21 Feb 2019

Measuring Air Pollutants II

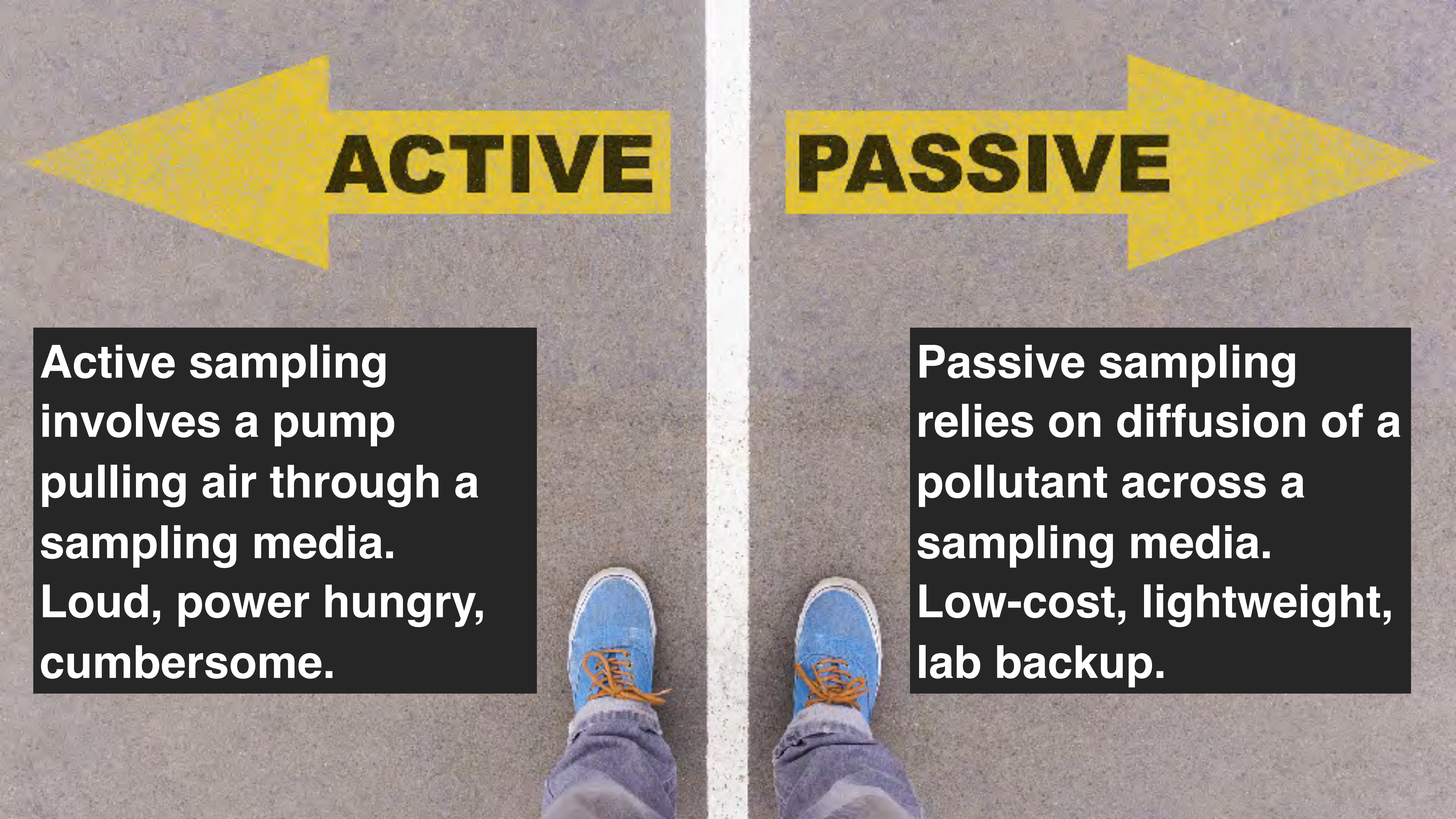
Gas and Particle Measurement

Measurement Hands-on

What'd you think?

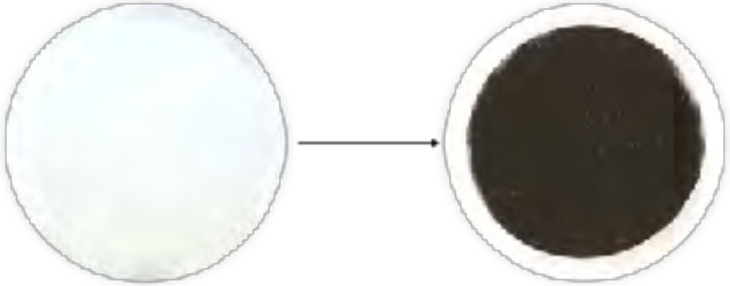
A little review

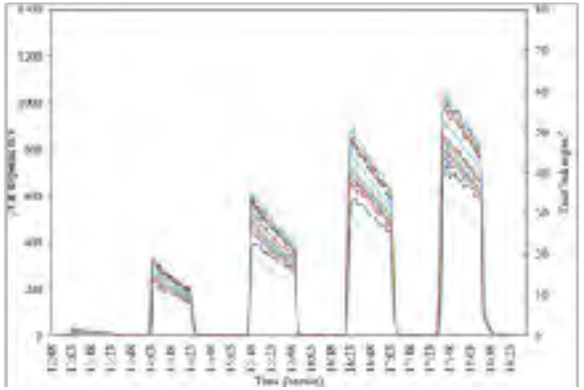

National and Regional Emissions Inventory
Local Emissions Inventories
Emissions Sampling
Emissions Sampling + Community Characteristics
Ambient/Environmental Sampling
Ambient/Environmental + Time Activity
Personal Exposure
Personal Exposure + Time Activity
Exposure Biomarkers
Effect Biomarkers
HEALTH EFFECT
Increasing Cost, Increasing Precision



Active sampling involves a pump pulling air through a sampling media. Loud, power hungry, cumbersome.

Passive sampling relies on diffusion of a pollutant across a sampling media. Low-cost, lightweight, lab backup.





