Purple Pipe Disinfection
Challenges and Alternatives for Safe Reuse

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New Jersey Water Environment Association

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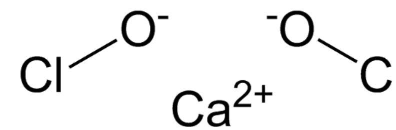
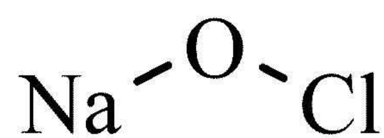
UNDERSTANDING
A VALUABLE RESOURCE

SEVERN
TRENT
SERVICES

Purple Pipe Disinfection Agenda

- Reuse Disinfection Background
- Ozone
- Peracetic Acid
- Chlorine Based
  - Calcium Hypochlorite
  - Commercial Sodium Hypochlorite (bulk)
  - On-site hypochlorite generation
  - Gas chlorination
  - Chloramines
  - Chlorine dioxide
- UV disinfection





Potable Water Disinfection

- Generally low turbidity, suspended solids
- High quality water
- Looking for breakpoint chlorination
- Concern for by products
- Need to maintain residual through distribution system

Waste Water Disinfection

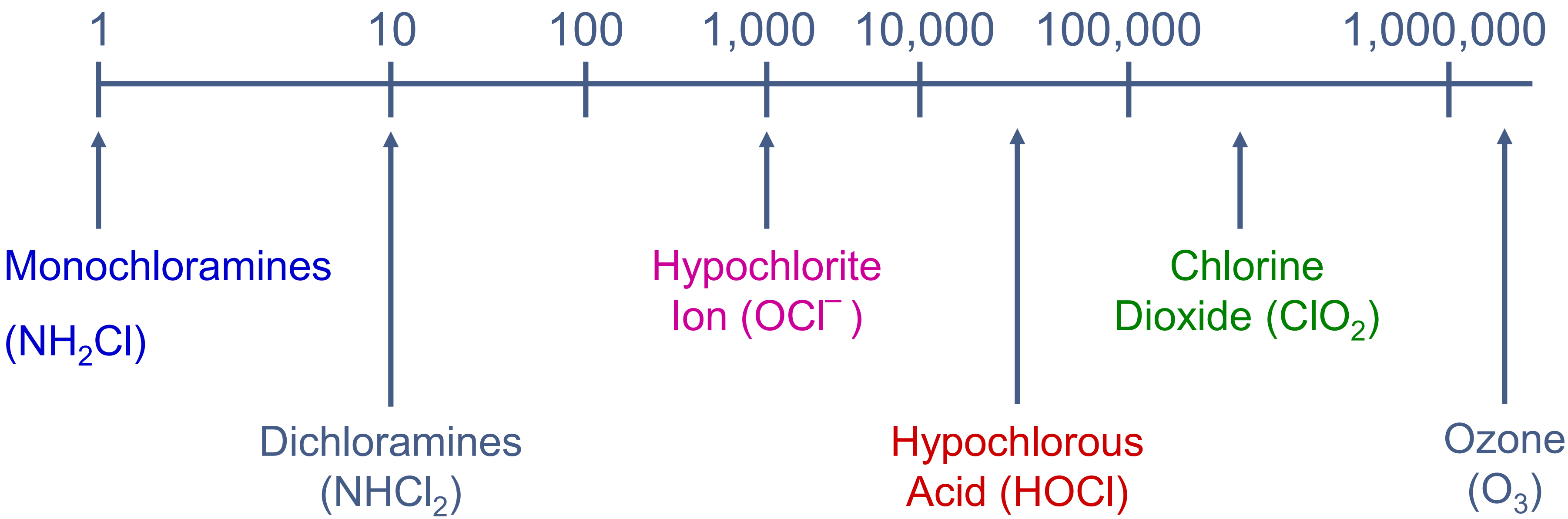
- Generally high turbidity, moderate suspended solids
- Low quality water
- Concern for by products
- Do not need discharge residual
- Potential need to declor

Reuse Water Disinfection

- Disinfection use specific
  - Groundwater discharge
  - Irrigation
  - Industrial uses – ie cooling towers, boiler water
  - Potable water
- Many uses cannot have chlorine residual
- Some uses require residual
- Concern for re-growth
- Many states still developing own regulations
- California Code of Regulations Title 22

DISINFECTION EFFECTIVENESS

EPA ESTIMATE



(Arbitrary Scale)

Ozone

Advantages	Disadvantages
• Very effective at typical pH	• Difficult to dose
• Not commonly used for wastewater	• No Residual
• No Residual	• Not easily stored
• Removes trace organic compounds	• Expensive per pound
• Sometimes used to remove color	• Maintenance and operational complexity

Chlorine Dioxide

Advantages	Disadvantages
• Extremely effective oxidant	• Typically must be generated on-site
• Proven & reliable	• No lasting Residual
• No lasting Residual	• Not easily stored
• Often used in water pretreatment	• Expensive per pound chlorine
	• Not often used in wastewater

Peracetic Acid Disinfection

- Discription
  - Clear Odorless liquid
  - Mixture of Peracetic Acid (12%), Hydrogen Peroxide (18.5%) and inert ingredients.
  - Pungent acetic acid odor
  - Available in 12% solution
- Highly explosive in higher concentrations
- Typical Dosage:
  - Secondary effluent - 0.5 to 2 mg/l PAA
  - Enhanced Primary – 5-10 mg/l PAA
  - Raw Wastewater 10-20 mg/l PAA
- Contact time typically is 10-30 minutes

Peracetic Acid

Advantages	Disadvantages
• Strong disinfectant	• Not yet widely used
• Low capital cost	• High annual cost –limited production
• Ease of implementation	• Increases organic content
• Elimination of chlorine by products	• Expensive per pound
• Widely used in Europe for wastewater disinfection	• Maintenance and operational complexity

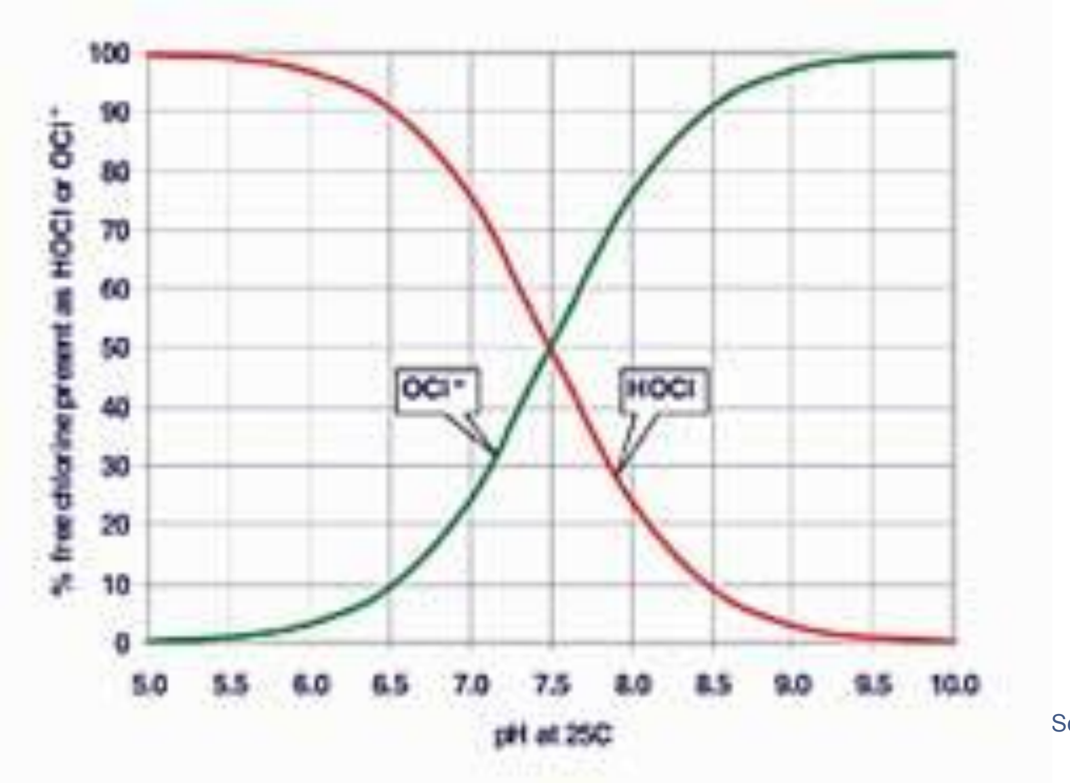
CHLORINE REACTIONS IN WATER

- **Chlorine + Water → Hypochlorous Acid + Hydrochloric Acid**

  $$Cl_2 + H_2O \rightarrow HOCl + HCl$$

- **Hypochlorous Acid Dissociation Reaction – pH Dependent**

  $$HOCl \rightarrow H^+ + OCl^-$$



Free Chlorine Chemistry

$HOCL$ & OCL^- = Free Residual Chlorine

\+

Chloramines = Combined Chlorine Residual

Total Chlorine Residual

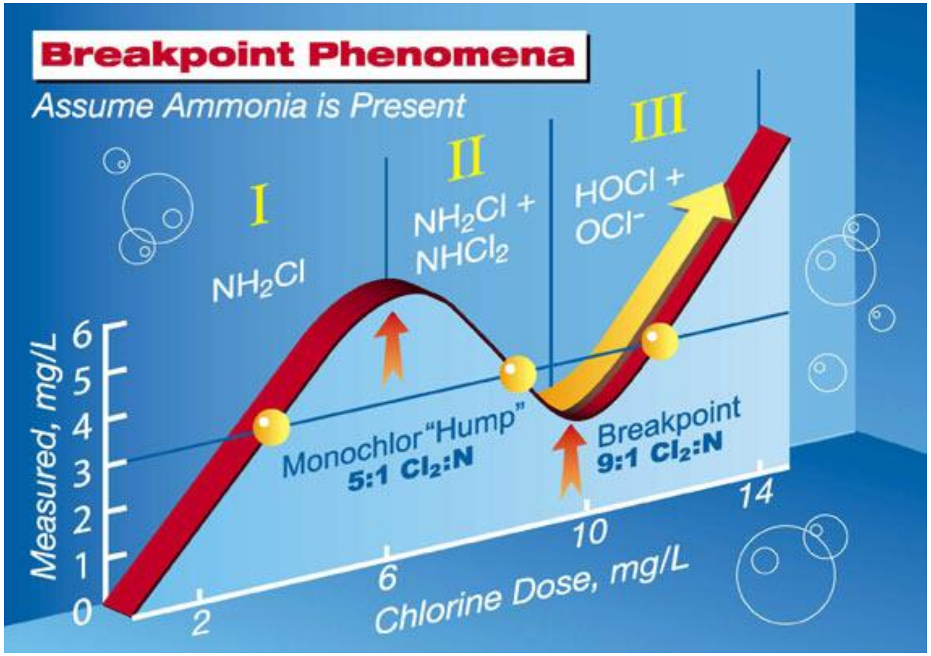
- Analytical methods can measure Free or Total Chlorine Residual
- Combined Chlorine Residual must be determined arithmetically

Breakpoint Chlorination

- Ammonia destruction reactions:

  $2NH_2CL + HOCL \rightarrow N_2 + H_2O + 3HCL$

  $NH_2CL + NHCL_2 \rightarrow N_2 + 3HCL$
- When dosage reaches approximately 8 to 10 times the ammonia concentration (theoretical ratio is 7.6) the "breakpoint" is reached.
- Complete destruction of ammonia seldom occurs at breakpoint and some chloramines persist beyond it.



Chloramine Reactions

- Cl_2 + $NH_3 \rightarrow NH_2Cl$ (Monochloramine)
- NH_2Cl + $Cl_2 \rightarrow NHCl_2$ (Dichloramine)
- $NHCl_2$ + $Cl_2 \rightarrow NCl_3$ (Trichloramine, Nitrogen Trichloride)

DECHLORINATION REACTIONS

- $SO_2 + H_2O \rightarrow H_2SO_3$
- $H_2SO_3 + HOCl^- \rightarrow H_2SO_4 + HCl$
  (Free)
- $H_2SO_3 + NH_2Cl + H_2O \rightarrow NH4Cl + H_2SO_4$
  (Monochloramine)

CHLORINE'S OTHER FORMS

- Sodium Hypochlorite + Water → Hypochlorous Acid + Alkali
  - $NaOCl + H_2O \rightarrow HOCl + NaOH$
- Calcium Hypochlorite + Water → Hypochlorous Acid + Alkali
  - $Ca(OCl)_2 + H_2O \rightarrow 2HOCl + Ca(OH)_2$

Calcium Hypochlorite

Advantages	Disadvantages
• Effective at typical pH	• Difficult to dose
• Proven & reliable	• Leaves a residual – potential need for declor
• Leaves a residual	• Dust concerns
• Easily stored	• Incompatibility with solvents
• Stable as solid	• Safety issues often overlooked
• Not highly regulated	• Expensive per pound chlorine
• Generally smaller facilities	

Commercial Sodium Hypochlorite

Typical Sodium Hypochlorite Dosing Station

Commercial Sodium Hypochlorite Highlights

- Delivered to site in usable liquid form
- Delivered as 12-15% chlorine
- Major system components include 1) storage tanks, 2) metering pumps 3) analytical instrumentation
- Use analyzer to pace flow based on need

Commercial Sodium Hypochlorite

Advantages	Disadvantages
• Very effective at typical pH	• Reacts with ammonia
• Proven & reliable	• Effectiveness decreases at high pH
• Widely used for wastewater	• Concentration decays quickly
• Leaves a residual	• THM Formation possible
• Simple chemical feed system	• Leaves a residual - potential for declor
• Low capital cost	• High cost per pound
• Liquid safer/more familiar than Gas	• Can cause severe burns
• No make down required	• Potential for off gassing
• Not highly regulated	• Hazardous material - secondary containment required
	• Safety issues often overlooked

