

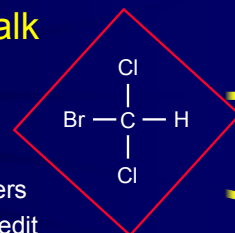
Minimizing DBPs With Multiple Disinfectant Barriers to Achieve Multiple Objectives

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**Maine Center for Disease Control and Prevention
Minimizing Disinfection By-Products – Training Session
Thursday, February 19, 2009**

Today's Talk

- The Ideal DBP Solution
- DBP Cases
 - 1. Pre chlorination
 - 2. Chlorine on top of the filters
 - 3. Long chlorine C*T for Credit
 - Switching to Ozone or UV as the primary disinfectant
 - 4. Most DBPs formed in the distribution system
 - Switching to chloramines with a short chlorine C*T
 - Switching to chloramines with no chlorine C*T



Acknowledgements

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- NE-WTTAC and Professor Collins
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- My Research Assistants: Jen Wagler, Jim Ropp, Jeff Shaw, Evan Griffiths, Greg Snicer, Annette Doucette, Bryan Townsend, Laurel Passantino, Craig Douglas, Steven Farabaugh, David Gaithuma, Nicola Ballester, James Collins, Ashlee Fuller and Heidi Borchers
- Sponsors: AwwaRF, EPRI, USEPA, NHDES
- Collaborating Utilities: (75 project in 7 countries)

Take Home Messages

- Before adopting a DBP Minimization strategy develop an understanding of why your specific system is generating higher than allowed DBPs
- Remove as much DBP precursor material as possible within the limits of facility costs, space constraints and operational skill and reliability
- Try to minimize Chlorine use as a pre-oxidizer and as a primary disinfectant – does switching to UV or Ozone make sense for your system
- Finally and if needed carefully consider the pros and cons to switching your secondary disinfectant to Chloramines

THE IDEAL SOLUTION

- NEVER FORM THE DBPs IN THE FIRST PLACE BY USING A COMBINATION OF:
- REMOVE AS MUCH OF THE DBP PRECURSOR MATERIAL (ORGANIC MATTER) AS POSSIBLE
- OPTIMIZE THE LOCATION AND MINIMIZE THE DOSE OF CHLORINE NEEDED TO ACHIEVE YOUR SPECIFIC WATER QUALITY GOALS AND REGULATORY COMPLIANCE



DBP Case 1 – Pre-chlorine

- A significant amount of the DBPs generated by my facility are due to the need to pre-chlorinate the raw water to control iron and manganese or slime growth or algae or tastes and odors
- Control strategy one:**
- Switch from chlorine in the raw water to chlorine dioxide or to potassium permanganate to achieve preoxidation

DBP Case 1 – Pre-chlorine

- A significant amount of the DBPs generated by my facility are due to the need to pre-chlorinate the raw water to control iron and manganese or slime growth or algae or tastes and odors

Control strategy two:

- Continue the pre-chlorination practices at the lowest possible chlorine dose and reduce additional DBP formation downstream to meet water quality objectives and achieve compliance



I am NOT a Bear !

Rather I am an ancient marsupial!

The Kangaroo and the Wombat are my cousins

DBP Case 2 – Chlorine on Filters

- A significant amount of the DBPs generated by my facility are due to the need to chlorinate before (on top of) the filters to improve filter performance control slime growth and/or improve iron and manganese removal

Control strategy one:

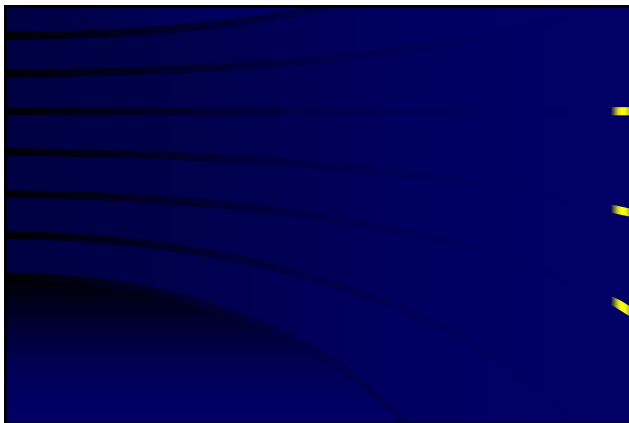
- Optimize precursor removals prior to the filters and continue the chlorination on top of the filters at the lowest possible chlorine dose and reduce additional DBP formation downstream to meet water quality objectives and achieve compliance

DBP Case 2 – Chlorine on Filters

- A significant amount of the DBPs generated by my facility are due to the need to chlorinate before (on top of) the filters to improve filter performance control slime growth and/or improve iron and manganese removal

Control strategy two:

- Optimize precursor removals prior to the filters and change to chlorine dioxide or ozone prior to the filters and if needed reduce additional DBP formation downstream to meet water quality objectives and achieve compliance



