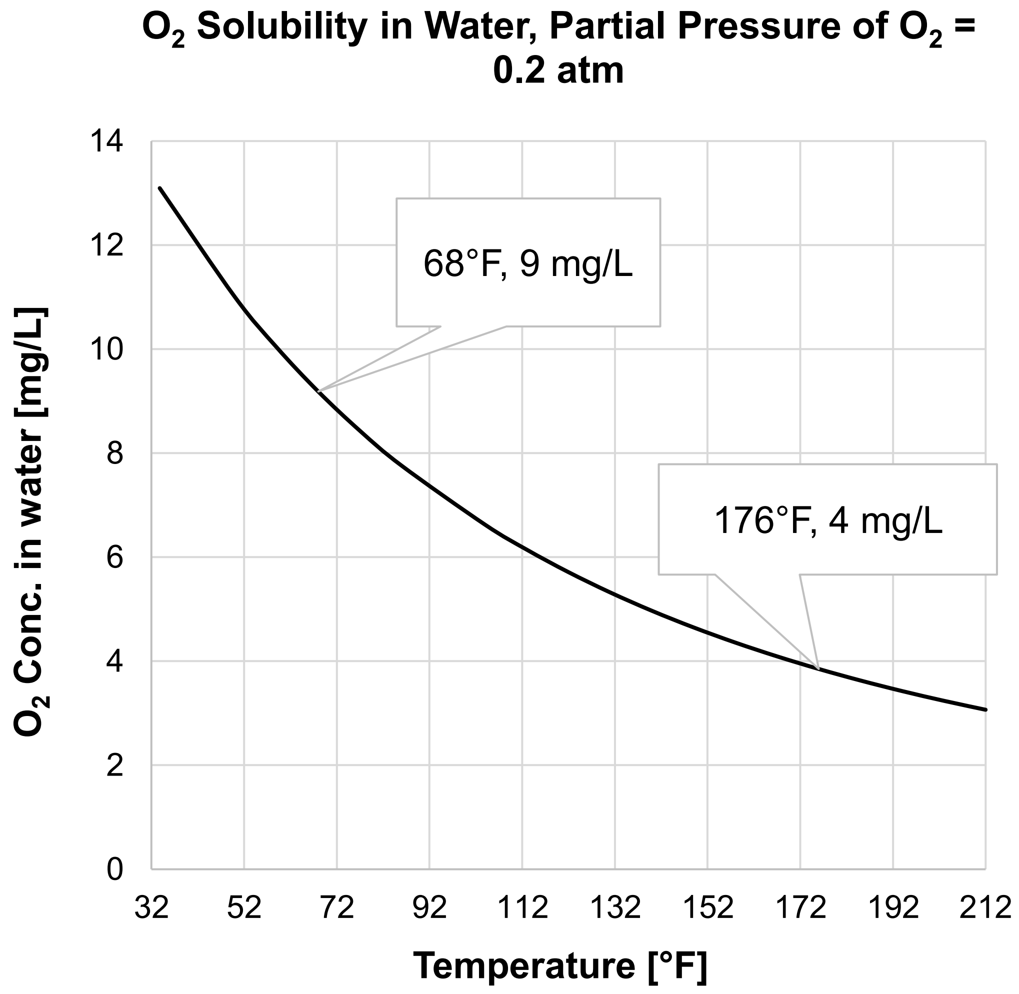
	Activated Carbon	**Ion Exchange Resin**
Thermal degradation of material properties	Not anticipated	Not recommended for use for temperature > 60 °C (140 °F) • Bulk material degradation
Capacity change at hot temperature	Likely	Potential due to hydrolysis of functional groups
Iodine speciation	Decreased [I_2] at hot temperature	Increased [I^-] at hot temperature

Bubbles

- **Dissolved gas in the potable water bus could evolve bubbles at the heater as O_2 solubility decreases**

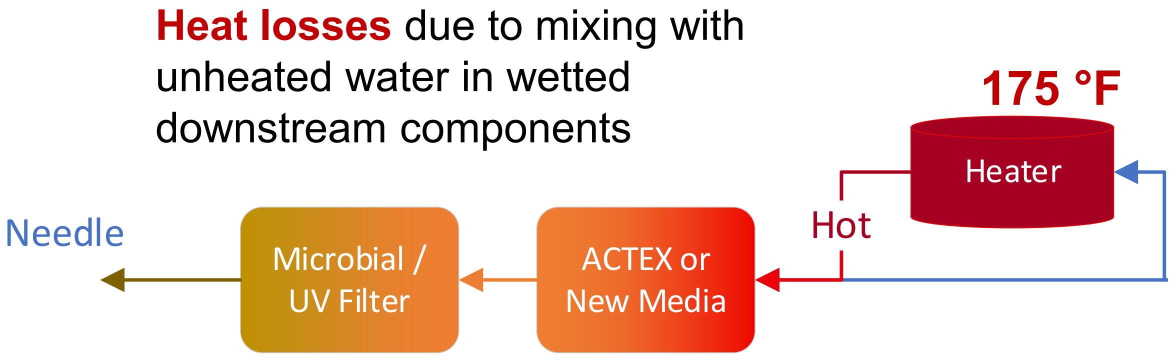
Downstream component impacts:

- **ACTEX**
  - Concern for reduced contact time of I_2 stream with removal media
  - Potential for clogging depending on how tightly packed the ACTEX is
- **New potential I_2 removal media**
  - Material-dependent. Same concerns as ACTEX
- **UV Filter (xPWD baseline)**
  - No adverse effects expected
- **Microbial filter (ISS PWD, potential alternate for xPWD)**
  - Pore blockage, potential for complete loss of flow

