Ultrapure Water for SRF Applications

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USPAS:

Ultrapure Water: Overview and Application

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Objective

- **Provide a basic understanding of Ultrapure Water (UPW) systems**
  - Subsystems, primary unit operations
  - Design guidelines
  - Performance monitoring
  - Troubleshooting
- **Provide useful information to enable you to better communicate and engage with those more involved with UPW systems**
  - "Enough information to be dangerous"

Outline

- Importance and application of ultrapure water (UPW) in SRF
- How to make UPW – System fundamentals
- Materials used in UPW systems
- Monitoring UPW systems
  - Online and off-line analytical
- Troubleshooting quality issues
- Brief look at hot UPW systems
- Overview of Jefferson Lab's UPW system
- System Tour (time pending)

Why is UPW Important

- UPW is used extensively in the making of SRF cavities
  - Fabrication, chemical surface polishing, component cleaning, and final rinsing
  - Every RF surface is exposed to UPW
  - High quality UPW contributes to high performing SRF cavities
  - The use of UPW is part of the approach to eliminating field emission

UPW – Where and How is it Used

Cavity Process Tools

- **Horizontal and Vertical Electropolish** (HEP and VEP)
  - Post EP fill and dump cycles, ~70F
  - Final rinse through cavity to quality, ~70F
- **Buffered Chemical Polish Tool**
  - Post EP fill and dump cycles, ~70F
  - Final rinse through cavity to quality, ~70F and ~176F (hot UPW)
- **High Pressure Rinsing**
  - Typical pressure is 1200 psig, temperature is ~70F
  - Flow depends on pressure and nozzle configuration

UHV Cleaning

- **All ultrasonic cleaning stations**
  - UPW + Surfactants (Micro-90 and Liquinox)
  - UPW only
  - Component cleaning prior to cavity assembly
  - Parts clean prior to electron beam welding

What is Ultrapure Water

General Description

- Water that is devoid of all dissolved, suspended, organic and inorganic impurities
- Reality is the water is not 100% completely devoid of all impurities
- Devoid to the detection limits of analytical methods used to quantify the quality
  - Detection limits are often expressed in
    - PPM: Parts per Million (mg/L)
    - **PPB: Parts per Billion (µg/L) – Most relevant for SRF applications**
    - PPT: Parts per Trillion (ng/L)
    - PPQ: Parts per quadrillion (pg/ml)

1 ppb is roughly the equivalent of one drop in 250 chemical drums

More meaningful definition

- Water that has been purified to a specific standard or quality specification
- As many definitions as there are specifications

Typical Ultrapure Water System Fundamentals

with

References to Jefferson Lab's UPW System

Drinking Water to Ultrapure Water

- Start with the end in mind – UPW specification
- Quantify the quality of the city drinking water
- Producing UPW is a series of separation steps
  - Remove the dirt, sand and silt
  - Remove the larger organics and the chemicals the city adds to control harmful bacteria
  - Remove the dissolved mineral salts
  - Remove the dissolved solids
  - Remove the bacteria and microspores
  - Remove the very small particles
  - Remove the dissolved gases - Not in SRF
- Repeat until ppb levels are achieved

Ultrapure Water Specification

In the US, the most widely used requirements for UPW quality for microelectronics/semiconductor are documented by

- American Society for Testing and Materials International (ASTM) D5127 "Standard Guide for Ultra-Pure Water Used in the Electronics and Semiconductor Industries"
- Semiconductor Equipment and Materials International (SEMI F63) "Guide for ultrapure water used in semiconductor processing"

ASTM D5127 (2007)

Other industry specifications include:

- Electric Power Research Institute (EPRI) (power)
- American Society of Mechanical Engineers(ASME) (power)
- International Association for the Properties of Water and Steam (IAPWS) (power).
- Pharmaceutical plants follow water quality standards as developed by the United States Pharmacopeia

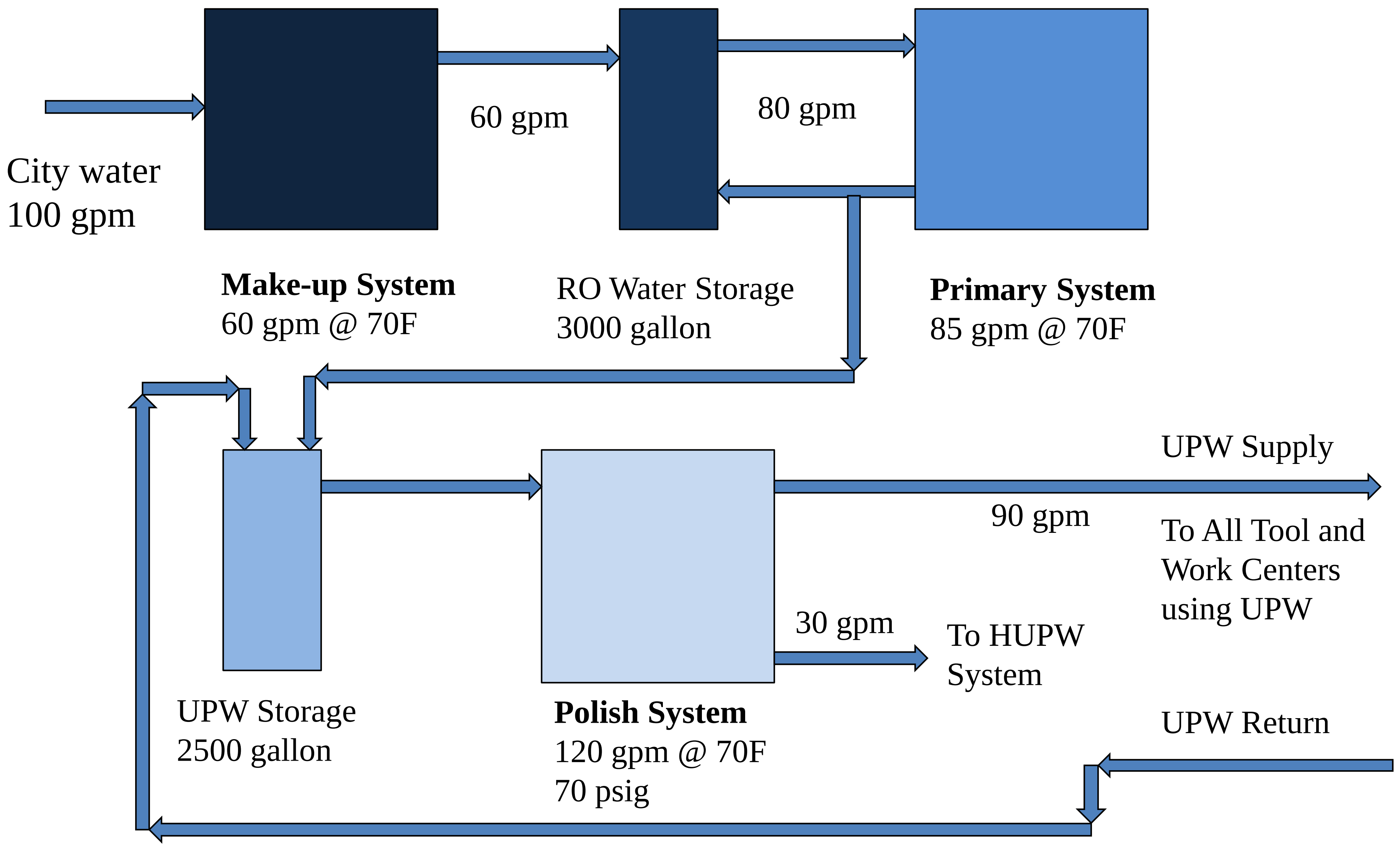
D5127 UPW Quality Specification

Parameter	Type E-1.1 (2007)	Type E-1.2 (2007)
Resistivity (Mohm-cm)	18.2	18.2
TOC (ppb)	2	1
On-line Particles (N/L) 0.05 - 0.1 microns 0.1 – 0.2 0.2 – 0.5 0.5 – 1.0 >1.0	 1000 350 100 50 20	 200 100 10 5 1
Bacteria (CFU/100ml)	3	1
Silica – total (ppb)	3	1
Silica – dissolved (ppb)	1	0.5
Anions (ppb)	0.05 max per anion	0.03 max per anion
Ammonium	0.1	0.02
Metals (ppb)	0.02 max per metal	0.002 – 0.005 max per metal
Boron (ppb)	0.3	0.05