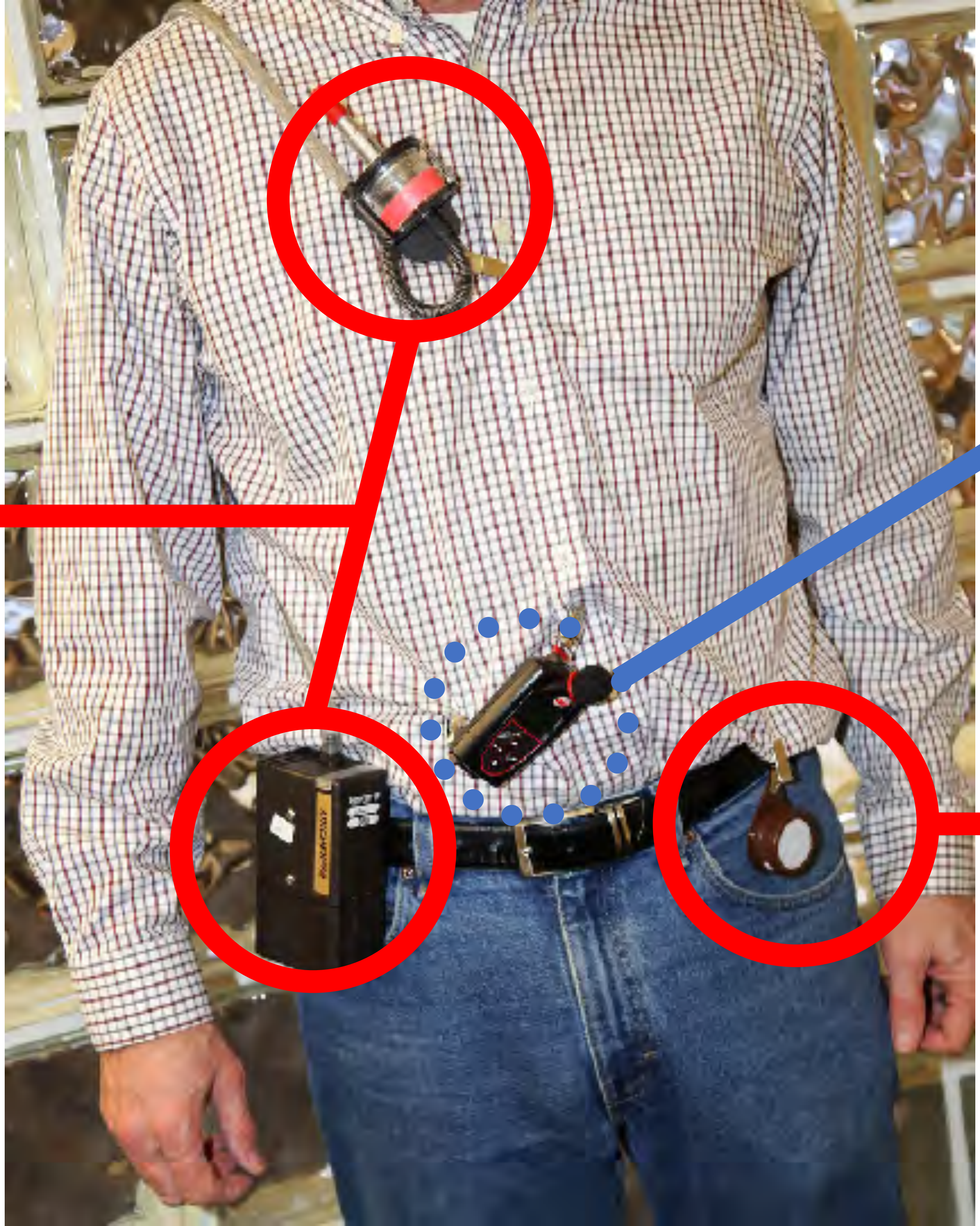
INTEGRATED

Single measure over period of time
Collection of mass on a filter, length of stain in a tube
Gold-standard measures

CONTINUOUS

Usually sensor-based methods for getting a measurement at a user-defined interval
Calibration, lifetime, sensitivity issues

Active or passive?
Continuous or Integrated?



Active Sampler
Integrated

Noise Dosimeter
Continuous

Passive Sampler
Integrated

Measuring Gases

Gases: Background

Gases Commonly Measured

Carbon monoxide (CO) has been a primary focus as both marker and primary agent.

Volatile organic compounds (VOC), sulfur dioxide (SO_2)

Instrumentation

Development driven largely by occupational health sector

As with PM, dependent heavily on personal monitoring devices

Metrics

Measured on a molar basis (e.g. parts per million- ppm) or mass basis (e.g. mg/m^3)

Molar basis changes slightly depending on the temperature and pressure but can be adjusted and/or converted to mass concentration ($PV=NRT$).

Gas Detection

1. Colorimetric
2. Semiconducting Metal Oxide (SMO)
3. Electrochemical
4. Infrared

Colorimetric Badges

Passive Diffusion Tubes

1 Colorimetric

2 Semiconducting Metal Oxide (SMO)

3 Electrochemical

4 Infrared

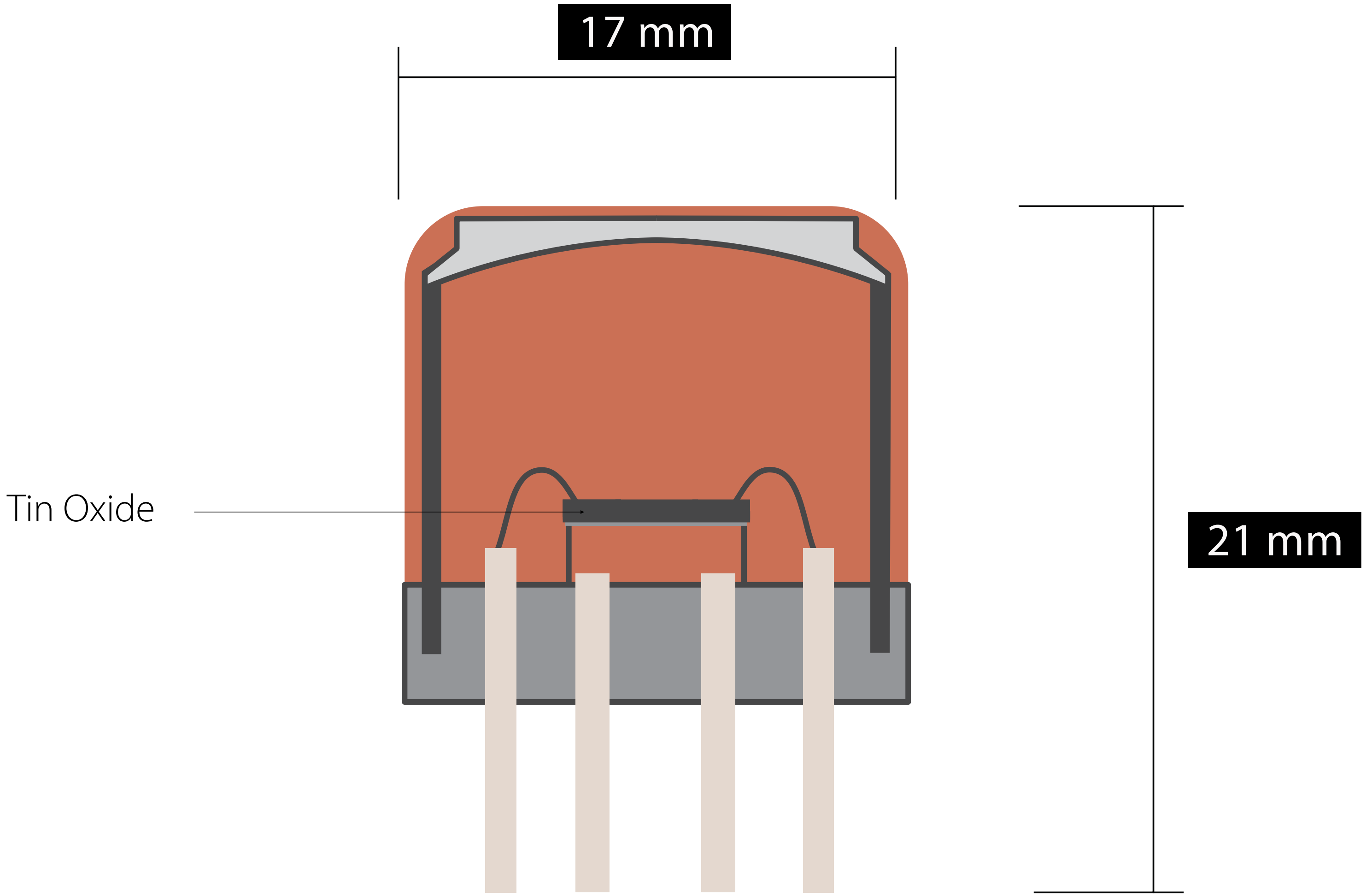
Badges best for qualitative assessment of gas presence