DBP Case 3 – Long Chlorine C*T

- A significant amount of the DBPs generated by my facility are due to the need for a long Chlorine C*T to achieve my 3-log Giardia requirements

Control strategy one:

- Optimize precursor removals prior to the filters and change to UV disinfection as the primary disinfectant followed by chlorine addition for virus disinfection credit and distribution system residual maintenance

Pros and Cons of UV

Pros

- Highly Effective Against Giardia, Crypto, Bacteria and “most” Human Viruses
- No Significant DBP Formation Found to Date
- Low Capital and O&M Costs

Cons

- Difficult to Verify Performance – No Measurable Residual
- Ineffective as a Preoxidant
- Concerns During Long-term Operation With Issues Such as Sleeve Fouling, Sensor Stability and On-Line Lamp Breakage
- Higher UV Doses Needed for Adenovirus

Is UV Ready for Prime Time?



Aquionics MP UV for a PWS in Fort Benton, Montana

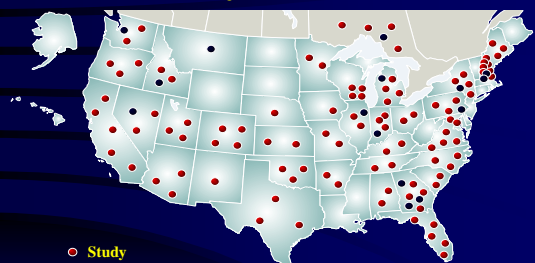
Trojan UV8000™ LP System PWS Research-SBWD



UV Makes Signing the Stage 2 Agreement in Principle Possible (Signed in Fall 2000)

- Agreed that UV “available and feasible” for:
 - up to 3-logs *Cryptosporidium* inactivation
 - up to 3-logs *Giardia* inactivation
 - No new DBP Formation, Possible Reduction in DBPs
- EPA will publish a UV Guidance Manual concurrent with proposed LT(2)ESWTR (Draft Final ~ Late Summer 2003):

UV Activity in North America



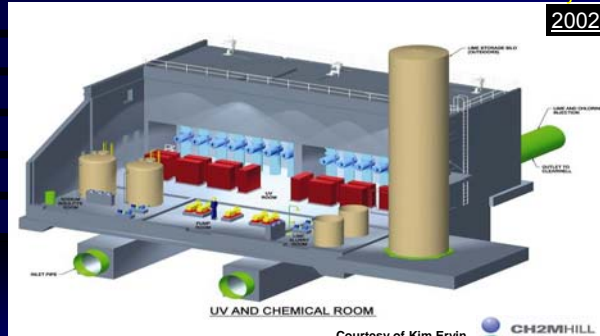
Courtesy of Tony Myers



Wedeco B-Series LPHO Unit – Norfolk, MA



Seattle Public Utilities 180 MGD UV Disinfection Facility



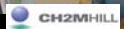
Courtesy of Kim Ervin



Henderson, NV 15 MGD 3 Reactors + 1 Back-Up



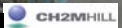
Courtesy of Paul Swaim



Henderson, NV 5 MGD Hanovia Photon MP UV Reactor



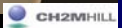
Courtesy of Paul Swaim



Wedeco LPHO Layout for Clayton County, GA



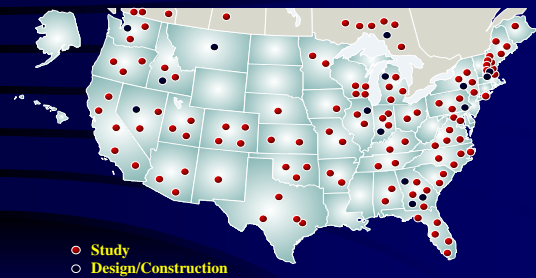
Courtesy of George Aiy



UV at NY City's 2.6 Billion Gallon per Day Plant – UNH Alum Leads Effort



UV Activity in North America



Courtesy of Tony Myers



Typical Drinking Water UV Facilities

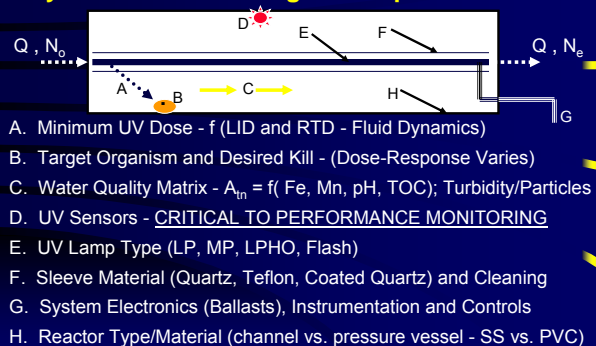


Regulations Finalized

- In 2006 the Long Term Stage 2 Enhanced Surface Water Treatment Rule (LT2ESWTR) was finalized.
- In 2006 the Disinfectant/Disinfection By-Product Rule was finalized making a switch to UV attractive for some systems.
- In 2006 the Groundwater Rule was finalized (leaving UV use essentially up to the discretion of the states in terms of the Adenovirus dose issues).
- Nov. 2006, UVDGM finalized after 6 year process: www.epa.gov/safewater/disinfection/lt2/pdfs/guide_lt2_uvguidance.pdf
- Implications are that the UV market will be restarted and will grow significantly over the next 5 years since implementation schedules for these rules show enforcement beginning in 2012.