Newport News City Water Analysis

Parameter	Range	Units
pH	6.6 - 8.5	-
conductivity	195 – 310	µS
Total Dissolved Solids	125-200	ppm
TSS	1	ppm
Turbidity	0.03 - 0.60	NTU
Silica	2.8 - 8.0	ppm
M Alkalinity	45 - 55	mg/l as CaCO3
HCO3 Alkalinity	45 - 55	mg/l as CaCO3
CO3 Alkalinity	0.5 - 1.5	mg/l as CaCO3
Total Alkalinity	21 - 61	mg/l as CaCO3
Calcium	45 - 105	mg/l as CaCO3
Magnesium	4 - 14	mg/l as CaCO3
Barium	0.03	mg/l as CaCO3
Strontium	0.15	mg/l as CaCO3
Total Hardness	52 - 105	mg/l as CaCO3
Iron	0.03 - 0.05	ppm
Manganese	0.01	ppm
Aluminum	0.1	ppm
Chlorine/Chloramines	1	ppm
Ammonia	0.5 - 0.7	ppm
Sodium	6.0 - 34.0	ppm
Potassium	1.6 - 2.2	ppm
Chloride	17 - 43	ppm
Sulfate	45 - 90	ppm
Nitrate	1 - 4	ppm
Fluoride	1 - 3	ppm

Typical UPW System



Make-up System

Purpose

- “Make up” for the water consumed in making and using the UPW and hot UPW

Configuration

- Typically pretreatment followed by one or more reverse osmosis (RO) systems
  - Pretreatment
    - Specific to raw water quality
    - Removes contaminants harmful to reverse osmosis systems
  - Reverse Osmosis (RO)
    - Considered to be the “work horse” of UPW systems
    - Removes dissolved solids, organics, silica and particulates

Typical Pretreatment Unit Operations

  - Multi-media Filters
    - Removes suspended solids such as fine silt and sand
  - Activated Carbon Filters
    - Removes higher molecular weight organic compounds
    - Removes oxidizers such as chlorine and chloramines
  - Water Softeners
    - Removes calcium and magnesium salts
  - Chemical Injection
    - Sodium bisulfite as a reducing agent
    - Antiscalant to help prevent precipitation of salts in the RO system
  - RO Pre-filters
    - Used to remove particulates nominally 1 micron and larger

Typical UPW Make-up System

City water

110 gpm

Activated Carbon Filters
- Large organics
- Oxidizers

Water Softeners
- Mineral salts

Heat Exchanger
- Heats to 70F

10 gpm to Boilers

100 gpm

NaOH Injection

115 gpm

15 gpm

85 gpm

1st Pass RO

Suspended and dissolved solids , organics

2nd Pass RO

30 gpm to recovery

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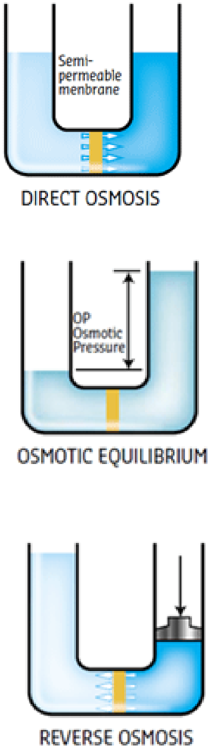
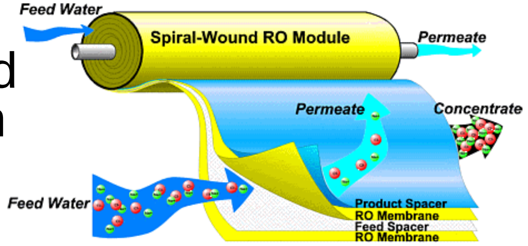
Reverse Osmosis

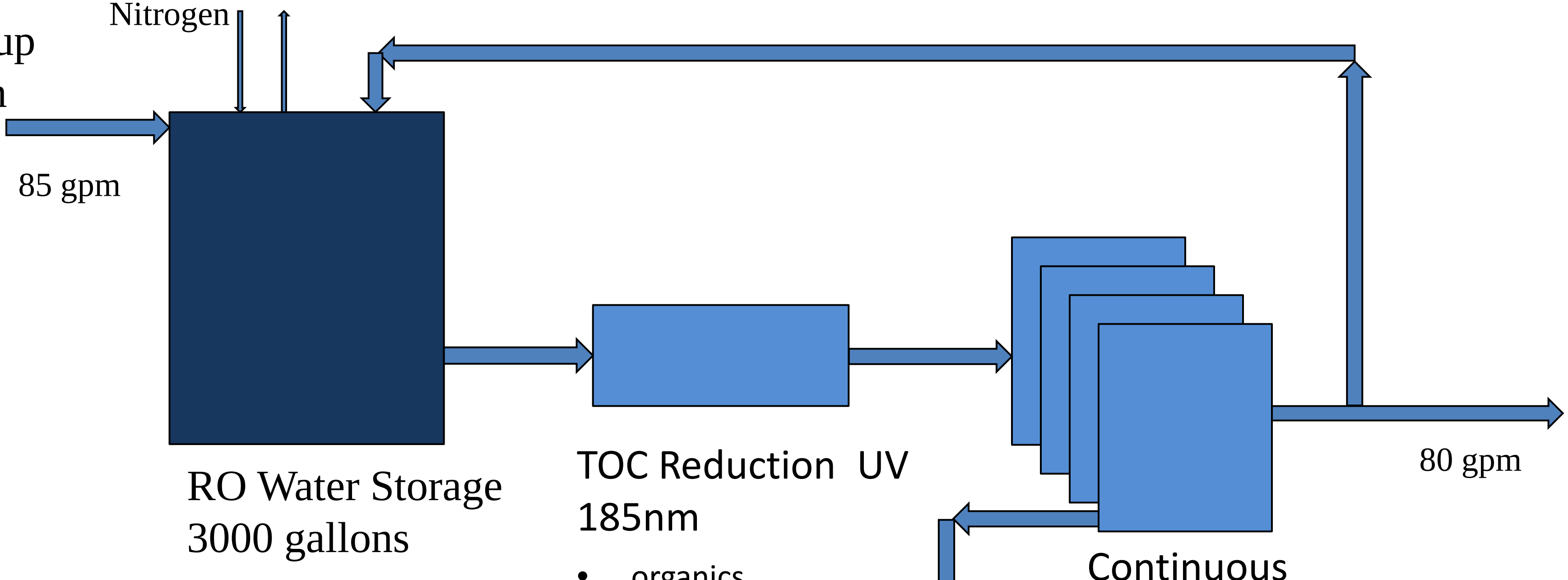
Overview

- Reverse of osmosis
- Water flows across the surface of a semi-permeable membrane
- Pressure, higher than the osmotic pressure, is used to drive water through the membrane
- Typically removes > 98% of dissolved solids, organics, silica and particles
- Performance can be measured in terms of permeate flux, salt rejection and recovery rate
  - **Flux is the volume of permeate produced per membrane surface area per time**
  - **Rejection is a percentage which compares the salt concentration in the permeate to that in the feed**
  - **Recovery rate is the fraction of the feed flow that passes through the membrane**
- Performance is affected by feed water quality, temperature and pressure
- Membranes are subject to silt and bio fouling and scaling (solubility limits are exceeded resulting in precipitates)