On-Site Sodium Hypochlorite Generation

Typical 24 lb On-Site Hypochlorite Generation System

On-site Sodium Hypochlorite Highlights

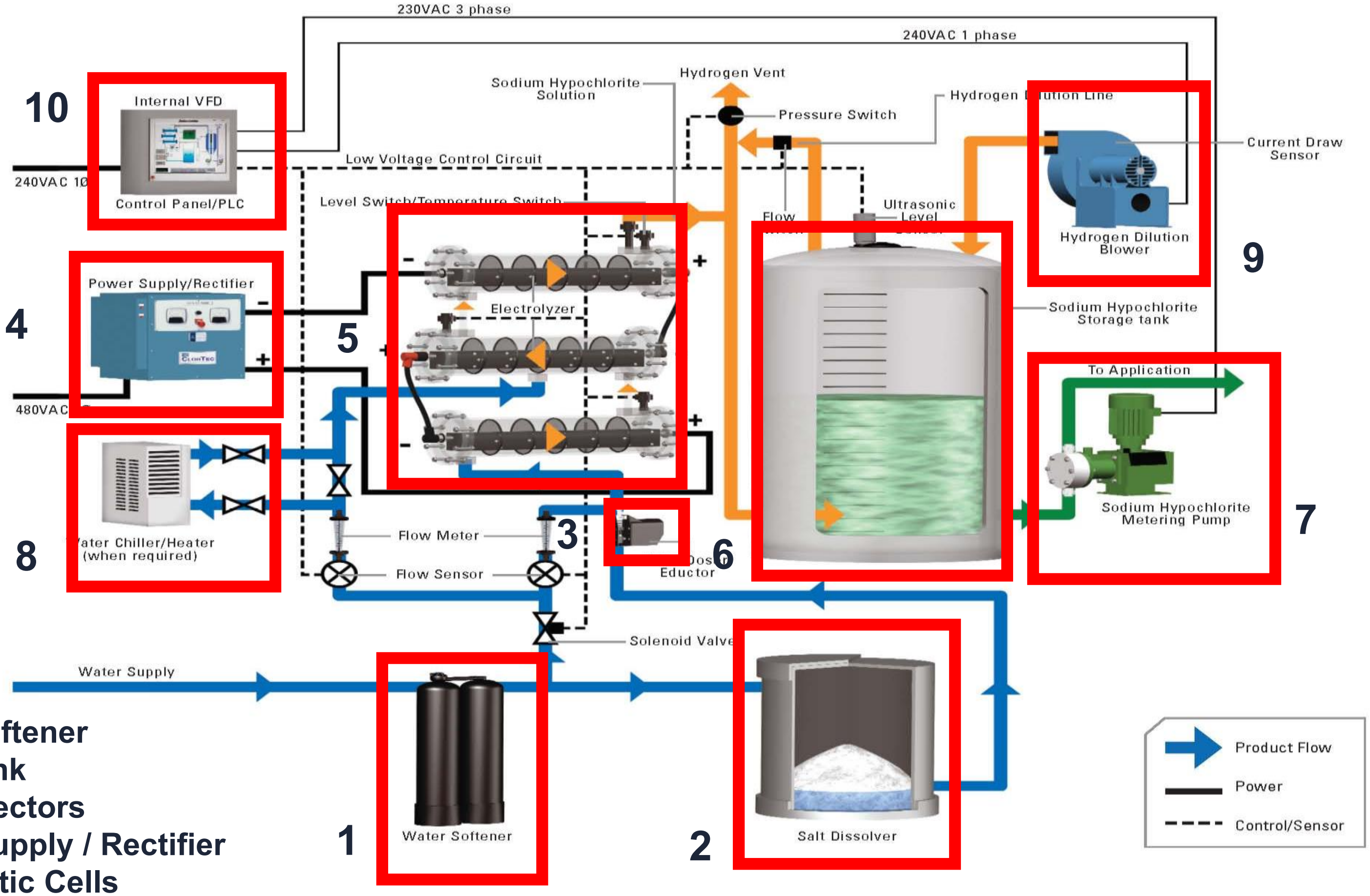
- Delivered to site as salt
- Sodium hypochlorite produced on-demand with minimum storage
- 0.8 % sodium hypochlorite solution produced
- Utilizes DC current, salt, water
- Storage tank and feed pumps
- 3-5 days storage typical

On Site Sodium Hypochlorite Generation

$$NaCl + H_2O + 2E = NaOCl + H_2$$

- For each lb. equivalent of Cl2:
  - Salt (NaCl) 3.0 lbs
  - Softened Water 15 gal
  - Electrical energy 2 kWh DC
- For each pound of Cl2 equivalent produced:
  - (15 gallons of 0.8% concentration Sodium Hypochlorite)
  - 1/35 lb. of H2 gas produced (5.6 ft3)
- H2 gas Immediately diluted upon production with air blower 100:1 to reduce H2 to 25% of LFL

On-site Sodium Hypochlorite Generation



1. **Water Softener**
2. **Brine Tank**
3. **Brine Injectors**
4. **Power Supply / Rectifier**
5. **Electrolytic Cells**
6. **NaOCl Tank**
7. **NaOCl Dosing System**
8. **Water Chiller / Heater**
9. **Hydrogen Dilution system**
10. **Control Panel**

On-Site Hypochlorite Generation System Schematic

On-site Sodium Hypochlorite Generation

On-Site Generated Sodium Hypochlorite

Advantages	Disadvantages
• Very effective at typical pH	• Reacts with ammonia
• Proven & reliable	• Effectiveness decreases-high pH
• Often used for wastewater	• THM Formation
• Leaves a residual	• Leaves residual - potential need for declor
• Minimal concentration decay	• More complex process than bulk
• Low cost per pound	• Higher capital cost than bulk
• 0.8% liquid safer than bulk	• Generates H2 gas which is vented to atmosphere
• Deliver & store salt. Small quantity of chlorine on-site	• Larger volume required
• Not highly regulated	• Can cause eye irritation and burns
• Secondary containment not required	• pH lower than 12% hypochlorite

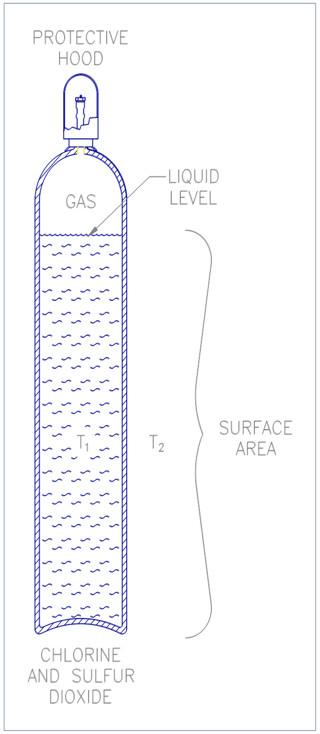
Chlorine Gas Feed Systems

Typical Chlorine Gas Feed System

Chlorine Gas System Highlights

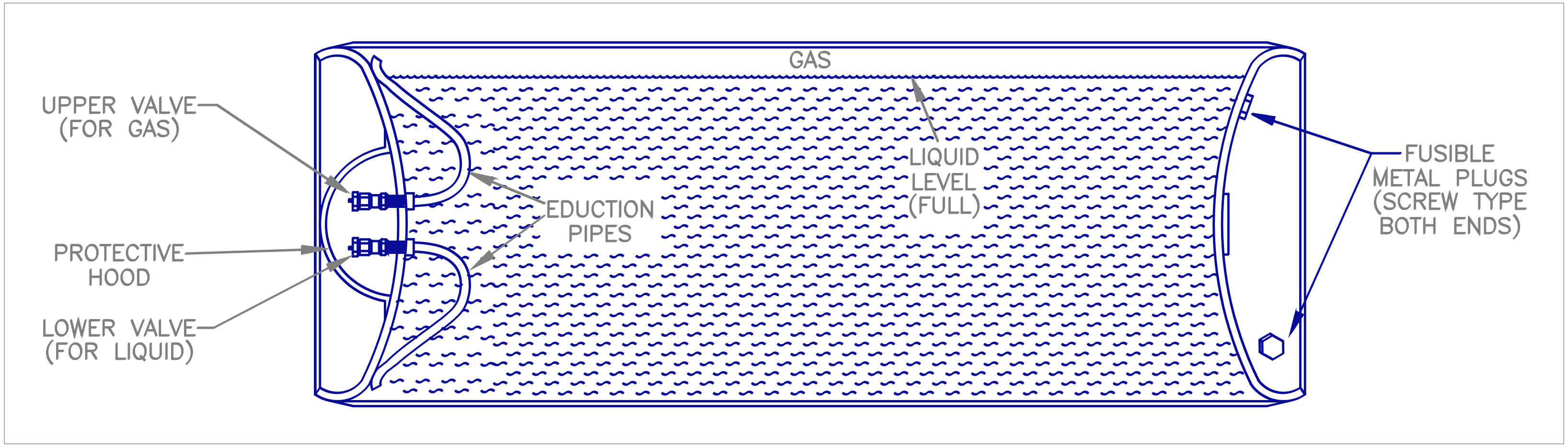
- Delivered to site as gas in cylinders or containers or rail cars
- Stored on-site in original containers
- Chlorine removed form containers as liquid or gas
- Mixed with water prior to injection
- Automatic control valve controlled by residual analyzer

Chlorine Gas Storage Cylinders



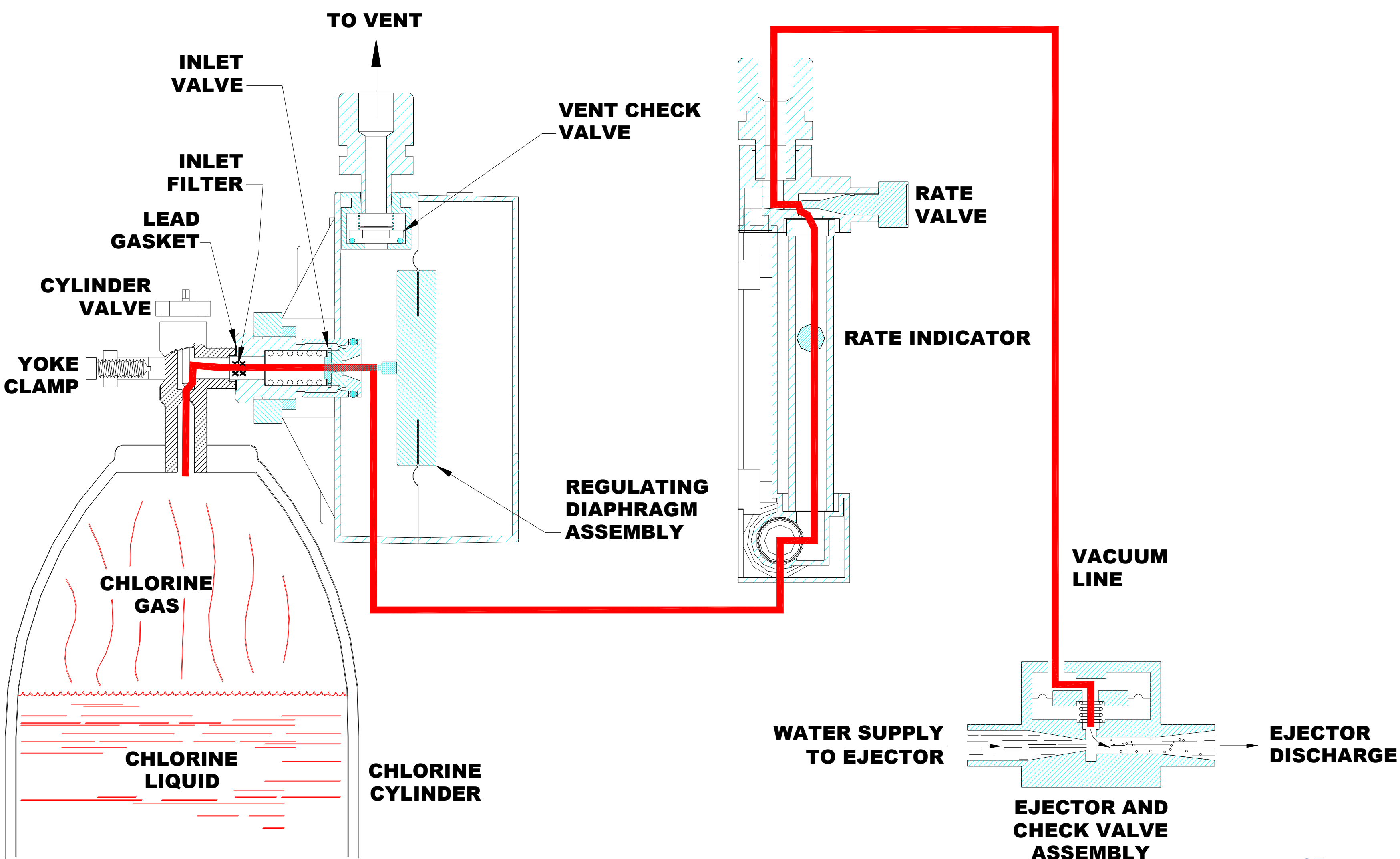
Chlorine Gas Cylinders
Capacity 1 to 150 lb
150 lb. predominate
One opening - valve connection
Standard cylinder valve with pressure relief device &fusible metal plug
Fusible plug melts at 158-165°F

One - Ton Chlorine Containers



- Capacity - 2000 lb.
- Two identical valves
- Can use as gas feed (upper valve)
- Can use as liquid feed with vaporizer (lower valve)
- Six (6) fusible plugs - three (3) in each end, melt at 158-165°F

