Impact of Chloride:Sulfate Mass Ratio (CSMR) Changes on Lead Leaching in Potable Water

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Early Work on Galvanic Corrosion of Lead

• “…solution of lead was assisted by contact with other metals” such as copper-lead connections
  (Wolffhugel, 1887)

• “…in practice, contact with iron pipes, solder, etc., is an important factor in assisting the attack on lead by water”
  (Lindsay, 1859)

• “…galvanic action is a most powerful agent in promoting the corrosive action of certain waters upon lead”
  (Stirling, 1859)

• “Occasionally the insertion of copper pipe can produce particularly bad results and despite satisfactory pH control it may be impossible to obtain satisfactory samples”
  (Britton and Richards, 1981)
Previous Work on Chloride & Sulfate

• Oliphant (1983) and Gregory (1985, 1986) linked lead contamination of waters to galvanic corrosion of lead solder

  – Found benefits from $\text{SO}_4^{2-}$ and detriments from $\text{Cl}^-$
Previous Work

• Dodrill & Edwards (1995): more lead with higher chloride and lower sulfate

• Pb poisonings in NC
  • Pb action level exceedance when coagulant changed from alum to PACl, shifting CSMR from low to high
“A 2-year old has been diagnosed with lead poisoning...They took the aerator off the sink [faucet] and tapped it into the counter. It looked like asphalt pebbles, but it was solder”

*Raleigh News and Observer, 2005*
Outline

• Galvanic corrosion theory
• Mechanistic study
• How concerned should you be?
• Practical studies
  – Solder
  – Brass
  – Lead pipe
Outline

• Galvanic corrosion theory
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Typical Case

Anode
Oxidized
“Sacrificed”

Cathode
Reduced
“Protected”

Pb

Pb\(^{2+}\)  
“Lewis” Acid

Cu

\(2e^-\)

O\(_2\)

OH\(^-\)  

Lower pH
Higher pH
Sulfate “Good”

- Sulfate precipitates lead at the anode

\[ \text{Pb}^{+2} + \text{SO}_4^{-2} \rightarrow \text{PbSO}_4 \text{ solid} \]

Insoluble even at very low pH
Cu → Pb

V

Oxidized “Sacrificed”

Anode

Pb

Pb$^{+2}$ released

SO$_4^{-2}$ drawn to anode

Cathode

Reduced “Protected”

2e$^-$

Cu

Lower pH

Higher pH
Cu Pb V

Anode

Oxidized
“Sacrificed”

Pb

Protective
PbSO$_4$
Coating

Lower pH

Cathode

Reduced
“Protected”

Cu

2e$^-$

Higher pH
Chloride “Bad”

- Chloride complexes lead

\[ \text{Pb}^{+2} + \text{Cl}^- \rightarrow \text{PbCl}^+ \]

- soluble
- prevents formation of solid
Anode Oxidized “Sacrificed”

Cathode Reduced “Protected”

Pb

Cl⁻ drawn to anode

Pb⁺² released

Lower pH

Higher pH

Cu

2e⁻
Anode
Oxidized
“Sacrificed”
Pb

Cathode
Reduced
“Protected”
Cu

Coating Dissolved

PbCl⁺

Lower pH
Higher pH
Chloride to Sulfate Mass Ratio (CSMR)*
Sample Calculation

Chloride to Sulfate Mass Ratio (CSMR) = \frac{Bad}{Good}

= \frac{[\text{Cl}^-]}{[\text{SO}_4^{2-}]} = \frac{10 \text{ mg/L } \text{Cl}^-}{20 \text{ mg/L } \text{SO}_4^{2-}} = 0.5

* Oliphant, 1983; Gregory, 1985; Dodrill and Edwards, 1995
Outline

• Galvanic corrosion theory
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Macroscopic Simulated Soldered Joint

- Silicone Stopper
- \( \frac{3}{4} \)" Cu Pipe, Length = 12.25"
- Tubing connecting copper pipes
- \( \frac{1}{2} \)" Cu Pipe, Length = 2.5"
- Silicone Stopper
- 50:50 Pb/Sn Solder Wire
- Multimeter Connection
Mechanistic Study – Setup
Mechanistic Study – pH at Microlayers

