Designing Sampling for Targeting Lead and Copper: Implications for Exposure

marc edwards

VirginiaTech

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Key Points

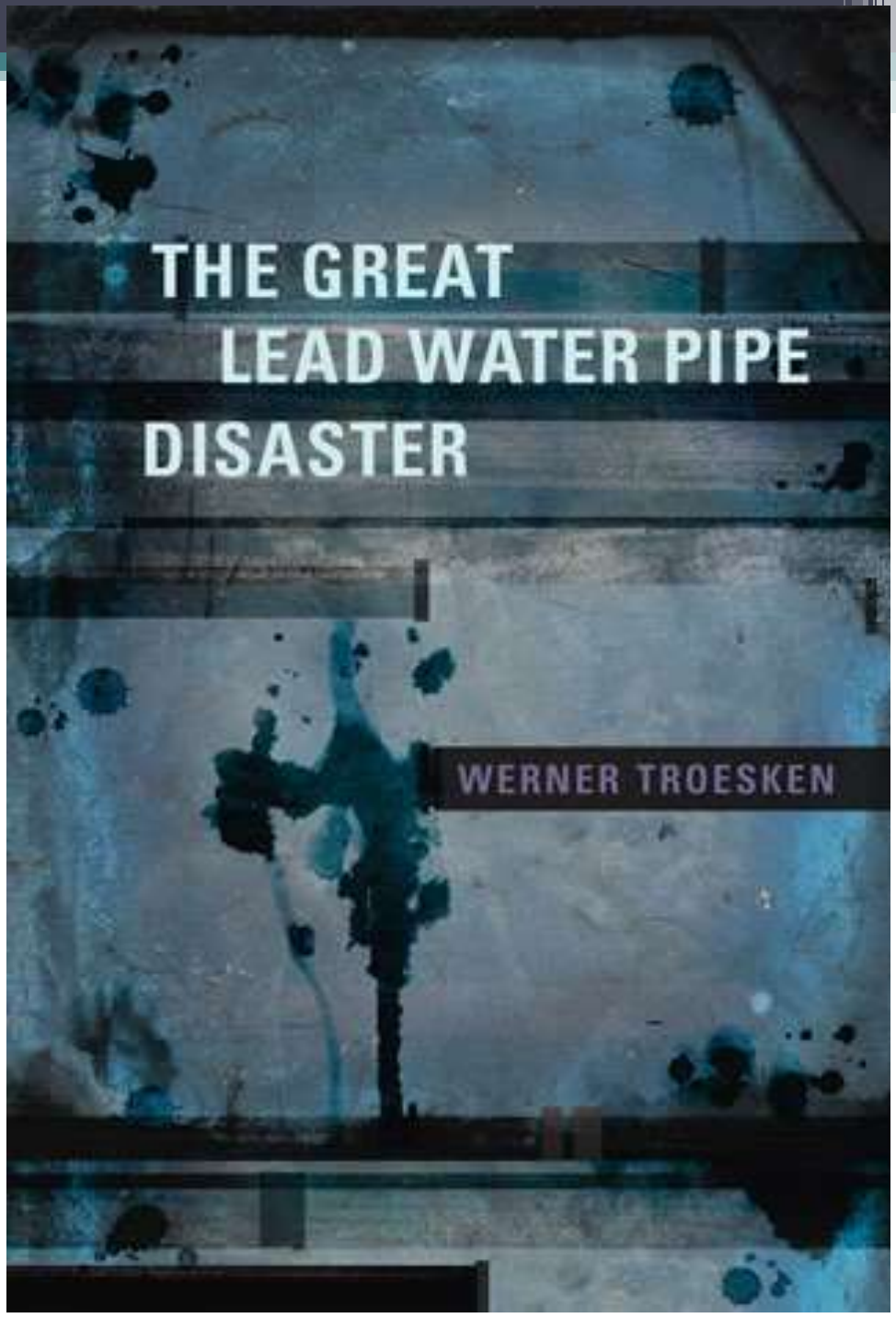
We know how to find risks from high water Pb (unfortunately we are often doing just the opposite)

Missing lead in water hazards during sampling provides a false sense of security to all parties and endangers public health

Current levels of lead in U.S. potable water pose an unacceptable acute/chronic health threat

Decision by cities to allow/require use of lead service lines….

caused one of the most serious environmental disasters in US History



Perspective on Legacy Plumbing Lead Sources

Lead-Bearing Plumbing Material	Age of US Homes at Potential Risk	Estimated number of US homes at potential risk	Estimated Mass of Lead per home at potential risk (kg)	Responsibility/ Average Performance Lifetime
Brass Plumbing Components **If 2% lead by weight** **If 8% lead by weight** **> 8% lead by weight**	All All Pre 1986	All All 81million[a]	0.1[b] 0.3[b] 0.4[b]	**Mostly private ≈ 20-70 years**
Lead pipes, lead service lines, and lead goosenecks (100% lead by weight)	Pre 1986	3.3 - 6.4 million[c]	19.1[d]	**Undeniable Public Responsibility ≈ 100-1000 years**
Lead solder (40% - 50% lead by weight)	Pre 1986	81 million[a]	Highly variable, but believed very significant[e]	**Mostly private ≈ 20-70 years**
Lead joints in water mains (100% lead by weight)	Pre 1986	All homes served by water mains installed pre 1986	Unknown but believed inconsequential[f]	NA

Modified from Triantafyllidou and Edwards (2011)[18]

Even 1 foot of lead pipe, contains enough lead to raise every drop of water used by a family of 4 over 100 years, to over the 15 ppb AL

Lead pipe is the most concentrated lead source in US homes, and it directly affects a product (tap water) that is intended for human consumption

Changes affecting peak LSL Lead since 2000

Recent Changes	Decreases Pb	Increases Pb
Utilities Add Less Chlorine		X
Aggressive Water Conservation		X
Chloramine Instead of Chlorine		X
Reduce Phosphate Doses to "Optimize" Corrosion Control and Save $$		X
Created Millions of Disturbed and Partially Replaced LSLs		X
More Exposed Iron Pipe in Mains → More Fe, Less Cl_2 = More Pb		X
More Accumulated Pb Scale, More Pb Particulates from Corrosion Control and Older Pipes		X
Higher temperatures?		X

Science Predicts Higher Peak LSL Pb Release in Many Systems Due to These Changes-Little Reason to Hope Things are Improving

Utility Sampling Instructions Have Evolved (Devolved) to Miss Many LSL Pb and Particulate Pb Problems in Water When Present