Chlorine Gas Vacuum Feed Flow Diagram

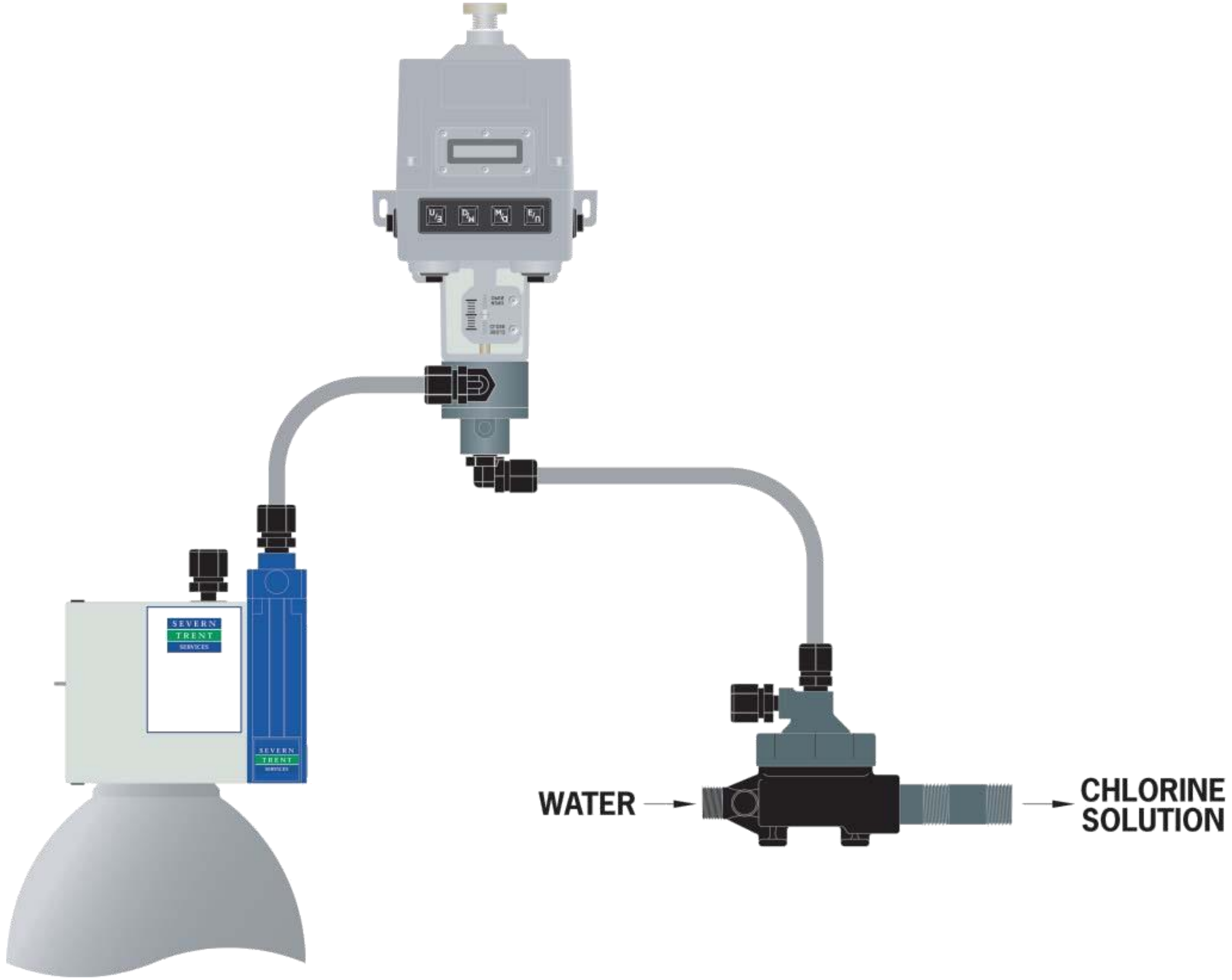


STANDARD MOUNTING

Cylinder

Ton

VALVE LOCATION



Start with Chlorinator sizing:

Gas Feed Rate = Water Flow Rate X (factor) X Dosage

PPD = GPM X .012 X PPM (or mg/l)

PPD = MGD X 8.34 X PPM (or mg/l)

Where:

PPD = (pounds per day) chlorine added to a process in a 24-hour period

GPM / MGD = (gallons per minute / million gallons per day) water flow rate

.012 / 8.34 = Unit conversion factors

PPM = (parts per million) unit weight of chlorine per million unit weights of water

mg/l = (milligrams per liter) milligrams of chlorine per liter of water

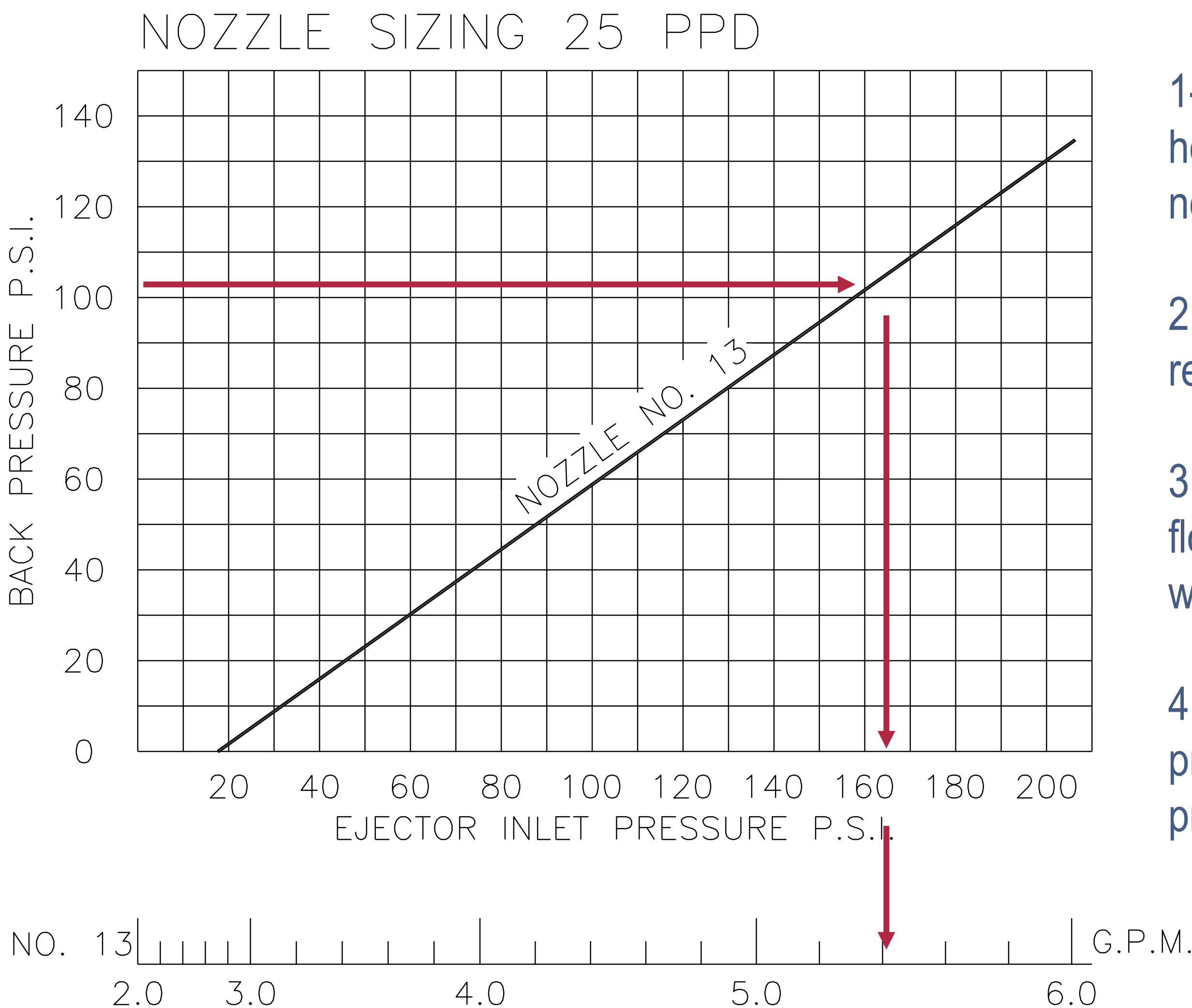
Example: Assume a well has a pumping rate of 1,000 gpm and requires a dosage of 1.0 ppm (mg/l)

PPD = GPM X .012 X ppm
PPD = 1,000 gpm X .012 X 1.0 ppm
PPD = 12.0
Use a feeder with a max capacity of 25 PPD

Choose the Correct Vacuum Regulator

- Vacuum Regulators- NXT3000 and Series 200
  - Chlorine - 500 PPD (10 kg/h);
  - NXT3000 - 3000 PPD (60 kg/h)
  - Sulfur Dioxide - 475 PPD (9.5 kg/h)
  - Ammonia - 250 PPD (5 kg/h)
  - Carbon Dioxide - 390 PPD (7.8 kg/h)
- Vacuum Regulators- Series 480
  - Up to 100 PPD (2 kg/h)
  - Chlorine

EJECTOR - HYDRAULICS



1- Start with back pressure, follow horizontally to the intersection of nozzle curve

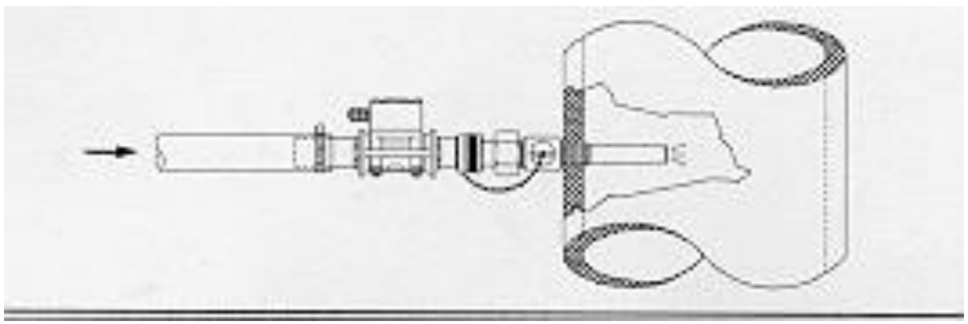
2 - Read supply pressure and flow required

3 - Add 10-15% to the pressure and flow requirement to allow for pump wear & real world back pressure

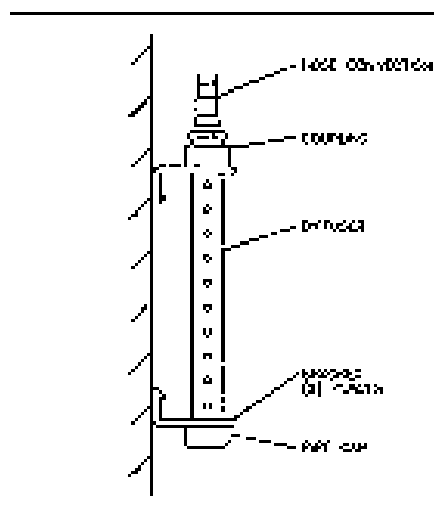
4.- Remember that both the proper pressure and flow is required to produce an operating vacuum.