UV is
Ready !!!

Key Factors in UV Design and Operation



Estimation of UV Attenuation (A_{tn})

$$\%T = 100 \times 10^{-A} \text{ or } A = \log_{10} (1 / T) \quad (2)$$

$$\text{Beer-Lambert Law: } A = \varepsilon L C \quad (3)$$

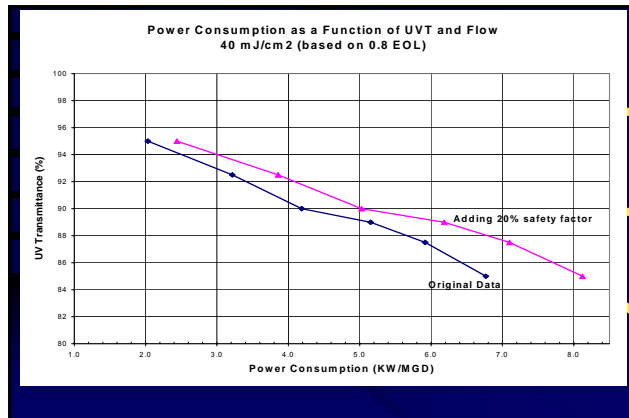
$$\text{For Water We Define } \alpha = \sum \varepsilon_i C_i \text{ and } A = \alpha L \quad (4)$$

$$\text{Attenuation } (A_{\text{tn}}) = (E_i / E_o) = \exp [-\alpha L] \quad (5)$$

$$\alpha = (A / L) \ln(10) = 2.303 (A / L) \quad (6)$$

$$A / L = UV_{254} \text{ Determine by Std. Mtds. 5910} \quad (7)$$

BUT HOW MUCH ADJUSTMENT FOR A_{TN} CAN WE AFFORD



Where Should I Put UV in My Water Plant ?

- UV Alone Is Not Effective as a Pre-Oxidant
- UV Would be Attractive Prior to Filtration But:
 - No Data Exists to Support Its Use in That Location
 - Concerns That Amorphous Solids Carry-Over from Settling/DAF Would Blind the UV System
 - Carrying Oxidant Residuals Such as Ozone or Permanganate into a UV System is not Recommended
- Placing UV Post-Filtration is the Only Location Justified by the Existing UV Disinfection Data Sets
 - Using Other Locations Will Require Pilot Demonstrations

In Running UV Plants Day to Day

- Need to Control Hydraulics
 - Surges
 - Turn-down (Average Flow/Minimum Flow)
 - Flow Pacing the Dose
 - Water Hammer
- Need to Insure UVT of the Water is Known and the UV Sensors are Working Properly
- Need to Insure Reliability
 - Uninterruptible Power Supply (UPS)
 - Redundant Reactors and/or Lamps

Future Directions: Reactor Validation

- German DVGW
- Austrian ONORM
- US – NWRI/AwwaRF
- USEPA UVDGM (November 2006)
- Rely Upon Bioassay (Biodosimetry)
 - B. subtilis Spore
 - MS-2 Bacteriophage Virus
- Importance of RED Bias in Validation
- Giardia and Cryptosporidium Required Doses Suggests Use of a New Test Organism: Q-Beta; T-7; *T-1* and *phiX174* for lower flow validations
- Caution Needed Since Newer Test Organisms May Have Limitations in Terms of Titers; QA/QC and the Organisms Relative Action Spectra

UV Dose, Validation and log Credit

LT2ESWTR	Log Inactivation							
$D_{\text{req'd}}$ Values (mJ/cm ²)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
<i>Cryptosporidium</i>	1.6	2.5	3.9	5.8	8.5	12	15	22
<i>Giardia</i>	1.5	2.1	3.0	5.2	7.7	11	15	22
Virus	39	58	79	100	121	143	163	186

Key UVDGM Equations:

$$D_{\text{validated}} \geq D_{\text{req'd}} \quad \{\text{RED is Reduction Equivalent Dose}\}$$

$$D_{\text{val}} = \text{RED}_{\text{calculated}} / \text{Validation Factor}$$

$$\text{VF} = (\text{Bias in the RED}) \times (1 + \text{Uncertainty in Validation})$$

$$\text{VF} = [B_{\text{RED}} \times (1 + U_{\text{val}})]$$

RED Bias vs. Test Organism

Test Organism	RED Bias*	Validation Factor (VF)**
B. Subtilis	1.68	2.10
MS-2	1.78	2.23
Q-Beta	1.55	1.94
<i>T-1</i>	1.20	1.50
<i>phiX174</i>	1.00	1.25

