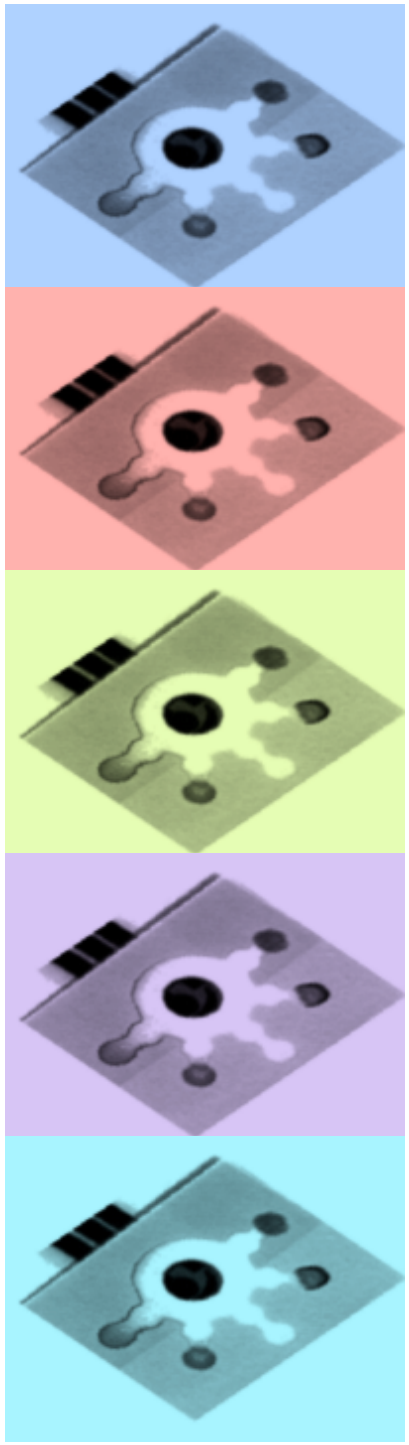


Arts and Crafts for the 21st Century Industrial Hygienist:

How Crayons, Paper, and Pencils Can Revolutionize Occupational and Environmental Health

John Volckens

AIHA RMS Conference, 17 Sep 2014

Colorado State University

There Are Serious Problems with Our Paradigm for Personal Exposure Assessment

- **Coverage**
  - Nowhere near enough of it
- **Time**
  - Too much needed to get the job done
- **Cost**
  - Way, way too high
- **Usability**
  - I've read stereo instruction manuals that are more user friendly than this piece of equipment

Point #1:
Pollutant Concentrations Rarely Follow a Normal Distribution

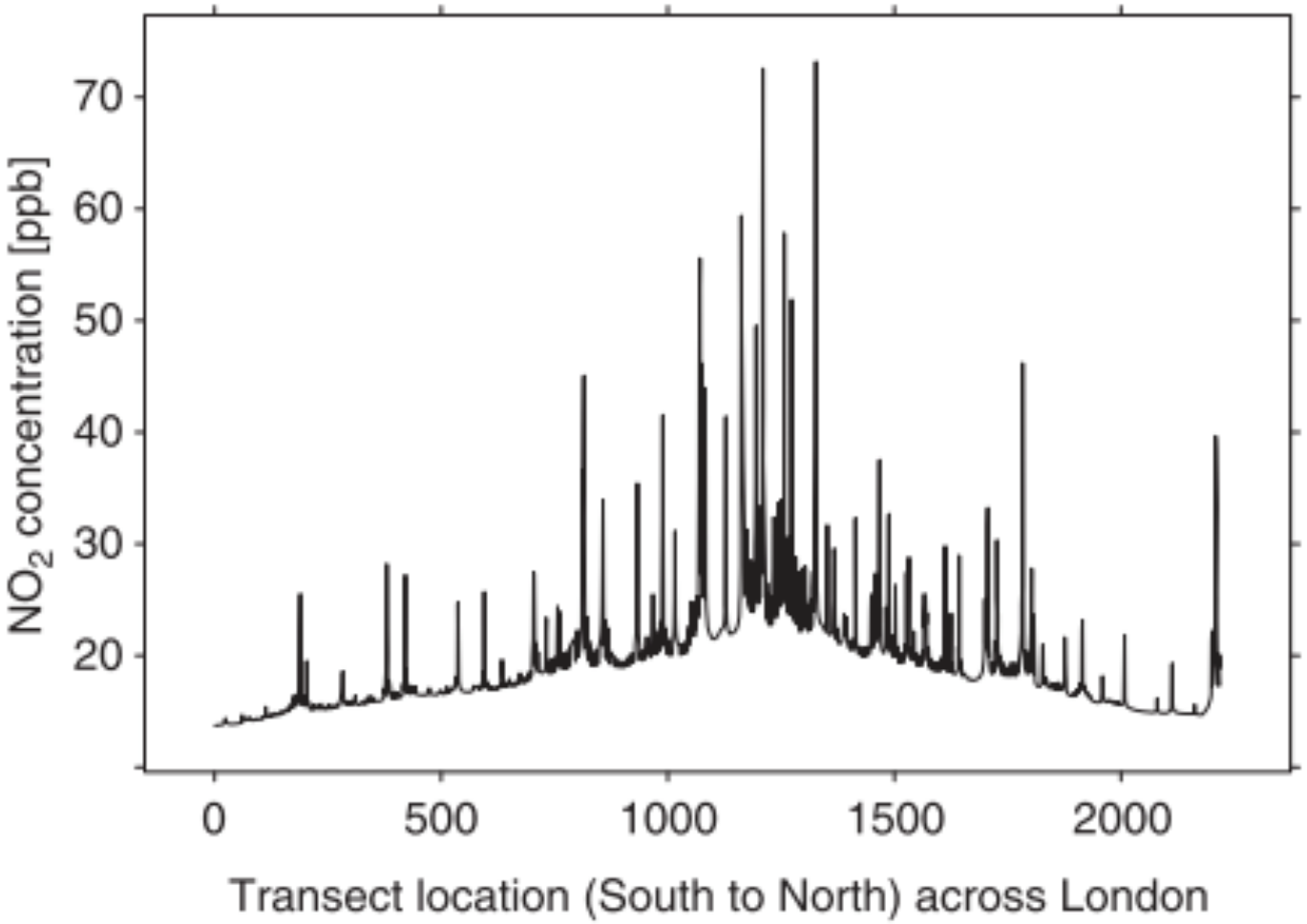


Figure 3. A transect of the annual mean NO_2 concentrations (parts per billion (p.p.b.)) for the year 2008 in London. The transect follows the vertical black line in Figure 2.

Beevers et al., *J. Exp. Sci. & Env. Epid.* (2013) **23,** 647–653

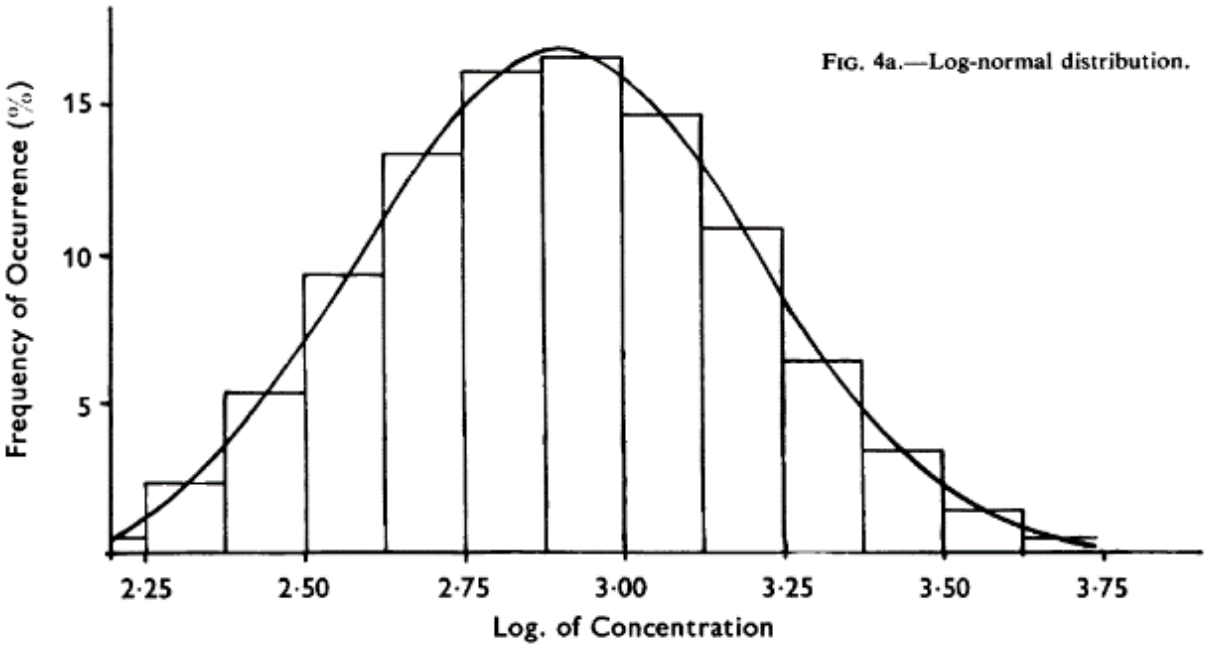


FIG. 4a.—Log-normal distribution.

BJIM 16(4) 1959

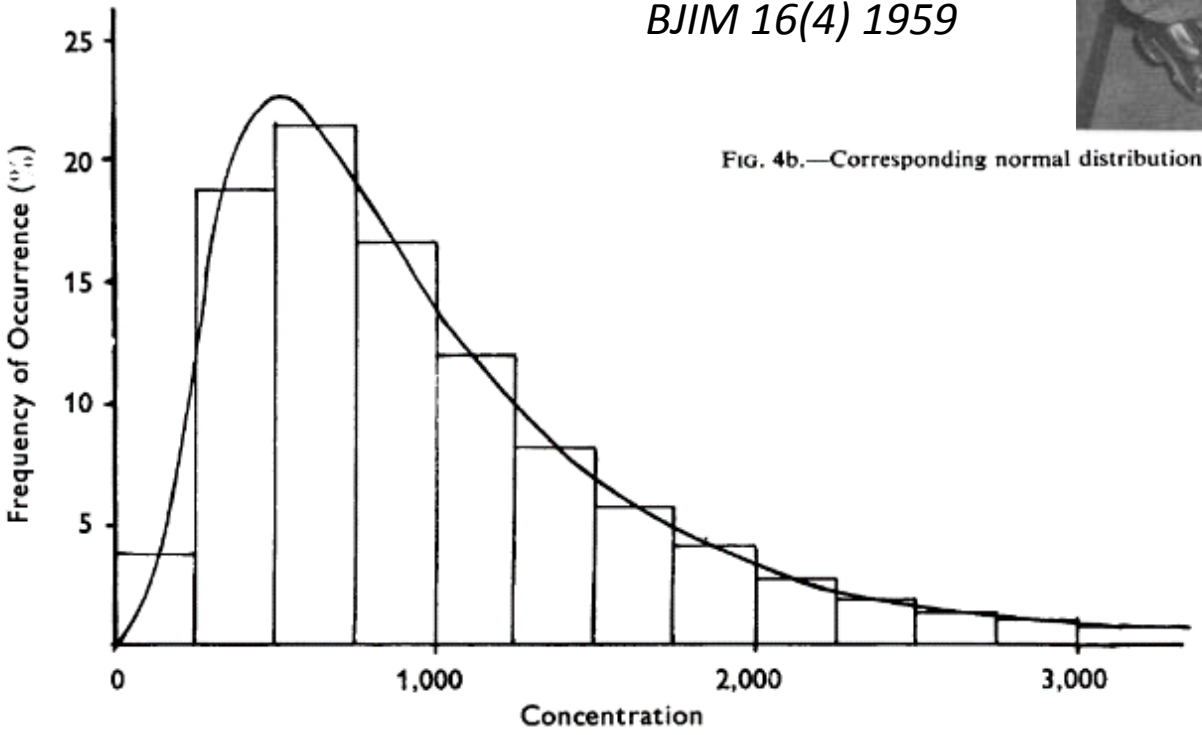


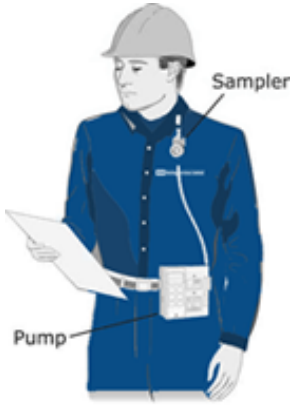
FIG. 4b.—Corresponding normal distribution.