Typical UPW Primary System



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UPW Primary System

Purpose

- Serves as the “primary” deionization stage
- Further reduce dissolved ions and organics

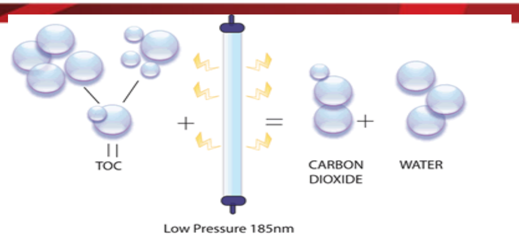
Configuration

- Typically flows in a loop starting from RO permeate storage tank through organic oxidizers followed by ion exchange then back to RO storage

Typical Primary Unit Operations

- Ultraviolet oxidation
  - 185 nm wavelength
- Ion exchange
  - Mixed bed, containing both anion and cation exchange resin in same unit
  - Electrodeionization (EDI) (a.k.a continuous deionization (CDI))
- Ultraviolet sterilizer
  - 254nm wavelength
- Water is sent to UPW storage tank in Polish system as needed, triggered by water level in UPW tank

UPW Primary System

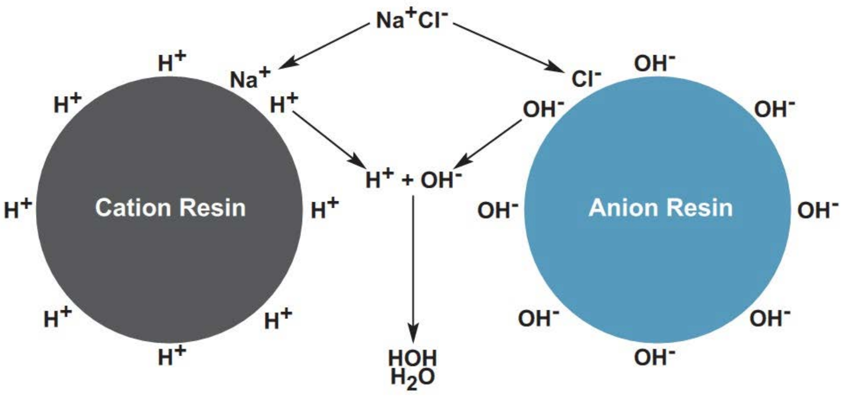


Photolytic Oxidation

- Uses 185nm ultraviolet light
- Oxidation occurs by direct UV absorption and through production of hydroxyl radicals
- Generally, organics are broken down to CO2 + H2O

Ion Exchange

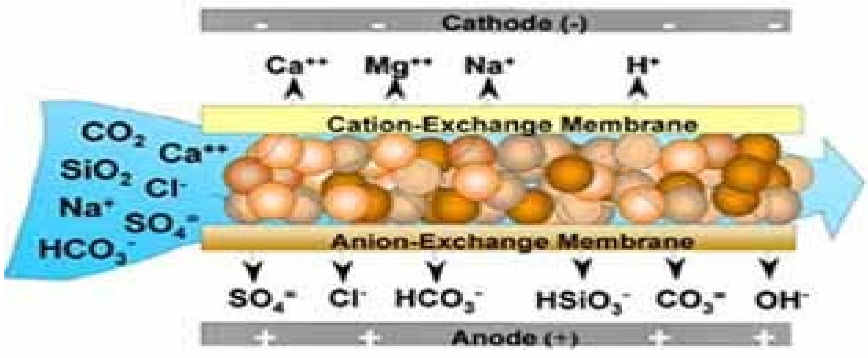
- Cation resin in the H+ form
  - H+ is exchanged for cations
  - R'H + $Na^+ \rightarrow$ R'Na + H^+
- Anion resin in the OH- form
  - OH- is exchanged for anions
  - R''OH + $Cl^- \rightarrow$ R''Cl + OH^-
- H^+ and OH- combine to form H_2O
- Process is reversible
  - Resin is regenerated back to original form using strong acid and base



Continuous Electrodeionization

Advantages

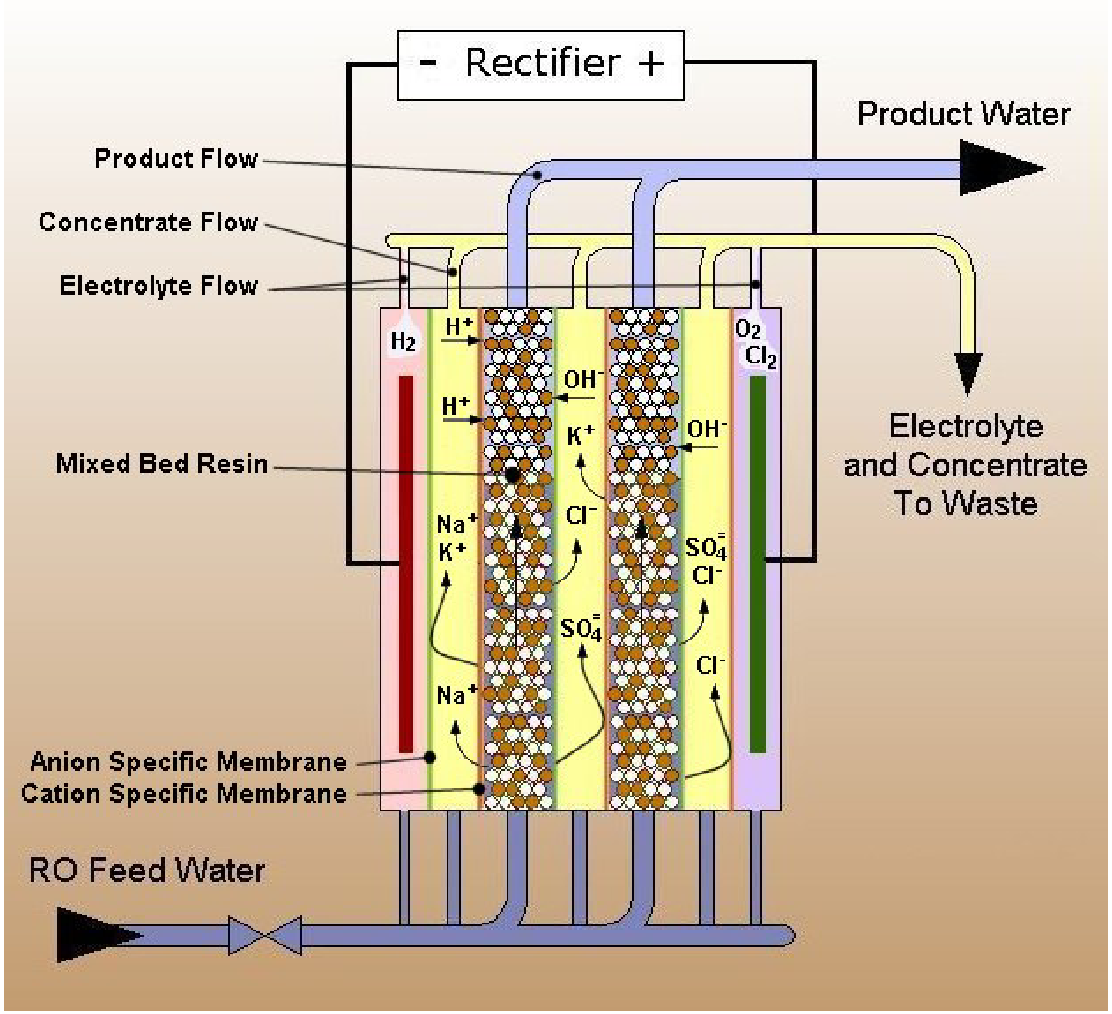
- Capable of producing water with resistivity > 17.0 Mohm
- Has a reject stream of 5% to 10%
- Resin does not need to be regenerated



How CEDI works:

- Feedwater entering the system flows inside resin/membrane product and concentrate compartments.
- The feed stream flows parallel to the membrane surface.
- Resins capture dissolved ions.
- Electric potential drives captured cations through the cation membranes and captured anions through the anion membranes.
- Cation-permeable membranes transport cations out of the diluting compartment, but prevent anions from leaving the concentrate compartment.
- Anion-permeable membranes transport anions out of diluting compartment, but prevent cations from leaving the concentrate compartment.
- Waste stream removes concentrated ions from the system.
- Product water leaves the system.