* 4-log Crypto, UVT 90%, $U_{val} = 25\%$, $B_{poly} = 1$

**Note that VF = 1.00 is the Ideal Condition.

UV in the LT2 for Open Reservoirs

- Albany, NY (~40 MGD is an early example)
- Many systems around the US studying and designing UV for this application at present
- Examined for Los Angeles for many years
- Proven effective for the 3-log Giardia and Cryptosporidium credit and readily accepted by the USEPA and the States
- No cases where it has been selected, designed, operated or approved for the 4-log virus credit
- Adenovirus will be the target virus for credit so most open reservoir systems are relying on chlorine CT

UV Dose, Validation and log Credit

LT2ESWTR	Log Inactivation							
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UV and Virus Credit

- Viral Nucleic Acid is Attacked By UV
 - Protein Coat Can Provide Some UV Protection
 - DS-RNA or DS-DNA are Harder to Inactivate
- 40 mJ/cm² Achieve 4-log Inactivation for:
 - poliovirus, hepatitis-A, rotavirus, and coxsackie
- Adenovirus more resistant due to repair mechanisms especially with LP and LPHO systems
 - >140 mJ/cm² needed in U.S. for 3-log credit
 - >180 needed in U.S. for 4-log credit
- Adenovirus was a poor basis for GWR
 - It is what it is so now we are moving on to address this

Adenovirus Background

- Obligate Intracellular Parasite
- Enteric virus
- Structure:

Icosahedral 70-90 nm

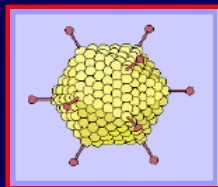
Non-enveloped

Capsid with Spikes

- Nucleic Acid

Linear

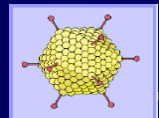
Double-stranded DNA



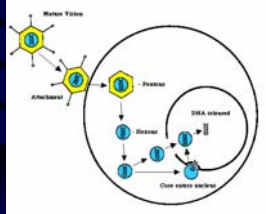
Source: Stannard, Department of Medical Microbiology, University of Cape Town

Adenovirus Risk

- 51 serotypes
- Acute self-limiting disease unless immunocompromised
- Upper Respiratory Infection, Gastroenteritis, etc.
- Transmission - fecal-oral route and inhalation
- EPA Candidate Containment List prior to CCL3
- UV Guidance Manual Focus on Adenovirus



Infectious Cycle of Adenovirus

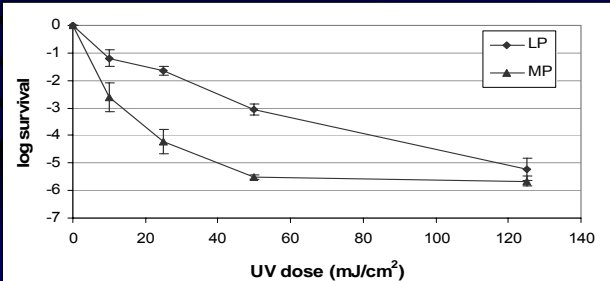


Source: www.tulane.edu/~dmsander/WWW/335/Adenoviruses.html

- Viral proteins mediate attachment and transport from host cell surface to nucleus of cell
- Attachment and Transport can occur in virus with damaged DNA
- Repair can then occur in the nucleus through host cell enzyme activity

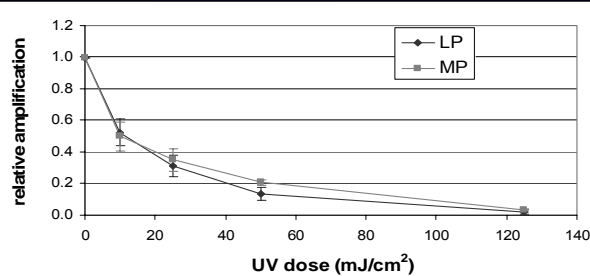
Very Recent Research Results "DNA Damage Assessment in UV-Treated Adenovirus" paper presented by Anne C. Eischeid, Joel N. Meyer and Karl G. Linden at AWWA -WQTC 2008, November 19, 2008 in Cincinnati, OH

Adenovirus Inactivation versus UV Dose



Very Recent Research Results "DNA Damage Assessment in UV-Treated Adenovirus" paper presented by Anne C. Eischeid, Joel N. Meyer and Karl G. Linden at AWWA -WQTC 2008, November 19, 2008 in Cincinnati, OH

Adenovirus DNA Damage for LP and MP Light



So How Can We Use UV for Virus ?