FIG. 4.—The frequency distribution of concentrations.

Point #2: Our Sample Coverage is Poor

- How many samples are needed to characterize a log-normal distribution (μ, σ_g)?
  - 30 samples per environment? *(Buringh, AIHAJ 1991)*
- What about quantifying within/between worker variability for compliance-based sampling?
  - 20+ samples, 2-5 per worker *(Rappaport et al., AOH 1995)*
- How many samples are typically collected during a site visit?
  - OSHA 21D Consultation Programs: 0 – 3

Point #3: Reporting Time is Too Long.
At best, 2 weeks from Sampling to Results
(4 weeks is more common)

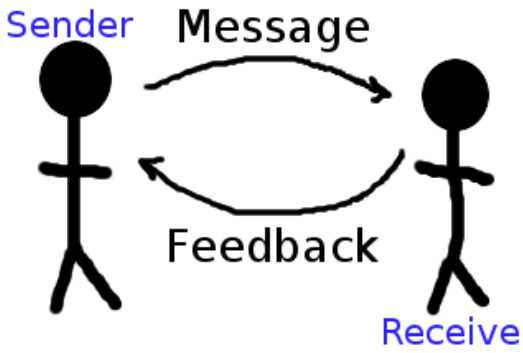


Sampling: 2 days, pre/post

Shipping: 2 days

Sample analysis: 5 days

Data analysis: 1 day?

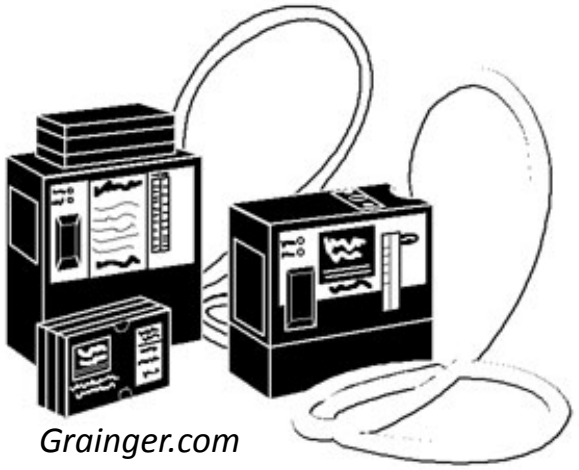


Risk Communication: 1 day

Point #4: Lack of Coverage is also Due to Cost

- **Instrument cost:**
  - $50,000 - $150,000

- **Personal Sampling Pumps:**
  - $500 - $3,000 each!



Grainger.com

- **Sample analysis cost:**
  - $100 for the first metal, $20 for each additional one

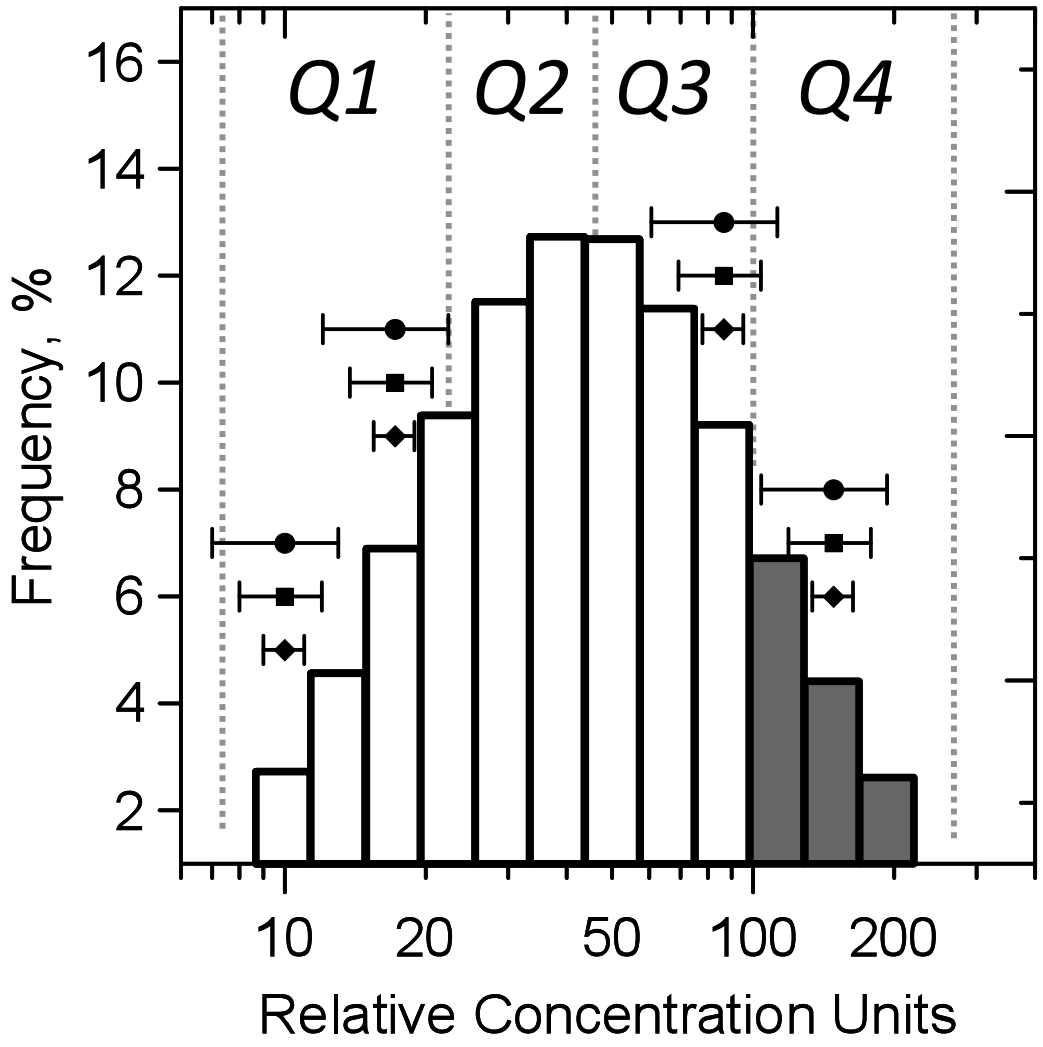
Cost Perspective

- The U.S. Census estimates a population of 466,400 welders, cutters, solderers, brazers nationally.

- Cost to measure each individual's exposure to one metal just once per year:
  - ~ $50M USD in analytical costs
  - ~ $10M in capital costs
  - ~ $10M in personnel costs

~$70M per year

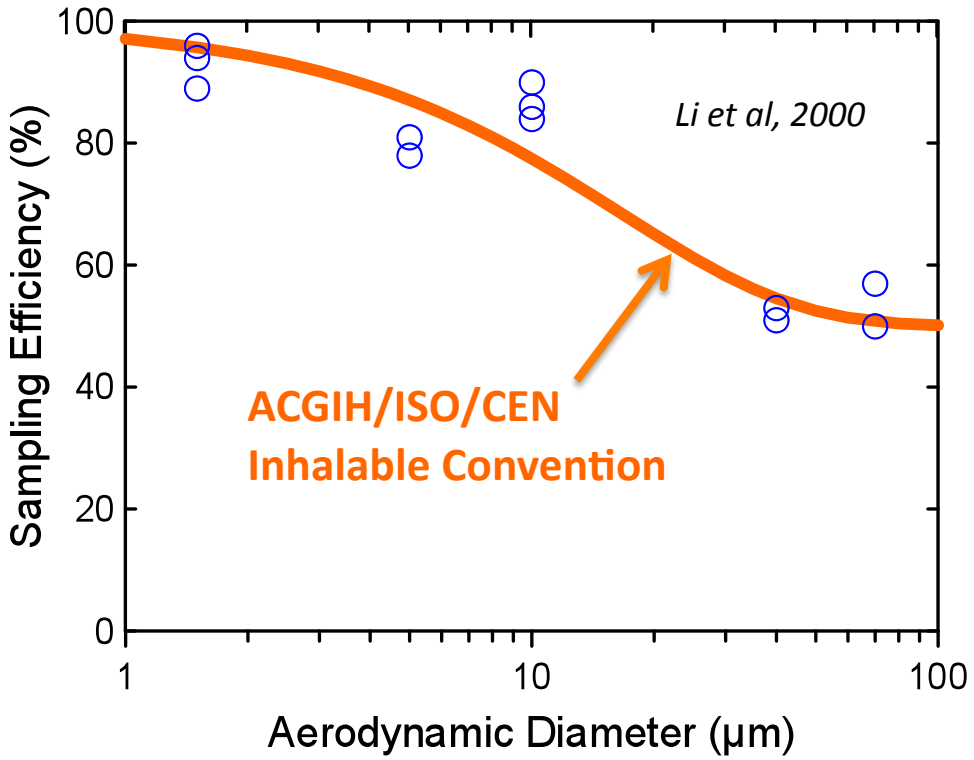
Cost vs. Accuracy/Precision



Measurement Uncertainty

30%
20%
10%

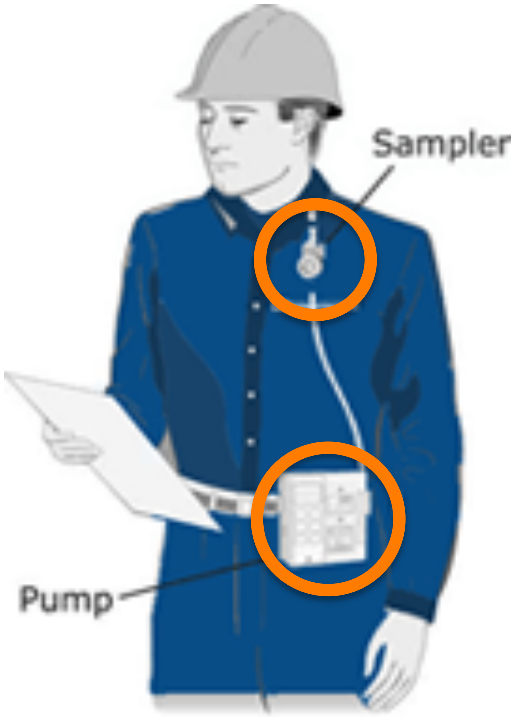
Representativeness vs. Usability: The IOM Dust Sampler as an Example



- Physiologically-relevant estimate of intake

- Cost: $85 - $275
- Not disposable
- Not exactly simple

Ideal Personal Exposure Measurement

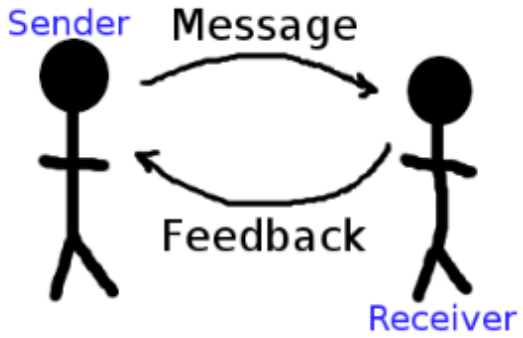


Want a sampler that is:

- Inexpensive
- Disposable
- User friendly
- Physiologically relevant

Want an analytical technique that is:

- Inexpensive
- Fast
- Reliable



Want sample coverage that is:

- Comprehensive
- Affordable

37-mm Closed-Face Cassette (CFC)?