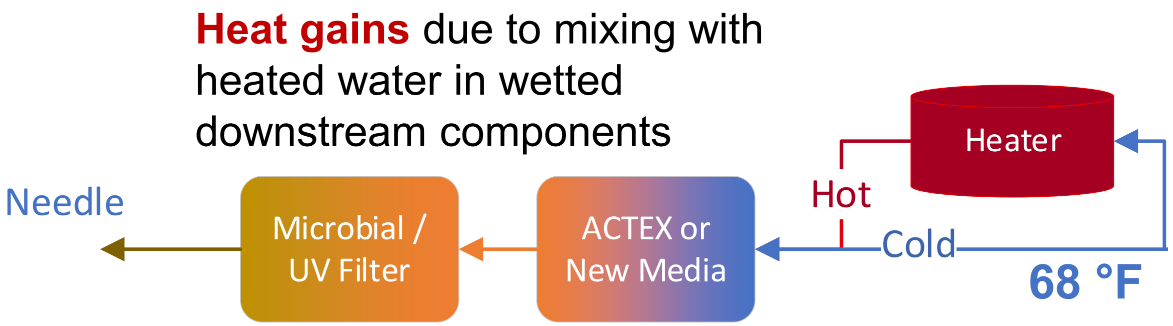


Delivery Temperature

- **Hot dispense:** Increased risk that hot dispenses will not meet minimum temperature requirements.



- **Ambient dispense:** dispenses immediately following a hot dispense may be too hot.



Path to a Solution

What can we test/model to determine feasibility?

- Iodine Equilibrium Capacity Testing
- Thermally Robust Media
- Bubbles
- Delivery Temperature

Media

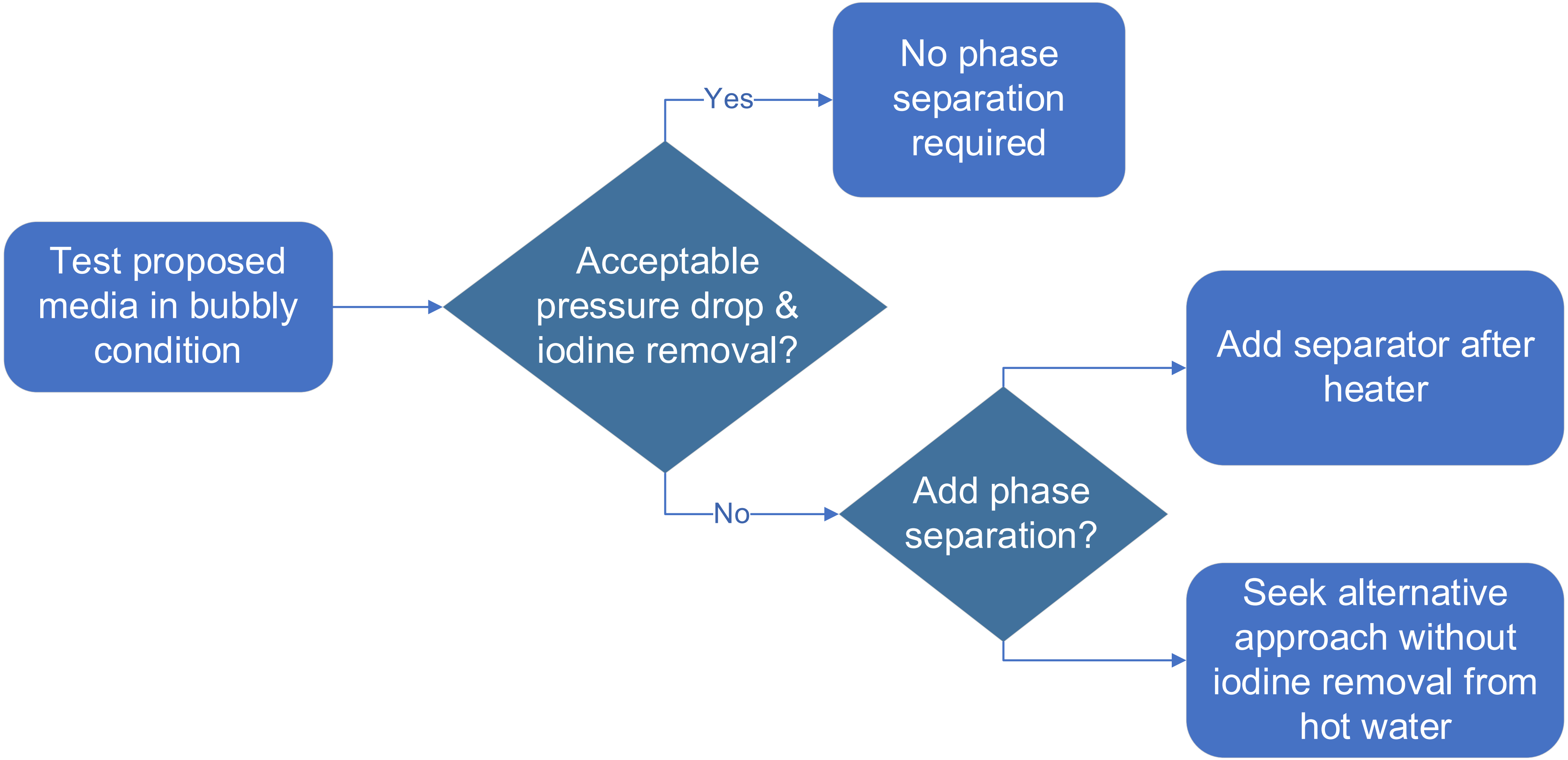
Thermally robust media identification:

- Current ion exchange resin degrades at temperatures > 60 °C (140 °F) → team procured several commercially available alternatives with higher thermal limits
- Activated carbon is not expected to experience physical degradation at 90 °C
- See ICES-2026-5 (companion paper/presentation) for more details

Iodine equilibrium capacity testing:

- Iodine removal capacity of the current media is expected to decline at hot temperatures → adsorption 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
- Literature review of advanced high temperature iodine/iodide sorbents ongoing through 2026