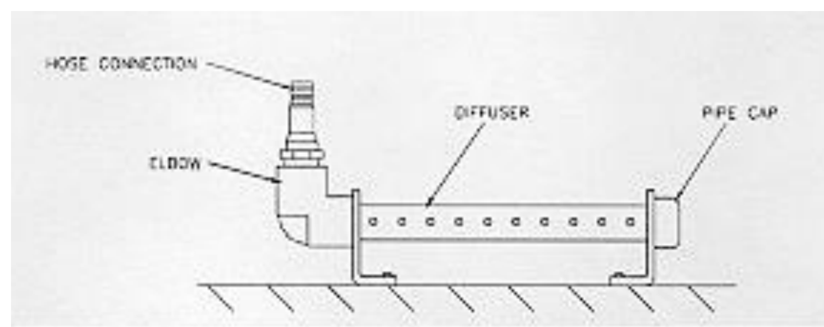
SOLUTION DIFFUSERS

Preferred- Close-coupled Corp. Stop

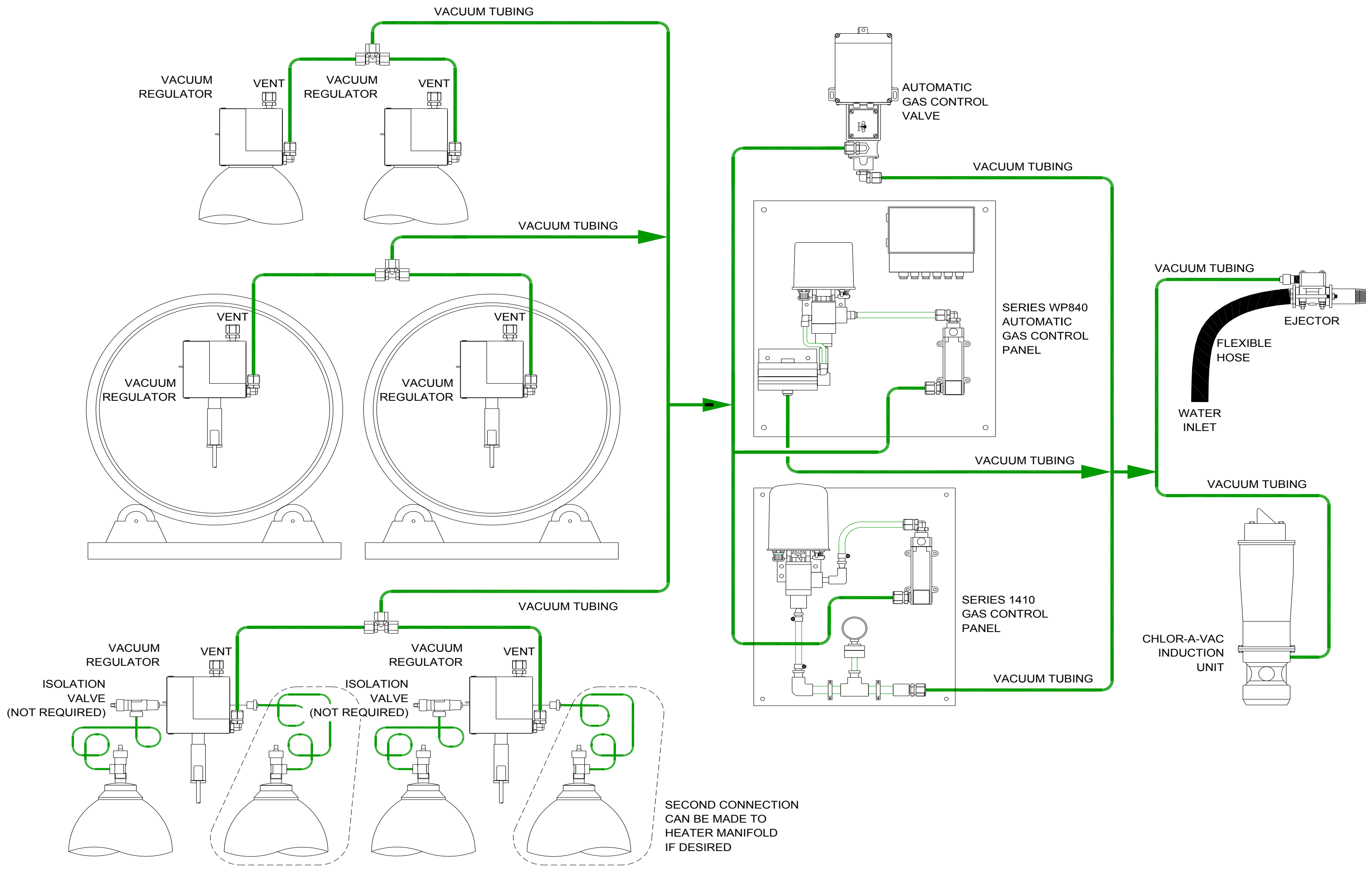


Vertical or Horizontal Sch. 80 PVC Diffusers





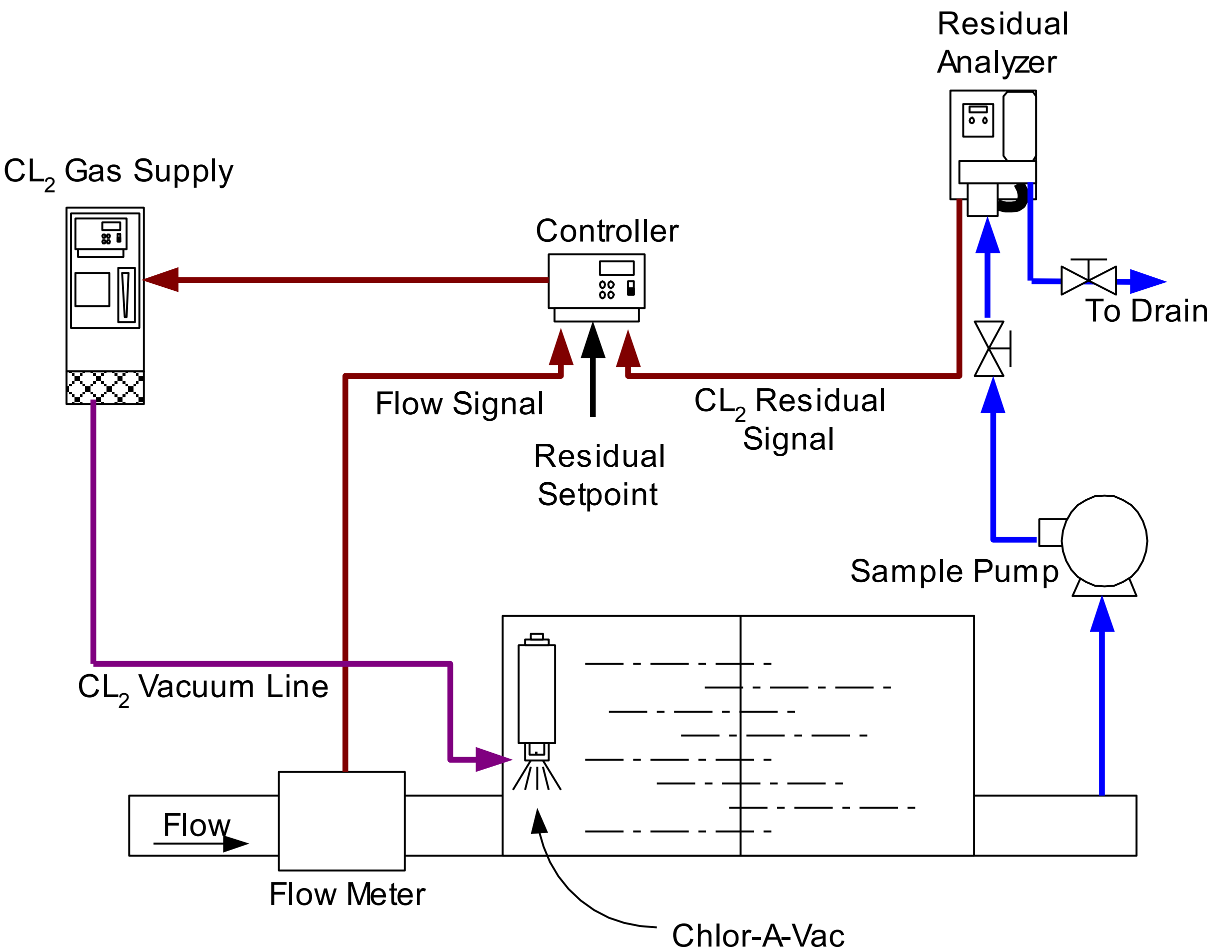
Auto System: Dual Switchover



CHLORINE RESIDUAL ANALYZER PRODUCTS

- Products that use Amperometric Technology:
  - 1770 bufferless analog analyzer
  - Proven, reliable 1870E buffered analog analyzer
  - Microprocessor based CL500 buffered
  - Microprocessor based CL1000 buffered

Compound Loop Control

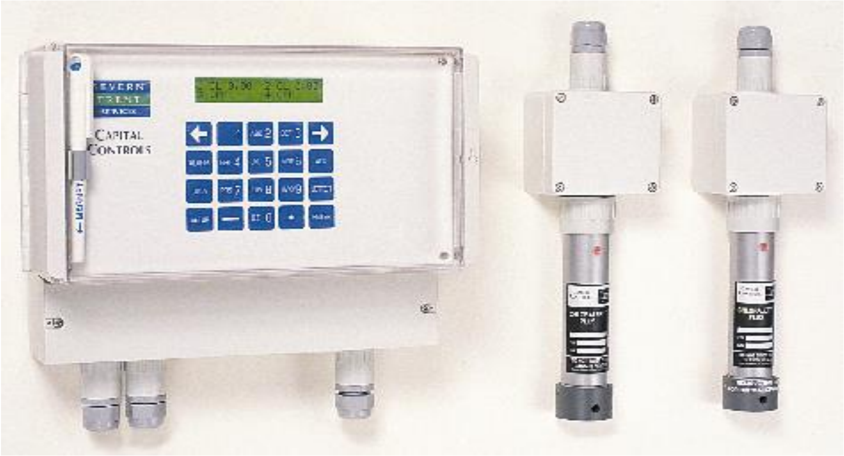


- Controller combines the water flow and chlorine residual analyzer signals
- Controller may be mounted in the chlorinator cabinet or on the wall
- Example: Water & Wastewater disinfection

GAS DETECTORS

- Chlorine, Sulfur Dioxide Gas Detector
  - 0-5, 0-10, 0-50 ppm Cl_2
  - 0-10, 0-20, 0-100 ppm SO_2
- Single Point or Up to 4 sensors w/1000 ft separation

17CA3000



1610 & 1620

- Chlorine, Sulfur Dioxide Gas Detector
  - 0-5, 0-10, 0-50 ppm Cl_2
  - 0-10, 0-20, 0-100 ppm SO_2
  - 0-50, 0-100 ppm NH_3
  - Single Point or Up to 8 sensors w/1000 ft separation

Automatic Valve Shut Off Systems

Automatic Actuator - 150 Lb Cylinder

Automatic Valve Shut off System Highlights

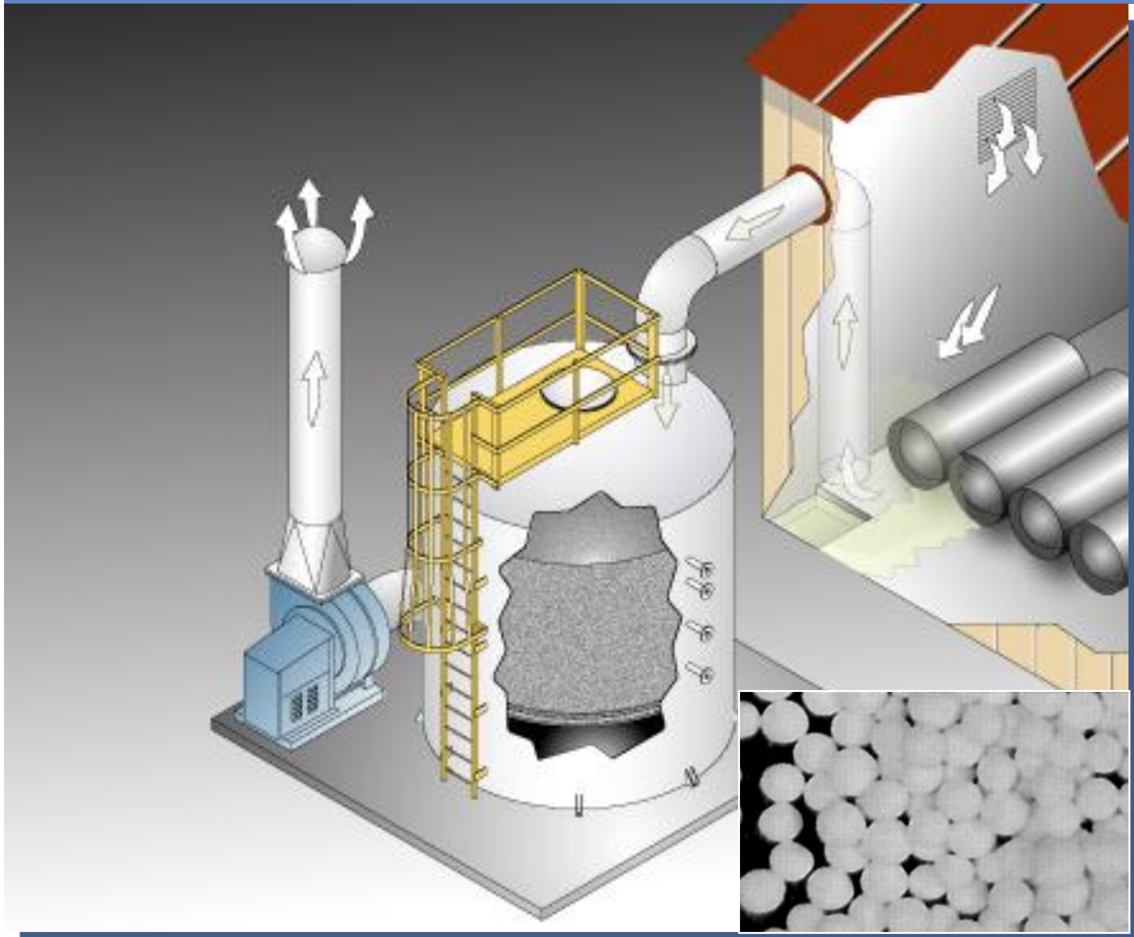
- Actuators mount directly to standard valve assemblies on ton containers and cylinders
- Fully automated system to automatically close the valves
- Can be activated by
  - Leak Detector
  - Panic or Emergency Button
  - SCADA and Fire Alarm System

Chlorine Containment Systems

Typical Chlorine Containment Systems for Ton Container

Chlorine Containment Highlights
Steel shell containment system
Available for 150 lb. cylinders or one ton containers
Put in place – anchor bolt to floor
Gas connections on outside
Hinged door seals shut

Emergency Chlorine Scrubbers



Typical Emergency Chlorine Scrubbers System

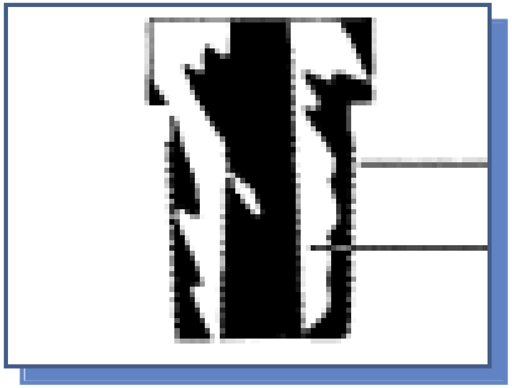
Emergency Chlorine Scrubber Highlights

- Wet or Dry Scrubbers Available
- Major Components: 1) Instrumentation for activation 2) Exhaust Blower, 3) Treatment System 4) Vents to Atmosphere
- Fully automatic – Start and stop based
- Chlorine Room Design Very Important