Electrodeionization



UPW Polish System

Purpose

- "Polishes" water to final quality, including temperature and pressure
- Further reduce dissolved ions, organics, particles and bacteria

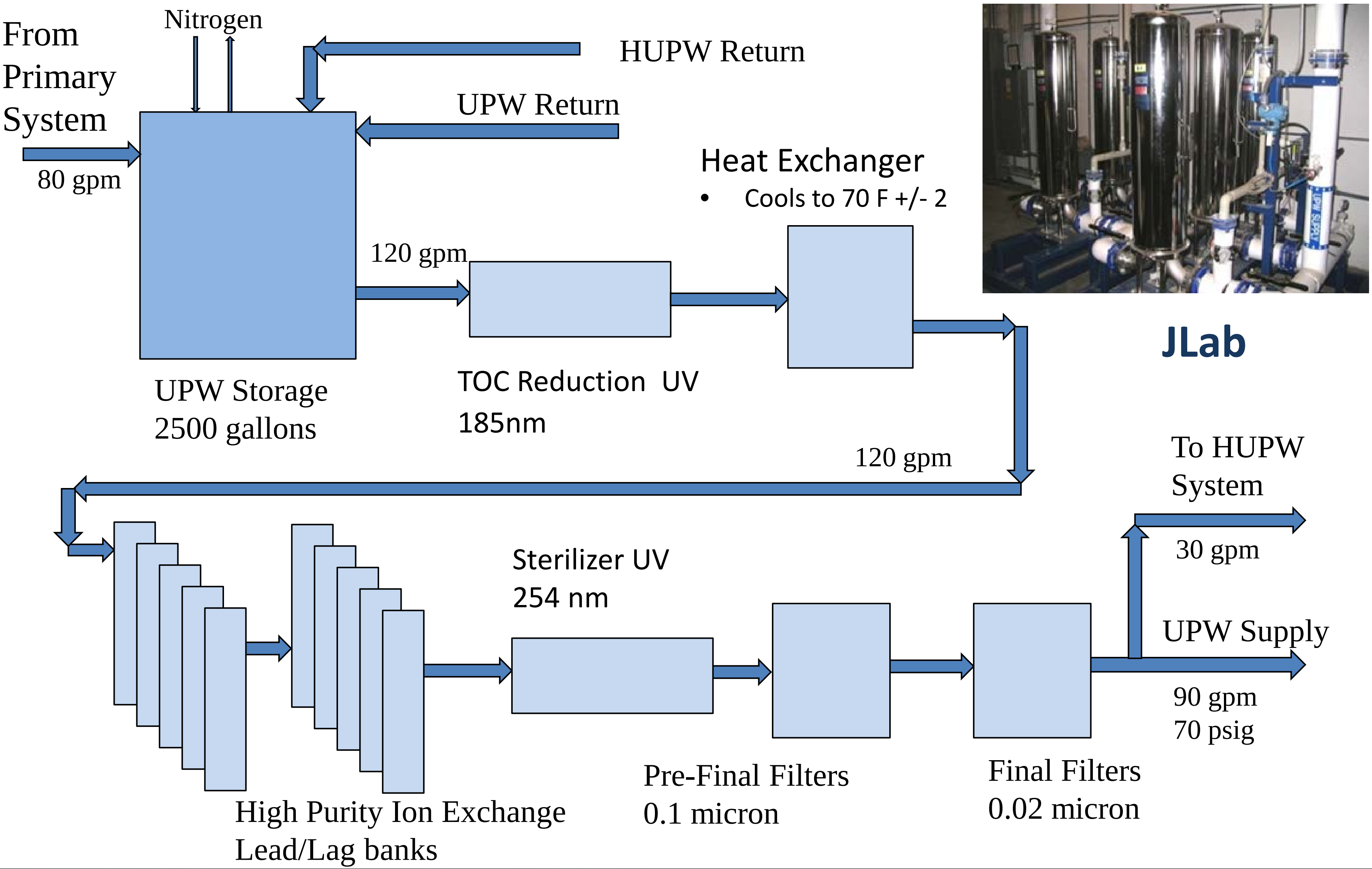
Configuration

- Typically flows in a loop starting from UPW storage tank through polish system, out to distribution and return to UPW tank

Typical Polish Unit Operations

- Ultraviolet oxidation
  - 185 nm wavelength
- Ion exchange
  - Mixed bed, containing both anion and cation exchange resin in same unit
  - Electrodeionization (EDI) (a.k.a continuous deionization (CDI))
- Ultraviolet sterilizer
  - 254nm wavelength
- Particulate Filtration
  - Pleated cartridge or Ultrafiltration (UF)
- Water is sent to UPW storage tank in Polish system

Typical UPW Polish System



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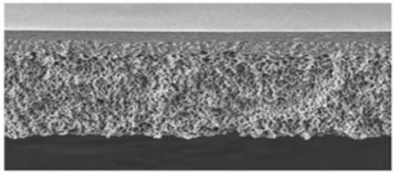
Filtration

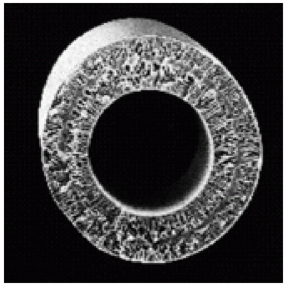
Pleated Cartridge

- Removal achieved by sieving through an asymmetric membrane
  - Some membranes have a charged surface
  - Materials include teflon, nylon and polysulfone
- Pre-final filters 0.1µ
- Final filters 0.04µ to 0.02µ range
- Filters housings are typically 316L stainless steel electropolished for a very smooth interior surface finish