Bubbles


Test proposed media in bubbly condition
Acceptable pressure drop & iodine removal?
Yes
No phase separation required
No
Add phase separation?
Add separator after heater
Seek alternative approach without iodine removal from hot water

Delivery Temperature Analysis

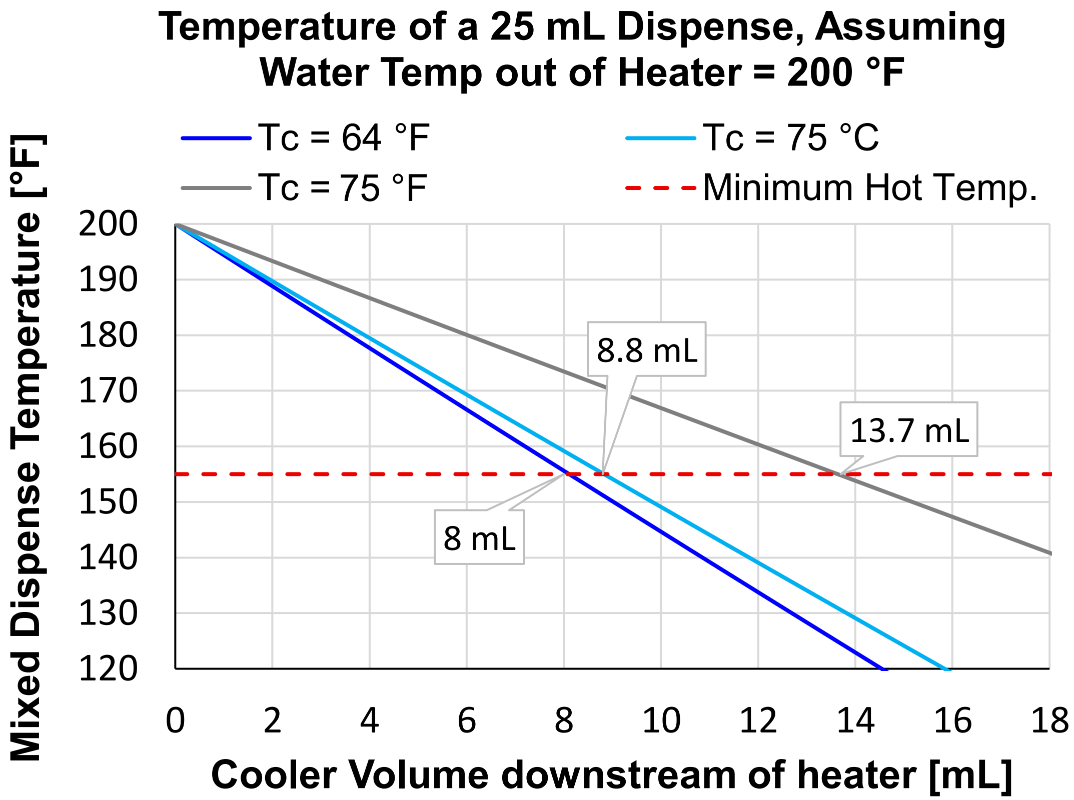
- **Simple thermal analysis, assuming no transient heating effects, bulk "hot slug" mixes with bulk "cold slug". Does not consider temperature of pipe walls or media.**
- **Heat lost = heat gained:**

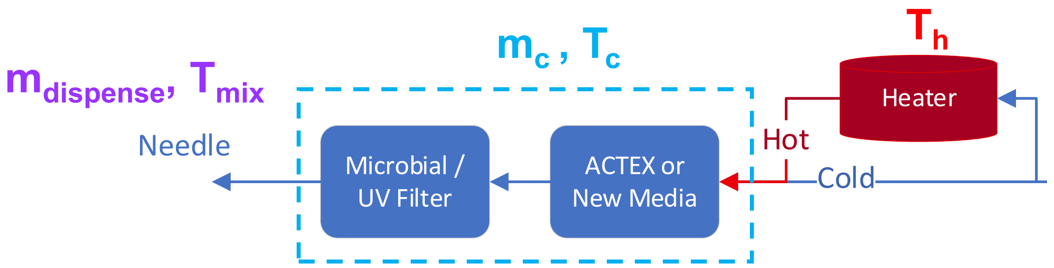
$$q = m\, c_p\, \Delta T$$

$$T_{mix} = \frac{m_{hot} T_{hot} + m_{cold} T_{cold}}{m_{hot} + m_{cold}}$$

- **Variables:**

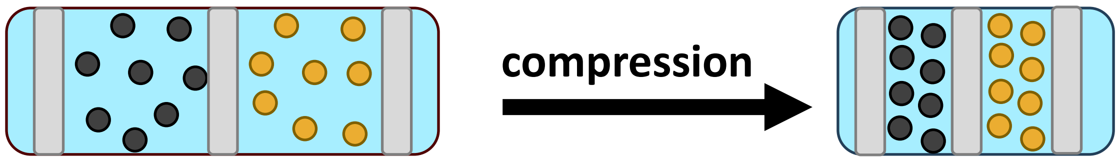
T_{cold}	temperature of cold downstream components
T_{hot}	temperature coming out of heater
m_{cold}	mass of cold water in downstream components
m_{hot}	mass of heated water ($m_{dispense} - m_{cold}$)
$m_{dispense}$	25 to 250 mL