**Initial pH**

- **Anode**
- **Cathode**

**pH**

3 4 5 6 7 8 9 10

*Initial pH*
Mechanistic Study – Cl⁻ at Microlayers

![Diagram showing chloride concentration at different layers: 11 X and 2.2 X compared to bulk water chloride.](image-url)
This provides 1st mechanistic explanation for why CSMR “works” in explaining trends in certain lead corrosion problems.
# Mechanistic Study - Water Quality (Utility I, MD)

<table>
<thead>
<tr>
<th>Water Conditions</th>
<th>CSMR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Alum-treated, free chlorine</td>
<td>1.4</td>
</tr>
<tr>
<td>2) Alum-treated, monochloramine</td>
<td>1.3</td>
</tr>
<tr>
<td>3) PACl-treated, free chlorine</td>
<td>5.3</td>
</tr>
<tr>
<td>4) PACl-treated, monochloramine</td>
<td>5.3</td>
</tr>
<tr>
<td>5) PACl-treated, +20 mg/L Cl, free chlorine</td>
<td>8.5</td>
</tr>
<tr>
<td>6) PACl-treated, +20 mg/L Cl, monochloramine</td>
<td>8.4</td>
</tr>
</tbody>
</table>

- pH 7.7 ±0.1
- 3.5 mg/L Cl₂
- 1 mg/L PO₄-P
Mechanistic – Pb vs. Current

Lead in water versus currents measured during 15 weeks of the study.

\[ y = -270x - 630 \]

\[ R^2 = 0.80 \]
Outline

• Galvanic corrosion theory
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• How concerned should you be?
• Practical studies:
  – Solder
  – Brass
  – Lead pipe
How Concerned Should You Be?

- Lead solder or partially replaced lead pipe in distribution system?
  - No: No Concern
  - Yes: CSMR < 0.2
    - Yes: No
    - No: CSMR > 0.2, but < 0.5
      - Yes: Significant Concern
      - No: CSMR > 0.5, and Alkalinity < 50 mg/L as CaCO₃
        - No: Serious Concern
        - Yes: No
Elevated CSMR from:

- Coagulants
  - Changing from sulfate-based coagulant to chloride-based coagulant
- Hypochlorite generator brine leak
  - Switching from chlorine gas to hypochlorite on-site generator
- Anion exchange
- Use of desalinated water
- Road salt runoff
Outline

• Galvanic corrosion theory
• Mechanistic study
• How concerned should you be?

• Practical studies:
  – Solder
    • Coagulants
    • Anion Exchange
    • Hypochlorite Brine Leak
    • Desalination
    • Illustrative Case Study
  – Brass
  – Lead pipe
Simple Bench Scale Case Studies

-Simulated copper joints - 50:50 Pb:Sn solder placed inside copper coupling
  • 50:50 Pb:Sn solder - 1” length, 3 mm diameter
  • Cu coupling – 1” length, ½” diameter
  • Exposed to 100 mL of test water in triplicate
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    • Coagulants
      • Anion Exchange
      • Hypochlorite brine leak
      • Desalination
      • Illustrative case study
    – Brass
    – Lead pipe
## Finished Water Chloride and Sulfate

<table>
<thead>
<tr>
<th>Coagulant</th>
<th>Cl&lt;sup&gt;-&lt;/sup&gt; (mg/L Cl)</th>
<th>SO&lt;sub&gt;4&lt;/sub&gt;&lt;sup&gt;2-&lt;/sup&gt; (mg/L SO&lt;sub&gt;4&lt;/sub&gt;)</th>
<th>CSMR</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% Alum</td>
<td>16</td>
<td>40</td>
<td>0.4</td>
</tr>
<tr>
<td>Alum and PACl Blends</td>
<td>21</td>
<td>30</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>22</td>
<td>24</td>
<td>1.1</td>
</tr>
<tr>
<td></td>
<td>23</td>
<td>18</td>
<td>1.5</td>
</tr>
<tr>
<td>100% PACl</td>
<td>22</td>
<td>12</td>
<td>1.8</td>
</tr>
<tr>
<td><strong>Raw Water</strong></td>
<td><strong>16</strong></td>
<td><strong>12</strong></td>
<td><strong>1.3</strong></td>
</tr>
</tbody>
</table>
100% Alum-treated water

100% PACl-treated water

Add disinfectant and Ortho-P; adjust pH

CSMR: 0.4 0.7 1.1 1.5 1.8

100% Alum-treated water

Alum and PACl-treated water

100% PACl-treated water
Coagulants

Lead release from new galvanic solder-copper coupons for a range of CSMRs during Weeks 22 and 23 for Greenville Utilities Commission, NC.
Outline

• Galvanic corrosion theory
• Mechanistic study
• How concerned should you be?