Asymmetric Membrane



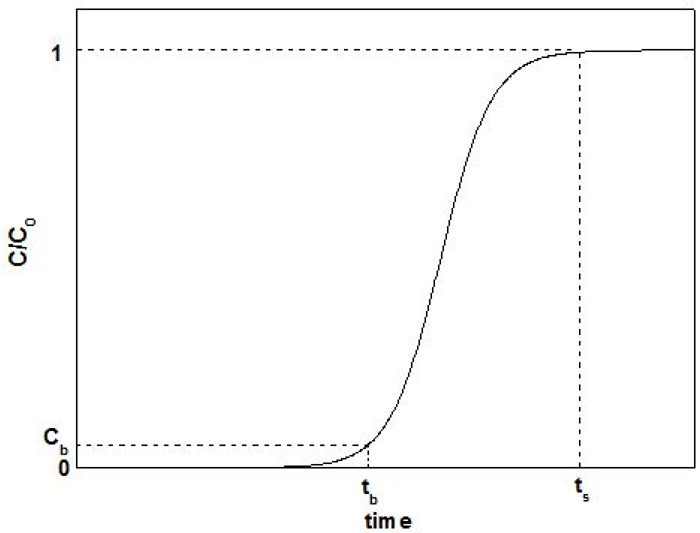
Ultrafiltration



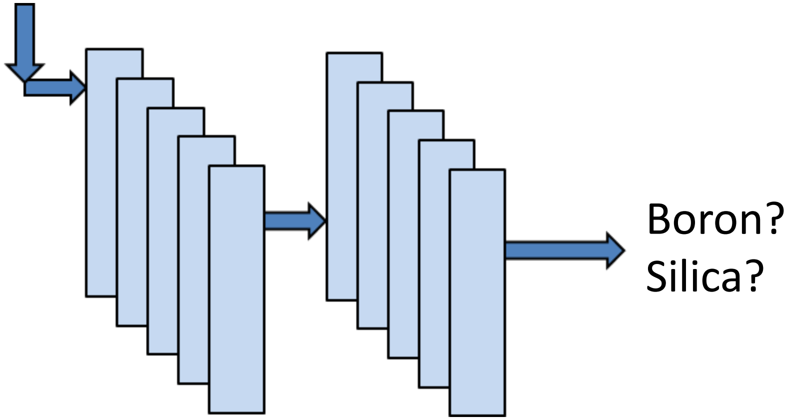
- Hollow fiber membranes bundled and packed into a housing
- Housings are packaged into a system sized for required flow
- Water flows tangential to the membrane surface
- Able to filter out smaller particles and low molecular weight organics
- Flow is from outside to inside
- Systems have a feed, permeate and retentate stream

Polish Ion Exchange

- Resin type should be selected specifically for UPW, low TOC ($$)
- Very clean as indicated by superior rinse up characteristics
- Mixed bed in the H+/OH- form
- Use virgin resin only
  - No regeneration
- Lead-lag operation is preferred
  - One pass requires inlet to be high resistivity (>18 Mohm)
- Change resin ahead of breakthrough



Representative breakthrough curve for ion exchange



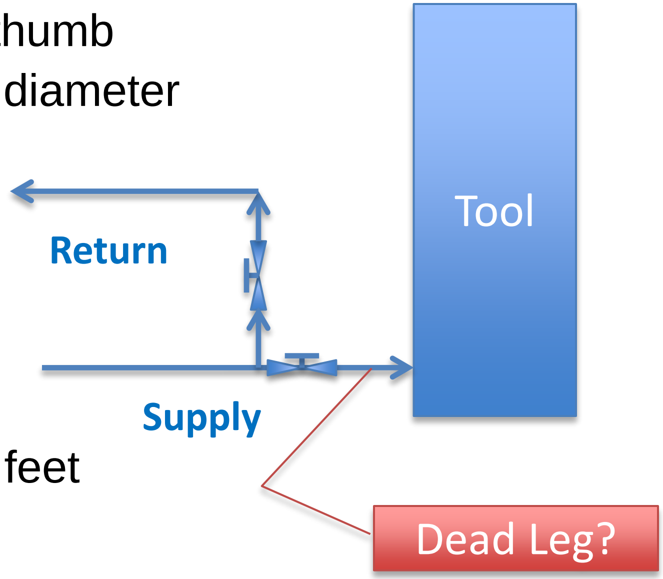
UPW Distribution and System Materials of Construction

UPW Distribution System

Sizing

- Continuously flowing in a temperature and pressure controlled loop
- Supply and return piping with a back pressure control station at the end of supply
- Loop flow can be determined using 1.8 x average total consumption
  - Used to accommodate peak demand and maintain proper velocities

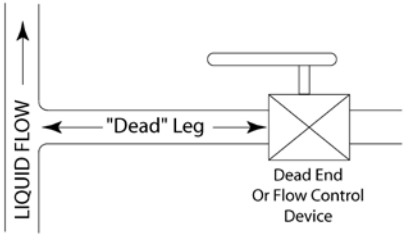
- Supply Piping
  - Turbulent flow to minimize growth of biofilm
  - Minimum of 4 fps is frequently used as a rule of thumb
  - Better to use Reynolds number to minimize pipe diameter
- Return Piping
  - Minimum of 0.5 fps
  - Minimize pressure loss on flow
- Laterals and Feed Lines to Tools
  - Must also flow in a loop with supply and return
  - Keep pressure drops to less than 2 psig per 100 feet



Dead Legs

Dead Legs are one of the villains of a properly designed ultrapure water distribution system

- "Dead Leg" refers to a stagnant zone of water
- Occurs any place in the system where there is no flow or very little flow for a pipe length equal to or greater than 4 to 6 pipe diameters
- Most often occurs at branch valves and tool connections
- **Promote bacteria growth**



Means to avoid

- Keep any section that will experience no flow to less than 4-6 pipe dia.
- Use "zero dead-leg" valves
- Install by-pass flows around pumps and control valves
- Install "trickle flow" paths to provide continuous flow
  - Wand head on the HPR is one example

Materials of Construction

General Guideline for Material Selection

- Wetted components that have smooth, non-porous surfaces
- Joining methods for piping and lining that minimize crevices and discontinuities
- Joining methods that minimize or eliminate the use of glues or solvents capable of migration into the water
- Materials that are free of biological degradable substances that can be nutrient sources
- Materials should not contain leachable additives, such as pigments

Piping System Materials and Valves

Make-up System

- Piping
  - Up stream of the RO system
    - Clean Schedule 80 PVC, solvent joints
    - PFA, FEP tubing, compression
    - EPDM (ethylene propylene diene terpolymer) gaskets
  - Down stream of the RO system
    - No PVC after the RO system
    - Polypropylene, fused
    - DuPont™ Viton®
- Valves
  - Up stream of the RO system
    - Sizes 3” or less use ball or diaphragm valves
    - Sizes greater than 3” use butterfly valves
  - Down stream of the RO system
    - Do not use ball valves, only diaphragm or butterfly based on size criteria

Primary System

- Piping
  - Up stream of the Ion Exchange system
    - Polypropylene, fused
    - PFA, FEP tubing, compression
    - DuPont™ Viton®
  - Down stream of the Ion Exchange system
    - Polypropylene, fused
    - Polyvinylidene fluoride (PVDF) preferred, IR fused
    - PTFE (Teflon) encapsulated Viton
- Valves
  - Up stream of the Ion Exchange system
    - Sizes 3” or less use diaphragm valves
    - Sizes greater than 3” use butterfly valves
  - Down stream of the Ion exchange system
    - Use high purity diaphragm and butterfly valves only
    - Polypropylene or Teflon lined valves

Piping System Materials and Valves

Polish and Distribution System

- Piping – All sections of the system
  - Polyvinylidene fluoride (PVDF),
    - Infrared (IR), Bead and Crevice Free (BCF) or Butt fusion
    - Avoid socket welds
    - Avoid threaded fittings
  - PFA and FEP tubing is an option for diameters less than 1 inch
    - Commonly used for feeds to tools
    - Use flared style joining technology
- Valves – All sections of the system
    - Sizes 3” or less use high purity diaphragm valves, teflon wetted materials
    - Sizes greater than 3” use high purity butterfly valves, telfon wetted materials
- Gaskets and Seals – All sections of the system
    - ePTFE – expaned teflon
    - Teflon encapsulated DuPont™ Viton®