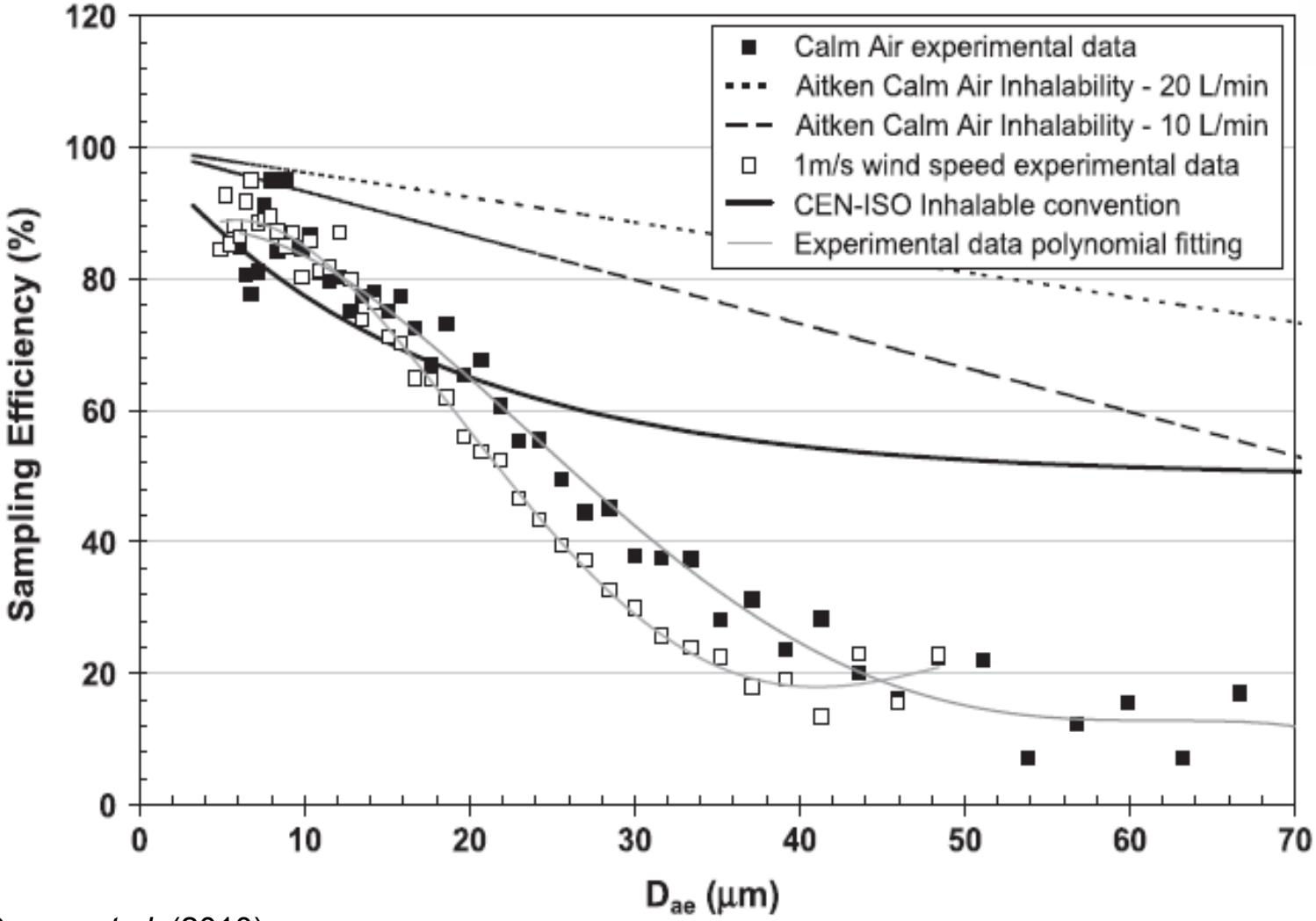
Advantages

- Disposable
- Inexpensive ($1)
- Simple

Disadvantages

- Does not meet inhalable criterion
  - Under-samples particles larger than about 20 µm
  - High internal losses

Personally, I Wish the CFC Worked Better



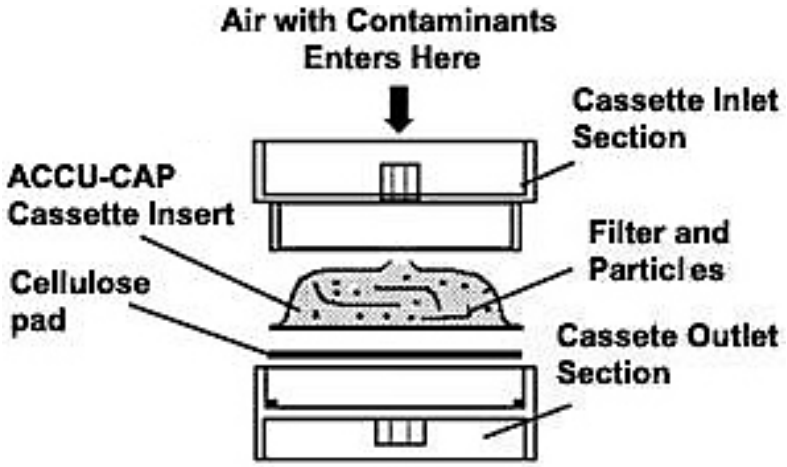
Gorner *et al*. (2010)

Evidence Supports Presence of Large Particles

Concentration Ratios When IOM & CFC are Co-located

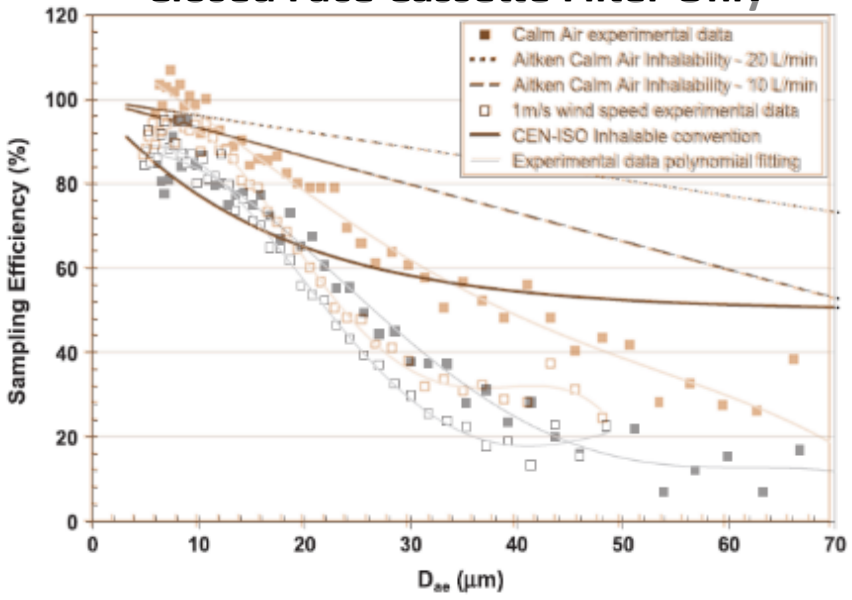
Environment	**Ratio,** (IOM / 37mm)	**Ref.**
Machining	3.0 ± 0.6	Wisley [1996]
Carbon Black	2.3 – 3.5 (95%CI)	Kerr [2001]
Electroplating	1.3 – 3.7(95%CI)	Tsai [1996]
Wood Dust	1.2 – 19 (95%CI)	Harper [2002]
Metal Smelter	1.3 – 2.7 (95%CI)	Spear [1997]
Poultry Barn	2.0 ± 0.9	Reynolds [2009]
Flour Dust	2.4	Karpinski [2003]

Regarding Particle Losses in the CFC

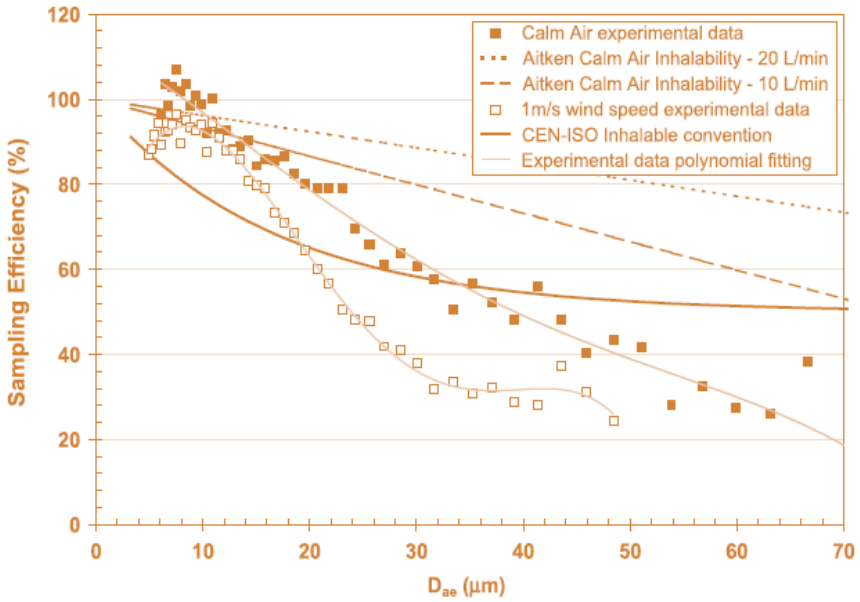


www.skc-inc.com

Closed Face Cassette Filter Only



Cassette with ACCU-CAP™



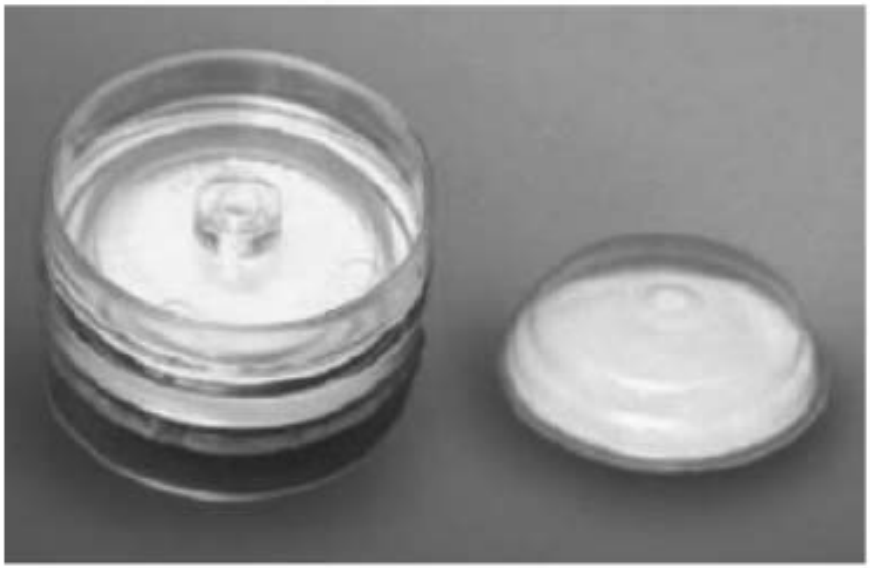
Gorner *et al*. (2010)