- 0.5 to 1 log virus credit and get the remainder with chemical disinfectants
- Use innovative approaches to validate the existing UV reactors to prove they achieve the specified UVDGM dose for 4-log credit
 - Site specific surrogates like *Bacillus pumilus* spores (MWRA Boston research)
 - Surrogates such as *Aspergillus niger*
 - Validation with live Adenovirus
 - Use of Dyed Microspheres
- Prove to states that (polychromatic) MP UV is more efficient at inactivating Adenovirus



DBP Case 3 – Long Chlorine C*T

- A significant amount of the DBPs generated by my facility are due to the need for a long Chlorine C*T to achieve my 3-log Giardia requirements

Control strategy two:

- Optimize precursor removals prior to the filters and change to ozone disinfection as the primary disinfectant followed by chlorine addition or preformed chloramine addition for distribution system residual maintenance

Pros and Cons of Ozone

Pros

- Highly Effective Against Bacteria, Virus, Giardia and Crypto in Warmer Waters (5 °C or Higher)
- Excellent Preoxidant Benefits (TAO, Microflocculation, etc.)
- Proven, Optimized Systems Exist - Reasonable O&M Costs

Cons

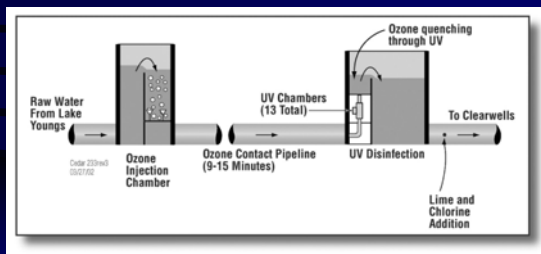
- High Capital Costs and Control Requirements
- Formation of Bromate a Concern in Some Waters
- Significantly Higher C*T's Needed for Crypto and Possibly Giardia in Cold Waters (1 °C or Lower)

Disinfection Processes for the 180 MGD Cedar River WTP in Seattle

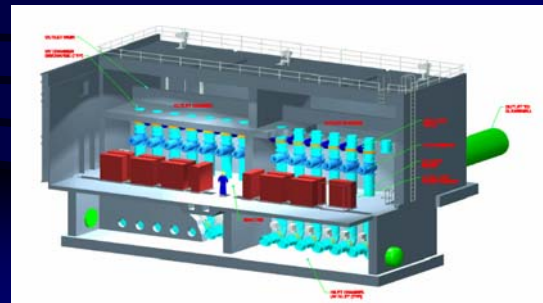


- Ozone
 - Giardia, taste and odor, and some Cryptosporidium
- UV
 - Cryptosporidium and Giardia
- Chlorine
 - distribution system residual and emergency Giardia and virus

Cedar Treatment Schematic



Seattle's Cedar UV Facility Layout



UV and Chemical Building Construction



Cedar UV Reactors



Cedar UV Reactors - Installed



Chloramines

- Chloramine Chemistry Basics
 - We want to form Monochloramine (NH_2Cl)
 - Importance of the Chlorine to Ammonia-Nitrogen Mass Ratio
 - Importance of pH Effects on Chloramine Species
 - Issues with Nitrification
- Chloramines and Lead in Washington, D.C.
The Chemistry Explains/Solves the Problem

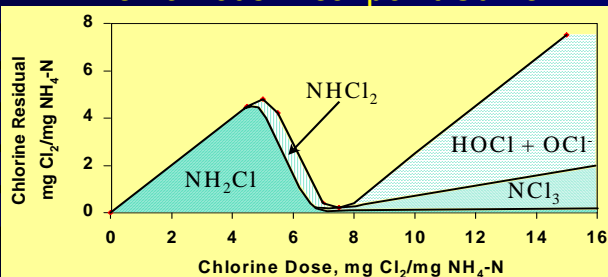
Chloramine Formation Equations

- Monochloramine (NH_2Cl):
 $\text{HOCl} + \text{NH}_3 \rightarrow \text{NH}_2\text{Cl} + \text{H}_2\text{O}$
- Dichloramine (NHCl_2):
 $\text{HOCl} + \text{NH}_2\text{Cl} \rightarrow \text{NHCl}_2 + \text{H}_2\text{O}$
- Trichloramine (NCl_3):
 $\text{HOCl} + \text{NHCl}_2 \rightarrow \text{NCl}_3 + \text{H}_2\text{O}$
- Organochloramines:
 $\text{HOCl} + \text{Organic Amines} \rightarrow \text{Organochloramines} + \text{H}_2\text{O}$

=====

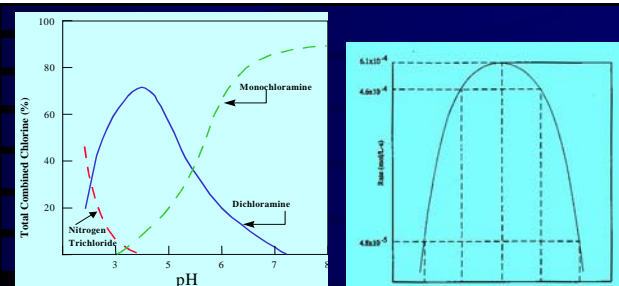
We select for Monochloramine since it is a stronger Disinfectant, is more stable and has less taste and odor issues
pH and Cl_2 to $\text{NH}_4\text{-N}$ mass ratio are the key factors to control