Delivery Temperature Analysis

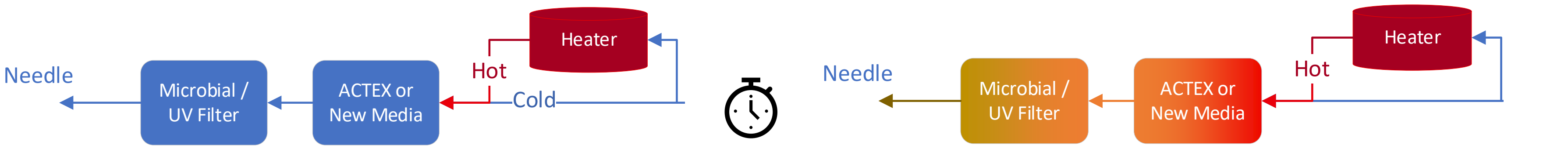
- **Hot dispense temperature requirement is most difficult to meet for a 25 mL dispense**
- **Real use case of hot dispense: rehydrate food packages, hot beverages**
  - Typically 200 – 250 mL dispense
  - Gives more leeway for allowable volume downstream of heater
- **Actual wetted volume of ACTEX is likely between 100 – 200 mL.**
  - Depends on packing density – currently not quantified for flight unit
- **For an ACTEX-like design with resin and activated carbon beds, the beds can be compressed to reduce void volume thereby reducing downstream water holdup**
  - However, this reduction in void volume comes at the cost of increased pressure drop across the bed



Dispense volume [mL]	T_h [°F]	T_c [°F]	T_{req} [°F]	Maximum V_c 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

Delivery Temperature Analysis - *Summary*

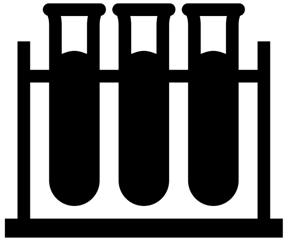
- **According to this conservative analysis, any iodine removal media (+ potential secondary microbial control) would need to have a wetted volume of ~8 mL to meet the hot dispense temperature requirement for a 25 mL dispense**
- **A more refined thermal model could provide a more realistic allowable downstream wetted volume for the NESC proposed configuration**
  - Accounting for transient heat transfer: Since the heater stays hot 24/7, it likely transfers heat to downstream components between lulls in dispenses. Depends on insulation, heat loss thru needle, etc.
    - This would be helpful for hot dispenses, but might make ambient dispenses too hot



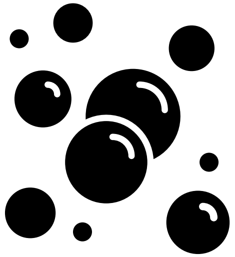
Immediately following ambient dispense | **Time for heat transfer from heater outlet to downstream.**

- **Next steps:**
  - Higher fidelity thermal modeling
  - Trade study on downstream configurations

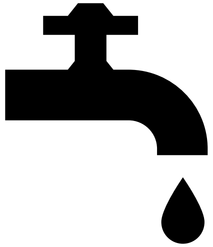
Path to a Solution – *Summary*



Material testing in progress at 90 °C



Iodine removal performance in bubbly conditions will be tested



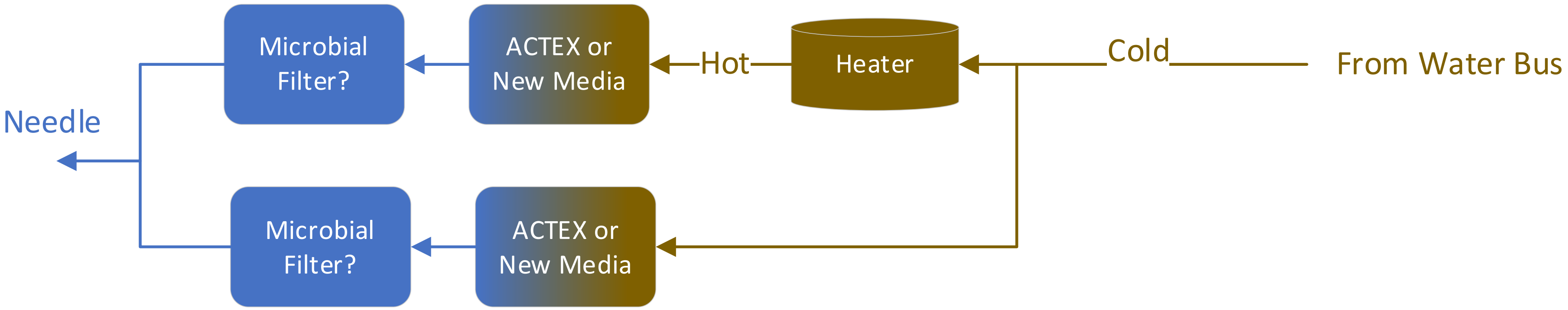
Dispense temperature will be challenging to meet – investigate configurational changes

Preliminary Trade Study

Preliminary Trade Study

- **NESC Recommendation:** find iodine removal media that is as efficient with “hot” water as the SOA media is with cold water.
- Even if iodine sorption media is as efficient as SOA in cold water, **team expects challenge to meet temp dispense requirements.**
- The team anticipates that moving the iodine removal bed downstream of the heater will require a **combination of solutions** including **changes to system architecture**
- **Key comparison parameters:**
  - **Non-iodinated Volume During Ops:** whether configuration minimizes the volume without biocide during operation or not
  - **Ambient Dispense Temp:** configuration likely to meet ambient dispense temperature requirement
  - **Hot Dispense Temp:** configuration likely to meet hot dispense temperature requirement
  - **Power Demand:** configuration impact to (x)PWD power demand
  - **Built-In Mass:** configuration impact to (x)PWD built-in mass
  - **Consumable Mass :** configuration impact to (x)PWD consumables mass
  - **Bubbles to ACTEX:** configuration impact to (x)PWD bubble risk