Generation of Pb Particles

Corrosion or Rusting

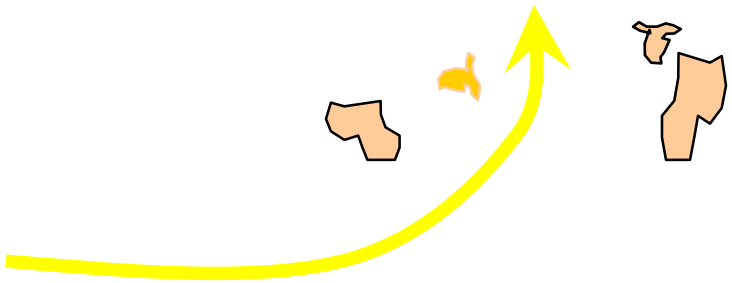
Lead Solder, Lead Scale or “Rust” layer

Lead Solder, Lead Pipe or Leaded Brass

Detachment During Flow

Faster water flow in some systems, means more particulate lead

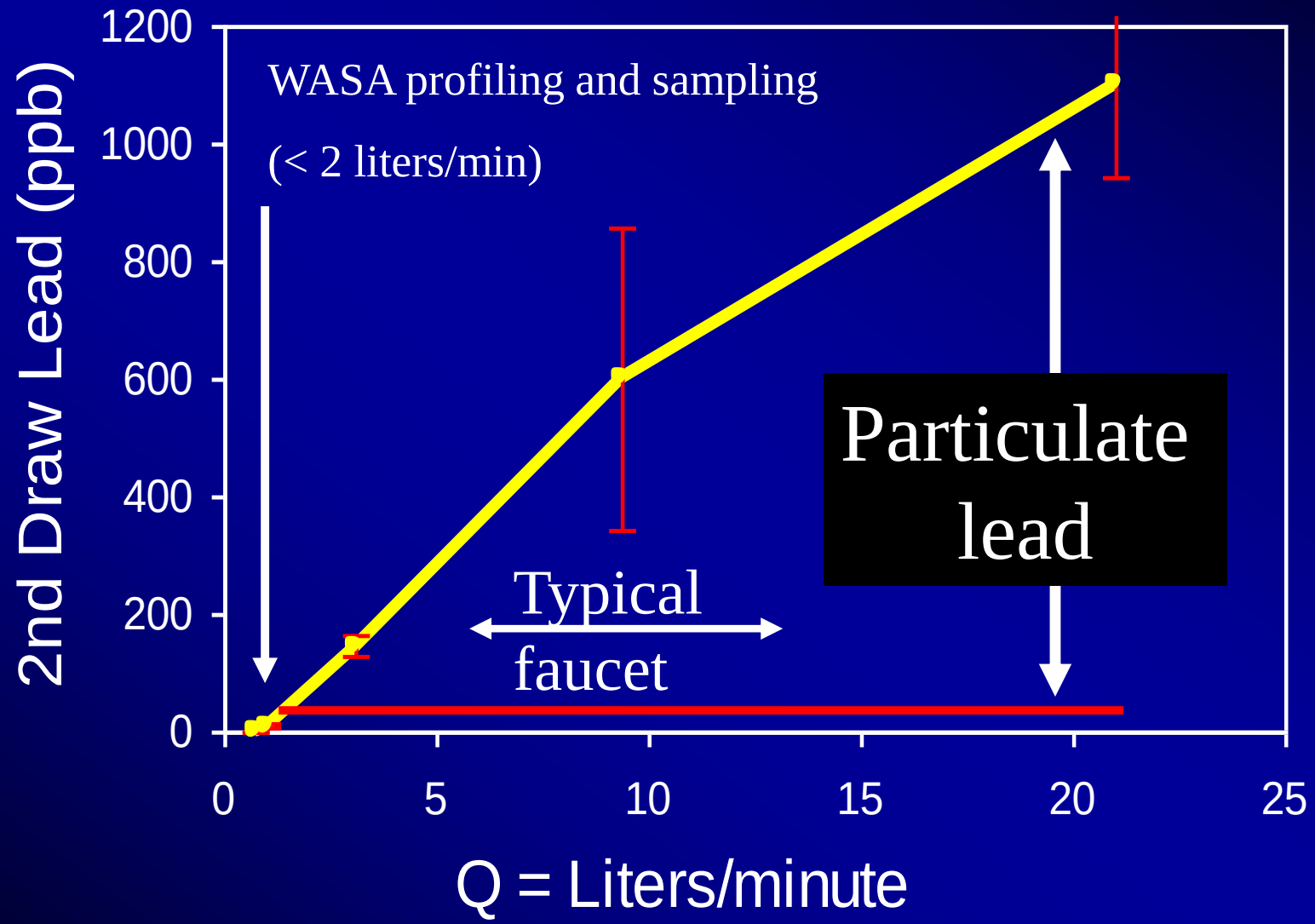
Scouring



Lead Solder, Lead Scale or “Rust” layer

Pb Plumbing Material

Water Samples of LSL Lead from DC in 2004

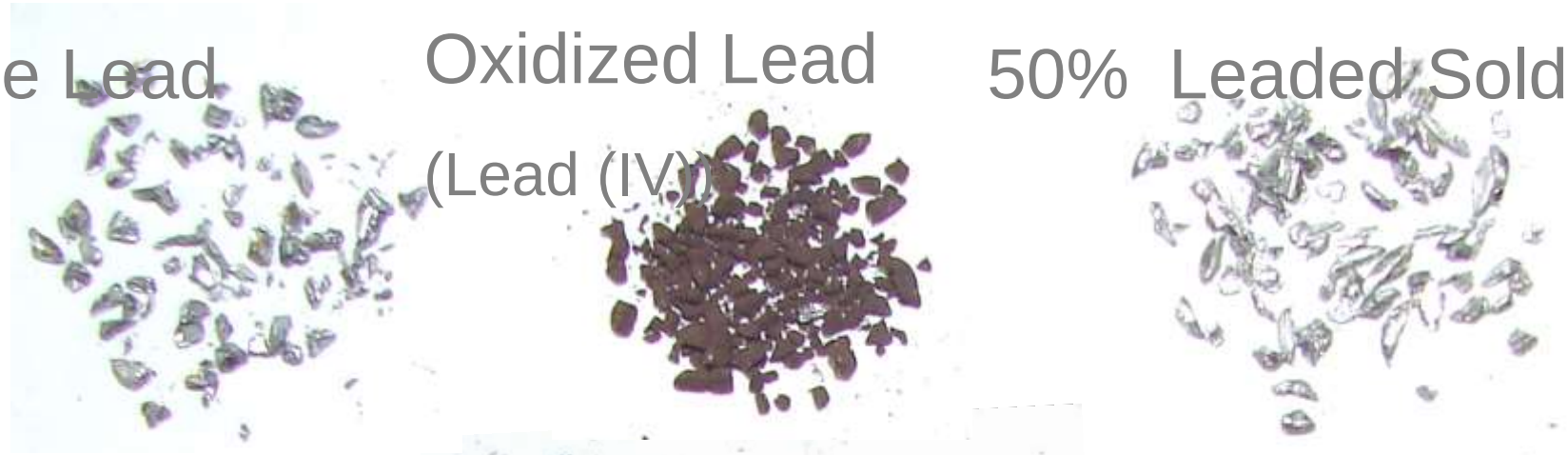


Pure Lead

Oxidized Lead

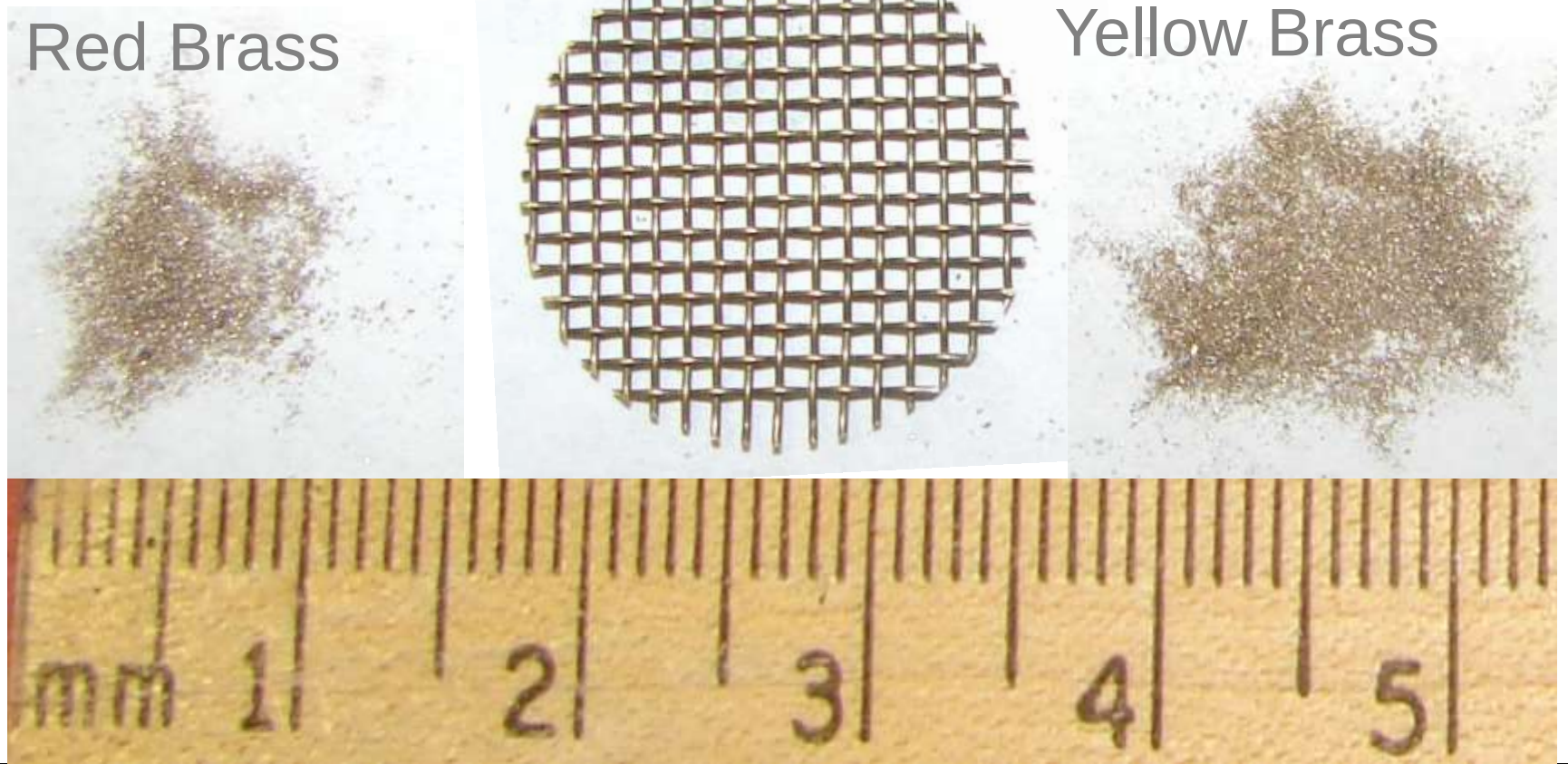
(Lead (IV))