• Practical studies:
  – Solder
    • Coagulants
    • Anion Exchange
      • Hypochlorite brine leak
      • Desalination
      • Illustrative case study
  – Brass
  – Lead pipe
Anion Exchange to Remove Arsenic

- Water naturally contained arsenic (As)
- Anion Exchange used to remove As by replacing it with Cl\(^-\) in water
- SO\(_4^{2-}\) also exchanged for Cl\(^-\) → infinite CSMR
- Following Anion Exchange, Pb in an apartment complex spiked >1,000 ppb
- One child’s BLL exceeded CDC BLL of concern (10 µg/dL) *

* Edwards and Triantafyllidou, 2007
No Anion Exchange Treatment → pH 7.0 →

Treated with Anion Exchange → Bubble CO₂, pH 5.5 →
# Anion Exchange Treatment

<table>
<thead>
<tr>
<th>Water Treatment</th>
<th>[As] µg/L As</th>
<th>[Cl\textsuperscript{-}] mg/L Cl\textsuperscript{-}</th>
<th>[SO\textsubscript{4}\textsuperscript{2-}] mg/L SO\textsubscript{4}\textsuperscript{2-}</th>
<th>CSMR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prior to Anion Exchange</td>
<td>4.5</td>
<td>4.4</td>
<td>4.1</td>
<td>1.1</td>
</tr>
<tr>
<td>After Anion Exchange</td>
<td>1.8</td>
<td>13.2</td>
<td>1.7</td>
<td>7.8</td>
</tr>
</tbody>
</table>
Average lead release for each of the three water treatments of Utility F, ME, water during the first six weeks of the study.
Outline

• Galvanic corrosion theory
• Mechanistic study
• How concerned should you be?

• Practical studies:
  – Solder
    • Coagulants
    • Anion exchange
  • Hypochlorite Brine Leak
    • Desalination
    • Illustrative case study
  – Brass
  – Lead pipe
Hypochlorite Brine Leak

Water Type

- Control (no P, 10 mg/L alk.)
- 1 ppm P
- +10 mg/L CaCO₃
- 1 ppm P, +10 mg/L CaCO₃

Lead Release (ppb Pb)

- No Leak (3 mg/L Cl)
- Brine Leak (15 mg/L Cl)

80 X
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    • Coagulants
    • Anion exchange
    • Hypochlorite brine leak

• Desalination
  • Illustrative case study
    — Brass
    — Lead pipe
This utility plans to blend desalinated water with their current distribution water.

<table>
<thead>
<tr>
<th>Blend</th>
<th>$[\text{Cl}^-]$ mg/L</th>
<th>$[\text{SO}_4^{2-}]$ mg/L</th>
<th>CSMR</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% distribution</td>
<td>54</td>
<td>68</td>
<td>0.8</td>
</tr>
<tr>
<td>100% desalinated</td>
<td>110</td>
<td>Below detection</td>
<td>$\infty$</td>
</tr>
</tbody>
</table>
Distribution (Dist.) Water

Desalinated (Nanofiltered, NF) Water

100% Distribution

75:25 Dist:NF

50:50 Dist:NF

25:75 Dist:NF

Add disinfectant and adjust pH

CSMR: 0.8 1.2 2.0 3.9
Average lead release from 50:50 Pb:Sn solder between Weeks 6-8 for the Utility K, CA study.
Outline

• Galvanic corrosion theory
• Mechanistic study
• How concerned should you be?