Preliminary Trade Study



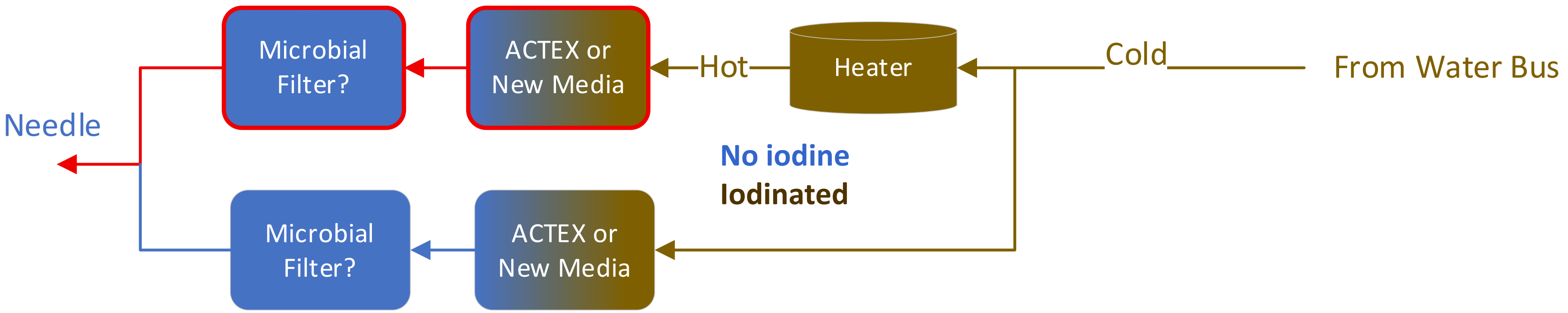
Alt. Config. 1: Separate Hot and Ambient Legs

Config.	Non-iodinated Volume During Ops	Ambient Dispense Temp	Hot Dispense Temp	Power Demand	Built-In Mass	Consumable Mass	Bubbles to ACTEX
1	Minimizes	Should meet req.	1st hot dispense after some time may not meet req. due to mixing with cooler downstream water	No added power	Adds piping for 2nd leg	Possible that each bed is replaced half as frequently	Does not include any bubble mitigation

Key	Favorable Condition	More Info. Needed to Determine Favorability	Unfavorable Condition

Preliminary Trade

Preliminary Trade Study



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

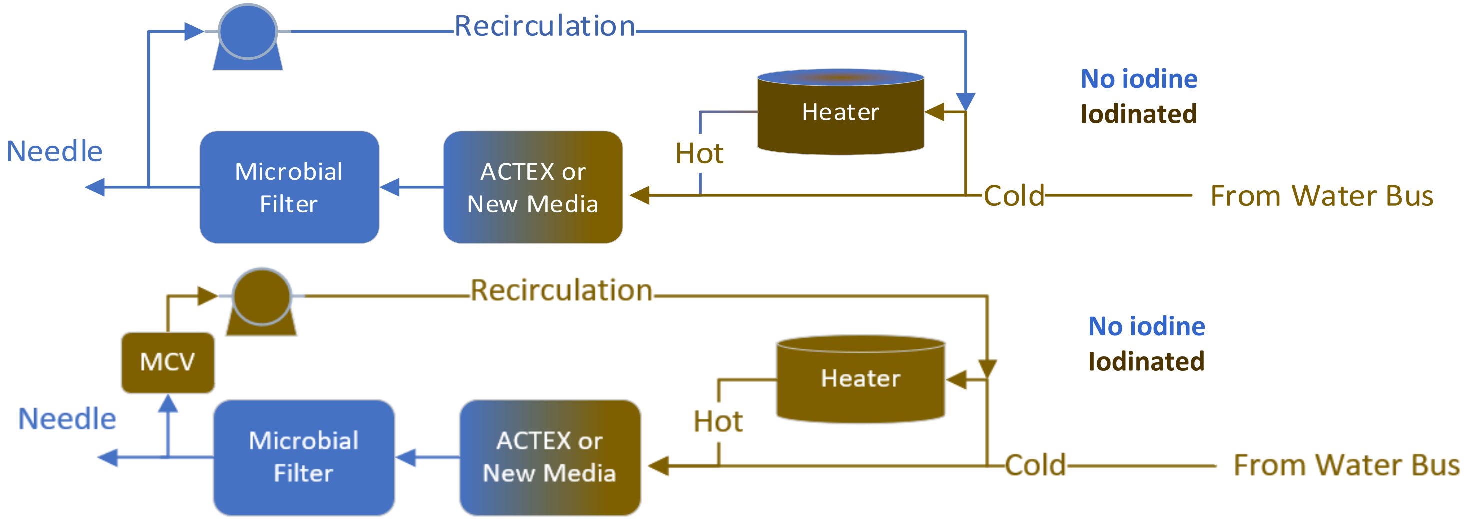
Config.	Non-iodinated Volume During Ops	Ambient Dispense Temp	Hot Dispense Temp	Power Demand	Built-In Mass	Consumable Mass	Bubbles to ACTEX
2	Minimizes	Should meet req.	Should meet req.	Power to heater wrap	Adds piping for 2nd leg	Possible that each bed is replaced half as frequently. Constant heating of hot bed may reduce lifetime	Does not include any bubble mitigation

Key	Favorable Condition	More Info. Needed to Determine Favorability	Unfavorable Condition