Monitoring Quality of UPW Systems

Online Monitoring

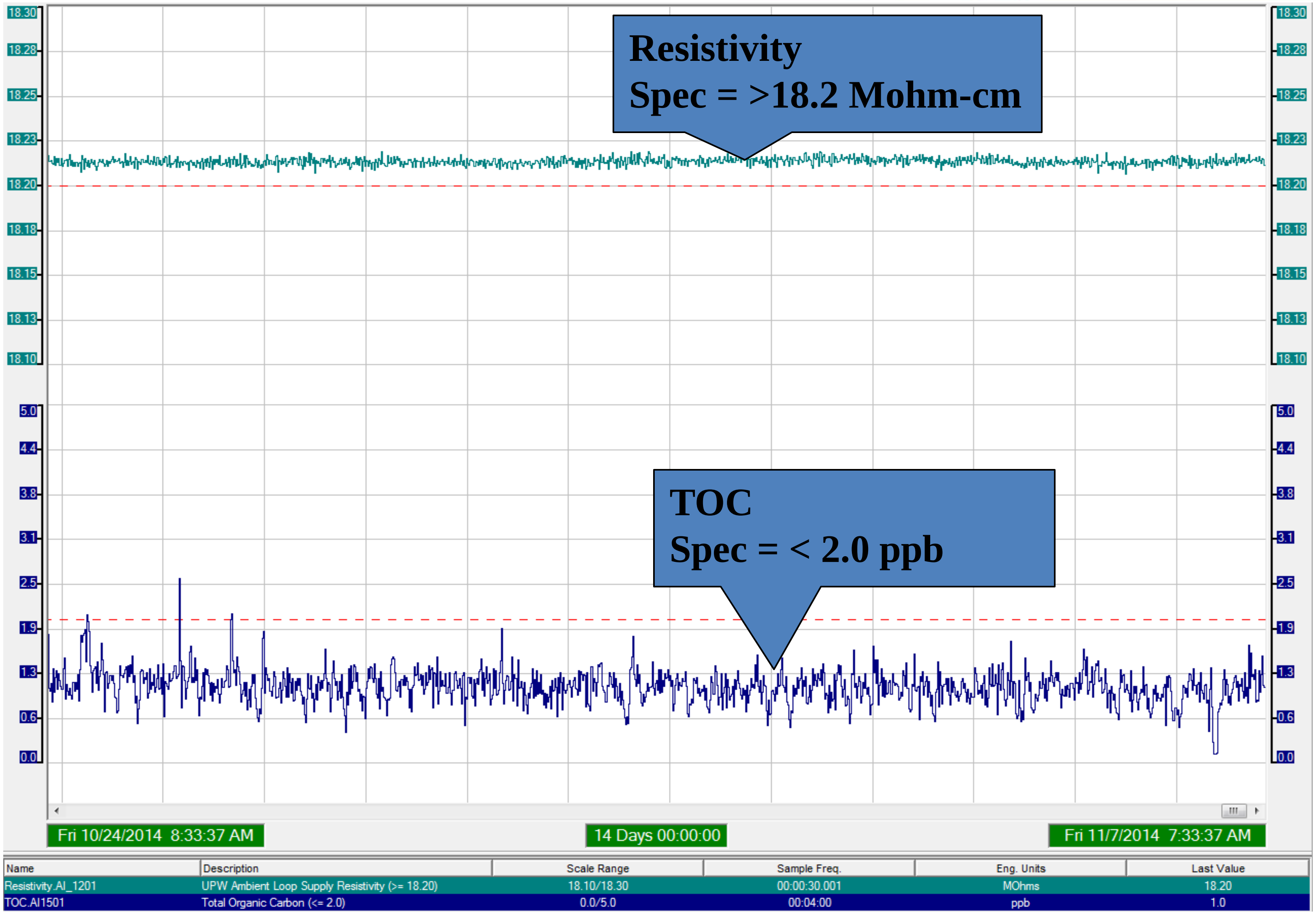
Parameter	Importance
Make-up System	
Pre-RO temperature	Needed to adjust RO feed water temperature
Pre and Post-RO conductivity	Needed to track RO salt rejection
Pre and Post-RO flowrate	Needed to track RO recovery and flux
Pre-RO oxidation/reduction potential	Needed to monitor effectiveness of oxidation reduction
Pre-RO pH	Needed to adjust pH upstream of RO
Primary System	
Pre and Post-ion exchange resistivity	Needed to monitor effectiveness of primary ion exchange
Temperature, pressure and flow of Primary Loop	Needed for basic troubleshooting

Online Monitoring

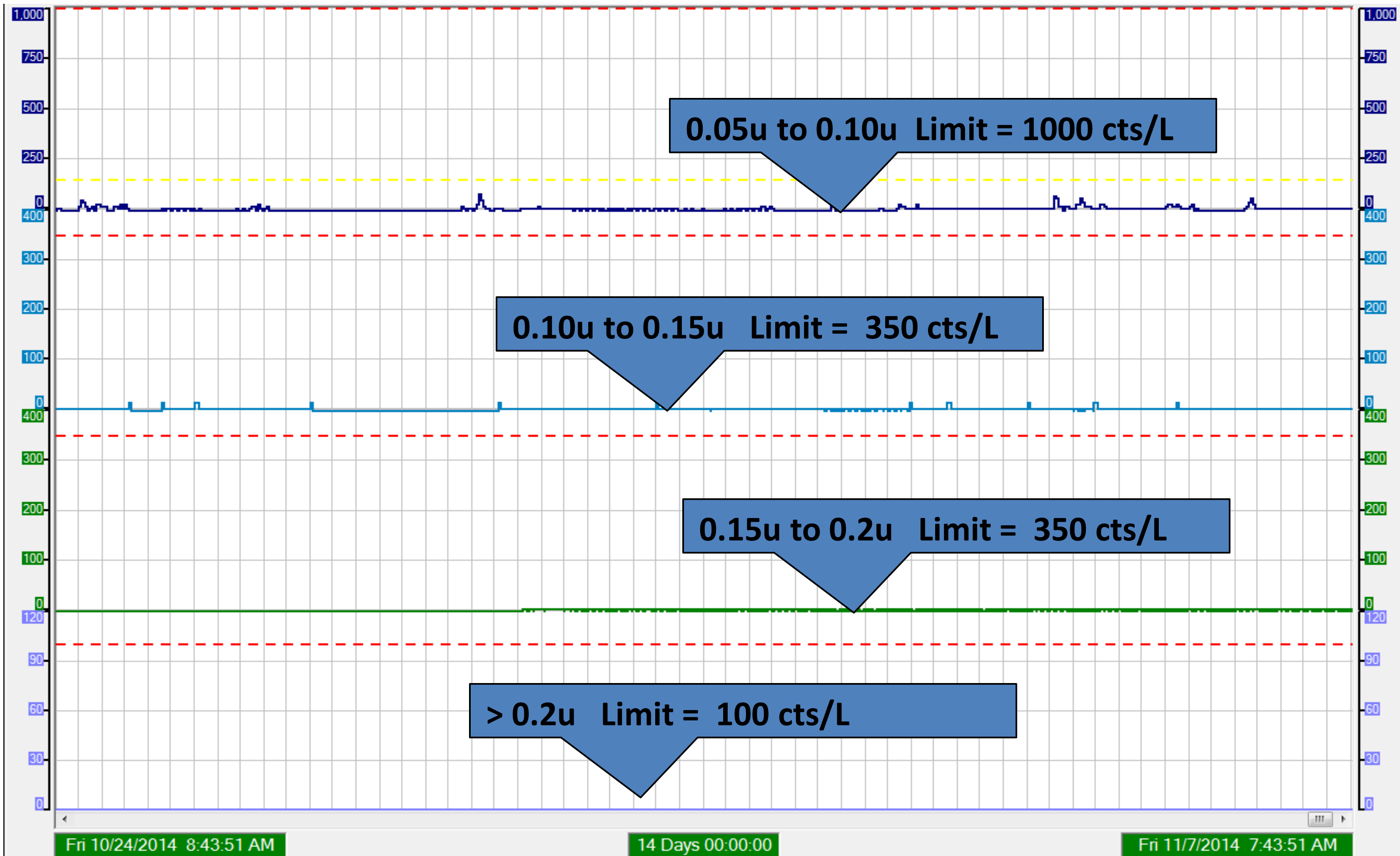
Parameter	Importance
Polish System	
Pre and Post-polish ion exchange resistivity	Needed to monitor effectiveness of polish ion exchange
Temperature, pressure and flow	Needed for basic troubleshooting
UPW Supply (post-polish system)	
Temperature	Needed to track and adjust UPW supply temperature
Resistivity	Needed to track supply quality
TOC	Needed to track supply quality
Silica	Needed as an indicator of ion exchange leakage
Particles	Needed to track supply quality and effectiveness of final filters
Pressure at end of Supply	Needed to monitor supply pressure