Emergency Chlorine Scrubber Design

FUSIBLE PLUG WORST-CASE

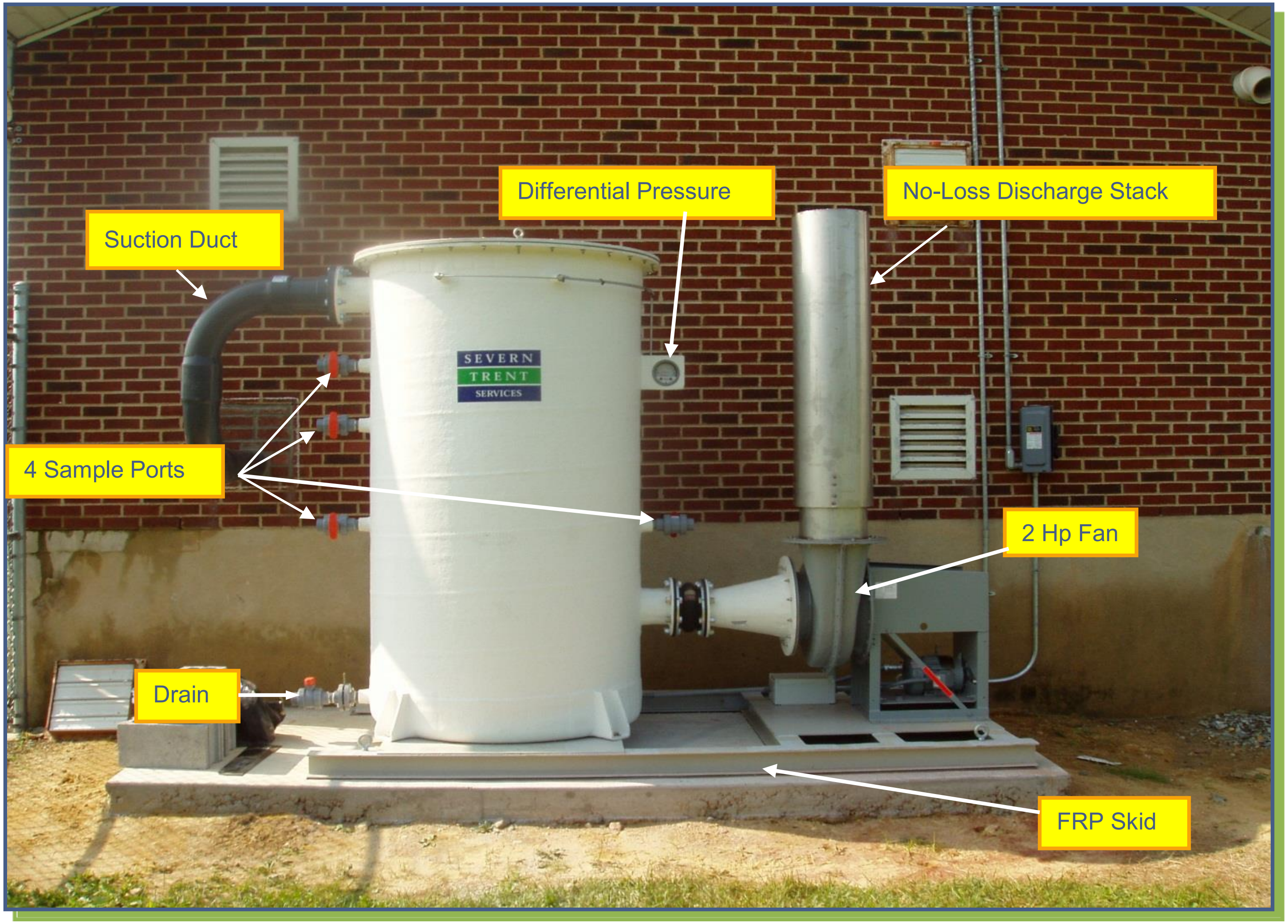
- Melts at approximately 160 ºF
- Cl_2 at 80 ºF = 117 psia vapor pressure
- Cl_2 at 160 ºF = 325 psia vapor pressure
- 0.34” diameter orifice = 437 lbs/min at 160 ºF
- Ton Container liquid plug empties ~ 5 minutes
- Design for release of 5 PPM chlorine



Keep room at negative pressure

- 437 lbs/min = 2380 scfm
- Trend is to specify 3,000 scfm systems for one-ton containers.
- 150 lb Cylinders: Gas Leak Rate is 20 lbs/min = 110 scfm
- Scrubber Rate: Typically 250 cfm

Dry Scrubber Skidded Assembly



Chlorine Gas

Advantages	Disadvantages
• Very effective at typical pH	• Reacts with ammonia
• Proven & reliable	• Effectiveness decreases-high pH
• Widely used for wastewater	• THM Formation
• Leaves a residual	• Leaves residual - potential need for declor
• Low capital cost	• Gas phase dangers
• Low cost per pound	• Higher risk -catastrophic accident
• Safe when used properly	• Highly regulated – OSHA, NFPA.USEPA, USDHS –
• Smaller room area required	• More training & reporting required • Risk management Plan
• Widely used in industry	
• Significant advances in safety systems decrease risk	

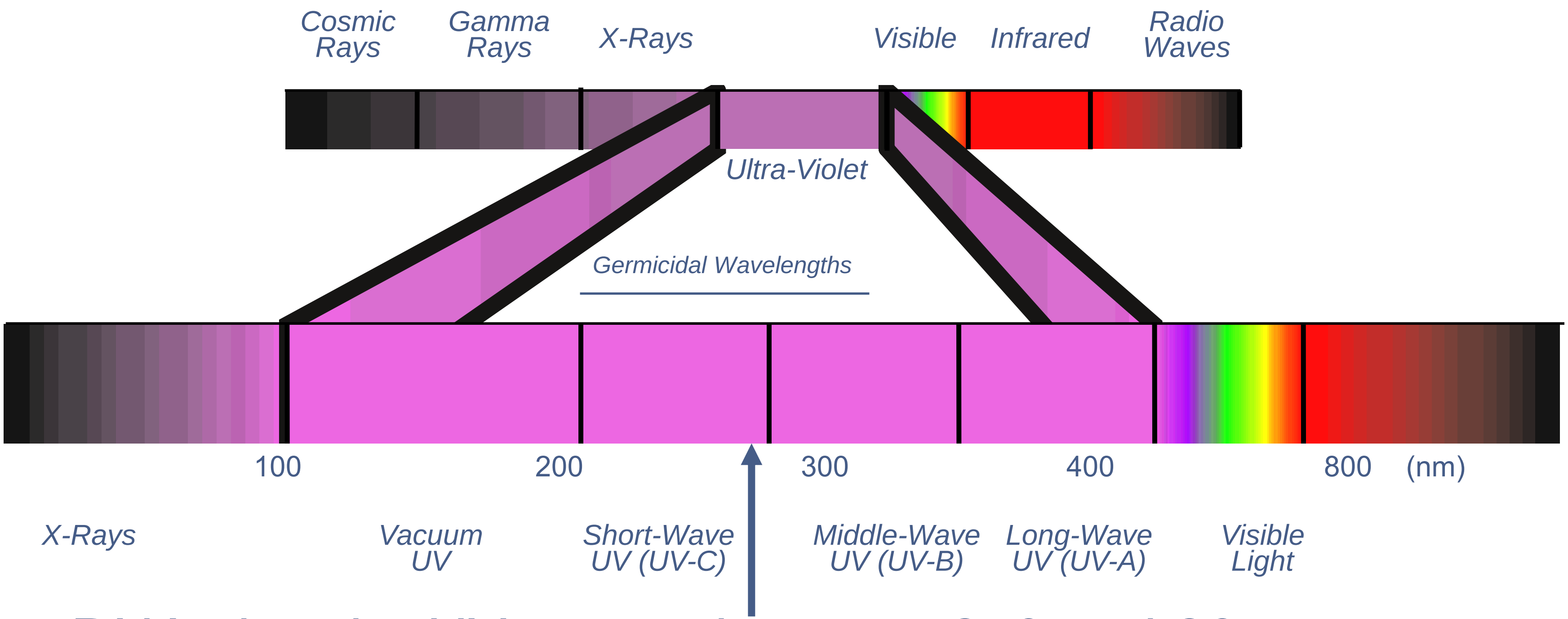
Ultraviolet Disinfection - History

- 1878 - Microbial inactivation utilizing Ultraviolet (UV) light from the sun identified.
- 1901- Mercury arc invented
- 1910 - First full-scale UV disinfection system in operation in Marseilles (France)
  - Option of utilizing chlorine for disinfection was cheap and readily accepted
  - UV disinfection became relegated to only a few niche industries, such as pharmaceutical, food and beverage production
- 1940's - Neon tubes invented
  - Advent of low pressure Mercury lamp
  - Economical source of UV
- 1950's - Ultraviolet Disinfection systems in the US
- 1980's - UV disinfection increased in popularity within the US

Ultraviolet Disinfection - History

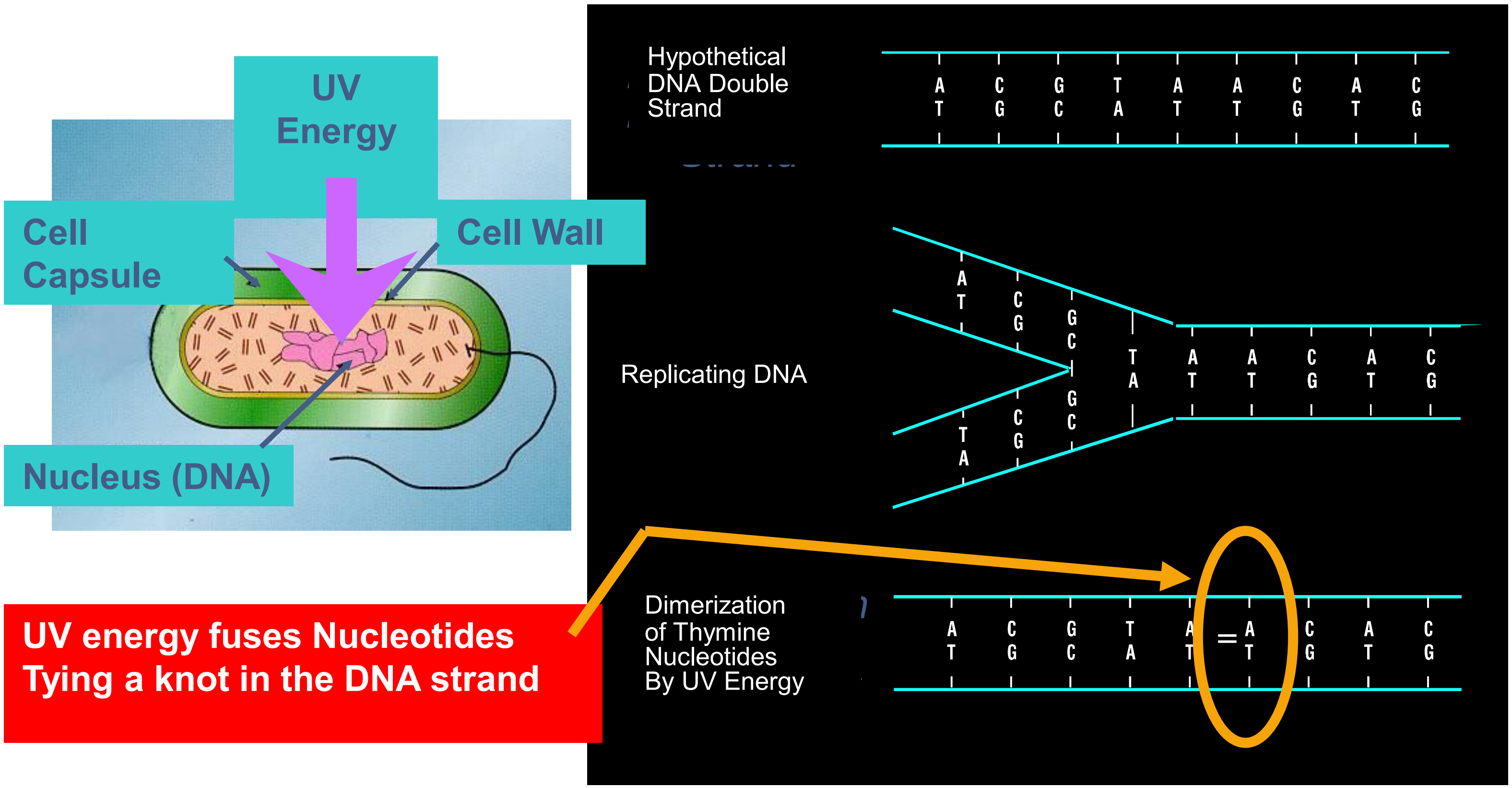
- US Regulatory requirements had influence on general acceptance of UV as alternative to chlorine
  - De-chlorination prior to discharging
  - Chlorine scrubbers required to protect against accidental release of chlorine gas (Uniform Fire Code)
  - Risk management plans required in case of an accidental release (OSHA)
  - EPA released UV Design Guidance Manual for drinking water plants in November, 2006

Theory of UV Disinfection



- DNA absorbs UV energy between 250 and 265nm wavelength
- low pressure UV lamps produce highest energy at 254nm wavelength