Least sensitive

Tubes are a good integrated measure if response is characterized appropriately

Cross-sensitivity, temperature, humidity, reversibility can be problematic

Cheap, easy, non-invasive



1 Colorimetric

2 Semiconducting Metal Oxide (SMO)

3 Electrochemical

4 Infrared

Small, reliable, durable, cheap

Long-lasting, stable baseline, stable outputs over time

Cross-sensitivities, humidity, temperature, power requirements

Well characterized - patent in 1962

1 Colorimetric

2 Semiconducting Metal Oxide (SMO)

3 Electrochemical

4 Infrared

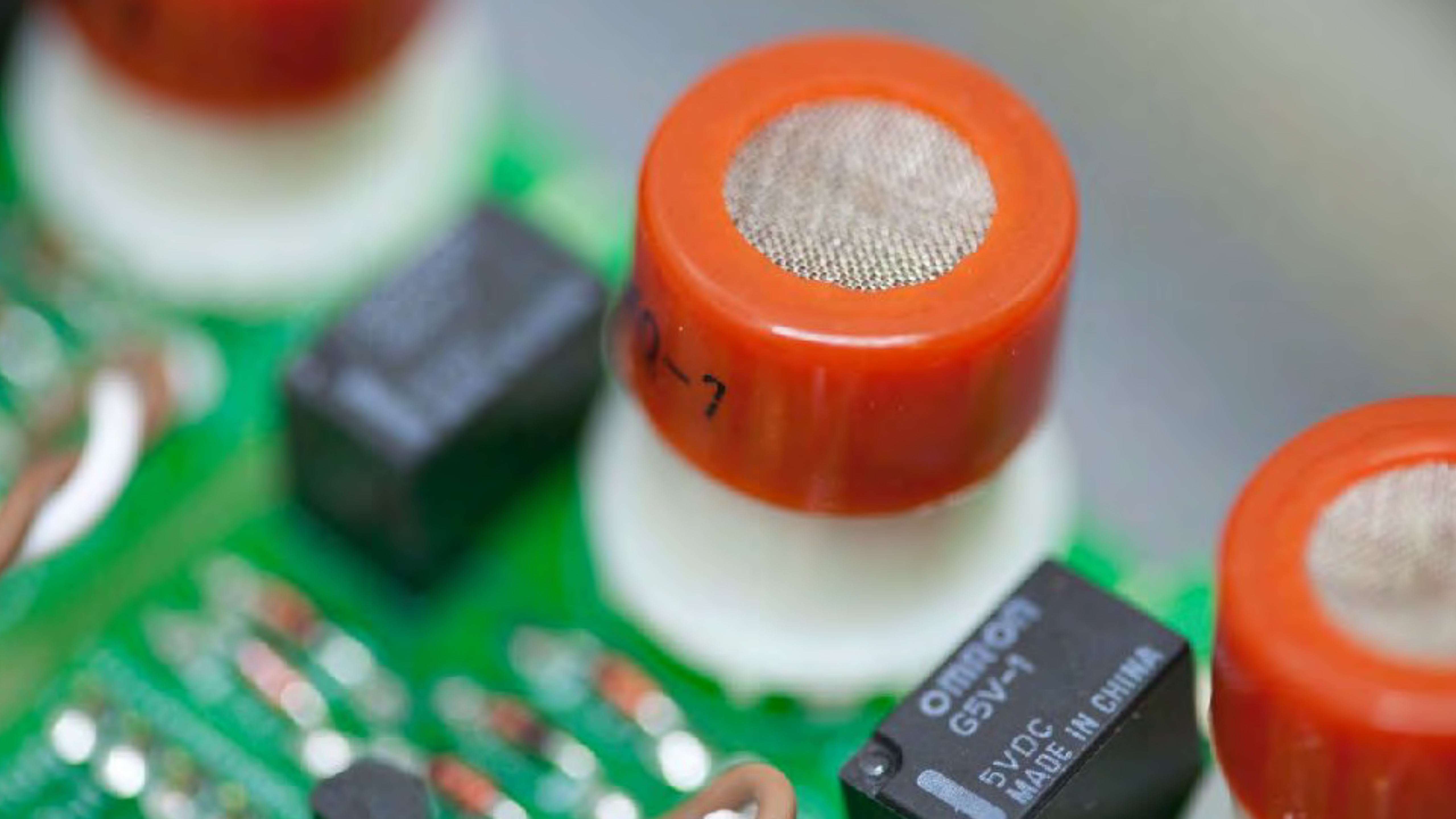
Metal oxides change their resistance based on exposure to gases in air