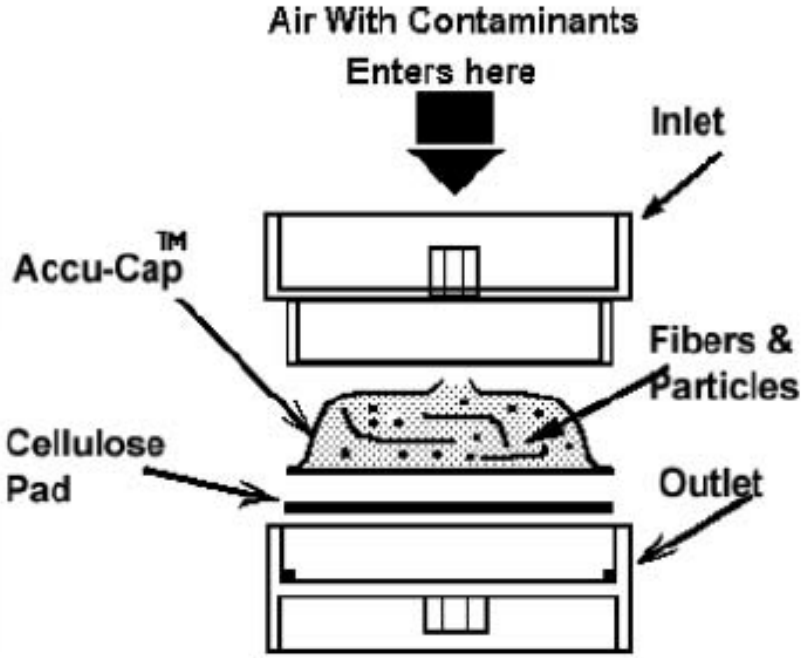
Journal of Occupational and Environmental Hygiene, 10: 297–306
ISSN: 1545-9624 print / 1545-9632 online
DOI: 10.1080/15459624.2013.777310

Acid-Soluble Internal Capsules for Closed-Face Cassette Elemental Sampling and Analysis of Workplace Air

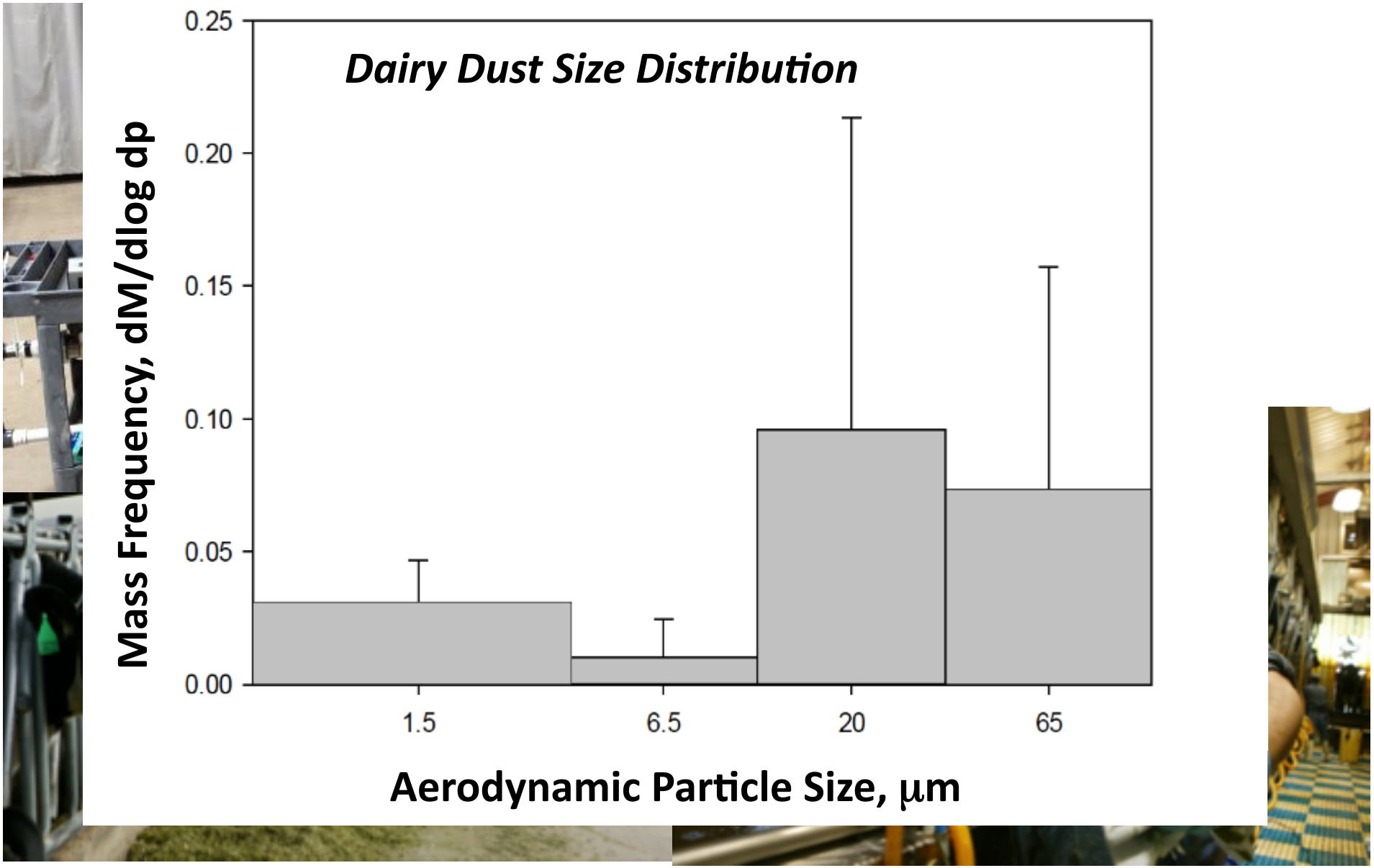
Martin Harper[1] and Kevin Ashley[2]

[1]National Institute for Occupational Safety and Health, Health Effects Laboratory Division, Morgantown, West Virginia
[2]National Institute for Occupational Safety and Health, Division of Applied Research & Technology, Cincinnati, Ohio



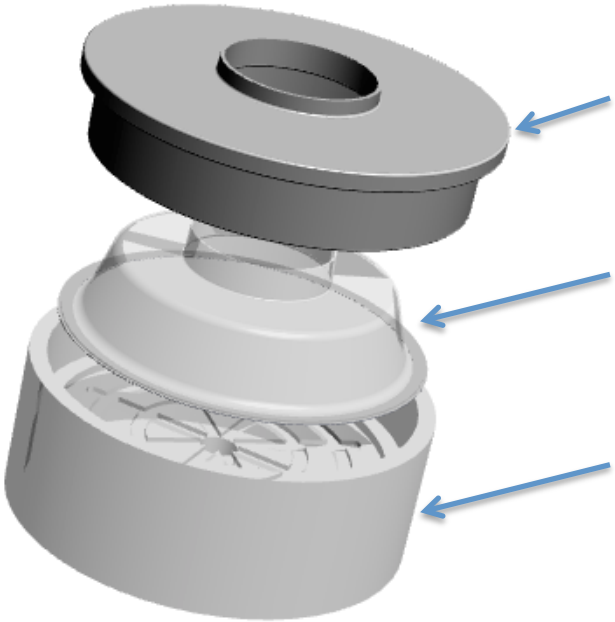


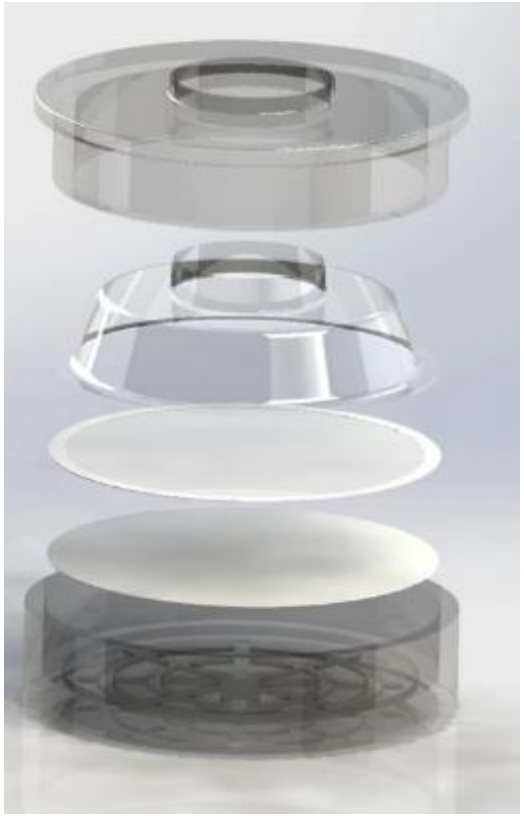
Inhalable Dust: Measurement of Larger Particles



Goal #1: Simple, Low-Cost Sampling Devices

Can We Combine the Best Aspects of the CFC with the IOM Inhalable Aerosol Sampler?





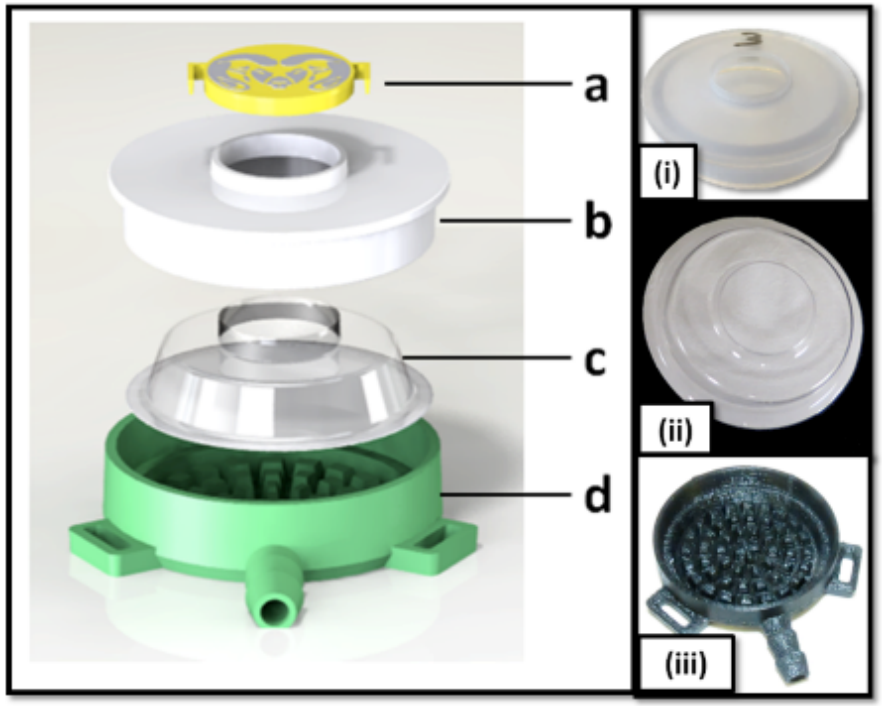
Want a sampling apparatus that is:

- Inexpensive
- Disposable
- User friendly
- Physiologically relevant

Capsule Design and Fabrication

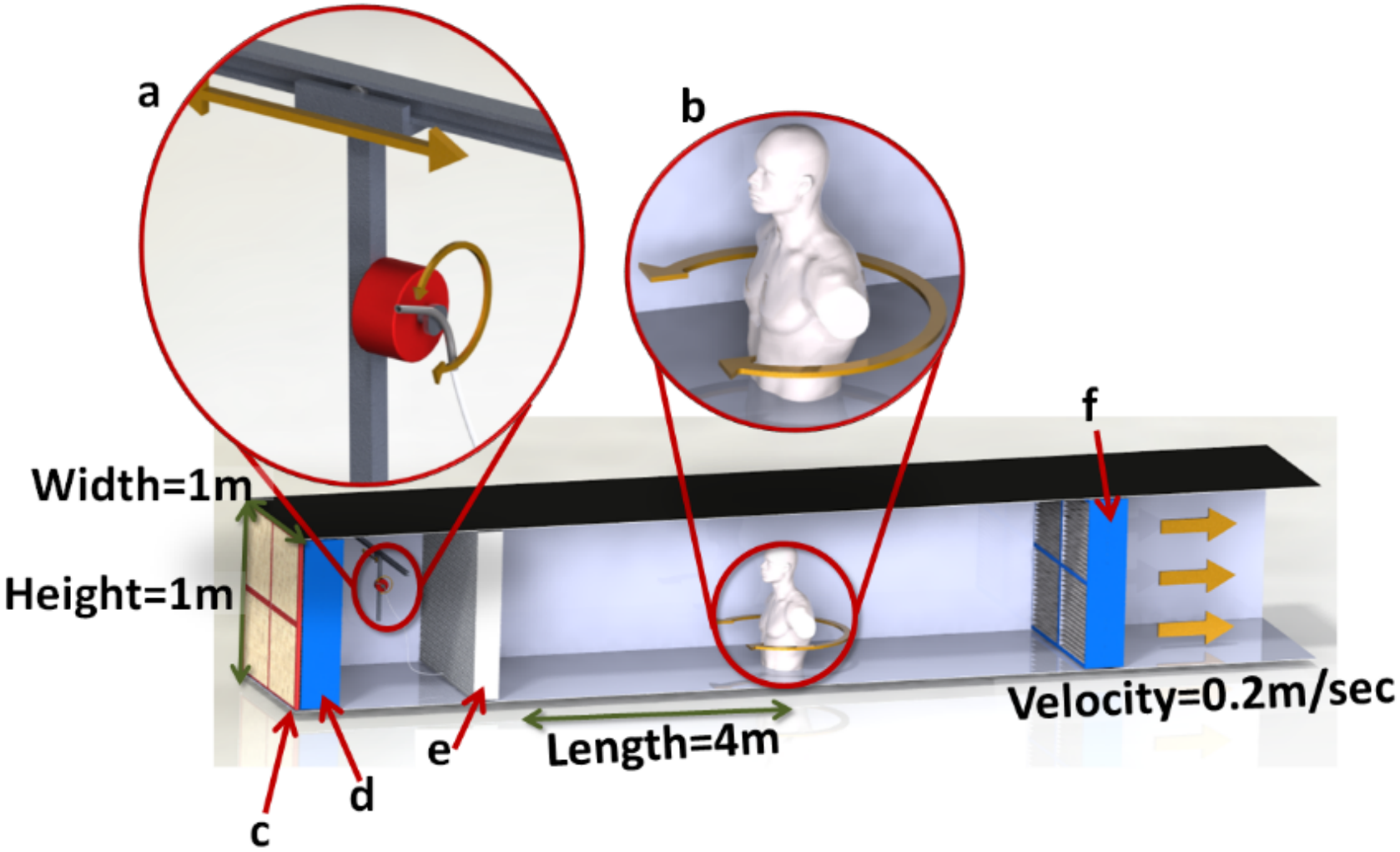
- Vacuum-formed polyethylene capsule (lightweight)
- Caps welded to filters using solvent (toluene)
- Wide range of bondable filter materials
- Low limit-of-detection

(gravimetric LOD: 10-30 µg)

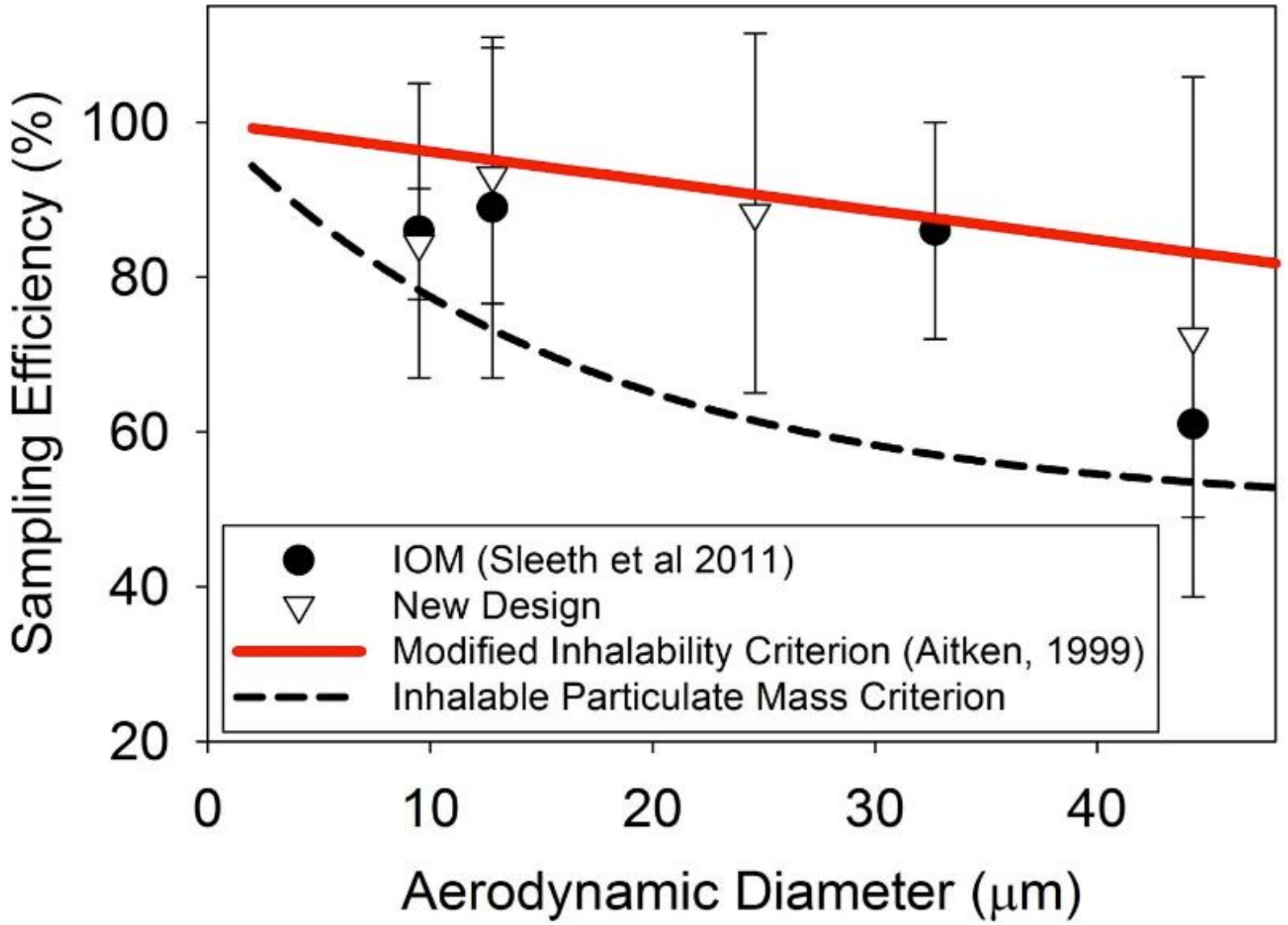


L'Orange et al. *Ann Occ Hyg.* submitted

Low-Velocity Wind Tunnel: Orientation Averaged Sampling Efficiency



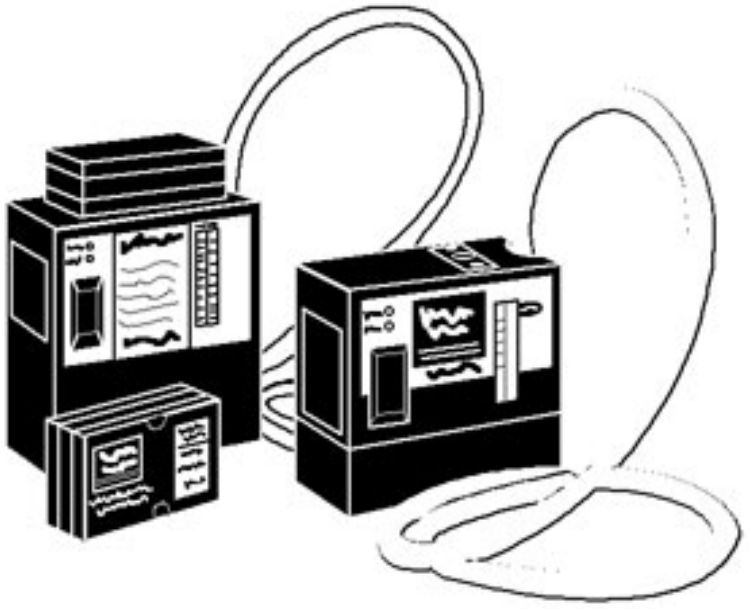
L'Orange et al. *Ann Occ Hyg.* Under review



L'Orange et al. *Ann Occ Hyg.* submitted

Personal Sampling Pumps
Neither Cheap, Nor Lightweight, Nor Quiet

- **Personal Sampling Pumps:**
  - $500 - $3,000 each!



Can we design an alternative?

Sampling Pump Design Options

Axial/Radial Fan

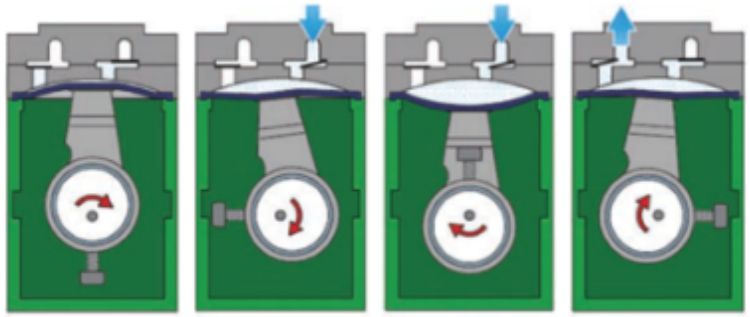
- Simple
- Inexpensive
- Mass-produced

- Poor pressure performance
- Easily fouled

Diaphragm Pump

- Good pressure performance
- Proven technology

- Many parts
- Expensive
- Pulsing flow

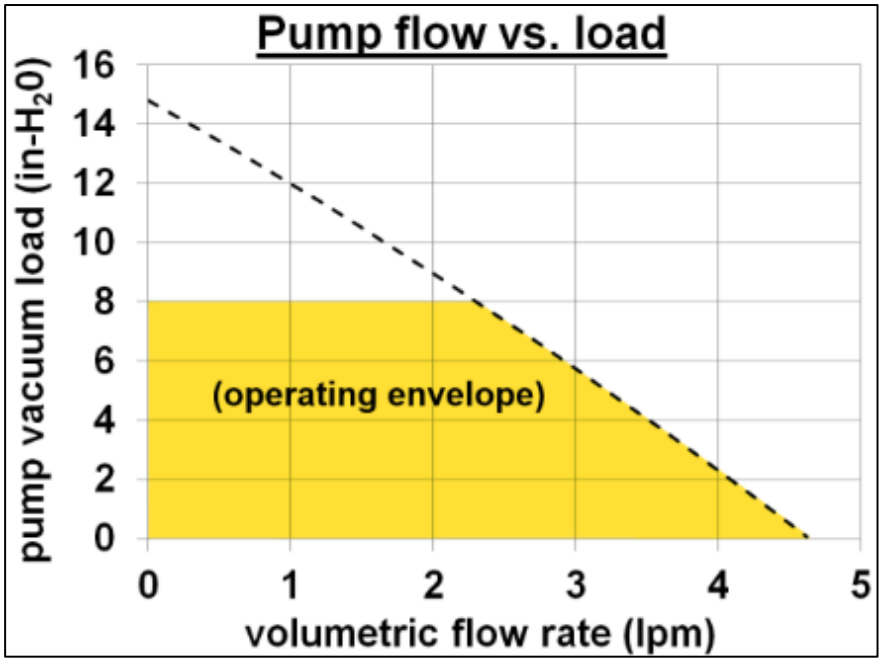


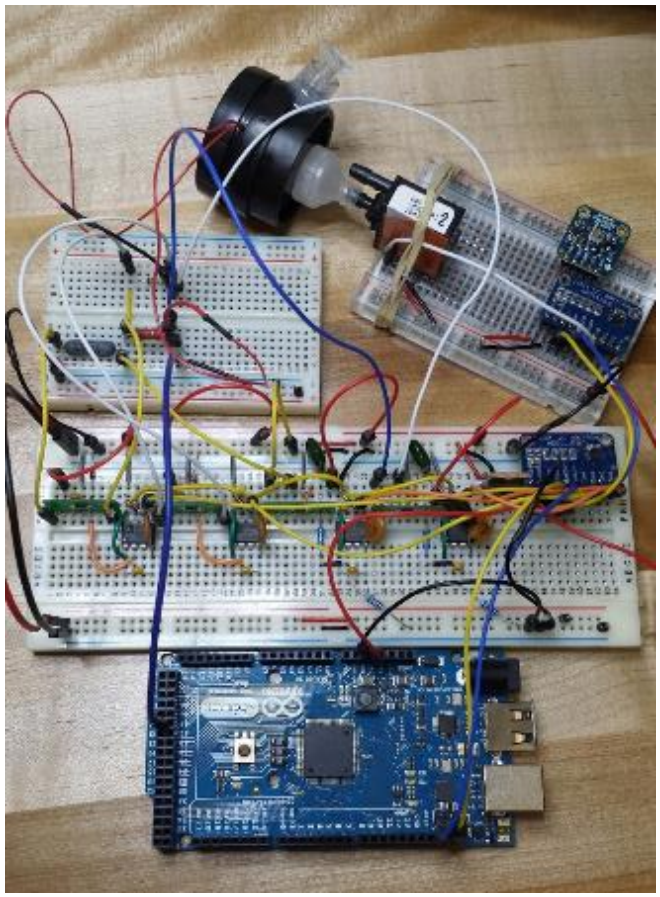
Ultrasonic Pump

- Fair pressure performance
- Inexpensive
- Silent

- Untested…
- Adequate pressure performance?