How UV Affects DNA



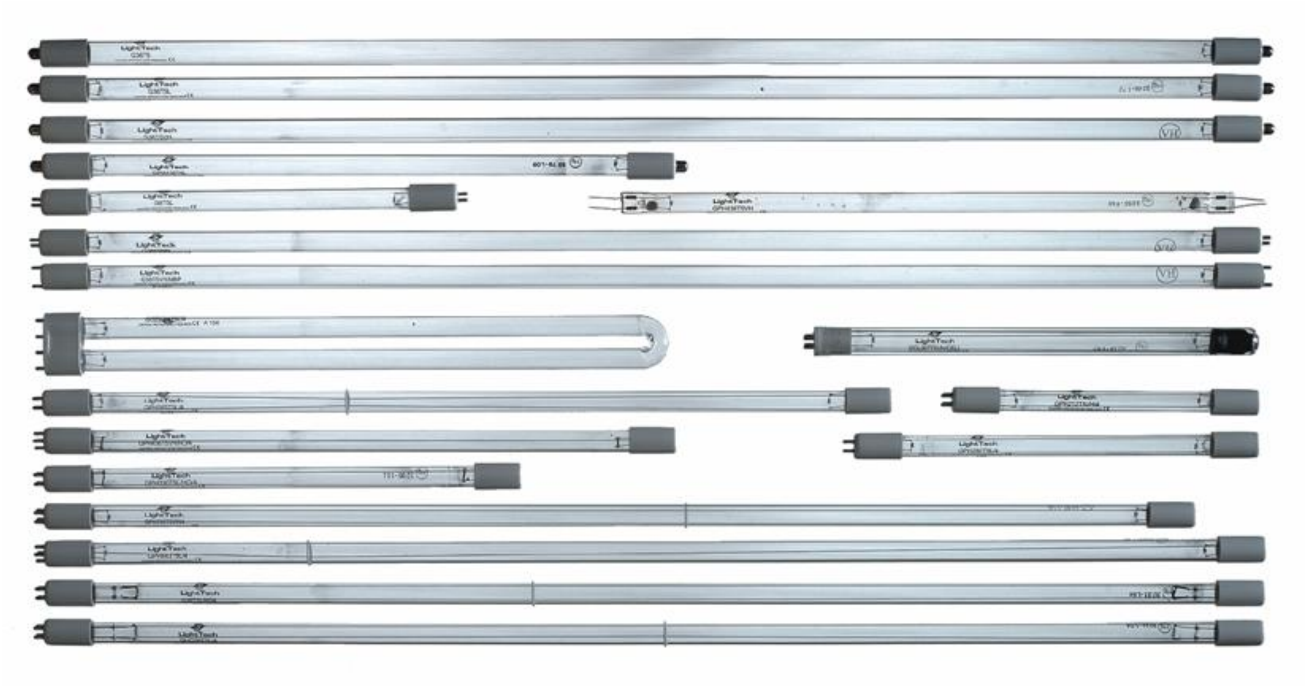
- UV energy alters genetic structure of the microorganisms stopping the reproductive process
- Microorganism is non-infective and is considered microbiologically dead

UV Dose

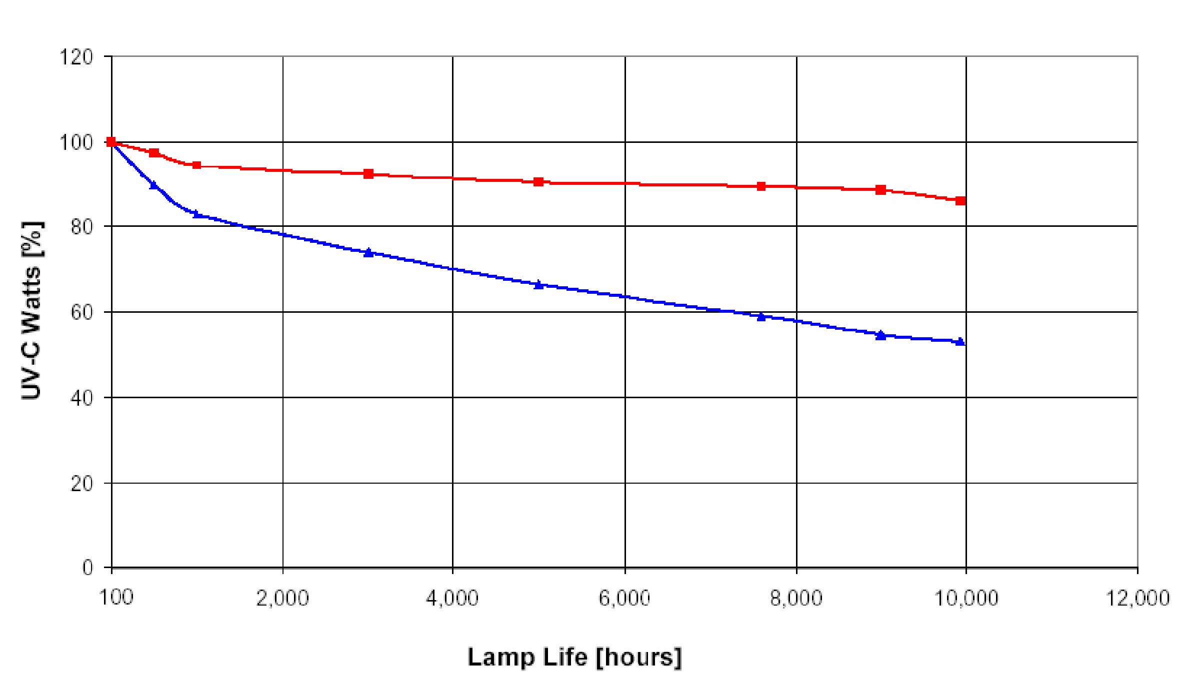
- UV is measured in “dose”, which is expressed in units of energy divided by time
- The higher the dose the higher the kill or deactivation
- Microorganisms susceptibility to UV has been measured, expressed in dose per log reduction

UV Lamp Technologies

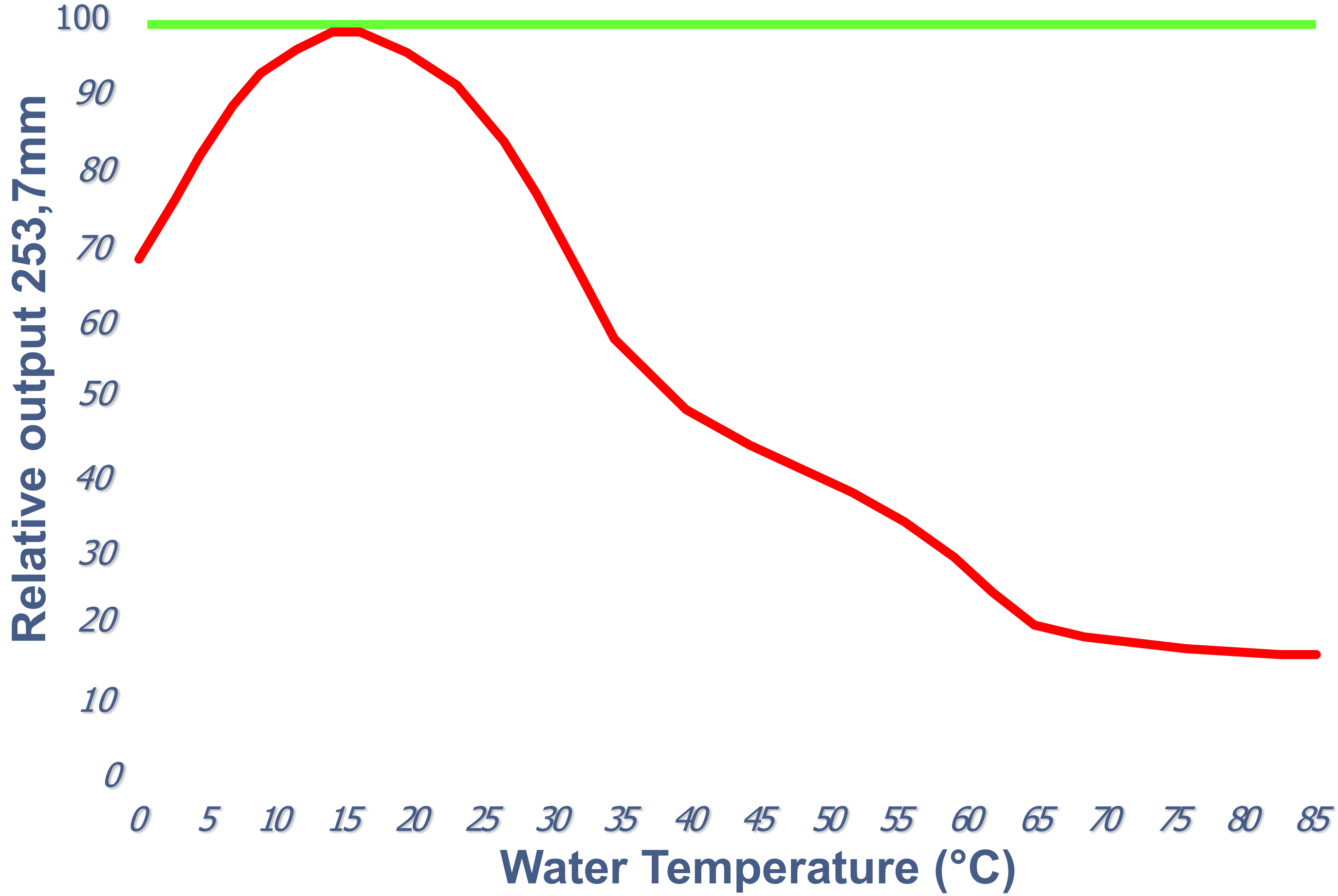
- Low pressure standard output (LP)
- Low pressure high output (LPHO)
- Low pressure high output amalgam
- Medium pressure (MP)



Lamp Degradation

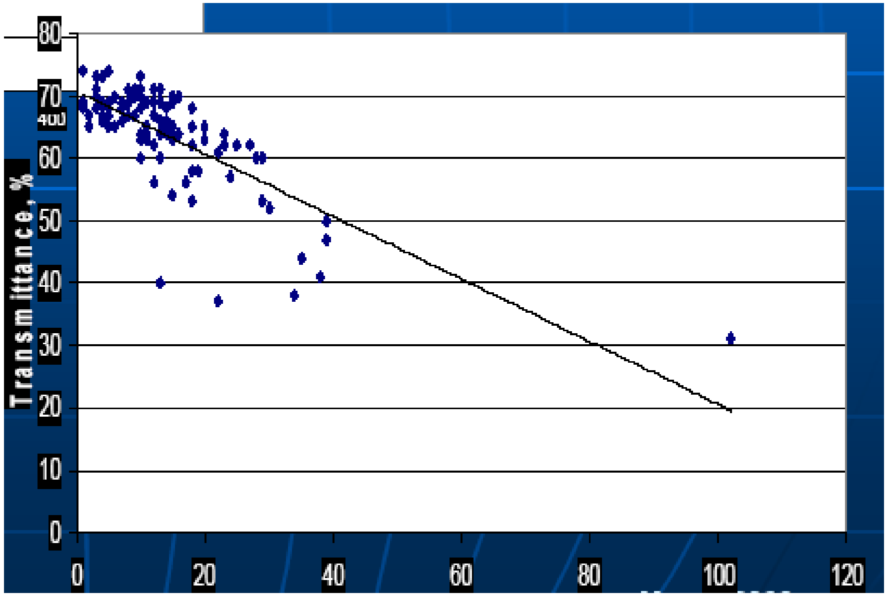


Factors affecting UV - Temperature Dependence



Factors Affecting UV - Total Suspended Solids

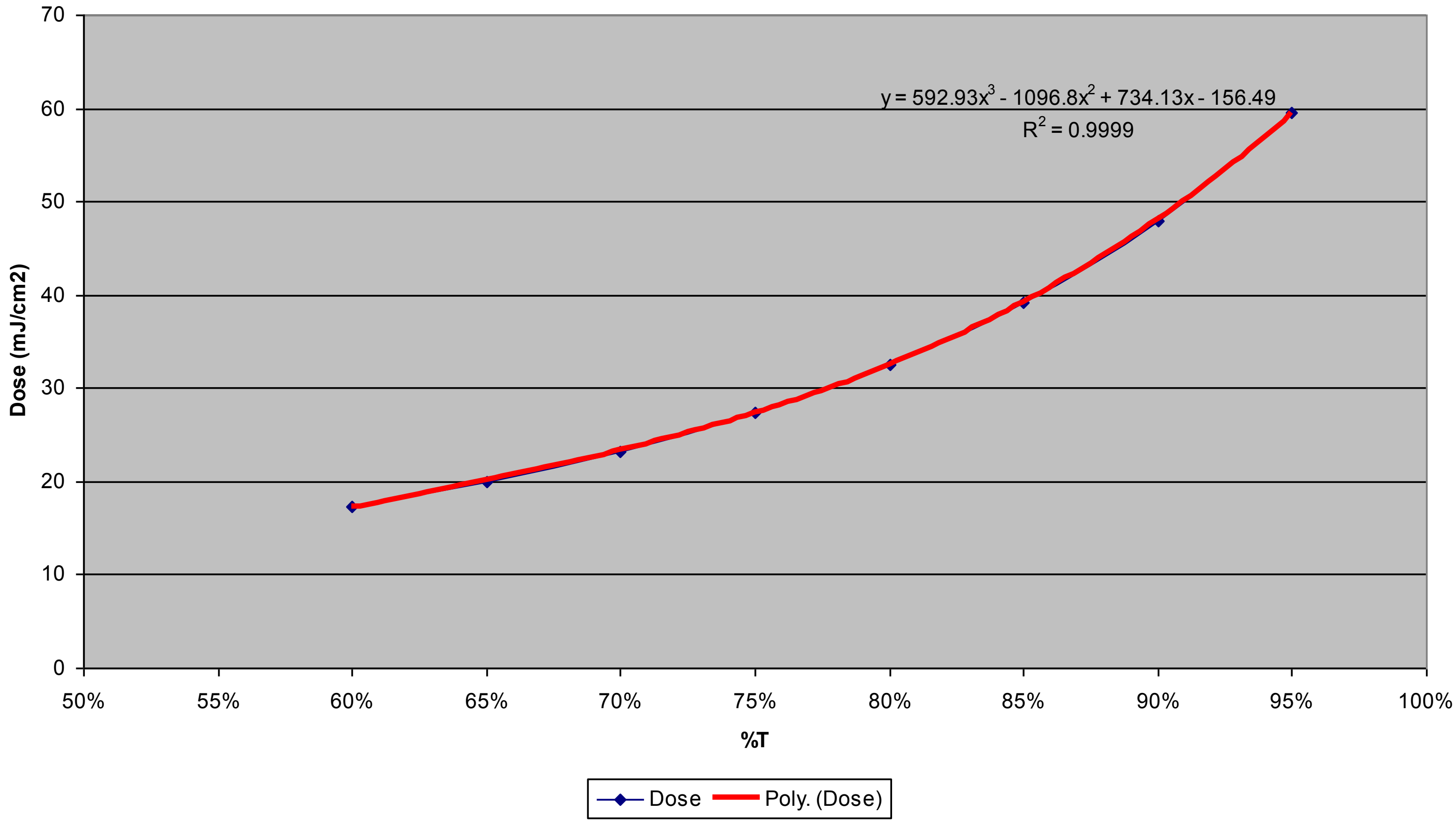
- As suspended solids increase in the water bacteria becomes occluded, or shadowed, from exposure to the UV light.
- Filtration is needed to decrease the amount of suspended solids, thus increasing the chance of disinfecting the water efficiently.
- TSS less than 30 is typical.