Preliminary Trade Study

Alt. Config. 3A: Recirculation

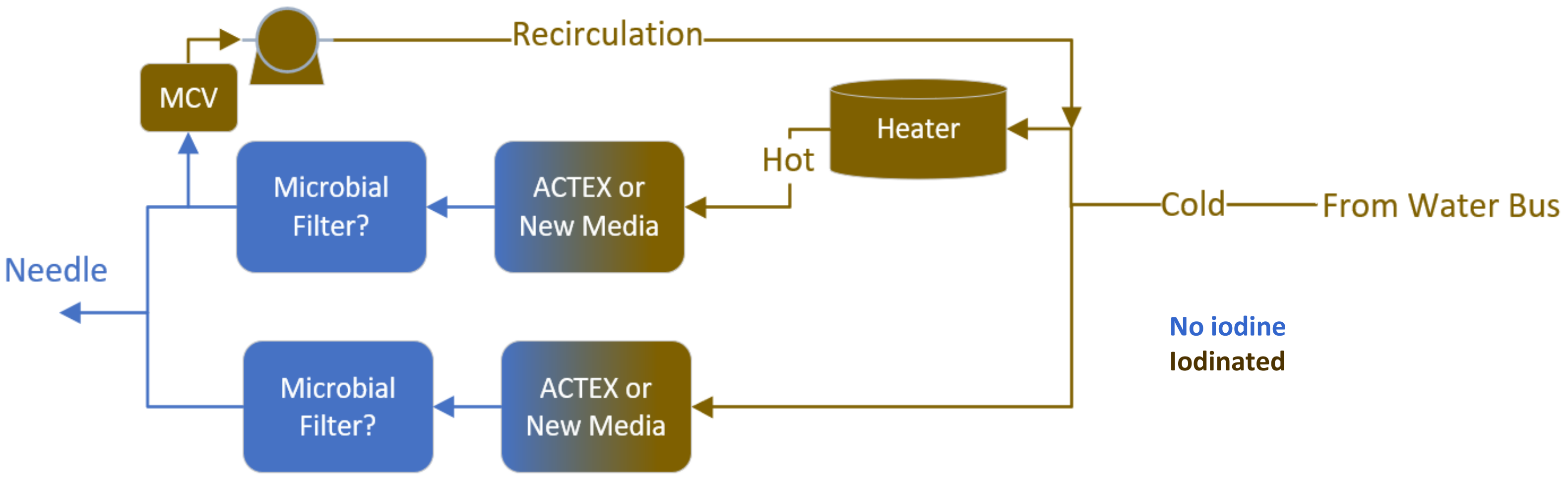
Alt. Config. 3B: Recirculation + Re-iodination



Config.	Non-iodinated Volume During Ops	Ambient Dispense Temp	Hot Dispense Temp	Power Demand	Built-In Mass	Consumable Mass	Bubbles to ACTEX
3A	Recirculation loop without iodine	May not meet req. after hot dispense	Should meet req.	Pump requires power	Adds piping	Constant heating of hot bed may reduce lifetime	Does not include any bubble mitigation
3B	Minimizes	May not meet req. after hot dispense	Should meet req.	Pump requires power	Adds piping	Second MCV, ACTEX removing extra iodine	Does not include any bubble mitigation

Key	Favorable Condition	More Info. Needed to Determine Favorability	Unfavorable Condition

Preliminary Trade Study

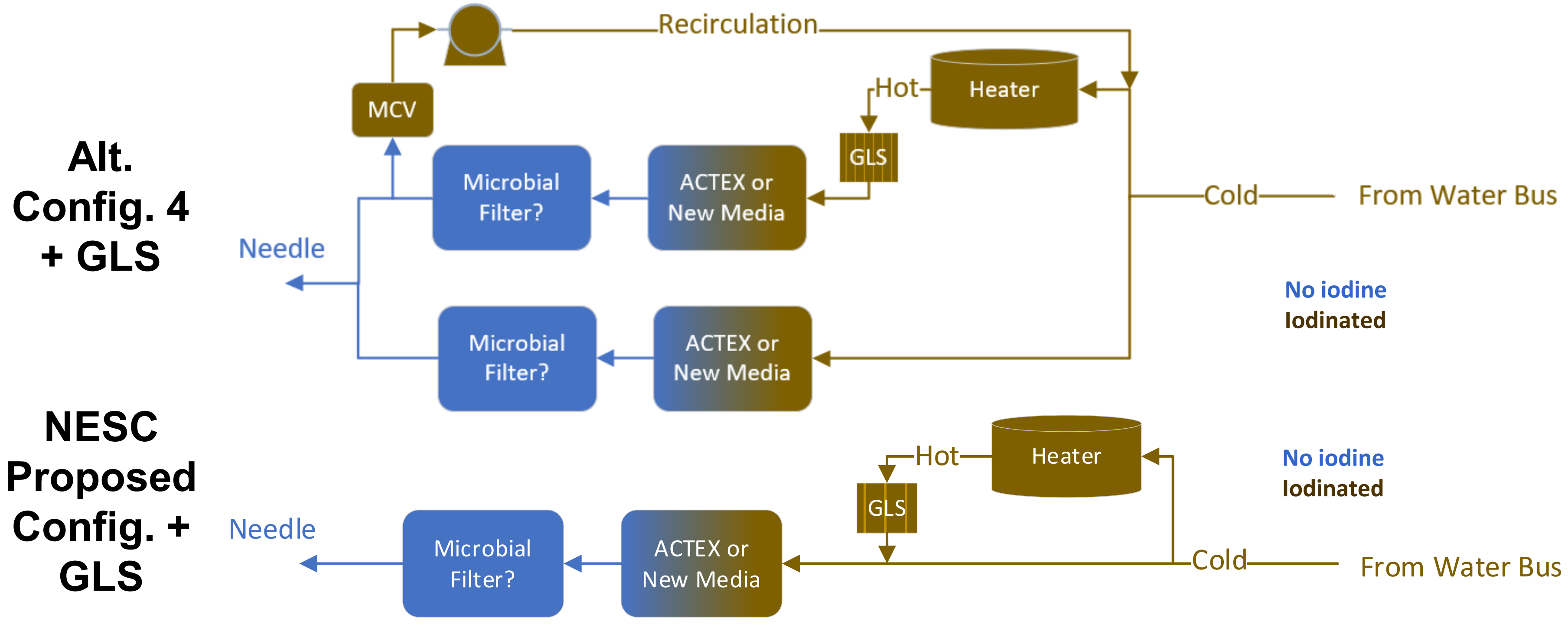


Alt. Config. 4: Separate Lines + Recirculation + Re-iodination

Config.	Non-iodinated Volume During Ops	Ambient Dispense Temp	Hot Dispense Temp	Power Demand	Built-In Mass	Consumable Mass	Bubbles to ACTEX
4	Minimizes	Should meet req.	Should meet req.	Pump requires power	Adds piping	Second MCV, ACTEX removing extra iodine	Does not include any bubble mitigation