Prototyping A Personal Ultrasonic Sampling Pump





Arduino-based, Rapid-Prototype, Personal Ultrasonic Sampling Pump

CAD Model ➔ Rapid Prototype Housing & Electronics

Bill of Materials for Pump Prototype

Component	Prototype Costs (USD)	Mass Production (USD)
Housing	$150	$5
Pump	$30	$20
Circuit/Wiring	$40	$12
Battery	$20	$15
Bluetooth	$8	$3
Hardware	$5	$2
TOTAL	**$253**	**$57 (est.)**

Traditional Analytical Chemistry Is Expensive

- **Instrument cost:**
  - $50,000 - $150,000

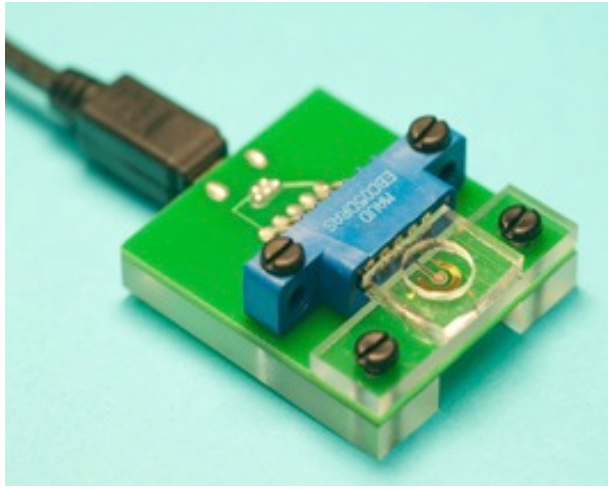
- **Sample analysis cost:**
  - $100 for the first metal, $20 for each additional one

Goal #2:
Lower the Cost of Sample Analysis

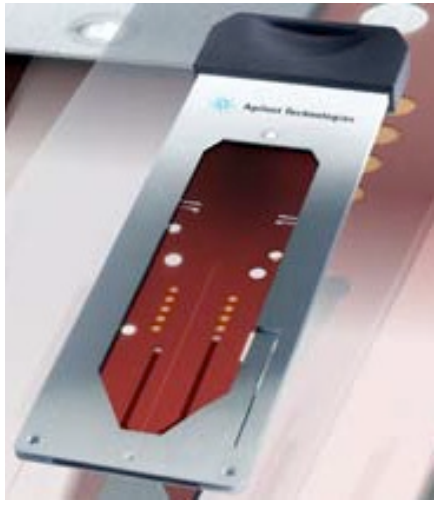
Wikipedia.org

Microfluidics?

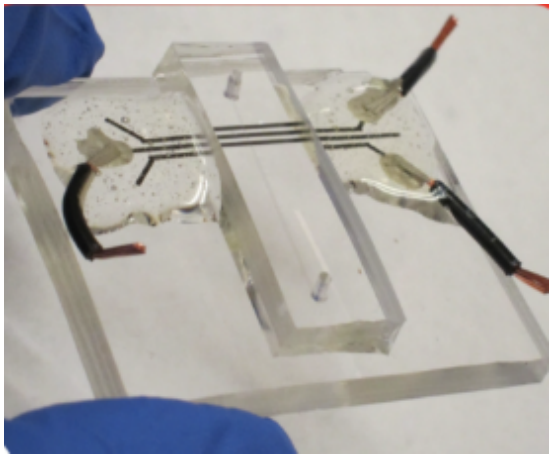
- Microfluidics is analytic chemistry using sample volumes on the order of *microliters* instead of milliliters
- **Why are we interested in microfluidics?**
  - Small quantities of reagents (lab on a chip)
    - Same sample analyzed in less volume -> increased sensitivity
  - Low cost and fast analysis



Manganese in blood[1]



Electrospray LC-MS[2]



Aerosol Reactivity[3]

[1]Jothimuthu P, *et. al. Lab on a Chip* (2011) [2] www.agilent.com [3] Sameenoi , *et al. JACS* (2012)

Microfluidics on Paper?

- **Microfluidic Paper-based Analytical Devices (mPADS)**
  - Paper patterned with wax (or other hydrophobic material)
  - Liquid transport by capillary action
  - Flow circuits designed for in-situ chemistry

- **Rapidly Growing Field**
  - Mostly biological applications to date

Whitesides, G. M. et al. *Bioassays,* 2007,

Dungchai et al. *Anal. Chim. Acta 2010*

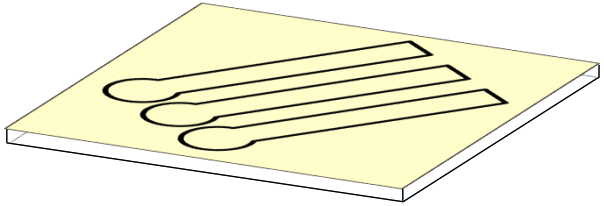
Advantages of mPAD Technology

- VERY inexpensive (less than 5¢ per device)
- Portable and disposable
- Easy to make, easy to use
- Rapid analysis (minutes)

Xerox Colorqube 8870

Epson R280

Print wax barrier

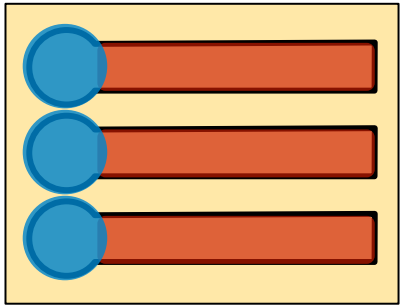


Melt wax barrier

Heat

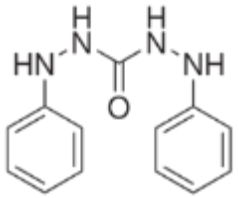
Detection regions

Pre-treatment zones

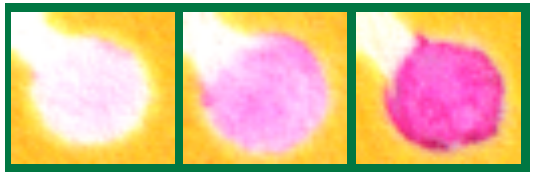


Many Applications for Environmental Monitoring

Inorganics [1]

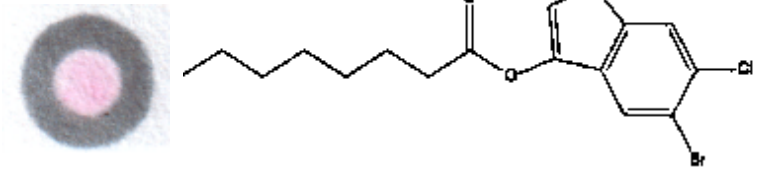


Chromium-VI + 1,5-Diphenylcarbazide →

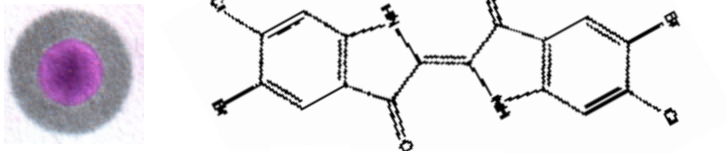


0.12 µg **1.5 µg** **6 µg**

Microorganisms [2]



esterase →



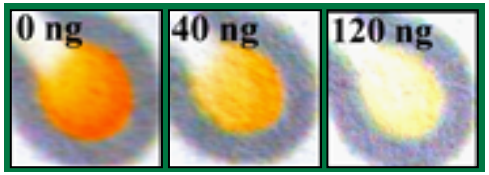
Magenta Caprylate

Salmonella Detection

Organics [3]

$PM_{2.5}$ + Dithiothreitol

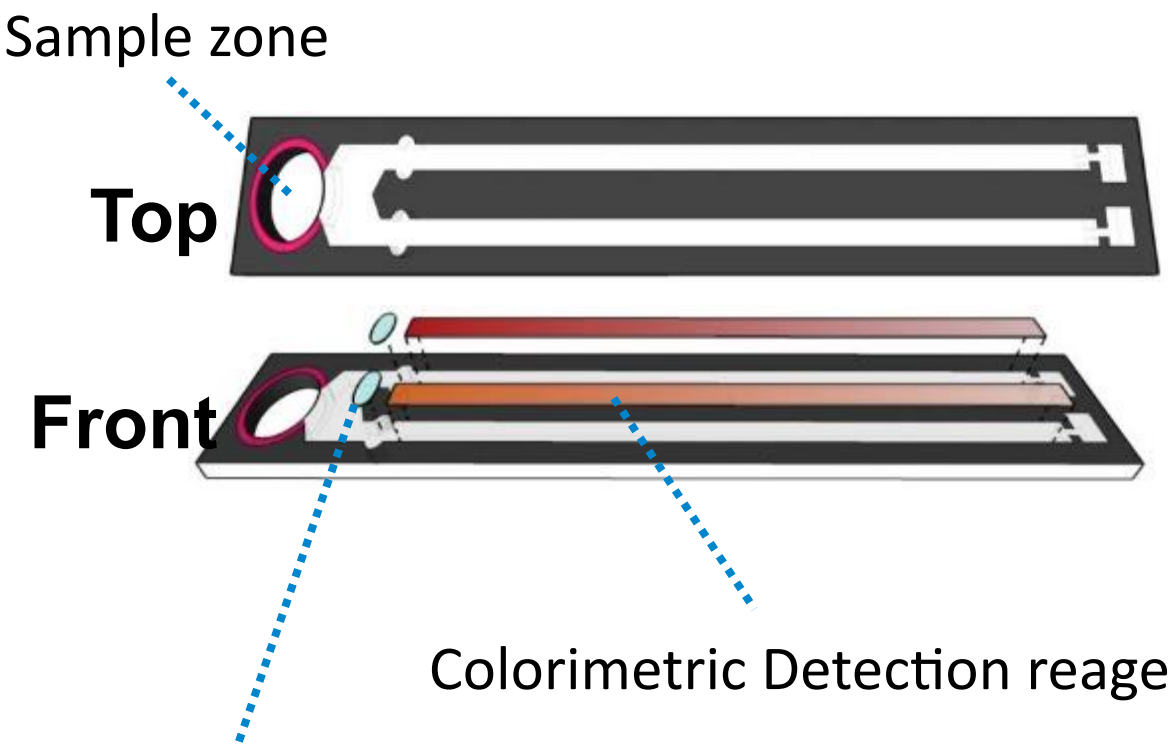
DTNB →

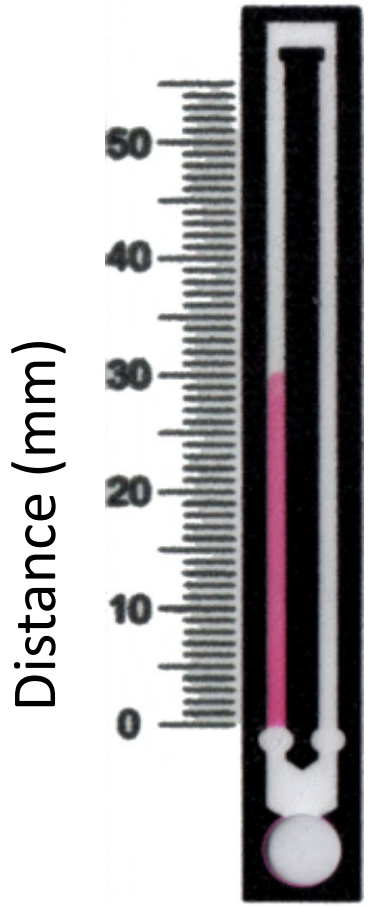


Aerosol ROS

(1) Mentele et al. *Anal Chem.* (2012) 84, 4474−4480; (2) Jokerst et al. *Anal. Chem.*, (2012), *84* (6), pp 2900–2907
(3) Sameenoi et al. *Environ. Sci. Tech. (*2013), *47* (2), pp 932–940