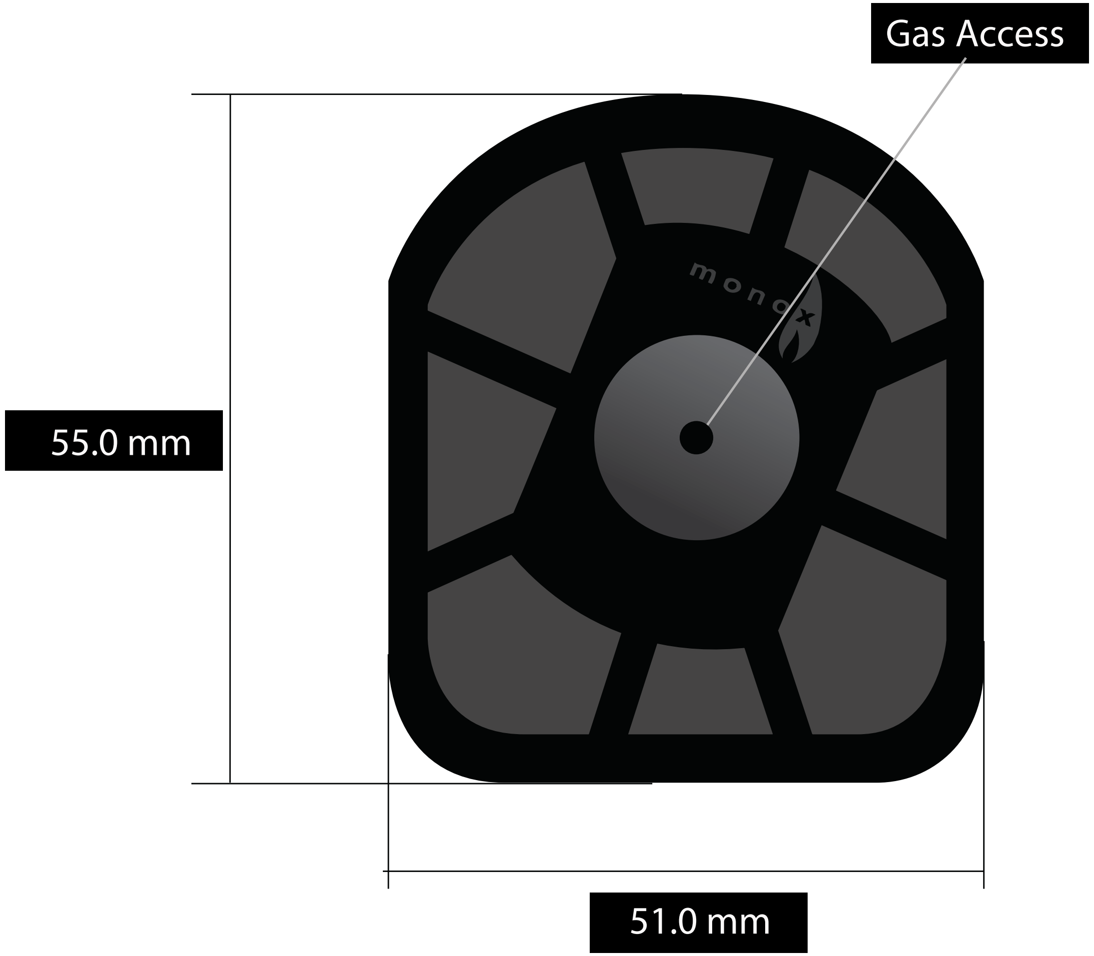
High resistance in clean air

In the presence of CO, resistance drops

We can measure the change in resistance - related to CO concentration

Thermal cycling caveat


omron
G5V-1
5VDC
MADE IN CHINA

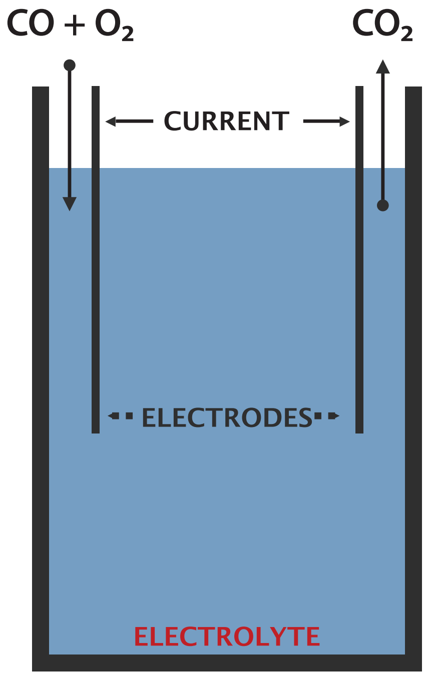


1 Colorimetric

2 Semiconducting Metal Oxide (SMO)

3 Electrochemical

4 Infrared



Working Reaction

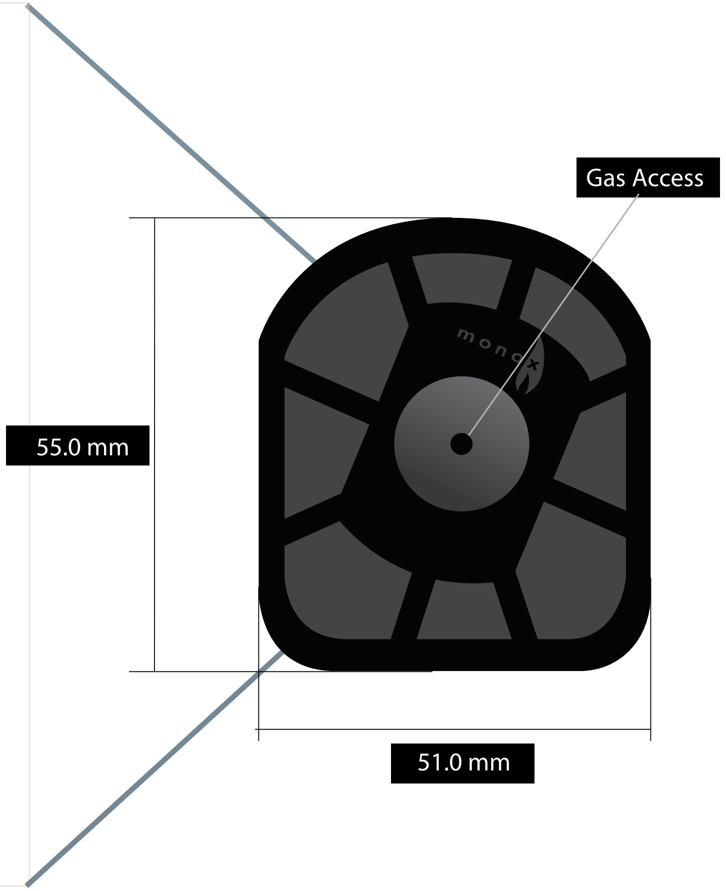
$CO + H_2O \text{ --> } CO_2 + 2H + 2e$

Counter Reaction

$2H + O + 2e^- \text{ --> } H_2O$

Net Reaction

$CO + O \text{ --> } CO_2$



1 Colorimetric

2 Semiconducting Metal Oxide (SMO)

3 **Electrochemical**

4 Infrared

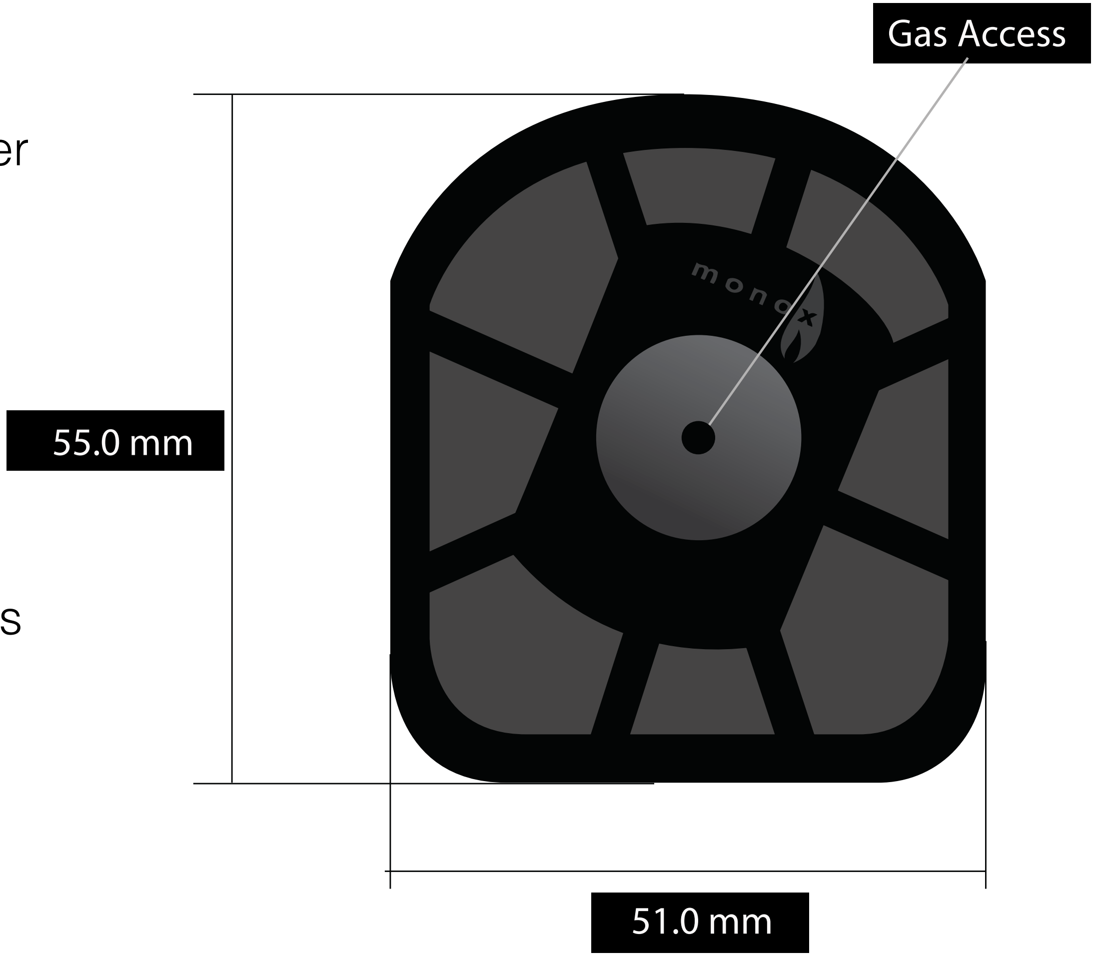
Good resolution, available for many gases, relatively low power demand