• Practical studies:
  – Solder
    • Coagulants
    • Anion exchange
    • Hypochlorite brine leak
    • Desalination

• Illustrative case study
  – Brass
  – Lead pipe
Illustrative case study – Greenville, NC

(Data from Edwards and Triantafyllidou, 2007)
Illustrative case study – Greenville, NC

(Data from Edwards and Triantafyllidou, 2007)
Illustrative case study – Greenville, NC

(Data from Edwards and Triantafyllidou, 2007)
Illustrative case study – Greenville, NC

- Chloramines had little effect
- High CSMR had a major effect
- Phosphate did not stop the problem

- Edwards and Triantafyllidou, 2007
Outline

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  – Lead pipe
Brass

Average lead from brass with 90% confidence intervals for Utility I, MD.
Conclusions (Solder)

• Simple bench scale test protocol
  – test treatment changes on lead leaching from solder-copper couplings
• Low pH measured at anode (pH 3.3)
• Anions (Cl\(^{-}\) and SO\(_4\)\(^{2-}\)) migrate to the lead anode
• Lead sulfate is relatively insoluble, while chloride complexes lead and increases lead leaching
• Increased lead levels correlated with increased galvanic current
  – Galvanic effects are very persistent in some systems.
Conclusions (Solder)

• Changes that increase CSMR can increase Pb release (and 90\textsuperscript{th} percentile Pb)
  — Coagulants
  — Hypochlorite generator
  — Anion exchange
  — Desalination
  — Road salt runoff

Effect limited to galvanic connections between Pb and Cu.
Conclusions (Solder)

- Effects of Alkalinity and Orthophosphate are site-specific
  - High orthophosphate or high alkalinity do not eliminate galvanic effects, but sometimes can reduce them.
  - Sometimes they make it worse

Because no universal solution exists, effects of inhibitors and treatment changes have to be evaluated on a site-specific basis using a simple protocol similar to that proposed here.
Outline

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• Practical studies:
  – Solder
  – Brass
  – Lead pipe
    • How big a problem is this?
Lead Service Lines

• “One of the most serious environmental disasters” in US history (Troesken, 2006)

• 3.3 - 6.4 million US homes with old lead service lines or connections, as of 1990 (Weston and EES, 1990)

• Contribute to an estimated 50 – 75 % of the lead in drinking water (Sandvig et al., 2008)

• Can contribute to violations of the 15 ppb LCR action limit for lead in drinking water
Partial Lead Service Line Replacement (PLSLR)

- **UK warning**: not recommended for lead level reduction, because “effects are unpredictable and may be contrary to those hoped for” (Chambers & Hitchmough, 1992)

- **US practice**: presumed to provide benefits over keeping the whole lead service line in place because “there will be a smaller volume of water in contact with the LSL” (US EPA, 2000)
Potential Adverse Consequences of Partial Lead Service Line Replacements

• Disturbing rust scale and/or creating metallic lead particles when the lead pipe is cut (Boyd et al., 2004; Sandvig et al., 2008)

• Galvanic corrosion of lead (Britton and Richards, 1981)

• Deposition corrosion of lead (Britton and Richards, 1981)
Galvanic Corrosion

Can accelerate corrosion of the lead pipe, above and beyond what would normally occur for lead pipe alone.
Galvanic Corrosion

Lead that is galvanically corroded does not all go into the water.
Galvanic Corrosion

Lead that is galvanically corroded does not all go into the water.
But particulate lead in rust can detach, somewhat randomly, and cause lead spikes.
Recent Work on Galvanic Corrosion

• “Partial replacements using copper piping can result in the creation of a galvanic cell, giving rise to increased and erratic levels of lead observed at the tap. The effect can be persistent and may well annul any beneficial effects of reducing the length of lead pipe in the system”  
  (Chambers & Hitchmough, 1992)

• “<Edwards' group>...documented lead levels as high as 45,000 ppb by galvanically connecting an old lead pipe to one made of new copper under varying water conditions”  
  (Renner, 2004)

• “The magnitude of galvanic impacts on aged and passivated LSL surfaces and on new copper surfaces is minimal, and in the long term, likely to be inconsequential”  
  (Reiber and Dufresne, 2006)

• “Deep corrosion localized in the area immediately adjacent to the pipe joints suggests a galvanic mechanism”  
  (DeSantis, Welch and Schock, 2009)

Definitive data are not available on the long-term implications relative to PLSLRs
Deposition Corrosion

A micro-galvanic effect

New Cu Pipe

Pb Pipe
Deposition Corrosion

A micro-galvanic effect

New Cu Pipe

Cu²⁺

Pb Pipe

Water flow

Cu

O₂, OH⁻

2 e⁻

Micro-Galvanic Cells

Underlying lead corrodes
## Scenarios of Galvanic and Deposition Corrosion

<table>
<thead>
<tr>
<th>Plumbing Type/ Sequence</th>
<th>Galvanic Junction(s)</th>
<th>Copper Deposition on Lead?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Service House</td>
<td>0</td>
<td>No</td>
</tr>
<tr>
<td>Service House</td>
<td>1</td>
<td>No</td>
</tr>
<tr>
<td>Service after PLSLR</td>
<td>2</td>
<td>Yes</td>
</tr>
</tbody>
</table>