Distance-Based Detection: Simple, portable unpowered, rapid analysis, μg (ppm) resolution





15 μg Ni

Multiplexed Analysis of Cu, Fe in Welding Fume

- Remove punch (10mm) from sampling filter
- Add 5 µL HNO_3 to digest metals
- Microwave for ~30 sec
- Neutralize sample with 8 µL $NaHCO_3$
- Place punch on µPAD
- Elute metals with 30 µL H_20
- Measure color change/intensity

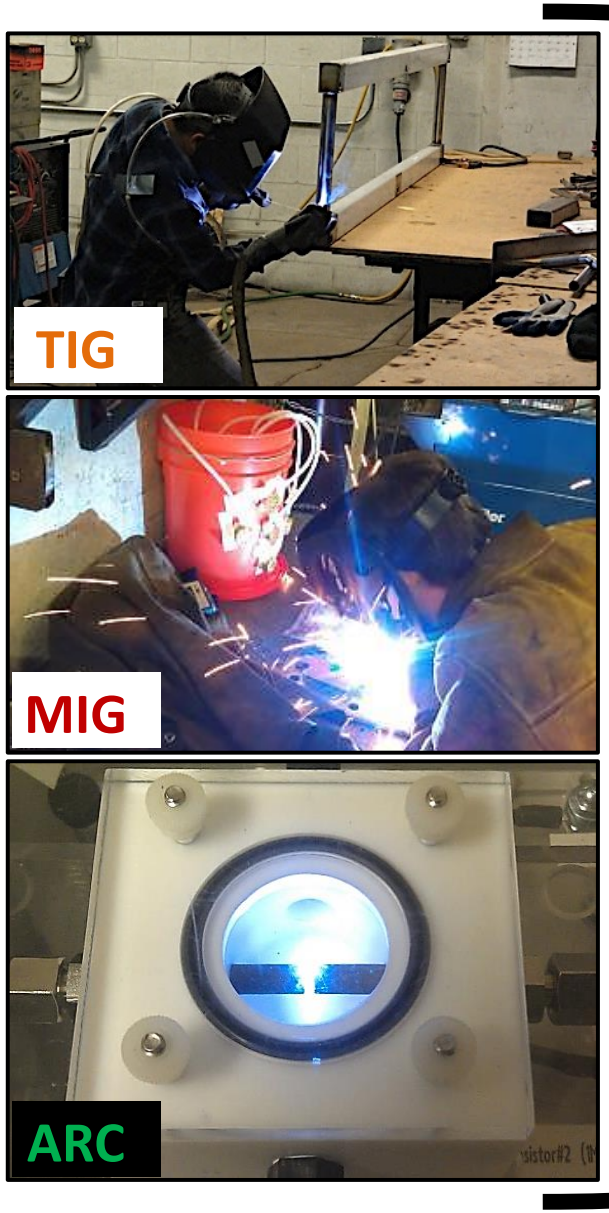
25 min elapsed time

mPAD Detection Limits Are Adequate in Most Occupational Settings

	mPAD 8-hr LOD	OSHA 8-hr PEL*
Metal	($\mu g/m^3$)	($\mu g/m^3$)
Fe	7.8	1,000
Ni	7.8	1,000
Cu	10.7	100
Cr(VI)	0.86	0.5

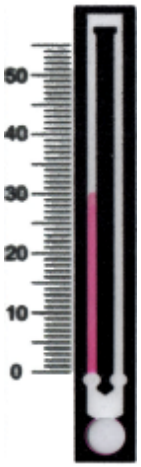
***Detection limits may be lowered by using smaller diameter filters for a given air flow rate*

Field Validation: Metals in Welding Fumes



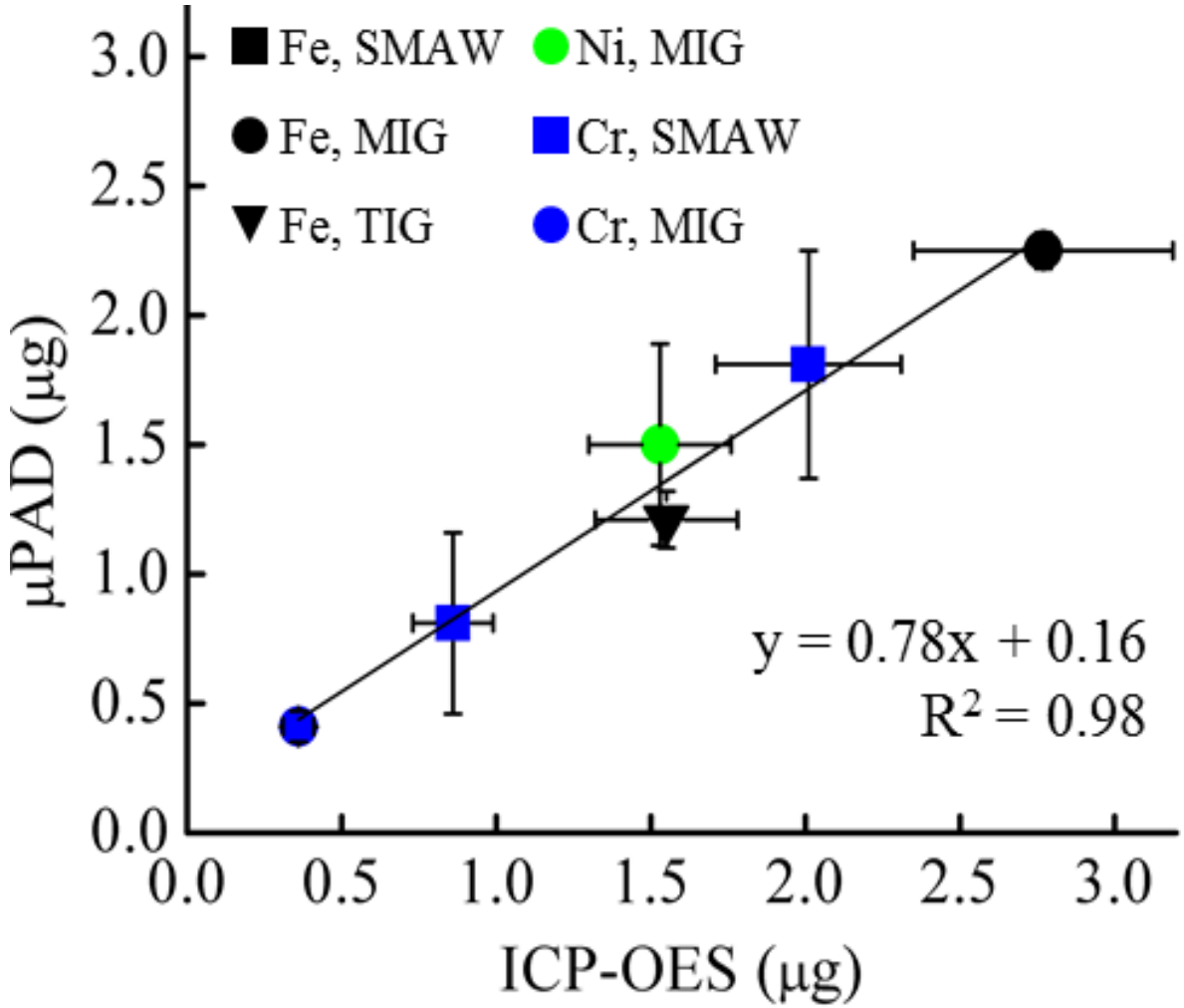
Sampler

Loaded Filter



mPAD Analysis

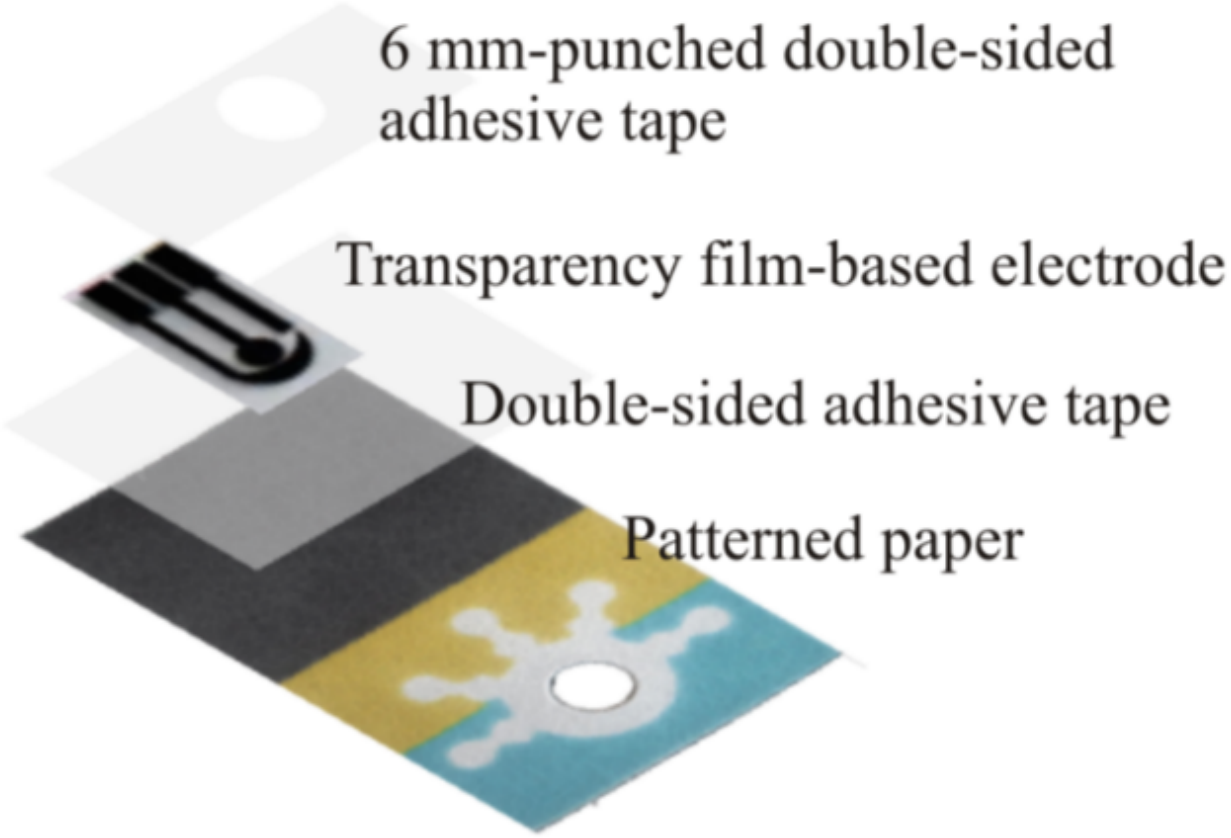
Metals in Welding Fume: mPAD vs. ICP-OES