50% Leaded Solder



Red Brass

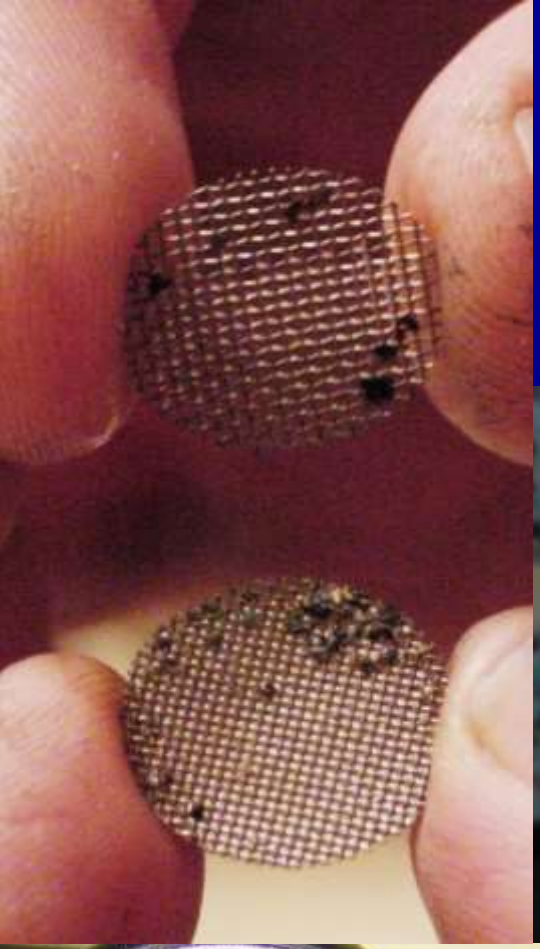
Yellow Brass

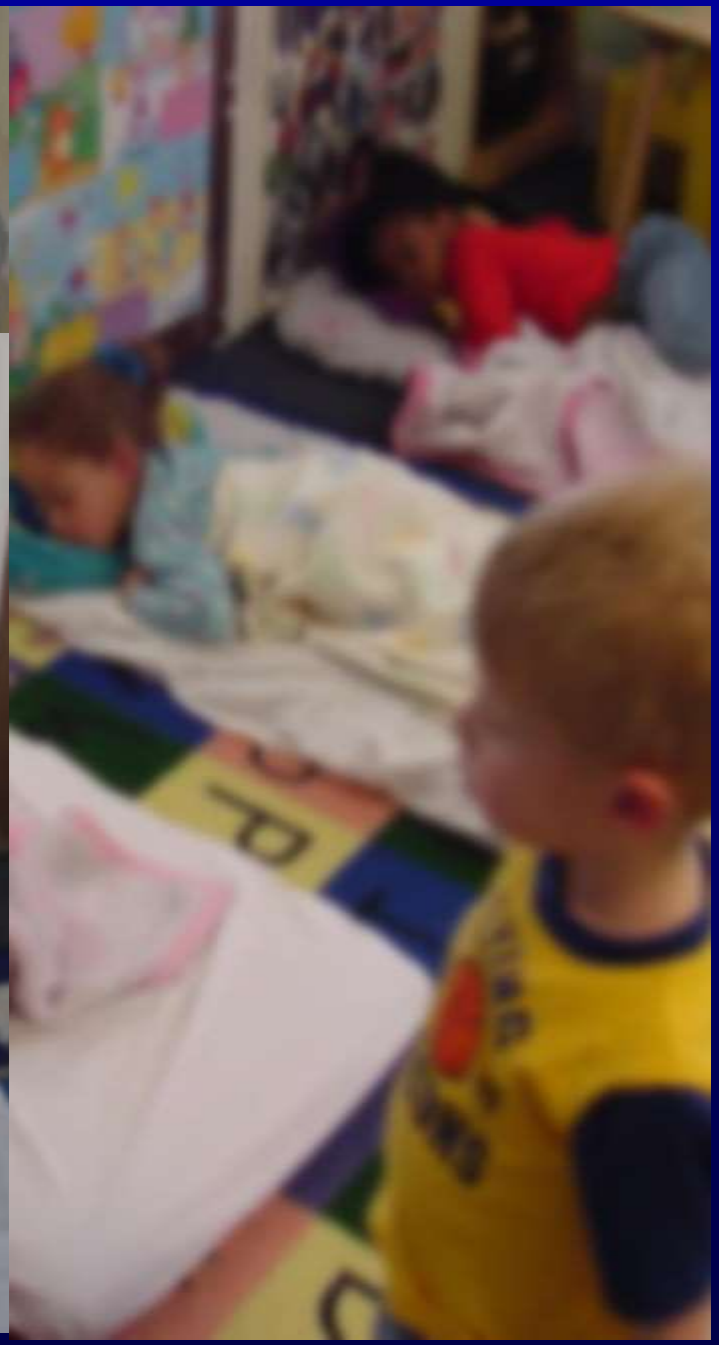


Sampling Instructions	Effect vs. Normal Use
Sample at low flow	Reduce particulate Pb
Open tap slowly	Reduce particulate Pb
Pre-flushing pipes	Reduce LSL and particulate Pb in first draw sample
Pre-clean aerator	Reduce particulate Pb

Use of these instructions and "missing" high risk sites has resulted in documented childhood lead poisoning when the utility was officially meeting the LCR and the water was supposedly "safe"

Day care





Enough lead behind this aerator to poison 5000 kids

(@ CPSC 175 ug Pb acute health risk and 25% bioavailability)

After cleaning aerator water tested "safe" 6 hours later

Example: DC WASA 2005-2008

Consumers instructed to pre-flush pipes **10 minutes** the night before LCR sampling to barely meet EPA AL

3 independent entities sampling tap water at this time found very high lead, and a coalition vehemently protested the use of pre-flushing:

EPA RIII/EPA OW allow pre-flushing in DC

CDC (2012) → More lead poisoned kids in DC Homes with LSLs in this time frame

Effect of Bottle Type

Recent Pb Health Data And Human Exposure Considerations

Lead and Adverse Pregnancy Outcomes Miscarriages/Fetal Death

*Read before the Yorkshire Branch of the British Medical Association at Bradford, January, 1905.

THE INCREASING USE OF LEAD AS AN ABORTIFACIENT;

A SERIES OF THIRTY CASES OF PLUMBISM.*

By ARTHUR HALL, M.A., M.D.Cantab., F.R.C.P.,
Professor of Pathology, University College, Sheffield; Physician, Sheffield Royal Hospital

NOV. 13, 1926] [THE BRITISH MEDICAL JOURNAL

LEAD AS AN ABORTIFACIENT.

SIR,—Some time ago, in country practice, I had a message from a neighbour asking me to see with him a case of acute abdominal disease. The history was this: A robust young woman (married three months) had had pain in the stomach a few days previously, and again on the day before, when she was first seen. On inquiry her doctor was

1900s Lead abortion pill dose exceeded by normal consumption of water in 15% of DC homes with lead pipe in 2003

Fetal Death and Reduced Birth Rates Associated with Exposure to Lead-Contaminated Drinking Water *ES&T* 2013

Trends in DC birth rate (miscarriages) and fetal death rates were consistent with prior work indicating that each 5 ug/dL increase in maternal blood lead doubles miscarriage risk. Fetal death rates correlated to water lead levels and measures of lead pipe occurrence.

ICRP Adult Blood Lead Model

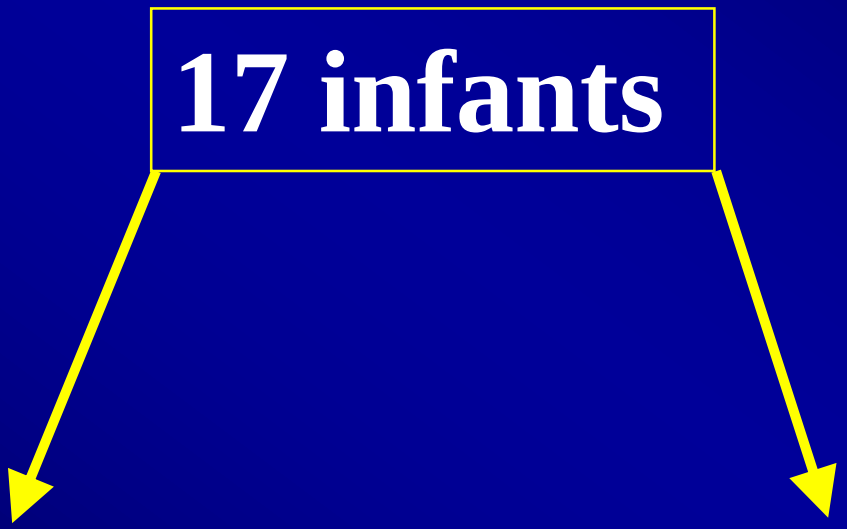
0 → 5 ug/dL in Maternal Blood Lead ≈ 60 ppb water Pb