“Reasonable Cost” - though varies widely depending on cross-sensitivities, lifespan, resolution, and range

Typically favored for field studies

Affected by humidity and temperature

Sensor drift & signal decay



1 Colorimetric

2 Semiconducting Metal Oxide (SMO)

3 **Electrochemical**

4 Infrared

Drager Pac 7000 (~$350)

Drager Pac 7000 (~$500)

Inexpensive (1ppm resolution), alarms, limited settings

Drager Pac III (~$750)

ToxiRAE Pro CO (~$550)

Slightly more robust, alarm-shutoff

Langen CO ($1500)

Great resolution (<1ppm), low upper limit, expensive, battery life

TSI Q-Trak ($2700)

IR Source
4.7 μm

Photodetector

Filter

Identify gas based on its unique IR Spectra

1 Colorimetric

2 Semiconducting Metal Oxide (SMO)

3 Electrochemical

4 Infrared

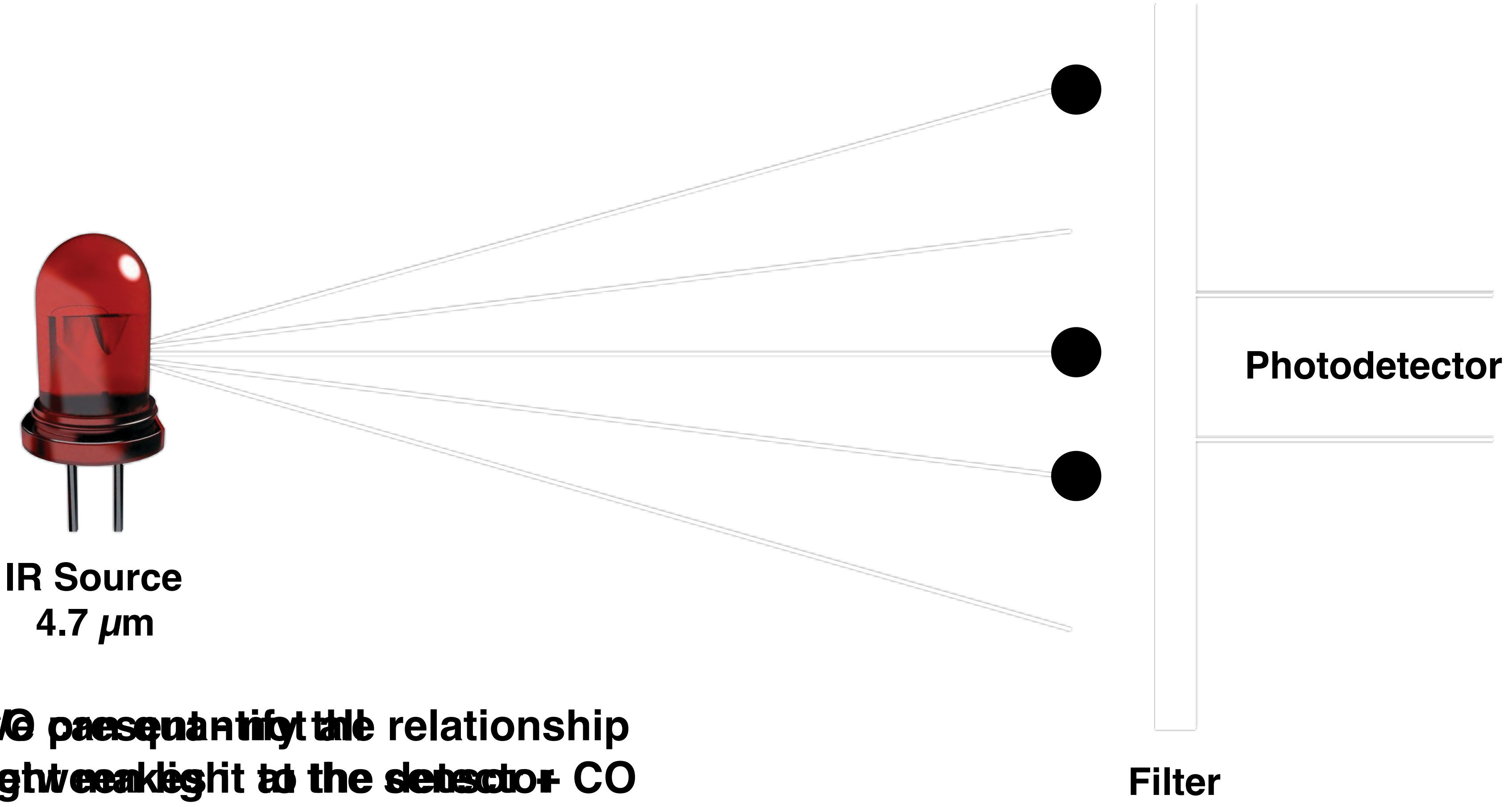
No Gas - all light passes to the photodetector

1 Colorimetric

2 Semiconducting Metal Oxide (SMO)

3 Electrochemical

4 Infrared



CO present = not all light makes it to the detector

We can quantify the relationship between light at the sensor + CO

1 Colorimetric

2 Semiconducting Metal Oxide (SMO)

3 Electrochemical

4 Infrared

More power demand, selective, sensitive, long life time, wide measurement range

Expensive and not available in “field-ready” form for most pollutants

Susceptible to misinterpretation if not properly cleaned/maintained

Size increases (bench) to resolve lower concentrations

Sample Bag

Best for “grab samples” or short duration sampling (meals)

Many compounds could be measured

Some pollutants require significant post-processing with laboratory equipment.

Transportation of sample bags can be difficult and expensive

“Calibration”: Gas

Calibration and/or Test Regularly:

1) Response
2) Decay time
3) Accuracy

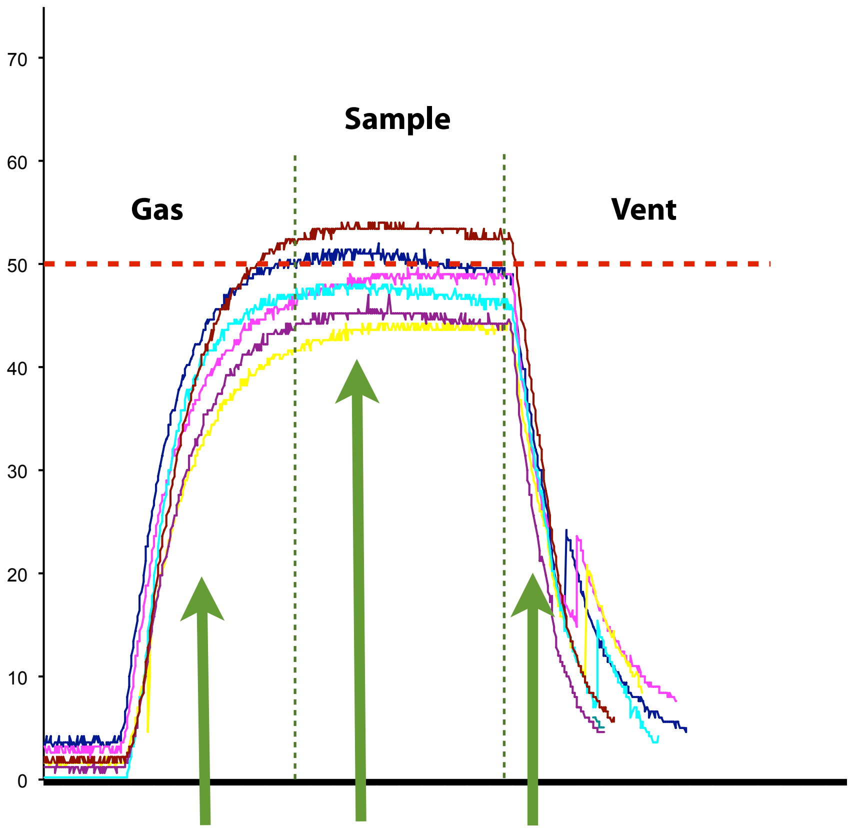
Cannot rely on manufacture “checks”