Key			
Key	Favorable Condition	More Info. Needed to Determine Favorability	Unfavorable Condition

Preliminary Trade Study



Adding a gas-liquid separator (GLS) after the heater could be an option for configurations 1-4

Config.	Built-In Mass	Bubbles to ACTEX
X	Adds GLS + piping	Includes bubble mitigation

Notes:

- *Iodine losses could occur through the GLS due to its high volatility*
- *Iodine compatibility with GLS materials?*

Preliminary Trade Study

- **The team recommends trading the configurations in FY26**
  - Trade mass, power, volume, and ability to meet system requirements

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

Key	Favorable Condition	More Info. Needed to Determine Favorability	Unfavorable Condition

Preliminary Trade Study

- **The team recommends trading the configurations in FY26**
  - Trade mass, power, volume, and ability to meet system requirements

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

- **Re-circulation requires pumps and either adds volume without biocide or requires adding iodine only to remove it again**
- **Future work will include testing the performance of the baseline configuration and potentially configurations 1 and 2**
- **The mass penalty of adding separate lines and/or downstream heating will be weighed with ability to meet temperature dispense requirements**

Key			
Key	Favorable Condition	More Info. Needed to Determine Favorability	Unfavorable Condition

Conclusions and Proposed Plan Forward

- **Summary**
  - We are actively characterizing performance of state of the art + newly identified materials in heated water
  - Moving ACTEX to needle → likely need to modify PWD configuration even with highly efficient material

- **Plan forward:**
  - Sharpen the pencil on bed size constraint for thermal effects downstream of the heater: how small does it really need to be?
    - Assess wetted volume (packed bed void fraction vs. pressure drop), transient thermal effects, and (x)PWD insulation
  - Trade different architectural solutions
    - Is additional heating required? Would separate hot vs. ambient beds be required?
    - Determine placement of UV filter
  - Testing to inform decision on degassing requirement

Thank you!

Questions?

Mary Lou Nadeau

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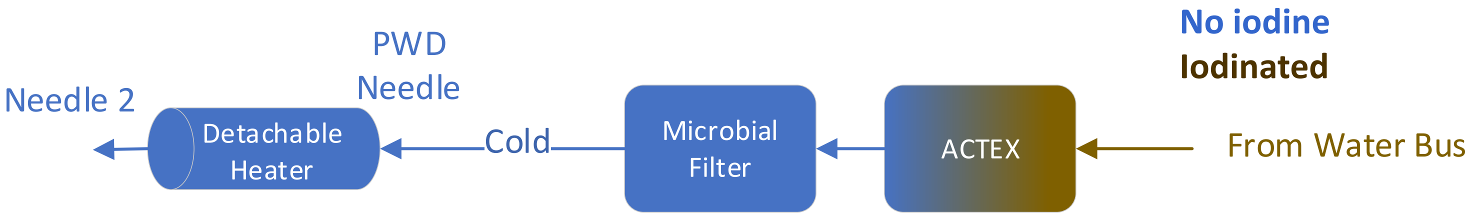
Backup

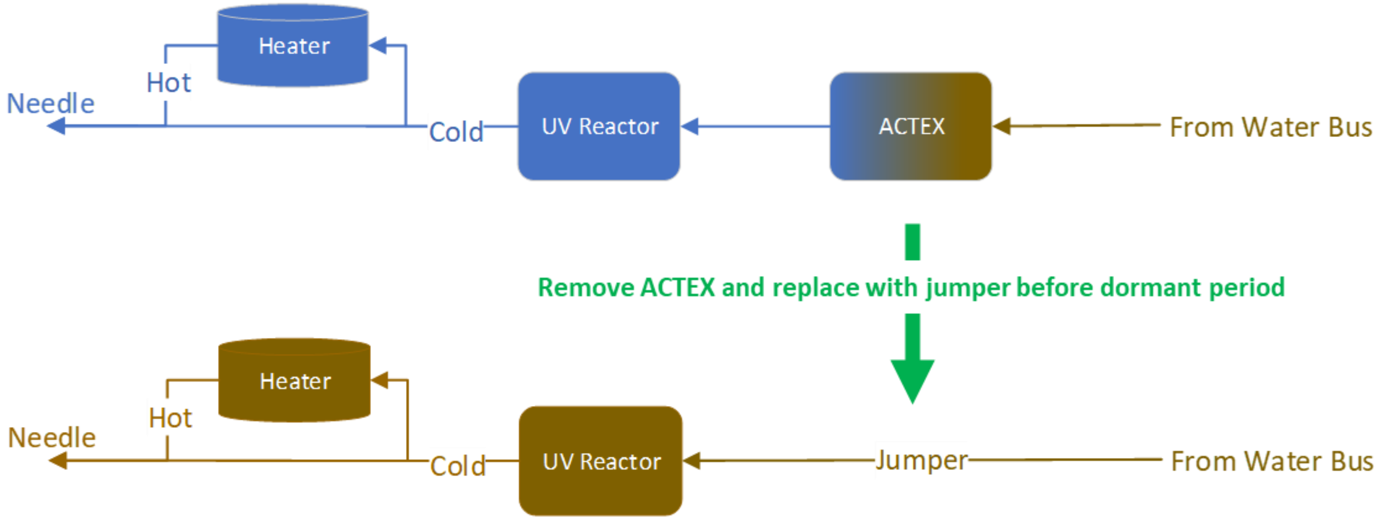
Preliminary Trade Study – *No Hot I_2 Removal*

Solutions that do not require iodine removal from hot water were identified:

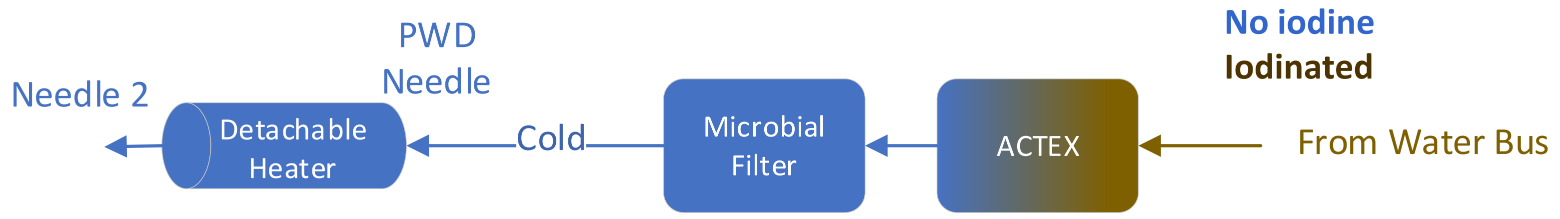
- **Point-of-use tankless heater**



- **Remove ACTEX and replace with jumper before dormancy**



Preliminary Trade Study – *No Hot I_2 Removal*



Alt. Config. 5: Detachable Point of Use Tankless Heater

- **This concept would need significant development / does not have current analog on station**
  - Could be turned on or off depending on dispense temperature preference
  - Could be a consumable that is replaced between missions
  - Could potentially be cleaned more easily by crew during the missions themselves
  - Increased risk of contamination due to increased crew handling.

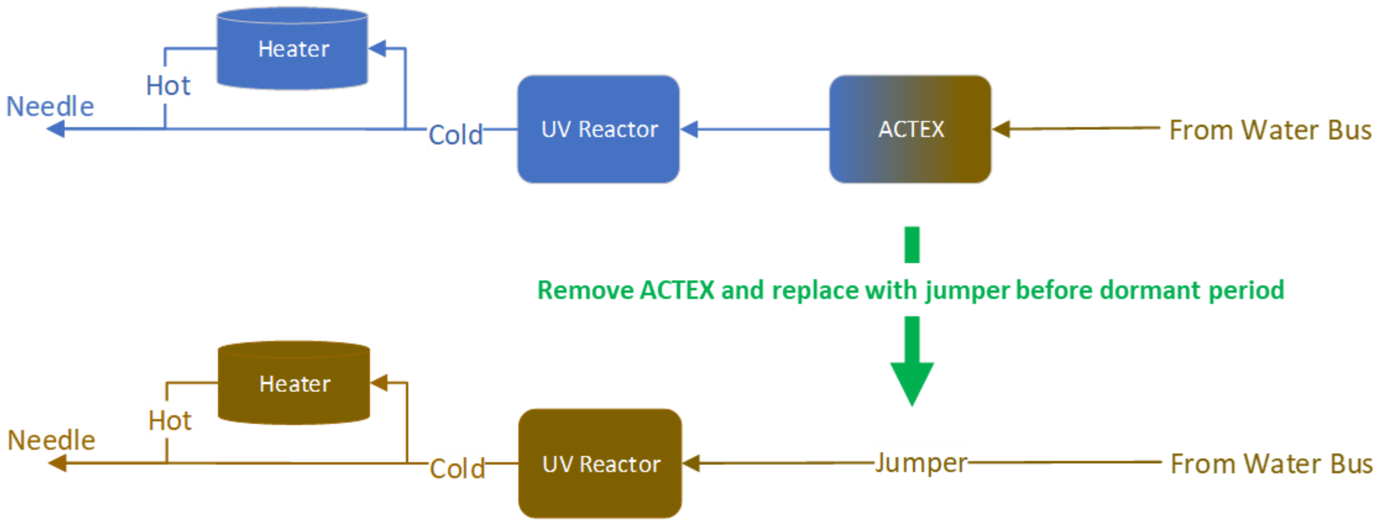
Config.	Non-iodinated Volume During Ops	Ambient Dispense Temp	Hot Dispense Temp	Power Demand	Built-In Mass	Consumable Mass	Bubbles to ACTEX
5	Minimizes non-iodinated vol. inside PWD, but increased handling may be problematic	Should meet req.	Should meet req.	Especially high peak power*	Reduces built-in mass	Does heater need to be replaced after dormancy?	Heater is downstream of ACTEX

Key: Favorable Condition (green) · More Info. Needed to Determine Favorability (yellow) · Unfavorable Condition (red)

How the cells are shaded:
- Non-iodinated Volume During Ops and Consumable Mass: More Info. Needed to Determine Favorability.
- Power Demand: Unfavorable Condition.
- Ambient Dispense Temp, Hot Dispense Temp, Built-In Mass and Bubbles to ACTEX: Favorable Condition.

**Preliminary research indicates that the peak power draw for induction tankless heaters < conduction tankless heaters*

Preliminary Trade Study – *No Hot I_2 Removal*



Alt. Config. 6: xPWD Config. + Jumper

- **Does not address NESC's concern of leaving downstream lines without biocide during non-dormancy**
  - Possible that biofilm forms downstream of the iodine filter during crewed ops.
- **Shocking the system with a high concentration of biocide before going dormant may mitigate biofilm**

Config.	Non-iodinated Volume During Ops	Ambient Dispense Temp	Hot Dispense Temp	Power Demand	Built-In Mass	Consumable Mass	Bubbles to ACTEX
6	Does not minimize	Should meet req.	Should meet req.	None	No extra	May require extra biocide shock between dormancy periods	Does not need any bubble mitigation

Key			
Key	Favorable Condition	More Info. Needed to Determine Favorability	Unfavorable Condition

Preliminary Trade Study – *No Hot I_2 Removal*

Config.	Description	Requires Hot I_2 Removal	Non-iodinated Volume During Ops	Ambient Dispense Temp	Hot Dispense Temp	Power Demand	Built-In Mass	Consumable Mass	Bubbles to ACTEX
5	Point of Use Tankless Heater	N							
6	Keep xPWD design, remove ACTEX before dormancy	N							
N/A	NESC Option 2: Replaceable End Leg	N							

Key			
Key	Favorable Condition	More Info. Needed to Determine Favorability	Unfavorable Condition