Representative Exposures of Concern for Lower Blood Lead Levels

Group	Increased BLL of Concern	Water Lead
Formula Fed Infants	0 → 1 ug/dL for 50% of those exposed	**3.5 ppb**
Formula Fed Infants	0 → 1 ug/L for 10% of those exposed	**2 ppb**
Formula Fed Infants	0 → 5 ug/dL for 10% of those exposed	**11 ppb**

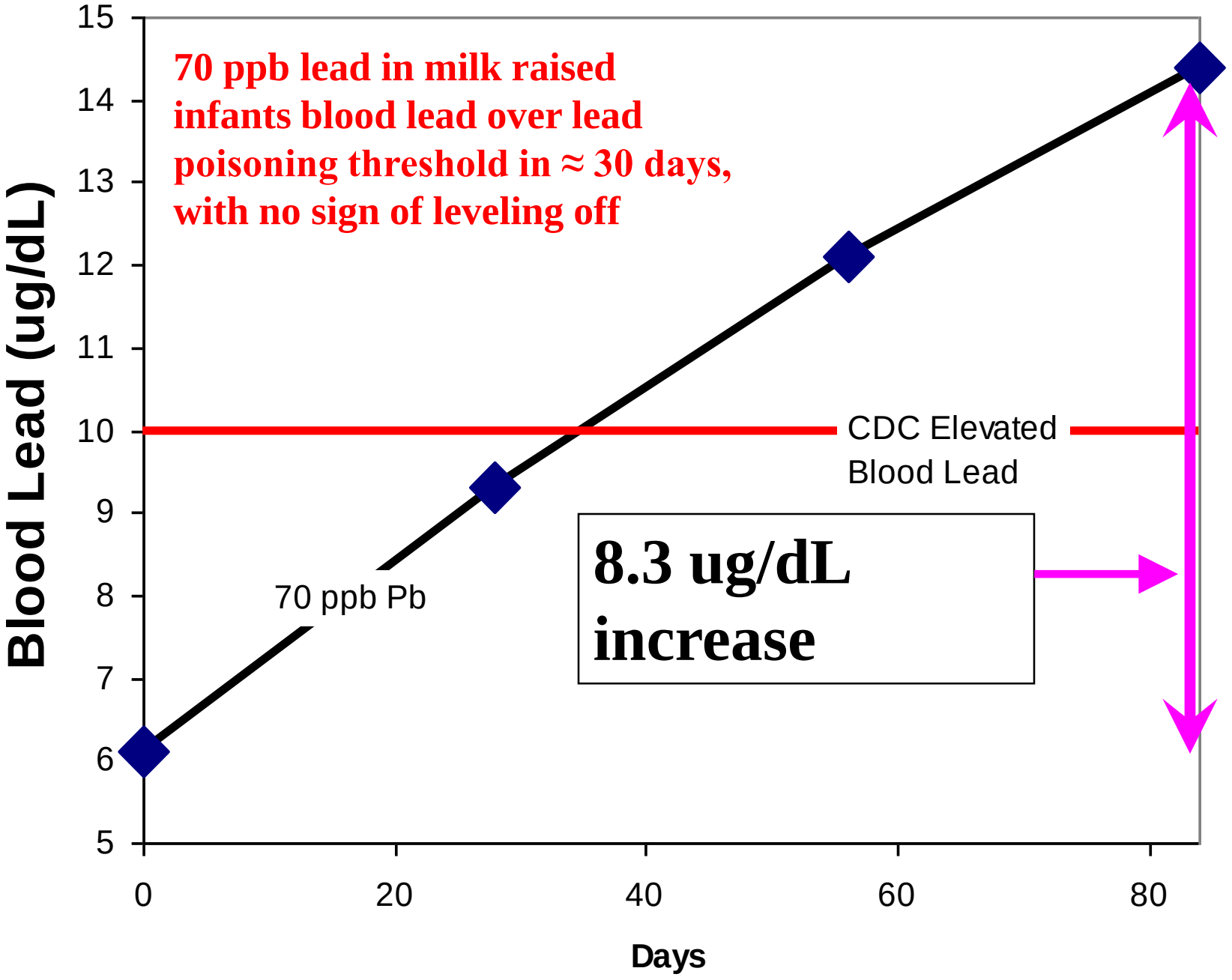
Triantafyllidou, S., Gallagher. D. and Edwards, M. Assessing risk with increasingly stringent public health goals: the case of water lead and blood lead in children. Journal of Water and Health. doi: 10.2166/wh.2013.067 58-68 (2014).

Ryu et al (1983)
Fed leaded milk to infants in US
All dietary Pb intakes accounted for