Multiple span gas concentrations ideal but one is better than none

- Lab-only devices (bronze standards) can be used but should be tested periodically with span

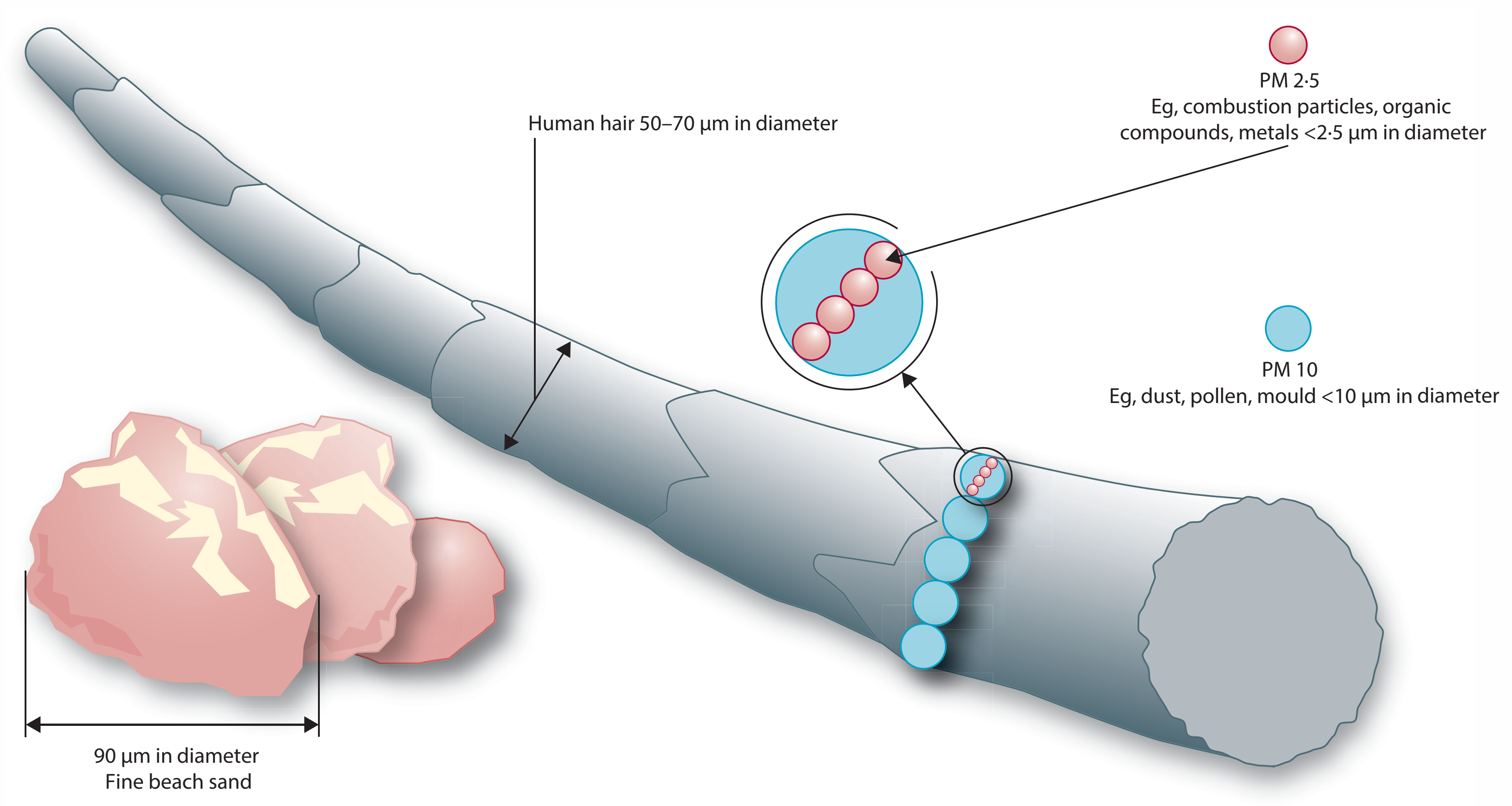
Simple testing chambers can be made from hardware store supplies

Calibration test results should be analyzed same-day and criteria for sensor replacement/instrument removal should be established.



Measuring Particulate Matter

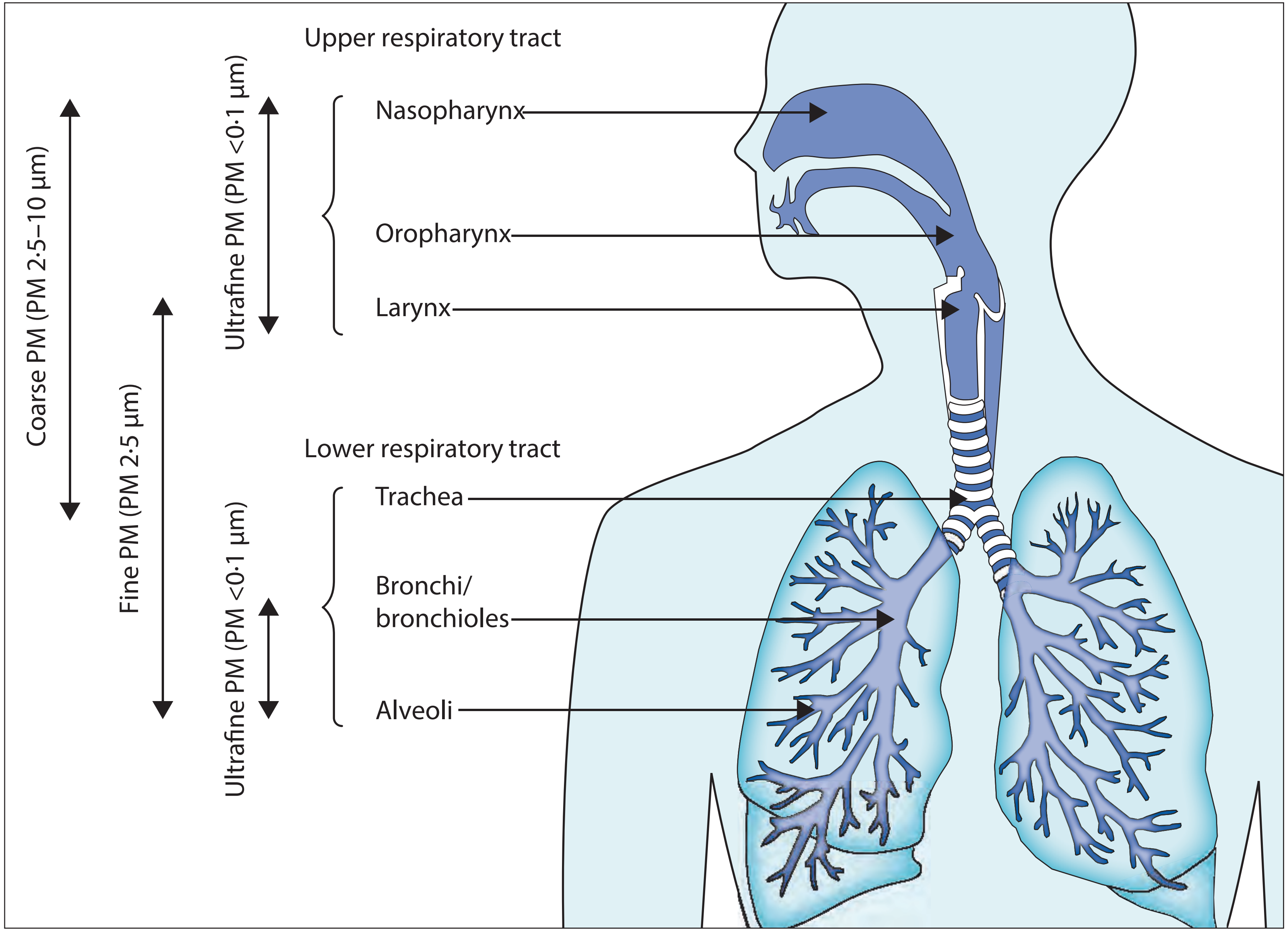
PM of primary concern from a health perspective