The Famous Breakpoint Curve



Target Ratio in Practice is 3:1 to 5:1 $\text{mg Cl}_2 / \text{mg NH}_4\text{-N}$

BE CAREFUL! In practice, poor blending/mixing can cause ratios as high as 12:1 which will have negative impacts



pH 8.3 to 8.4 is commonly used as the optimum target for monochloramine formation at a $\text{Cl}_2:\text{NH}_4\text{-N}$ mass ratio of 3:1 – 5:1

Potential for Nitrification

- When the $\text{Cl}_2:\text{NH}_4\text{-N}$ mass ratio is too low or for some other reason excess levels of $\text{NH}_4\text{-N}$ persist in the distribution system, there is strong potential for nitrification events especially in warmer water
- Nitrification – the two step microbial conversion of ammonia to nitrite and then to nitrate



- Factors that Effect the Potential:
 - Free $\text{NH}_4\text{-N}$ Concentration
 - Temperature
 - pH range – 7.5 to 8.5 is where it occurs fastest
 - Residence Time, Mixing/Stagnation Zones

Impacts of Nitrification

- Degrades chloramine residual
- Consumes dissolved oxygen
- Consumes alkalinity
- Can increase potential for corrosion either due to lower ORP (REDOX) potential in the system and/or lower pH
- Increases HPC counts and can indirectly lead to coliform rule violations
- Increases nitrite and nitrate levels
- Can result in taste and odor complaints

Control of Nitrification

- Increase Monitoring of HPCs, Nitrite and Nitrate to Understand Where and Why it is Occurring
- Conversion to Free Chlorine For Short Periods – {often termed a chlorine burn}
- Spot Chlorination “Tea-Bagging” of Water Towers
- Increase Chloramine Residual
- Increase Chlorine to Ammonia Nitrogen Mass Ratio
- Set pH for Optimum Monochloramine Formation
- Increase Flushing especially for dead ends
- Reduce Water Age

The Washington, D.C. Case Study

History

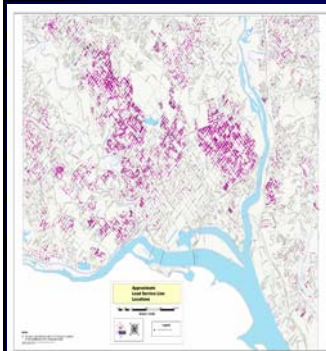
Water Source is the Potomac River



The U.S. Army Corp. of Engineers – Washington Aqueduct Operates Reservoirs and Two Conventional Treatment Plants: Dalecarlia and McMillan Producing about 180 MGD Total. The treatment plants use chlorine for disinfection and in November 2000 switched to Chloramines in the distribution system to control DBPs for lead and copper rule compliance the plants add Lime to maintain a positive Langelier Index and favorable Stability Index

Washington Water and Sewer Authority (WASA) – Provides water to 130,000 Service Connections (23,000 Lead Services) in the 8 Wards of Washington, D.C. - 725 Square Miles and 1,300 miles of piping.

Lead Problems in Washington, D.C.



Map of Lead services in DCWASA

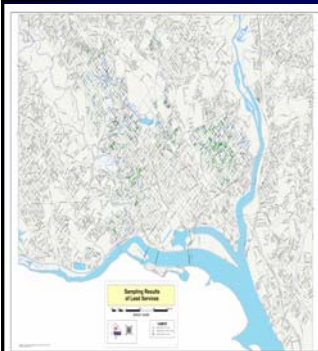
Fall 2001 – Spring 2003
53 Homes Exceed 0.015 mg/L
(Lead Levels Up to 0.600 mg/L Documented)

Spring 2002 to October 2003
5000 Homes Exceed Lead Limit

February 2, 2004 Washington Post Article Exposes the Lead Problem – “The Lead Hits the Fan” A Media Feeding Frenzy Results

March 2004 Two Congressional Hearings; USEPA Criticizes WASA; WASA Director Resigns

Lead Problems in Washington, D.C.



Map of Major Lead Levels in DCWASA

March 2004 WASA Convenes Panel of Corrosion Experts

April 7, Senators introduce the Lead-Free Drinking Water Act of 2004, S. 2733

April 8, WASA Completes the Shipment of 23,000 Filters to Homes with Lead Service Lines

May 2004 Washington Post and Times Magazine Articles Decree that Chloramines are Cause of the Lead Problem Noting Switch Back to Chlorine as Problem Solution Between April 2 and May 8, 2004

Lead Problems in Washington, D.C.