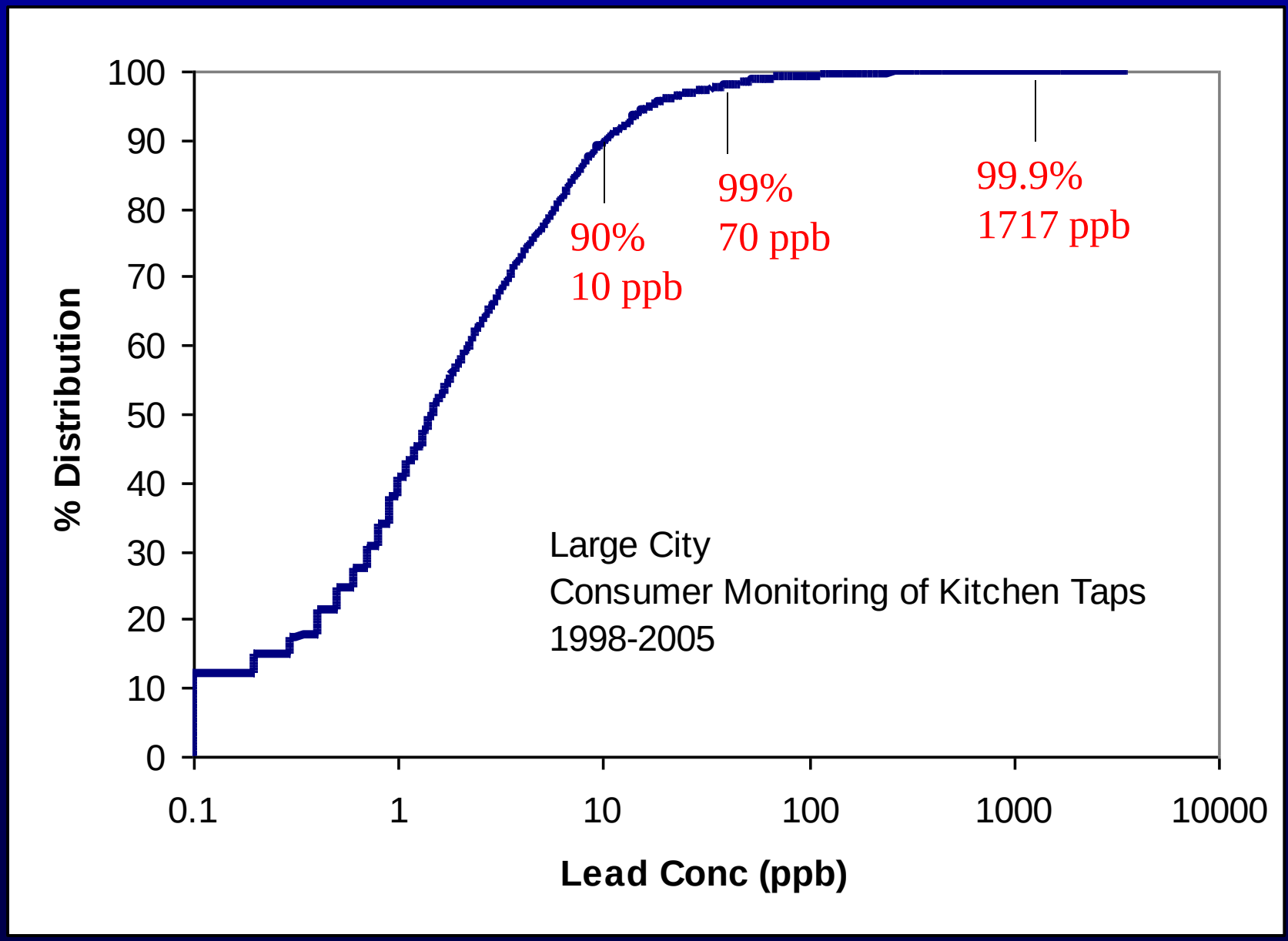


10 fed milk with avg. 10 ppb Pb

7 fed milk with avg. 70 ppb Pb


70 ppb lead in milk raised infants blood lead over lead poisoning threshold in ≈ 30 days, with no sign of leveling off
Blood Lead (ug/dL)
15
14
13
12
11
10
9
8
7
6
5
0
20
40
60
80
Days
CDC Elevated Blood Lead
70 ppb Pb
8.3 ug/dL increase

What do lead levels look like for a large US city currently meeting the AL, based on thousands of data points, and how does that translate to EBL?


100
90
80
70
60
50
40
30
20
10
0
% Distribution
0.1
1
10
100
1000
10000
Lead Conc (ppb)
90%
10 ppb
99%
70 ppb
99.9%
1717 ppb
Large City
Consumer Monitoring of Kitchen Taps
1998-2005

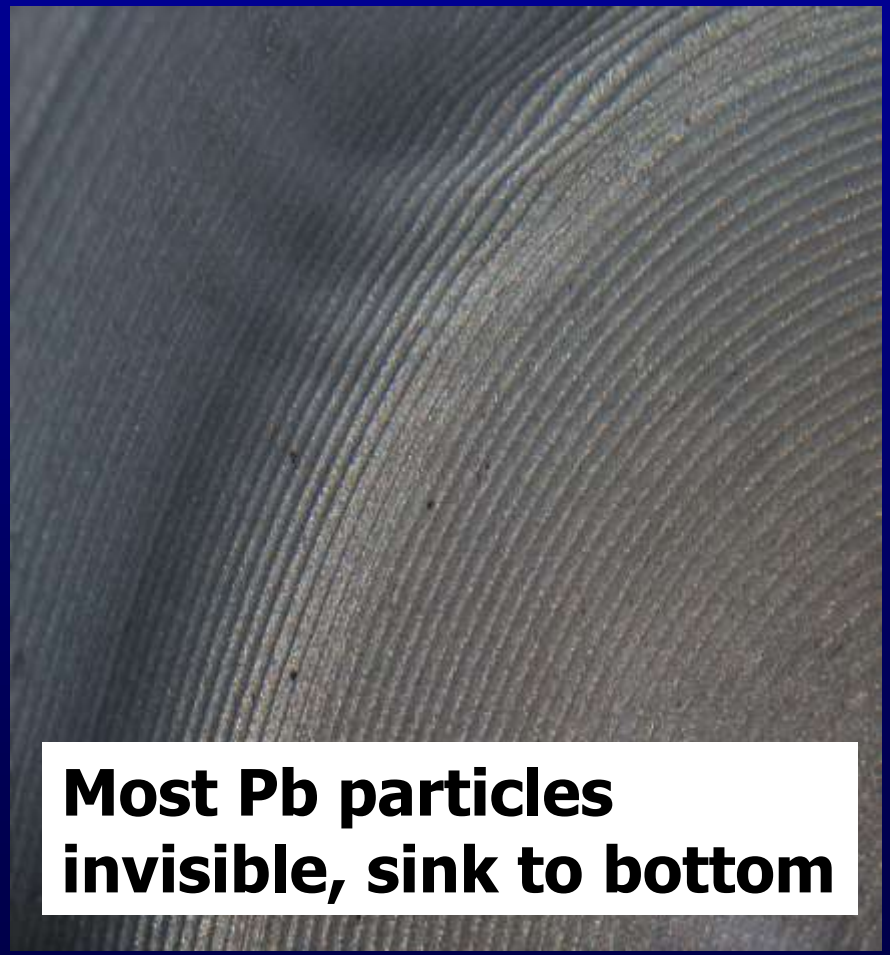
≈1% of children in this city predicted to have elevated blood lead (> 10 ug/dL) from tap water consumption alone (> 70 ppb)

in a city with 100,000 children that would be 1000 cases of childhood lead poisoning