Factors Affecting UV - Transmittance

- The percentage of light, at a wavelength 254 nm, to transmit through the water.
- Transmittance is not equivalent to NTU values.
- UV light is absorbed by water constituents
  - Humic acids, iron, floc, turbidity, TSS, etc
- 65% UVT is typical in waste water, 90% UVT in drinking water.

UVT vs UV Dose



UV System Components

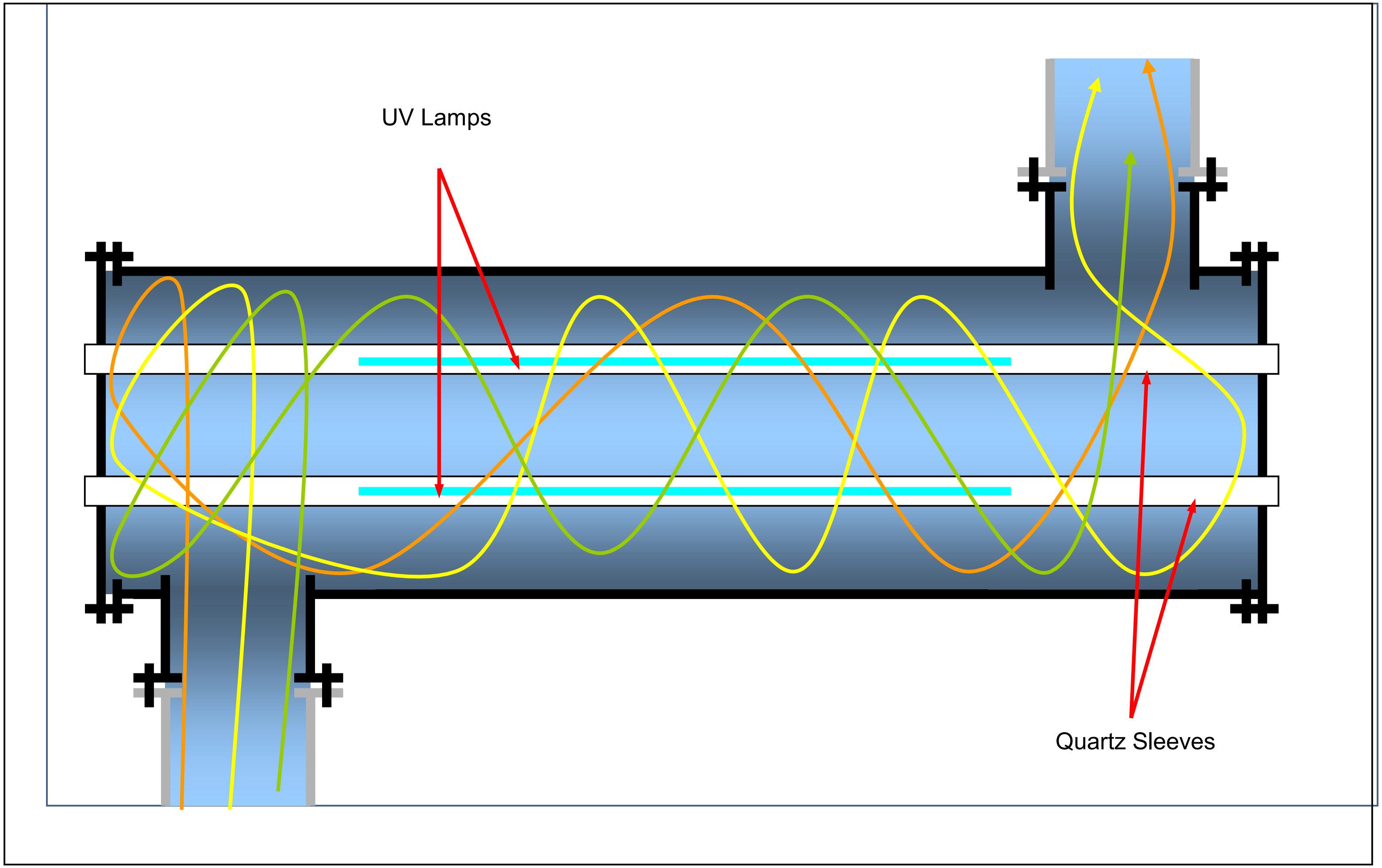
- Closed Vessel or Open Channel Reactor
- Lamps enclosed in quarts sleeves
- Ballasts drive lamps
- UV Intensity Sensors
- Control Panel
- Level Control

Types of Reactors

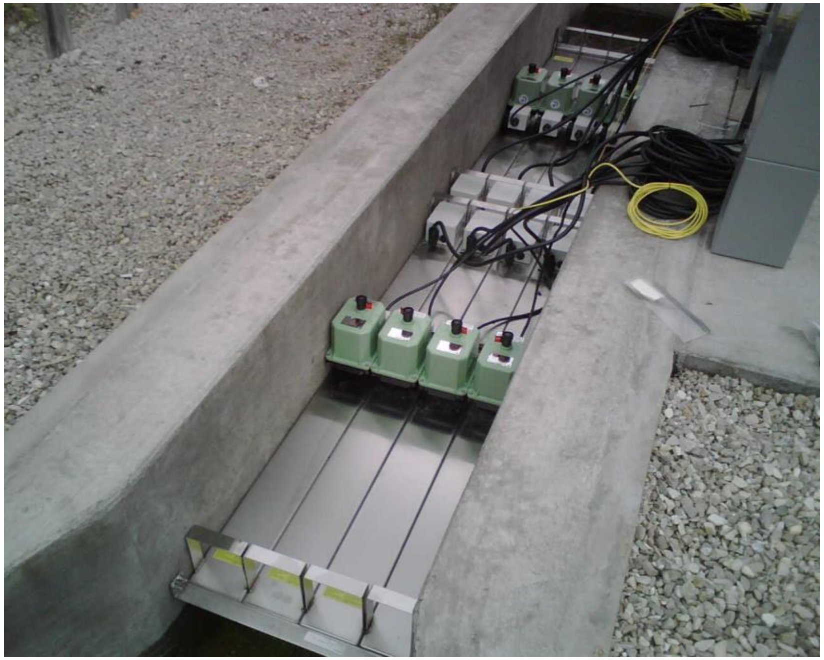
- Closed Vessel
  - Parallel Flow
  - Inline
  - Crossflow

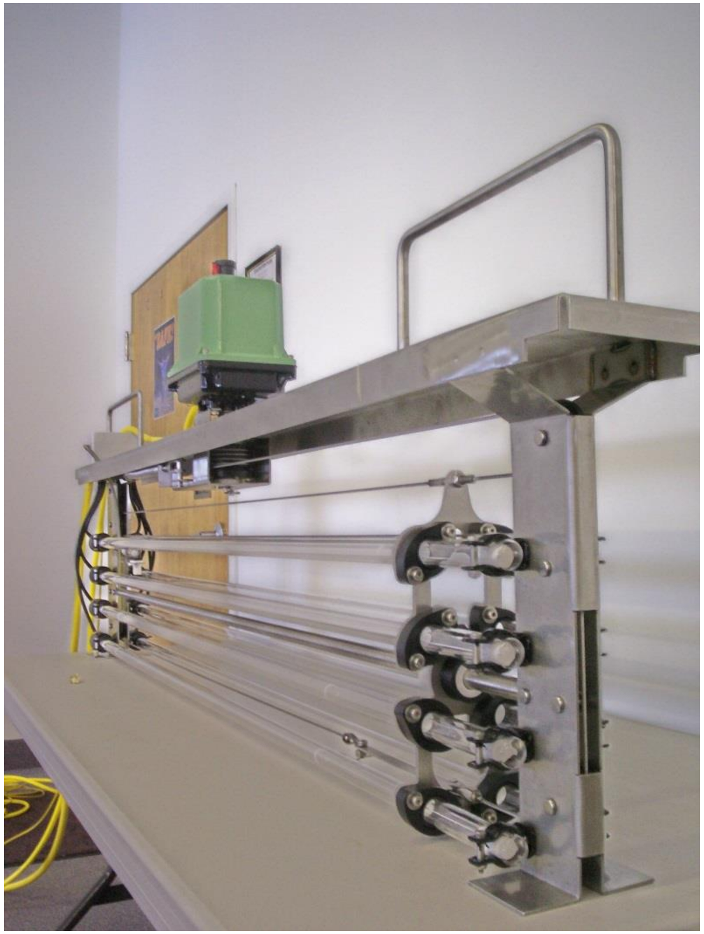
- Open Channel
  - Horizontal
  - Vertical

Closed Vessel - Parallel to flow



Open Channel - Horizontal





Open Channel - Vertical

Quartz Sleeves

- Lamps are housed in quartz sleeves to protect them from direct contact with the water.

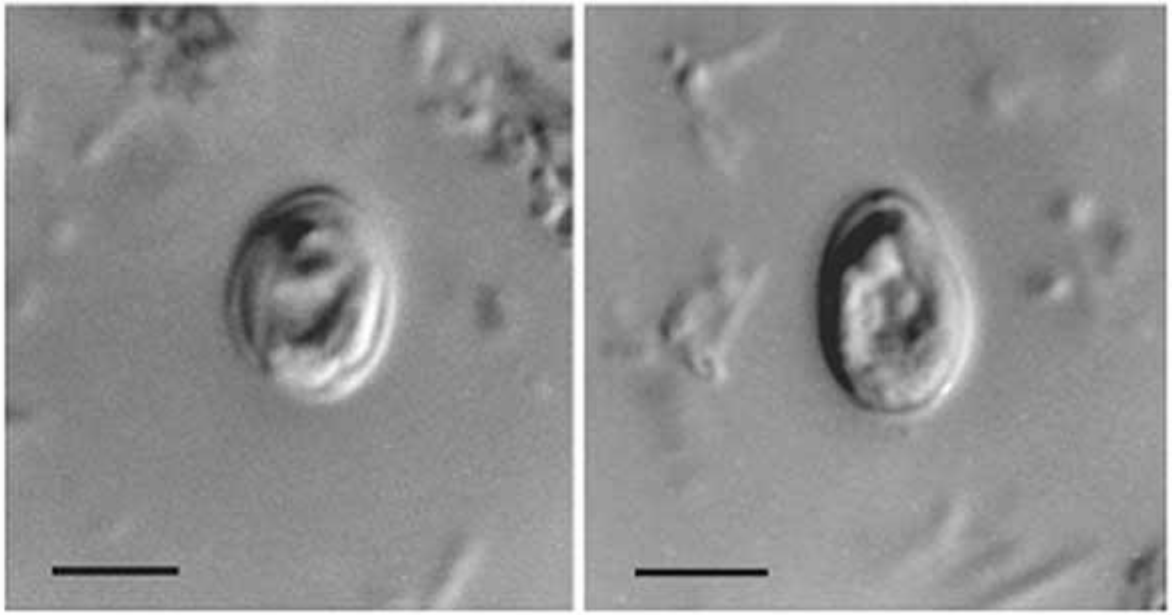
- Wiper Systems are used to clean sleeves
  - Automatic
  - Manual

UV in Reuse Water

- UV is used to remove pathogens
  - Cryptosporidium
  - Giardia
  - Viruses
- These pathogens have proven to be resistant to traditional disinfection methods such as chlorine and filtration
- UV provides up to 4 log reduction credits for Crypto / Giardia

Cryptosporidium

- Present in fecal mater of infected animals
- Makes its way into ground water and surface water
- Ingestion causes diarrhea, dehydration, even death



Dose-Response

Target Pathogens	Log inactivation							
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
Cryptosporidium	1.6	2.5	3.9	5.8	8.5	12	15	22
Giardia	1.5	2.1	3.0	5.2	7.7	11	15	22
Virus	39	58	79	100	121	143	163	186

UV Dose Requirements (mj/cm^2)

Reactor Validation

- Answers the Crypto challenge
- Validation scientifically measures the UV dose produced by a reactor
- Dose is “validated” or confirmed by a third party
- Relationship between validated dose and log reduction of Crypto (an other pathogens) is known

UV System Lamp Options

- Low Pressure - Standard Output
  - Up to 25 watts of UVc
  - Ideal for low flow applications
  - Good electrical efficiency
- Low Pressure – High Output
  - Up to 100 watts of UVc
  - Best used for medium flow rates
  - Best balance between flow rate and electrical efficiency
- Medium pressure
  - 1000’s of watts of UVc
  - Suited to very large applications
  - Low electrical efficiency

UV Control Schemes

- Intensity Set point
  - Ideal for smaller systems with fewer lamps
- Dose Pacing
  - Used for large system with multiple reactors to offset electrical efficiency concerns

UV for Reuse

- UV is used either on secondary or tertiary effluents.
- Deactivates coliforms in the effluent allowing the plant to stay within NPDES permit.
- Reduces or removes need for chlor / dechlor