Map of Lead Service Replacements in DCWASA

June 2004 Washington Aqueduct Begins Pilot Test of Orthophosphate (Zinc Free)

July 17, WASA and USEPA Enter a Multiphase Agreement to Address the Lead Problem

August 23, Washington Aqueduct Begins Feeding Orthophosphate (Zinc Free) System Wide

September 2004, Lead Levels Continuing to Drop, Class Actions Lawsuits Beginning and Legal Websites Popping Up All Over The Area

Lead Problems in Washington, D.C.



Map of Lead Service Replacements in DCWASA

2004 to 2006, chloramines were given a black eye and their use has been questioned by some citizens and groups

Present Day - we have learned from the Washington, D.C. case and have paid close attention to corrosion issues when changing distribution system water quality

Present Day - chloramine use continues to grow but carefully and with increased attention to potential for corrosion issues

What Happened in Washington, D.C. ?

Were Things Done Incorrectly ? - Yes

Could this happen to a New England Water Utility ? - Yes

Did the Switch to Chloramines Cause the Problem ? - Yes

Were Chloramines the Primary Cause ? - No

Do We Understand the Science ? - Mostly Yes

Can Chloramines Be Used Safely ? - Yes

What Happened in Washington, D.C. ?

- For over 20 years, Lead Service Line Replacement has been recommended in D.C. - its costs prevented it
- For over 20 years, Corrosion Control Issues have been raised in D.C. - little was done except Lime addition
- After switching to Chloramines in 2000, Corrosion problems were noted almost immediately especially in the form of pinhole leaks in copper services both at WASA and at its neighbor WSSC. WASA lead monitoring results in early 2001 showed increasing lead levels
- Chloramines changed the water chemistry resulting in higher lead leaching primarily from lead service lines and to a smaller degree from in-line brass fixtures - this put a system with a history of corrosion issues and lead risk over the top - with serious public consequences for us all

The Chloramine Chemistry Involved

- As we noted earlier, chloramine use normally depends on the formation of monochloramine as follows:

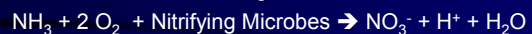


Two important differences between chlorine (HOCl) and monochloramine (NH₂Cl) of importance to corrosion are:

- Chlorine is a much stronger oxidizing agent and will insure more oxidizing conditions (higher ORP) in the distribution system than monochloramine
- Monochloramine introduces amines or ammonia into the distribution system and this nitrogen source can result in Nitrification which can further lower the ORP and in some systems lower the pH (this has been well proven in distribution systems especially those which have a long retention time and are in warmer climates).

Nitrification's Impacts

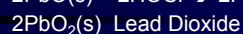
- Nitrification is the conversion of ammonia to nitrate by naturally occurring microorganisms under aerobic conditions. It follows the general reaction:



This reaction causes two very significant problems for corrosion control in distribution systems:

- It consumes oxygen making for more reducing conditions in the distribution system which leads to greater metals (lead and copper) solubility/leaching.
 - It produces acid (H⁺) lowering the pH or at least the buffering of the system which also leads to greater metals leaching (not a major factor in Washington, D.C.)
- In the Washington D.C. case the water buffering was adequate to prevent any lowering of pH

Review of Lead Chemistry

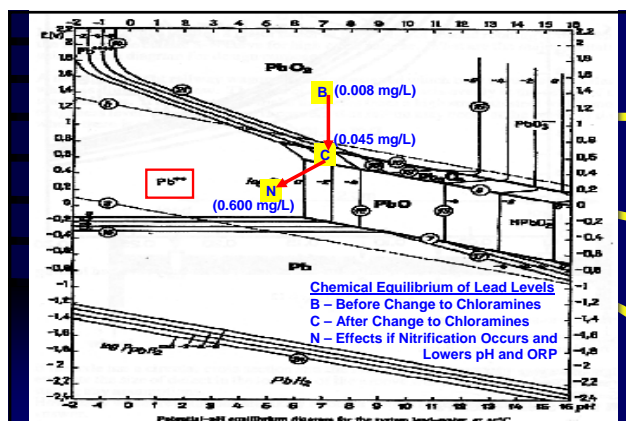
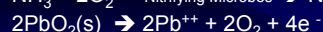
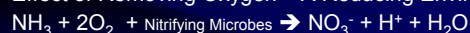


Lead dioxide is a critical intermediate in the leaching of lead and is very subject to water quality changes

Effect of Lowering pH



Effect of Removing Oxygen – A Reducing Environment



Steps to Resolve the Problem (1/3)

- Switch Back to Free Chlorine
 - Would help insure the $\text{PbO}_2(\text{s})$ Form Dominated So the Lead Levels in the DS Would Drop
 - Would eliminate the reducing environment and prevent Nitrification
 - Return to the Health Risk Concerns of High DBPs at the Consumer's Tap
 - Return to the Health Risk Concerns of Regrowth in the DS and No Residual Disinfectant Protection

Steps to Resolve the Problem (2/3)