PM size is conventionally referred to by its aerodynamic diameter: the diameter of a sphere of water with the same aerodynamic properties as the particles in question

Adapted from Guarnieri et al 2014

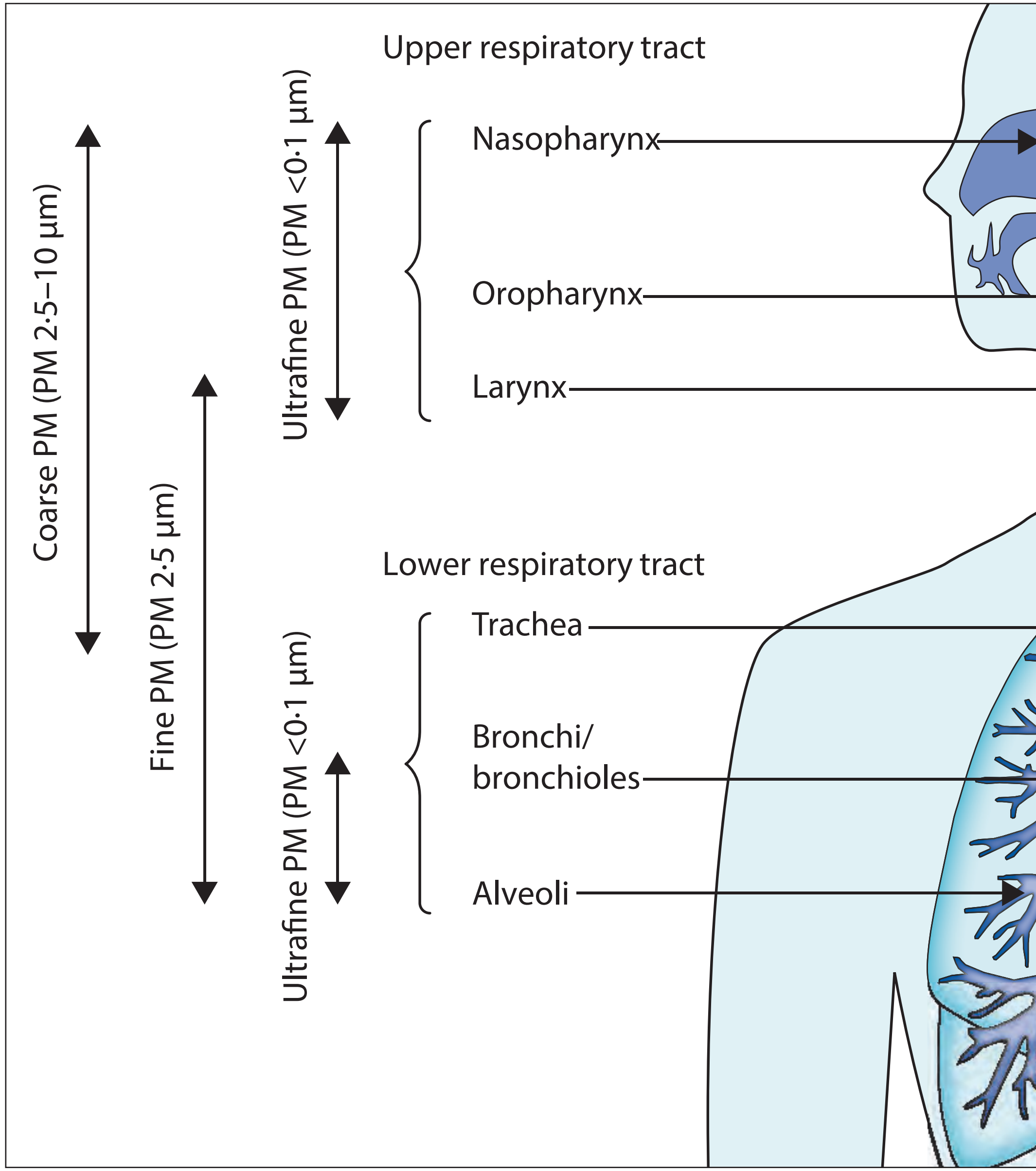
PM Size Conventions



Adapted from Guarnieri et al 2014

PM Size Conventions

Particle sampling devices and inlet-ports limit the particle sizes that are collected or measured in accordance with these cutoffs and/or distribution shapes.



Guarnieri et al 2014

Filter-based or gravimetric sampling

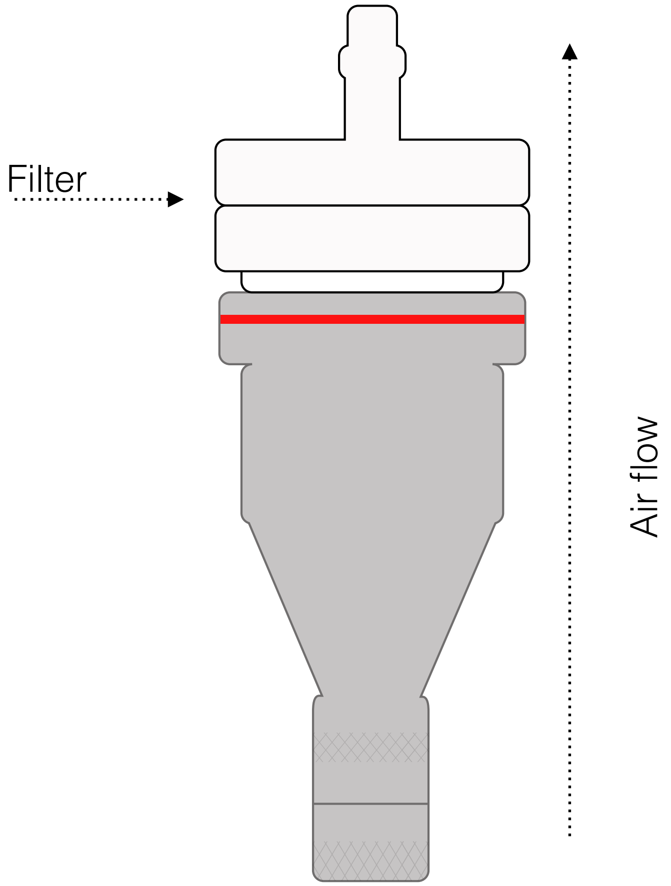
Gold-standard for PM sampling - Active, integrated

Basic Theory:

1) Air sample is passed through a filter using a pump, capturing or impacting particles onto the filter media, at a specific flow rate

2) Particle mass (ug) is measured using a microbalance and sampled air volume is calculated using measured flow rates.