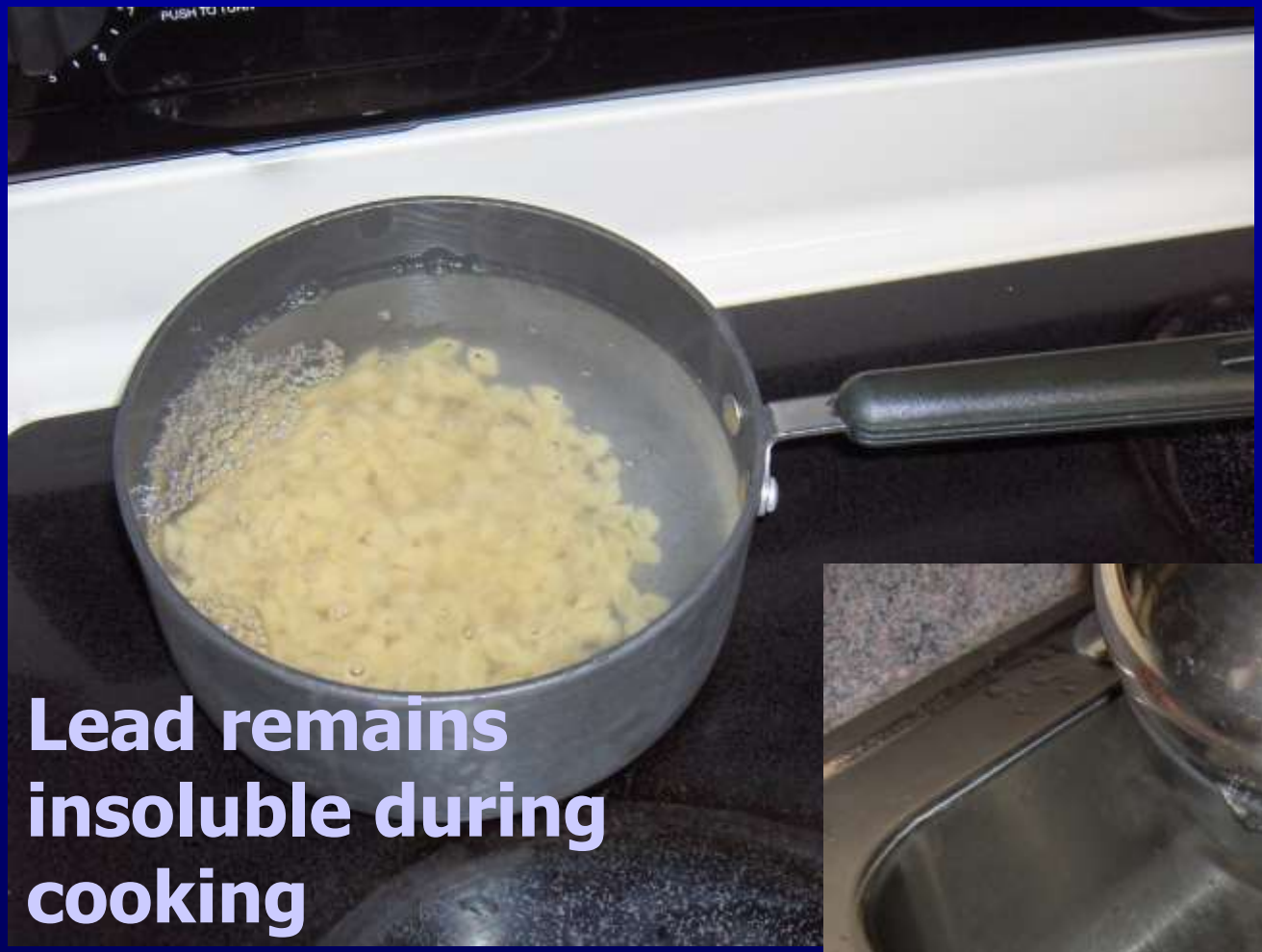
You do not even have to drink tap water to be exposed.

Water collected @ highest flow from faucet of poisoned child

1.5 liters at 535 ppb lead



Most Pb particles invisible, sink to bottom


Lead remains insoluble during cooking


< 5% particulate lead poured off

381 ug Pb 310 ug Pb

One serving of pasta prepared from tapwater in home of lead poisoned child had more lead than eating a dime size paint chip @ 1% lead.

A Revised LCR Needs-Pb

- public education that stops telling consumers with lead services/plumbing that **THEIR WATER IS SAFE***
- an attitude at EPA OW and CDC that acknowledges serious water lead health risks, emphasizes important DIRECT links between the LCR and public health, and stops “anything goes” messaging to utilities
- motivated utilities attempting to find high lead in water risks, and the will/means to punish bad actors– or else take LCR sampling completely out of utilities hands
- a plan for complete removal of all lead service lines

***unless it is not safe, in which case we told you so in fine print somewhere**

Marc Edwards received his bachelor's degree in Bio-Physics from SUNY Buffalo and an MS/PhD in Environmental Engineering from the University of Washington. In 2004, Time Magazine dubbed Dr. Edwards "The Plumbing Professor" and listed him amongst the 4 most important "Innovators" in water from around the world. The White House awarded him a Presidential Faculty Fellowship in 1996 and he was named a MacArthur Fellow in 2008.

He has received 6 outstanding research publication awards from peer reviewed journals, the Huber Research Prize from the American Society of Civil Engineers (2003), and the National Association of Corrosion Engineers Technical Achievement Award (2008). Volunteer (unfunded) research by Edwards and colleagues on health effects from lead in drinking water documented numerous cases of fetal death and childhood lead poisoning associated with lead in tap water nationwide, including those associated with the 2000-2004 Washington D.C. "Lead Crisis." That effort culminated in a Congressional Investigation of CDC, an Outstanding Paper Award in ES&T, a Praxis Award in Professional Ethics from Villanova University and the IEEE Barus Award for Defending the Public Interest.

Bibliography: Last 10 years peer reviewed research on Pb Corrosion Control and Water Pb Health effects

1. Clark, B., Masters, S, and Edwards, M. (2014). "Profile Sampling to Characterize Particulate Lead Risks in Potable Water." Environmental Science & Technology. DOI: 10.1021/es501342j.
2. St. Clair, J., B. Clark and M. Edwards. Issues Associated With Use Of Dielectrics In Drinking Water Systems. J. AWWA. DOI: http://dx.doi.org/10.5942/jawwa.2014.106.0065
3. Triantafyllidou, S., Gallagher. D. and Edwards, M. Assessing risk with increasingly stringent public health goals: the case of water lead and blood lead in children. Journal of Water and Health. doi: 10.2166/wh.2013.067 58-68 (2014).
4. Edwards, M. Fetal Death and Reduced Birth Rates Associated with Exposure to Lead-Contaminated Drinking Water. Env. Sci. and Tech. 2013 DOI: 10.1021/es4034952
5. Clark, B., C. Cartier, J. St. Clair, S. Triantafyllidou, M. Prevost and M. Edwards. Effect of Connection Type on Galvanic Corrosion between lead and copper Pipes. JAWWA 105(10) E576-E586 (2013).
6. Triantafyllidou, S., L. Trung, D. Gallagher and M. Edwards. Reduced Risk After Remediation of Lead (Pb) in Drinking Water at Two U.S. School Districts. Science of Total Environment. 466-467 1011-1021 (2014). http://dx.doi.org/10.1016/j.scitotenv.2013.07.111
7. Edwards, M. Discussion: Effect of Changing Water Quality on Galvanic Coupling. J.AWWA 104(12) 65-82 (2012).
8. Deshommes, E., R. Tardif, M. Edwards, S. Sauve and M. Prévost. Experimental determination of the oral bioavailability and bioaccessibility of lead particles. Chemistry Central Journal 6:138 doi:10.1186/1752-153X-6-138 (2012).
9. Triantafyllidou, S., Nguyen, C.K., and M. Edwards. Lead (Pb) Quantification in Potable Water Samples: Implications for Regulatory Compliance and Assessment of Human Exposure. Environmental Monitoring and Assessment. 185(2), 1355-1365 (2013).
10. Raetz, M, J. Parks, A. Martin, P. Scardina and M. Edwards. Flushing of Soldering Flux from Drinking Water Plumbing in New Construction. Materials Performance 52(1) 60-64 (2013).
11. Cartier, C.; Doré, E. ; Laroche, L.; Nour, S; M. Edwards and M. Prévost, M. Impact of Treatment on Pb Release from Full and Partially Replaced Harvested Lead Service Lines (LSLs). Water Research. DOI: 10.1016/j.watres.2012.10.033 (2012).
12. Arnold, R., and M. Edwards. Electrochemical Reversal of Galvanic Pb:Cu Pipe Corrosion. Environmental Science and Technology 46(20):10941-7. doi: 10.1021/es3017396. (2012).