- **Service House**: Lead (Pb) to PVC
- **Service House**: Lead (Pb) to Copper (Cu)
- **Service after PLSLR House**: Copper (Cu) to Lead (Pb) to Copper (Cu)
“Possible concern from inserting copper pipes or other apparatus upstream of and electrochemically linked to lead. Utilities should have clear advice/information systems so that such practices are avoided both by their own staff and by customers or tradesman.“

(Breach et al., 1991)
Simulated Small Scale PLSLR-Experimental Setup

External wired galvanic connection

Insulating spacer to separate the two metals

Cu pipe length X %
Pb pipe length (1-X) %

Total length = 3 ft

Stopper to hold water in
Research questions

• Do Cu-Pb connections always passivate quickly in terms of galvanic current or lead leaching?

• Are effects of galvanic corrosion consequential in PLSLR?
  - Low CSMR water
  - High CSMR water

Evaluate worst case scenario of long stagnation
No cutting or other opportunity to mobilize scale from pipes

All effects attributable to galvanic/deposition corrosion alone
## Water Chemistry/Experimental Protocol

<table>
<thead>
<tr>
<th></th>
<th>Cl⁻ (mg/L)</th>
<th>SO₄⁻² (mg/L)</th>
<th>CSMR</th>
<th>Alkalinity (mg/L as CaCO₃)</th>
<th>NH₂Cl (mg/L as Cl₂)</th>
<th>pH</th>
<th>Ionic Strength (mmol/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Low CSMR Water</strong></td>
<td>22</td>
<td>112</td>
<td>0.2</td>
<td>15</td>
<td>4</td>
<td>8.0</td>
<td>4.6</td>
</tr>
<tr>
<td><strong>High CSMR Water</strong></td>
<td>129</td>
<td>8</td>
<td>16</td>
<td>15</td>
<td>4</td>
<td>8.0</td>
<td>4.4</td>
</tr>
</tbody>
</table>

Static “fill and dump” protocol:
Water change 3 times/week
Effect of CSMR

Simulated partial replacement → more lead in water
Effect of Galvanic Connection for 50% Pb pipe

Galvanic corrosion → severe lead contamination of water
Laboratory study proves potential long-term detriments from galvanic and deposition corrosion arising from partial replacement
Linear Model

Partial Replacement of Pb with Cu → Beneficial
Low CSMR water, Deviation from Linear Model

- Linear Theoretical Model: No galvanic or Deposition Corrosion
- Simulated Partials, Low CSMR water
Low CSMR water, Deviation from 100% Pb

Simulated Partials, Low CSMR water
Low CSMR water

- Even in low CSMR water, detriments of galvanic corrosion do counter benefits of reduced lead surface area
- Net benefit depends on magnitude of galvanic corrosion, % LSL replaced, and other factors
High CSMR water, Deviation from Linear model

Graph showing Pb in water (ppb) vs % Pb pipe for linear theoretical model and simulated partials, high CSMR water. Theoretical model shows no galvanic or deposition corrosion, while simulated partials exhibit significantly higher Pb levels at various % Pb pipe levels, indicated by factors of 10X, 21X, and 30X.
High CSMR water, Deviation from 100% Pb pipe

![Graph showing Pb in water versus % Pb pipe](image-url)

- **Pb in water (ppb)**
  - 0
  - 2000
  - 4000
  - 6000
  - 8000
  - 10000
  - 12000
  - 14000
  - 16000

- **% Pb pipe**
  - 100
  - 83
  - 50
  - 33
  - 17
  - 0

- **Simulated partials, High CSMR water**

  - 8X
  - 10X
  - 6X
  - 4X
High CSMR water

• Detriments of galvanic corrosion outweigh the benefits of reduced lead surface area, in every simulated partial replacement