- Remove the Sources of Lead
 - Replace the Lead Service Lines
 - Impose Tougher Standards for "Lead Free" Brass (currently allow 8% lead by weight)
 - This is a costly effort and will take years to accomplish (it has begun in many Water Systems and will eventually be accomplished)
 - It may be impossible to identify and remove all sources of lead from the DS plumbing

Steps to Resolve the Problem (3/3)

- Apply A Different Corrosion Control Strategy and Keep Chloramines
 - Improve Distribution System Flushing and Maintenance Procedures
 - Use an Extended Free Chlorine Residual Flush or Do Twice per Year (to prevent Nitrification)
 - Switch to an Orthophosphate Corrosion Inhibitor and Work to Optimize System-wide pH Control
 - Increase monitoring and data analysis and then communication between all parties

Orthophosphate for Corrosion Control

Orthophosphate – Food grade phosphoric acid H_3PO_4 ; Trisodium orthophosphate $\text{Na}_3(\text{PO}_4)$; and Zinc orthophosphate $\text{Zn}_3(\text{PO}_4)_2$ are all used by water utilities to control corrosion. The later two are not used if Sodium is an issue (e.g., in MA) or if Zinc becomes a wastewater treatment issue as in the case of WASA. Typically 3 ppm is added at first and then the dose is optimized often to the 0.5 to 2 ppm range. The phosphate ion can then react with the pipe (metal) material that is corroding to form a protective phosphate solid coating ($\text{Pb}_3(\text{PO}_4)_2(\text{s})$):



Corrosion Control is Complex

- Much success with corrosion control has been achieved in drinking water and much has been learned by researchers but there are cases where the chemistry of the water and the distribution system are complex and corrosion control strategies are unsuccessful.
- Careful control of pH and system ORP is very important as is careful selection and application of corrosion control chemicals. Good monitoring is vital
- A thorough understanding other factors such as water treatment plant processes; nature and role of organic matter (TOC) in the system; electrochemical aspects such as mixing of pipe materials; electrical grounding; and biofilm aspects may all be important

DC WASA Pledge in USEPA Agreement Twelve Point Plan of What WASA is Actually Implementing:

- Significantly accelerate the replacement of all District public space lead service lines compared to EPA's requirements.
- Work in partnership with a local financial institution to create a means tested loan program to help customers finance the replacement of lead service line pipes on private property.
- Continue to work with District government agencies to identify public grant funds to help District residents with lead service line pipe replacements.
- Appoint a Lead Service Coordinator reporting directly to the General Manager to manage all day-to-day WASA activities regarding lead service line replacements, community outreach, communications and water testing.
- Launch a Mobile Community Response Unit to more readily address customers concerns.
- Work closely with WASA stakeholders, including elected officials, faith-based, community and civic organizations, and others to ensure communications are clear and reach audiences appropriately, including those that don't speak English.

DC WASA Pledge in USEPA Agreement

Twelve Point Plan (continued):

- Measure communication effectiveness in a quantitative manner.
- Strengthen its partnership with the D.C. Department of Health to address any health concerns of D.C. residents regarding lead leaching.
- Work closer with the Washington Aqueduct regarding production of water provided to D.C. residents. System-wide Orthophosphate Now in Use
- Further develop corporate partnerships to benefit resident and rate payers which will specifically address the further distribution of water filters and the availability of bank loans to residents in order to finance lead service line replacements on private residential property.
- Work with the D.C. Department of Health and experts from the George Washington University School of Public Health to more fully understand and communicate to residents information now available from local research and analysis regarding the health effects of water-based lead exposure.
- Convene a National Water Authority Peer Group Workshop so experts, scientists and health professionals can discuss and explore the D.C. experience with other utilities in an effort to better frame future policy discussions for the nation and our policymakers.

Take Home Messages

- Chloramines Reduce DBP Risks to Public Health
- Chloramines Reduce Microbial Regrowth and Risk in Distribution Systems and in Hospitals
- Chloramines WILL Change the Water Quality Conditions in a Distribution System (especially the ORP)
- Chloramines alone DO NOT cause Corrosion Problems
- The Decision to Switch to Chloramines Requires:
 - An Experienced Team Effort
 - Careful Planning Including Public Education
 - Careful Implementation of Switching to Chloramines
 - System Monitoring of Key Water Quality Parameters {e.g., pH; Cl_2 to $\text{NH}_4\text{-N}$ Mass Ratio; Lead and Copper; Microbes, Ammonia, Nitrite and Nitrate} is Needed

Take Home Messages

- Before adopting a DBP Minimization strategy develop an understanding of why your specific system is generating higher than allowed DBPs
- Remove as much DBP precursor material as possible within the limits of facility costs, space constraints and operational skill and reliability
- Try to minimize Chlorine use as a pre-oxidizer and as a primary disinfectant – does switching to UV or Ozone make sense for your system
- Finally and if needed then carefully consider the pros and cons to switching your secondary disinfectant to Chloramines

Minimizing DBPs With Multiple Disinfectant Barriers to Achieve Multiple Objectives

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TIME FOR QUESTIONS !