13. St. Clair, J., C. Stampoulous and M. Edwards. Increased Distance Between Galvanic Pb:Cu Pipe Connections Decreases Lead Release. Corrosion. 68:779-783 (2012).
14. Hu, J., S. Triantafyllidou and M. Edwards. Copper-Induced Metal Release from Lead Pipe into Drinking Water, 68(11) 1037-1048 Corrosion (2012).
15. Cartier, C; R.B. Arnold, S. Triantafyllidou, M. Prévost and M. Edwards Effect of Flow Rate and Lead/Copper Pipe Sequence on Lead Release from Service Lines. Water Research, 46(13) 4142-4152 (2012).
16. Triantafyllidou, S., Raetz, M., Parks, J. and Edwards, M. Understanding how brass ball valves passing certification testing can cause elevated lead in water when installed, Water Research (2012), doi:10.1016/j.watres.2012.03.022
17. Triantafyllidou, S., and M. Edwards. Galvanic Corrosion After Simulated Small-Scale Partial Lead Service Line Replacements. Journ. American Water Works Association 103 (9) 85-99 (2011).
18. Triantafyllidou, S., and Edwards, M. Lead (Pb) in Tap Water and in Blood: Implications for Lead Exposure in the United States. Critical Reviews in Environmental Science and Technology, 42 1297-1352 (2011).
19. Zhang, Y., and M. Edwards. Zinc Content in Brass and Its Influence on Lead Leaching. J. AWWA. 103 (7) 76-83 (2011).
20. Cartier, C, L. Laroche, E. Deshommes, S. Nour, G. Richard, M. Edwards, M. Prevost. Investigating dissolved lead at the tap using various sampling protocols. J.AWWA 103(3) 55-67 (2011).
21. Nguyen, C.K., Clark, B.N., Stone, K.R., and M. Edwards. Acceleration of galvanic lead solder corrosion due to phosphate. Corrosion Science 53(4), 1515-1521 (2011).
22. Nguyen, C.K., Stone, K.R., and M. Edwards. Nitrate Accelerated Corrosion of Lead Solder in Potable Water Systems. Corrosion Science 53(3), 1044-1049 (2011).
23. Nguyen, C.K., K.R. Stone and M. Edwards. Chloride-to-Sulfate Mass Ratio: Practical Studies in Galvanic Corrosion of Lead Solder. J. AWWA 1:103 81-92 (2011).
24. Elfland, C., Scardina, P., and M. Edwards. Lead Contaminated Potable Water from Brass Devices in New Buildings. J. AWWA. 11:102 66-76 (2010).
25. Deshommes, E., Y. Zhang, K. Gendron, S. Sauve, M. Edwards, S. Nour, and M. Prevost. Lead Removal from Tap Water Using Point-of-Use Devices. J.AWWA. 10:102 (2010).

26. Nguyen, C.K., Stone, K.R., Dudi, A., Edwards, M. Corrosive Microenvironments at Lead Solder Surfaces Arising from Galvanic Corrosion with Copper Pipe. Environmental Science and Technology 44(18) 7076-7081 (2010).
27. Lambrinidou, Y., Triantafyllidou, S., Edwards, M. Failing Our Children: Lead in US School Drinking Water. New Solutions 2010. V. 20(1):25-47.
28. Sandvig, A. M., S. Triantafyllidou, M. Edwards, D. Heumann, G. Boyd, and G. Kirmeyer. 2009. NonLeaded Brass – A Summary of Performance and Costs. Journal AWWA 101(7):83-94.
29. Zhang, Y., A. Griffin, M. Rahamn, A. Camper, H. Barieau and M. Edwards. Lead Contamination of Potable Water Due to Nitrification. Environ. Sci. Technol., 2009, 43 (6), pp 1890–1895
30. Edwards, M., Triantafyllidou, S., and D. Best. Elevated Blood Lead in Washington D.C. Children from Lead Contaminated Drinking Water: 2001-2004. Environmental Science and Technology. 43, 5 1618-1623 (2009).
31. Zhang, Y., Triantafyllidou, S., and Edwards M. Effect of Nitrification and GAC Filtration on Copper and Lead Leaching in Home Plumbing Systems. ASCE Journal Environmental Engineering 134(7) 521-530 (2008).
32. Triantafyllidou, S., and M. Edwards. A Critical Evaluation of the NSF 61/Section 9 Test Water. JAWWA 99(9): 133-143 (2007).
33. Edwards, M., and S. Triantafyllidou, S. Chloride to Sulfate Mass Ratio and Lead Leaching to Water. JAWWA 99(7): 96-109 (2007).
34. Triantafyllidou, S., J. Parks and M. Edwards. Lead Particles in Potable Water. JAWWA 99(6): 107-117 (2007).
35. Abhijeet, D., Schock, M., N. Murray, and Edwards, M. Lead leaching from In-Line Brass Devices: A Critical Evaluation of the Existing Standard. Journal American Water Works Association. V. 97, No. 8 66-78 (2005).
36. Edwards, M., Abhijeet, D. Role of chlorine and chloramine in corrosion of lead-bearing plumbing materials. Journal American Water Works Association. V. 96, No. 10 69-81 (2004).
37. McNeill, L.S., and M. Edwards. Phosphate Inhibitor Use at US Utilities. Journal American Water Works Association, V. 94, N. 7 57-63 (2002).
38. McNeill, L.S., and M. Edwards. Importance of Pb and Cu Particulate Species for Corrosion Control. ASCE Journal of Environmental Engineering, Vol. 130, No. 2,136-144 (2004).