• Net benefit only when replacing 100% Pb pipe
Visual Observations

Best Case

Pb Pipe

Worst Case

Cu

Pb
Visual Observations

Best Case

Week 7

Worst Case

Week 1
Week 7
Week 16
Week 46

random particle release
Effect of Alkalinity under High CSMR

![Graph showing the effect of different alkalinity levels on Pb in water. The graph compares the Pb in water (ppb) at different percentages of Pb pipe (100 and 50) at Alkalinity levels of 15 mg/L CaCO3 (red), 50 mg/L CaCO3 (blue), and 100 mg/L CaCO3 (green).]
Galvanic Current under High CSMR

Indicator of galvanic corrosion: Higher Current → Higher Pb Leaching
Conclusions from simulated PLSLR

Laboratory simulation of partial lead service line replacements under static “fill and dump” tests that lasted 1+ years showed:

• Galvanic corrosion significant both in Low CSMR and High CSMR water

• Increase of CSMR from 0.2 → 16 increased galvanic corrosion: Much more lead to the water and higher galvanic currents

• Increase of alkalinity from 15 → 50 → 100 mg/L as CaCO₃ did not reduce lead release or galvanic current magnitude, when the CSMR was high
Conclusions from simulated PLSLR

Galvanic effect can be persistent.

We therefore confirm prior research that shows galvanic effect may “well annul any beneficial effects of reducing the length of lead pipe in the system”
Future research questions on galvanic corrosion after simulated PLSLR

- Realistic flow patterns
- Effects of flow velocity (low versus high)
- Effects of protective film (harvested/passivated lead pipe versus new lead pipe)
- Effects of realistic couplings between lead and copper
Outline

• Galvanic corrosion theory
• Mechanistic study
• How concerned should you be?
• Practical studies
  – Solder
  – Brass
  – Lead pipe
    • How big a problem is this?
How big a problem is this?
HDR-CADMUS-EPA REGION III Study (2006)*

“Can ...galvanic currents under a worst-case scenario meaningfully contribute to lead corrosion and metals release?”

* The study provides a strong basis for discounting claims and concerns relative to accelerated metal release associated with PLSLR.

* http://www.epa.gov/dclead/Grounding_Effects_Study_Final_November_2006.pdf
Important update: lead-based water lines *

<The study of children in Washington DC>….suggest that when lead service lines are partially replaced.....children are more likely to have blood lead levels greater than or equal to 10 µg/dL..

* (Frumkin, 2010)
Explanations for disagreement

HDR/Cadmus/EPA R3 conclusion

• is not based on the worst case

• did not measure lead release
Explanations (cont’d)

For passivated lead pipe, galvanic impact is limited to only 1” of lead pipe next to joint, therefore, the galvanic effect is inconsequential.
Explanation #2

For passivated lead pipe, galvanic impact limited to only 1” of lead pipe next to joint

Agree with the 1” part of the conclusion.
1” length of typical lead pipe half eaten away by galvanic corrosion

= 24 g Pb

Sufficient to contaminate every drop of water consumed by a family of 4, over a more than a 10 year period, with lead concentrations above the 15 ppb AL.
It is sometimes even possible to see the effects of galvanic corrosion by eye.
Mineralogical Evidence of Galvanic Corrosion in Domestic Drinking Water Pipes

DeSantis, M., Welch, M. M., and Schock, M. R.
2009 WQTC

Obvious effects of galvanic corrosion sometimes apparent to naked eye
Consider rate at which Pb is generated at galvanic connection

<table>
<thead>
<tr>
<th>Galvanic Current</th>
<th>Pb (µg/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 µA</td>
<td>Very low rate</td>
</tr>
<tr>
<td>5 µA</td>
<td>Low rate</td>
</tr>
<tr>
<td>30 µA</td>
<td>High rate</td>
</tr>
<tr>
<td>100 µA</td>
<td>Very high rate</td>
</tr>
</tbody>
</table>

Bad News: “accessible lead greater than 175 µg could result in elevated blood lead levels in children”
CPSC (2005)

Good News?: Sometimes less than 1% of this lead is released to water, the rest goes into scale
There are many waters in which we are quite sure that Pb:Cu galvanic corrosion is not problematic at all.
Conclusions

The worst case can be quite bad.

When problems occur, they can be very hard to detect, due to erratic release of lead scale at joint. Sloughing of lead “rust” to a single sample could cause health concerns.

More research is needed to understand issues associated with sloughing of scale and galvanic corrosion.
Acknowledgements

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List of Presentations


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