Use of a data historian is recommended to retain and display key online quality parameters

UPW Resistivity and TOC Trend



UPW Particle Trend Chart



Name	Description	Scale Range	Sample Freq.	Eng. Units	Last Value
ParticleCounts0_05u.AI_1501_1	0.05 - 0.10 um (Limit <= 1000 cts/L)	0/1,000	00:30:00	counts/L	0
ParticleCounts0_1u.AE_1502_2	0.10 - 0.15 um (Limit <= 350 cts/L)	0/400	00:01:00	counts/L	1
ParticleCounts0_15u.AE_1502_3	0.15 - 0.20 um (Limit <= 350 cts/L)	0/400	00:01:00	counts/L	0
ParticleCounts0_2u.AI_1502_4	> 0.20 um (Limit <=100 cts/L)	0/120	00:01:00	counts/L	-1

Off-line Monitoring

Parameter	Post RO	Post Primary Ion Exchange	Post Final Filters	High Pressure Rinse Tool
In-house Bacteria	---	Weekly	Weekly	Weekly
Bacteria	---	Monthly	Monthly	Monthly
Total Silica	Monthly	Monthly	Monthly	Monthly
Dissolved Silica	Monthly	Monthly	Monthly	Monthly
Anions	Quarterly	Quarterly	Quarterly	Quarterly
Trace Metals	Quarterly	Quarterly	Quarterly	Quarterly
TOC	Monthly	Monthly	Monthly	Monthly
Particles (SEM)	---	Biannual	Biannual	Biannual

Good practice is to provide sample ports upstream and downstream of major unit operation (e.g. RO, ion exchange, UVs, etc.)

Troubleshooting UPW Systems Basics

UPW Basic Troubleshooting

Trouble	Possible Causes	Response
Resistivity drops below normal value (18.2Mohm-cm)	Resistivity meter has issues	• Check meter calibration • Check to see meter is working properly • Clean probe

	Ion exchange resin is depleting	• Check silica levels
		  • Online analyzer
		  • Offline grab samples
		• Check ion exchange change-out records
		  • When was last change out or regeneration?
		• Look for bad resin bed

	Higher organic load	• Turn off UV oxidizers, if resistivity returns to normal, then possible organic contamination

UPW Basic Troubleshooting

Trouble	Possible Causes	Response
TOC has increased above normal	TOC analyzer is not working properly	• Check against another analyzer if available • Check meter calibration • Check TOC levels offline via grab samples

	UV Oxidizer performance is degrading	• Check irradiance meter on UV unit
		    • Replace bulbs if low
		• Inspect quartz sleeves for discoloration
		    • Replace as needed

	Higher organic load	• Verify RO system is working properly
		    • Check conductivity of permeate, compare to normal
		    • If high, check each vessel

UPW Basic Troubleshooting

Trouble	Possible Causes	Response
Bacteria counts are higher than normal	Sample port is contaminated	• Clean sample port with IPA, then flush and exercise valve • If high count persist, and other locations are clean, replace sample valve
	Dead leg	• Check sample valve and piping system for sections of no flow or slow flow. • Eliminate dead leg (open valve, add a bleed flow) • Increase velocity by reducing pipe diameter
	254nm UV lamp performance has deteriorated	• Check irradiance meter on UV unit • Inspect quartz sleeves for discoloration • Test before and after UV

UPW Basic Troubleshooting

Trouble	Possible Causes	Response
Particle counts are higher than normal	Analyzer is not working properly	• Check for calibration • Last factory calibration?
	Bubbles (bubbles count!)	• Check feed line for air intrusion • Verify proper flow and pressure • Replace feed line and associated metering valve • Test using offline method, such as SEM
	Filter performance has degraded	• Check filter housings for loose or unseated cartridge • Check for filter integrity using integrity test
	RO system not working properly	• Check permeate conductivity • If high, look for problem vessel
	Higher load	• Look for sources of particle shedding

Hot UPW Systems (HUPW)

HUPW System

Purpose

- Hot UPW is reportedly more effective in some cleaning applications particularly those involving viscous acids
  - Currently: Buffered Chemical Polish
  - Future: Electropolish (sulfuric acid)