UV Transmittance

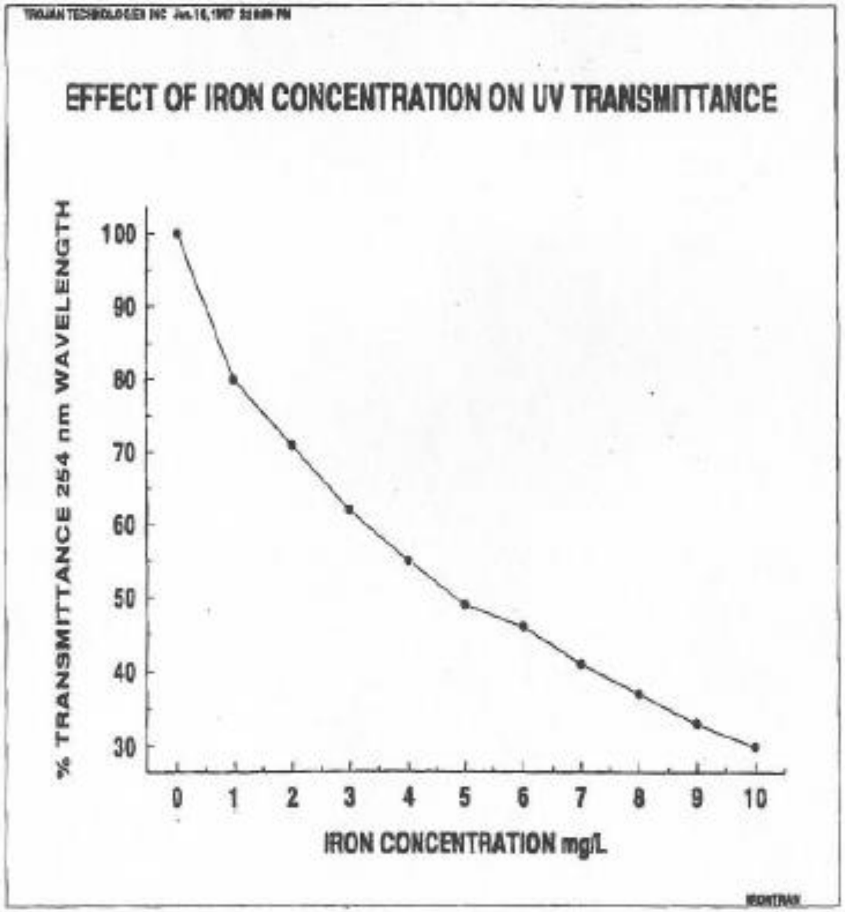
- Primary Effluent – 25 to 50%
- Secondary Effluent – 50 to 80%
- Secondary + Filtration - 60 to 80%
- Secondary MBR – 70 to 85%
- Secondary RO – 90 to 100%

Factors that impact UV transmittance

- UV transmittance
- Iron
- TSS
- Particle Size
- Fat, Oil, Grease (FOG)

Iron

- Iron is a major culprit of UV issues
- Fe is widely uses in WWTP's
- Iron particles absorb UV



Other Compounds

- Humic acids
- Tannin and Lignin
- Ring Compounds – Benzene, Phenol
- Dyes – Brighteners, Whitener, Color Fast
- UV Stabilizers – Paint, Coatings, Stains
- Sunscreen – Lotion, Cosmetics
- Tea and and Coffee

Typical UV Dose Targets Discharge

- Standard Disinfection Parameters
  - Minimum dose usually 30,000 μws/cm2 or 30 mJ/cm2
  - Use of UV intensity meters and their associated alarm connections
  - TSS< 30 mg/l
  - Fecal Coliform < 200 MPN/100 ml
  - UV Transmittance > 65%T
  - Subject to the "Ten States Standards"

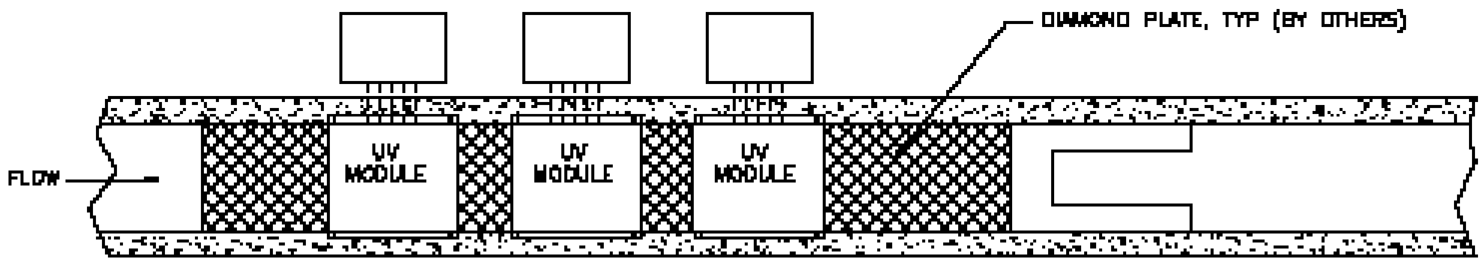
Beneficial Reuse Dose Targets

- NWRI validated UV dose:
  - >100 mJ/cm2 for standard filtered wastewaters
  - >80 mJ/cm2 dose for wastewaters pre-filtered through a membrane (MF or UF)
  - >50 mJ/cm2 dose for wastewaters pre-filtered through an RO membrane

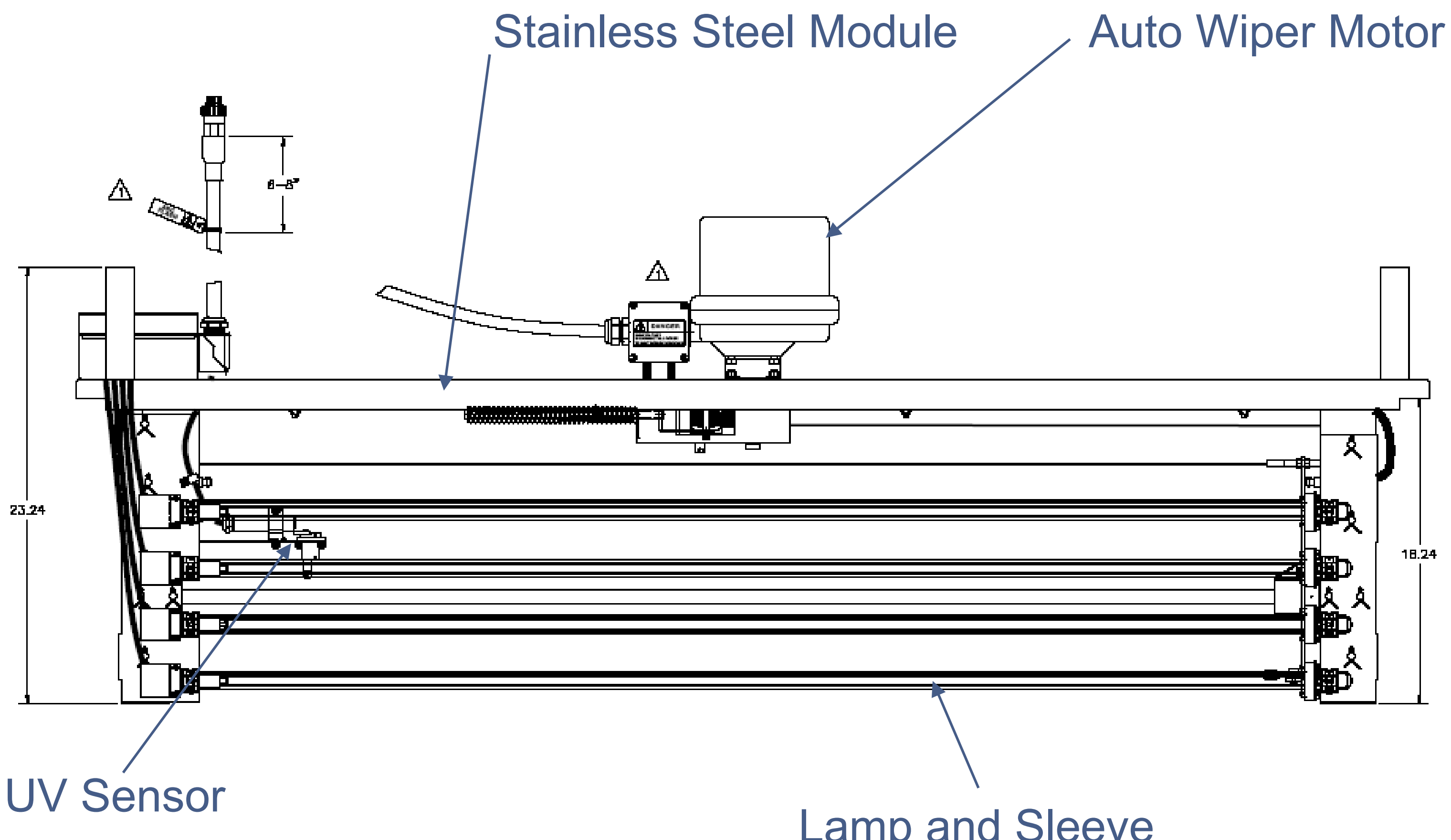
- Title 22 UV Dose
  - California standard, but has been adopted in neighboring states
  - Similar requirements to NWRI

UV System Control Options

- Dose / Flow Pacing
  - Found on larger systems
  - Turn modules on / off or modulates lamp power in accordance with flow
  - Used to lower power draw

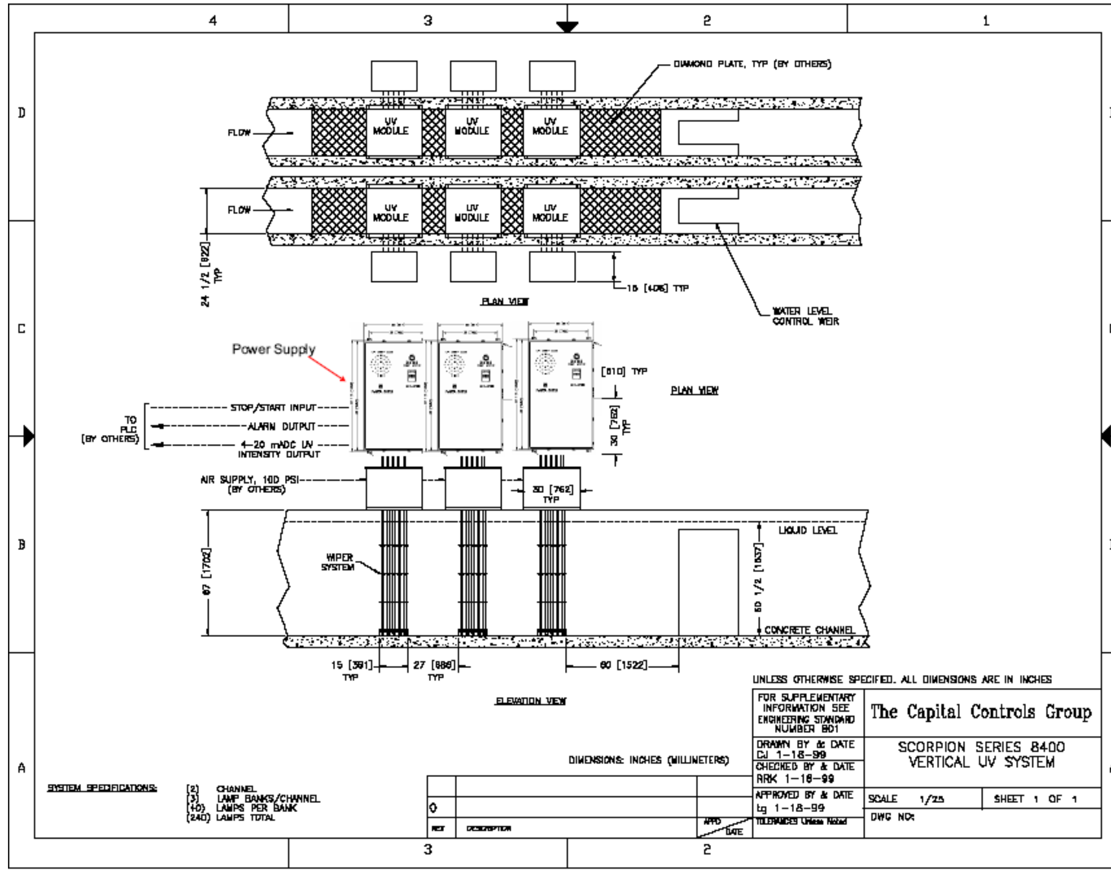


Horizontal Open Channel Module



Open Channel UV System Arrangement

- Lamp Module
- Bank of Modules
- Channel
- Weir
- Control Panel



Open Channel UV Installations

Ultraviolet Disinfection

Advantages	Disadvantages
• Very effective at Low SS	• Most effective in filtered effluent
• Proven & reliable	• Effectiveness decreases-high SS
• Widely used for wastewater	• High energy use
• Does not leave a residual	• Regular lamp replacement
• Moderate capital cost	• Effectiveness is water quality dependent
• Moderate O&M cost	
• No De-Clor Required	
• Effective for Cryptosporidium, Giardia & Virus	

Summary

- Ozone, Chlorine Dioxide and Peracetic acid are both strong oxidants capable of disinfecting reuse water but are not widely used
- Chlorine is the most widely used disinfectant for effluent reuse
- Chlorine comes in many forms but most common are chlorine gas and sodium hypochlorite
- On-Site hypochlorite generation also avoids many of the safety issues associated with chlorine gas but with a lower cost per pound of chlorine than commercial hypochlorite
- There are various methods to improve chlorine gas safety including containment systems, automatic shutoff valves and emergency scrubbers
- Ultraviolet light is becoming more popular due to concerns with cryptosporidium, giardia and virus
- The effectiveness of an Ultraviolet Light system is impacted by a variety of factors including turbidity, suspended solids and transmissivity

Questions?

THANK YOU!

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