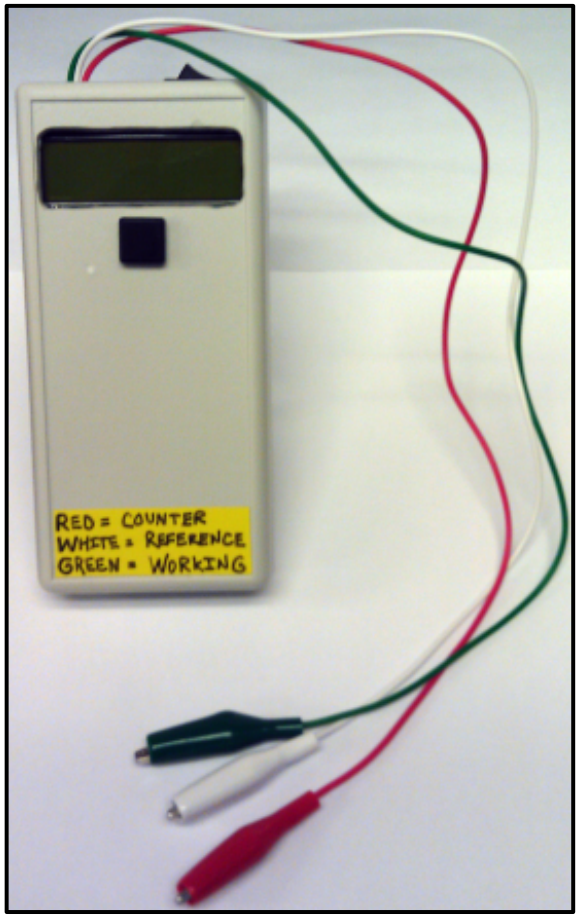


Cate et al. *Annals of Occ. Hyg.* (2014) 58 (4): 413-423

Colorimetric Detection Paper: 0.1 μg

Electrochemical Detection on Paper: 0.1 ng



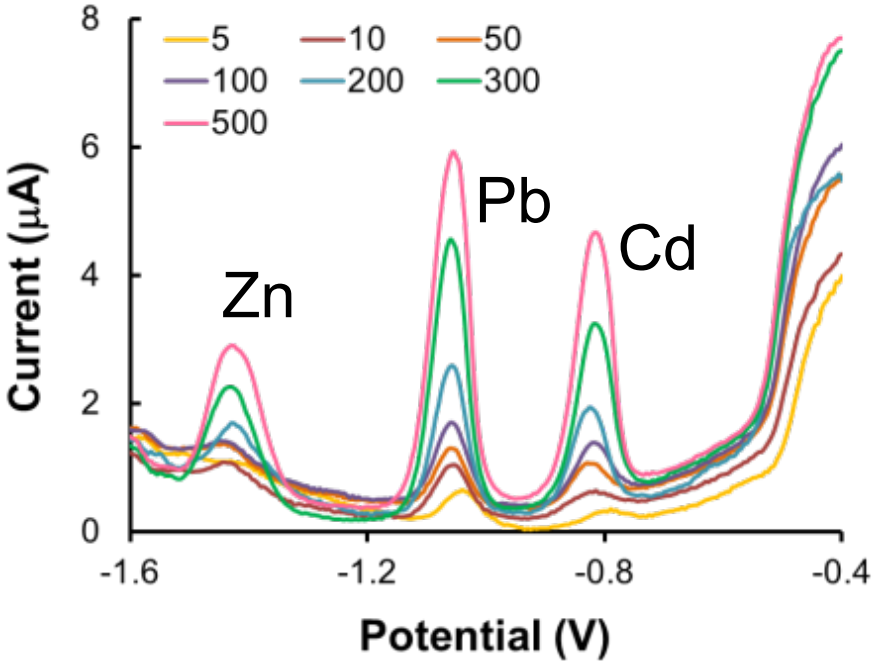


Anodic stripping voltammetry

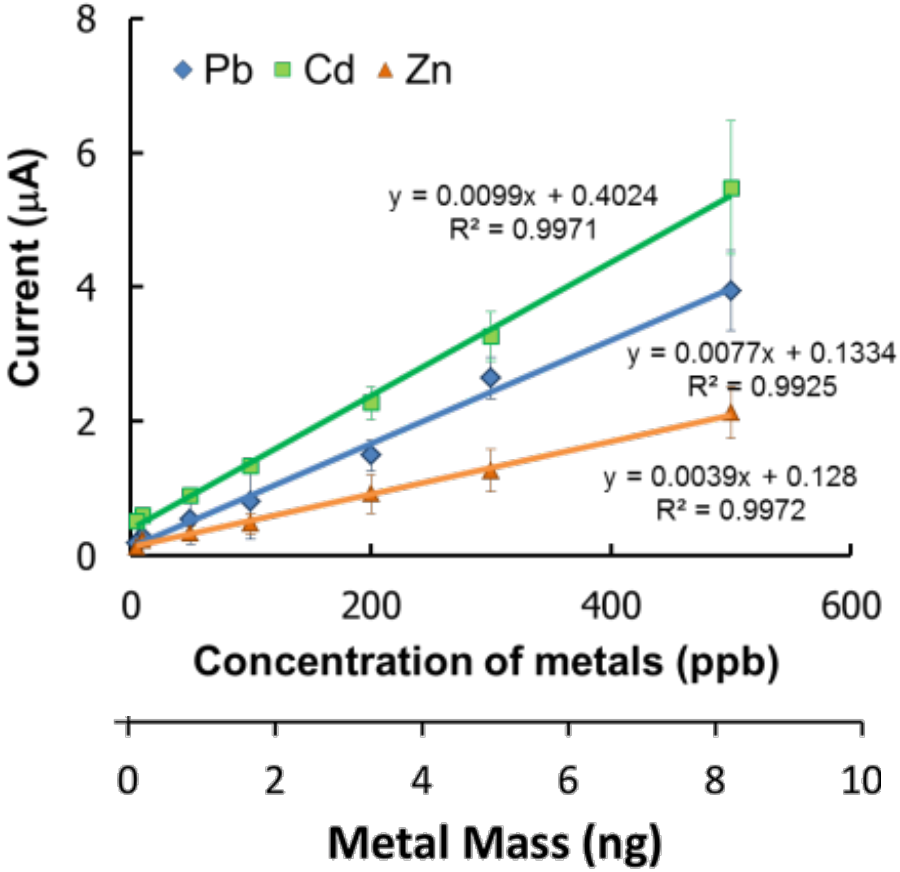
Rattanarnat et al. *Anal. Chem.*, (2014), *86* (7), pp 3555–3562

Rowe et al. *Plos One* (2011) DOI: 10.1371/journal.pone.0023783

Electrochemical Detection of Cd, Pb, and Zn in Air and Water



Anodic stripping voltammetry

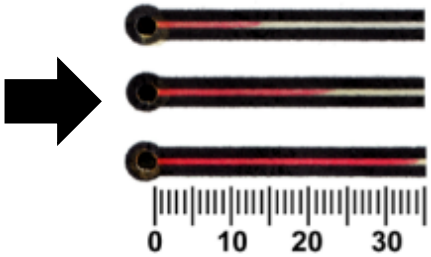


Making Low-Cost Environmental Measurements a Reality

Measurement

$25

Analysis

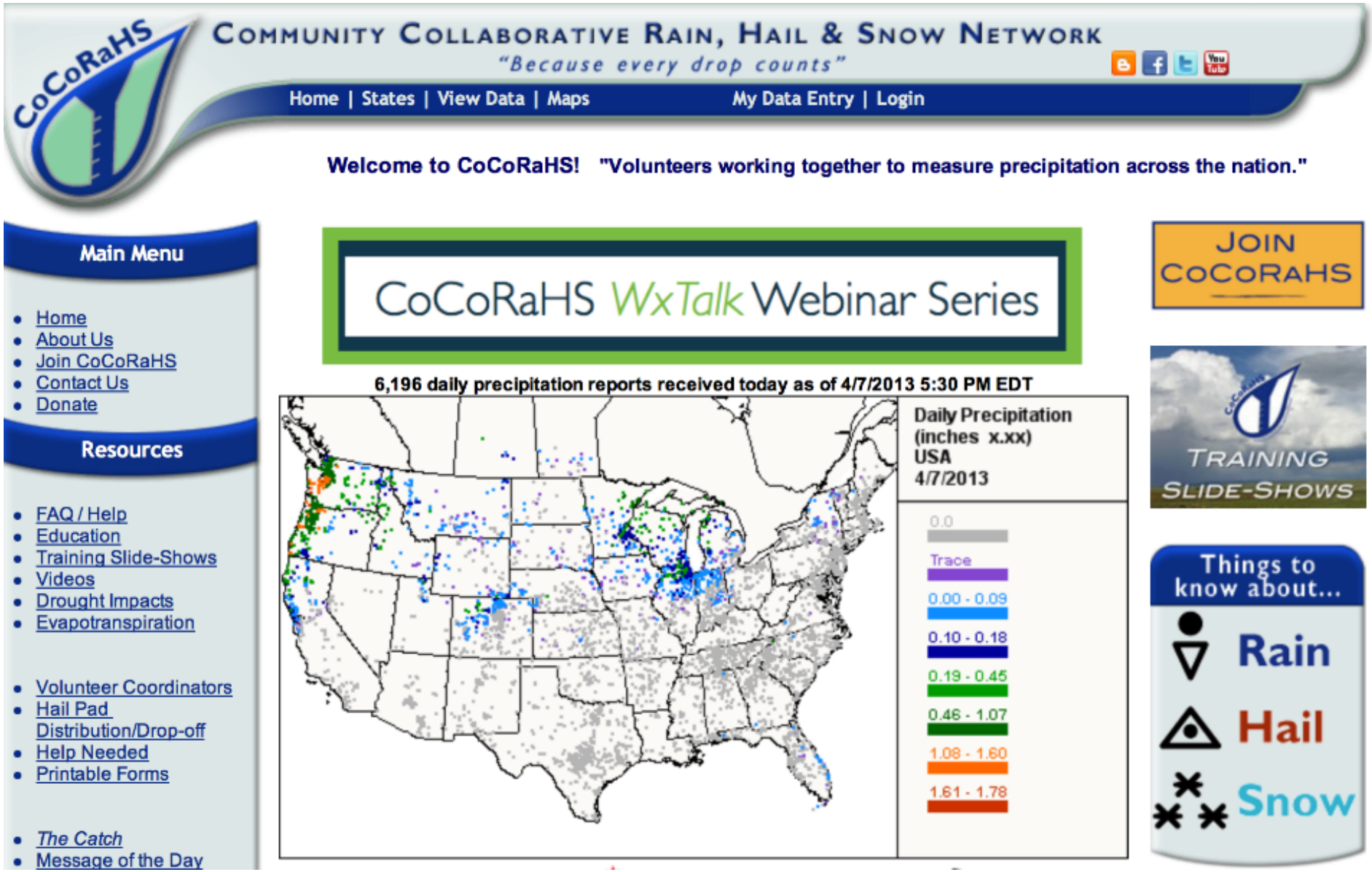


$2

Interpretation

You $$$

Can Citizen-Science Emerge within Industrial Hygiene?



Technology that Empowers Knowledge and Action

- 100 years ago you went to the doctor to have your temperature taken

- 25 years ago you did the same to find out if you were pregnant

- 10 years ago you needed official credentials to be called a journalist

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john.volckens@colostate.edu