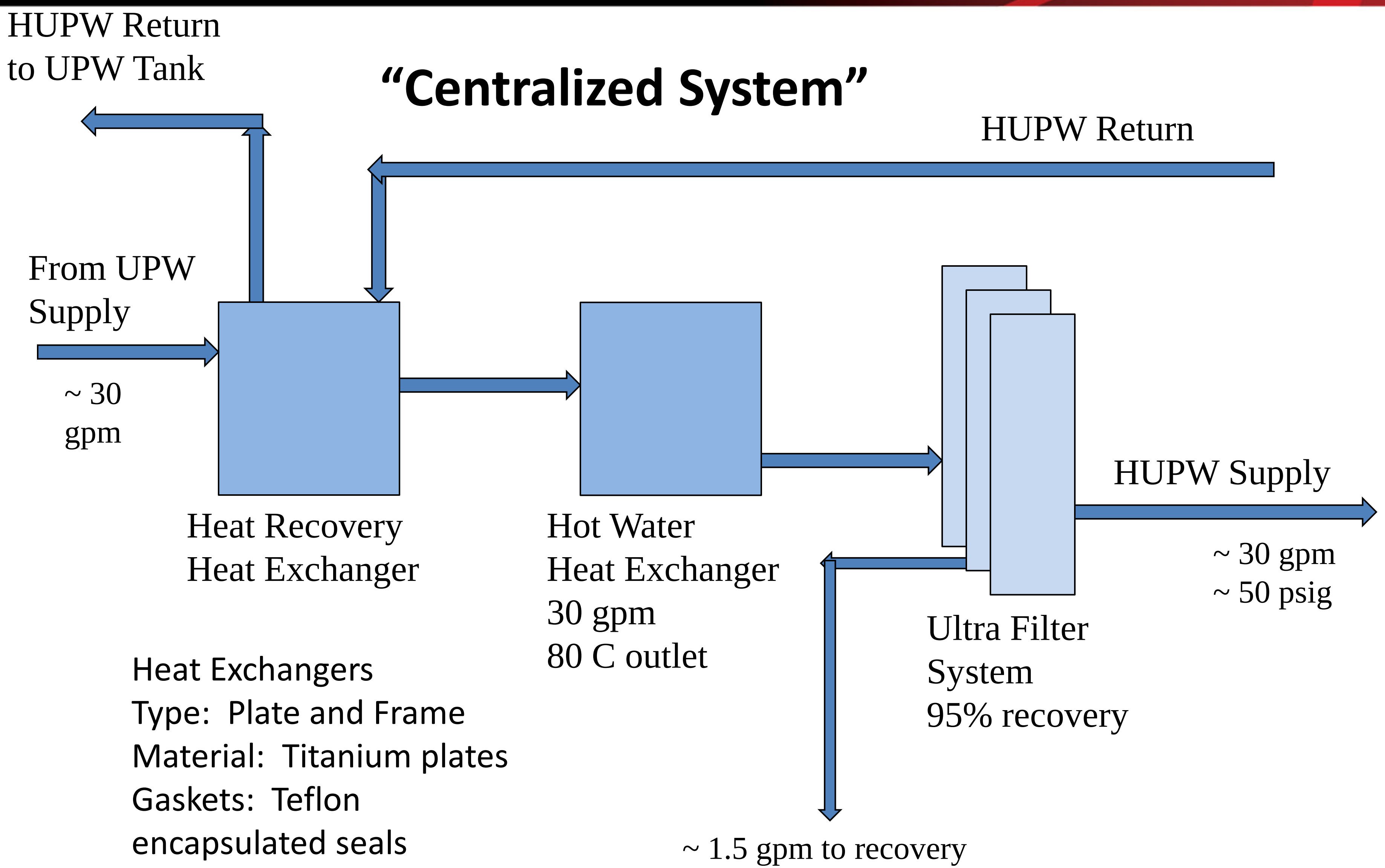
Configuration

- Fed from ambient UPW system
- Heats water to specified temperature – 80C

Configuration

- High Capacity
  - Heat recovery heat exchange: Recovers heat from HUPW return
  - Hot water heat exchanger: Uses hot water to heat UPW to specified temperature (80C)
  - Ultrafiltration: Removes added particles from pumps and heat exchangers
- Point of Use
  - Packaged electrical heaters, teflon wetted components, high electrical loads

Typical Hot UPW System



Heat Exchangers
Type: Plate and Frame
Material: Titanium plates
Gaskets: Teflon encapsulated seals

Jefferson Lab's UPW System Performance

Ultrapure Water Systems

Main UPW System

- Microelectronic Type E-1.1
  > 18.2 Mohm/cm^2, < 2 ppb TOC, < 2 ppb silica, < 1ppb all other ions
- **60 gpm (227 liters/min)** make-up capacity to loop (shared with HUPW)
- **90 gpm (340 liters/min)** polish loop
- Provides water to the HPR, BCP, HEP, VEP tools
- Provides water to all chemistry rooms
- ~ 50 psig Nominal (55 psig measured)

<u>Centralized</u> Hot UPW System

- **20 gpm (76 liters/min)** make-up capacity to loop
- **30 gpm (114 liters/min)** polish loop
- ~ 50 psig Nominal
- **80 C (176 F)**

- Primary RO Storage: 11360 Liters
- UPW Storage: 9460 Liters

JLab UPW Performance

Parameter	Specification	Weekly Average	
Resistivity	≥18.2 Mohm-cm	18.22	
Total Organic Carbon (TOC)	≤ 2 ppb	1.35	
Particles Counts		Average	Max
Chanel 1: .05-.1 um	≤ 1000 counts/L	6.35	120
Chanel 2: .1-.15 um	≤ 350 counts/L	1.33	19
Chanel 3: .15-.2 um	≤ 350 counts/L	0	0
Chanel 4: >.2 um	≤ 20 counts/L	0	1
	Temperature (ºF)	Pressure (psi)	Flow (gpm)
AUPW (Ambient)	70	70	89
HUPW (Hot)	176	66	17

Metrics / Specification

Typical Metrics / Specification

- System designed to Modified ASTM D5127 E1.1
  - No dissolved oxygen
  - No boron
- Online Measurements
  - Particles
  - TOC
  - Resistivity(s)
  - Temp, Flow, Levels etc..
  - Silica (Future)
- Lab Measurements
  - Bacteria
  - Silica
  - Various Anions & Metals

JLab UPW - Resistivity & TOC

	TOC (ppb)	Resistivity (MOhm-cm)
Maximum Value	3.5	18.23
Minimum Value	0.1	18.2
Average	1.070	18.214
Std. Deviation	0.316	0.006

Instrument:

Res. – Mettler-Toledo (Thorton): Model 230 sensor, Model 770Max Analyzer

TOC- GE (Sievers) Model 900 On-Line

JLab UPW - Particles

UPW Particles (cts/L)				
	.05-.10 um	.10-.15um	.15-.2um	>.2um
Maximum Value	94	14	1	0
Minimum Value	0	0	0	0
Average	2.88	0.30	0.00	0.00
Std. Deviation	9.10	1.76	0.06	0.00

Instrument:

Particle Measurement Systems (PMS) Model HSLIS 50e

Grab Sample Data

Item Description	Parameter	Units	Balazs Result	E1.1 Specification E1.1
Bacteria-ASTM Method-48 Hr Incubation	Bacteria/100mL	cfu/100ml	3	3*
Low-level Dissolved Silica	Silica, LL dissolved	ppb (ug/L)	0.2	1ppb
Total Silica	Silica, Total	ppb (ug/L)	0.7	3ppb
Anions				E1.1 (ppb)
Anions by IC (UltraPure)	Fluoride (F-)	ppb (ug/L)	*	0.05
Anions by IC (UltraPure)	Chloride (Cl-)	ppb (ug/L)	*	0.05
Anions by IC (UltraPure)	Nitrite (NO2-)	ppb (ug/L)	*	0.05
Anions by IC (UltraPure)	Bromide (Br-)	ppb (ug/L)	*	0.05
Anions by IC (UltraPure)	Nitrate (NO3-)	ppb (ug/L)	*	0.05
Anions by IC (UltraPure)	Phosphate (HPO4=)	ppb (ug/L)	*	0.05
Anions by IC (UltraPure)	Sulfate (SO4=)	ppb (ug/L)	*	0.05
Single Ion by IC (NH4)	Ammonium (NH4+)	ppb (ug/L)	*	0.1
Metals				E1.1 (ppb)
30 Elements Low Level in UPW by ICP-MS	Aluminum (Al)	ppt (pg/ml)	*	0.02
30 Elements Low Level in UPW by ICP-MS	Barium (Ba)	ppt (pg/ml)	*	0.02
30 Elements Low Level in UPW by ICP-MS	Boron (B)	ppt (pg/ml)	*	0.1
30 Elements Low Level in UPW by ICP-MS	Calcium (Ca)	ppt (pg/ml)	*	0.02
30 Elements Low Level in UPW by ICP-MS	Chromium (Cr)	ppt (pg/ml)	*	0.02
30 Elements Low Level in UPW by ICP-MS	Copper (Cu)	ppt (pg/ml)	*	0.02
30 Elements Low Level in UPW by ICP-MS	Iron (Fe)	ppt (pg/ml)	*	0.02
30 Elements Low Level in UPW by ICP-MS	Lead (Pb)	ppt (pg/ml)	*	0.02
30 Elements Low Level in UPW by ICP-MS	Lithium (Li)	ppt (pg/ml)	*	0.02
30 Elements Low Level in UPW by ICP-MS	Magnesium (Mg)	ppt (pg/ml)	*	0.02
30 Elements Low Level in UPW by ICP-MS	Manganese (Mn)	ppt (pg/ml)	*	0.02
30 Elements Low Level in UPW by ICP-MS	Nickel (Ni)	ppt (pg/ml)	*	0.02
30 Elements Low Level in UPW by ICP-MS	Potassium (K)	ppt (pg/ml)	*	0.02
30 Elements Low Level in UPW by ICP-MS	Sodium (Na)	ppt (pg/ml)	*	0.02
30 Elements Low Level in UPW by ICP-MS	Strontium (Sr)	ppt (pg/ml)	*	0.02
30 Elements Low Level in UPW by ICP-MS	Zinc (Zn)	ppt (pg/ml)	*	0.02

*Note: Second Sample = 0 cfu/100ml

Summary

Gained exposure to UPW in SRF:

- Importance, application, system fundamentals, materials, monitoring, basic troubleshooting, and a very brief look at hot UPW systems
- Overview of Jefferson Lab's UPW system

Hopefully, enough to make you "dangerous"

- Enhance communication and engagement
- What to look out for when (if) the need arises to select or improve a UPW system
  - Cavity quality issues may be related to UPW quality issues…

- **Time for a tour**?