Many filter media exist depending type of analysis (e.g. Teflon, PVC, Quartz, glass fiber, various coating combinations)

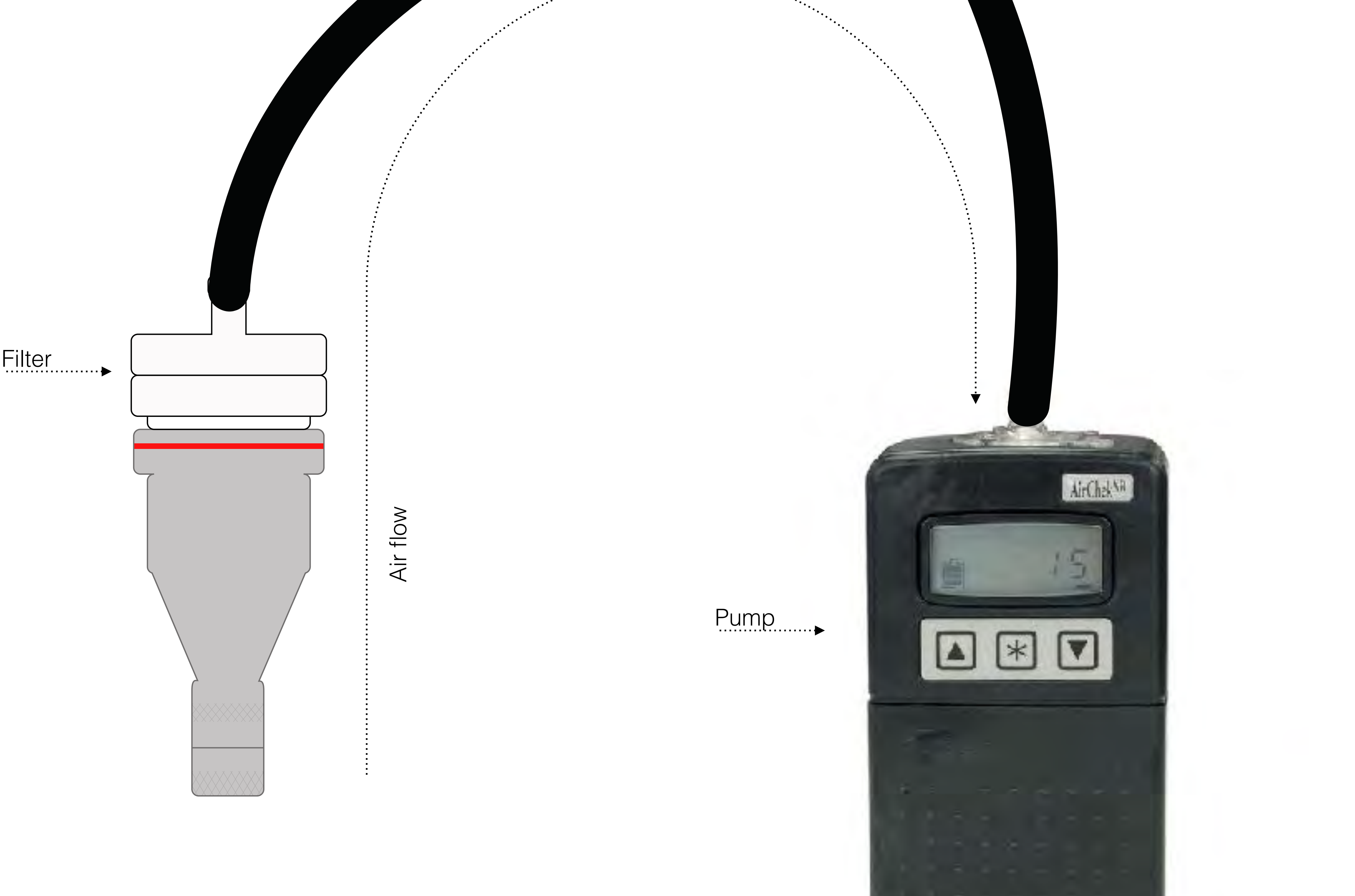


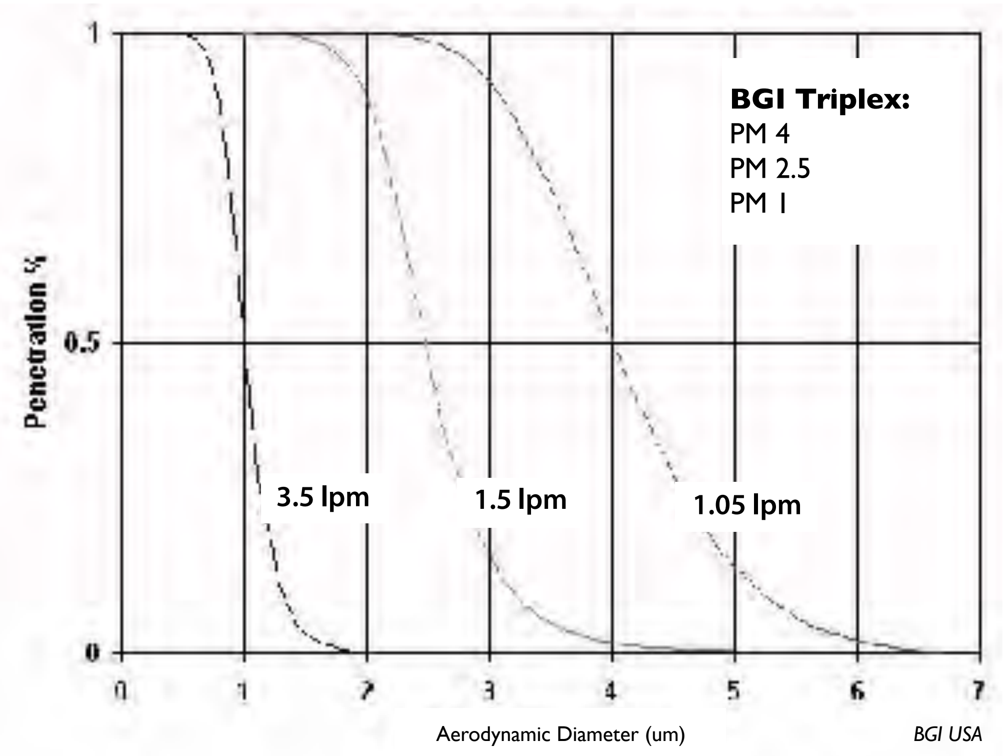
npling

filter using a
particles onto
w rate

using a
volume is
/ rates.

type of
glass fiber,



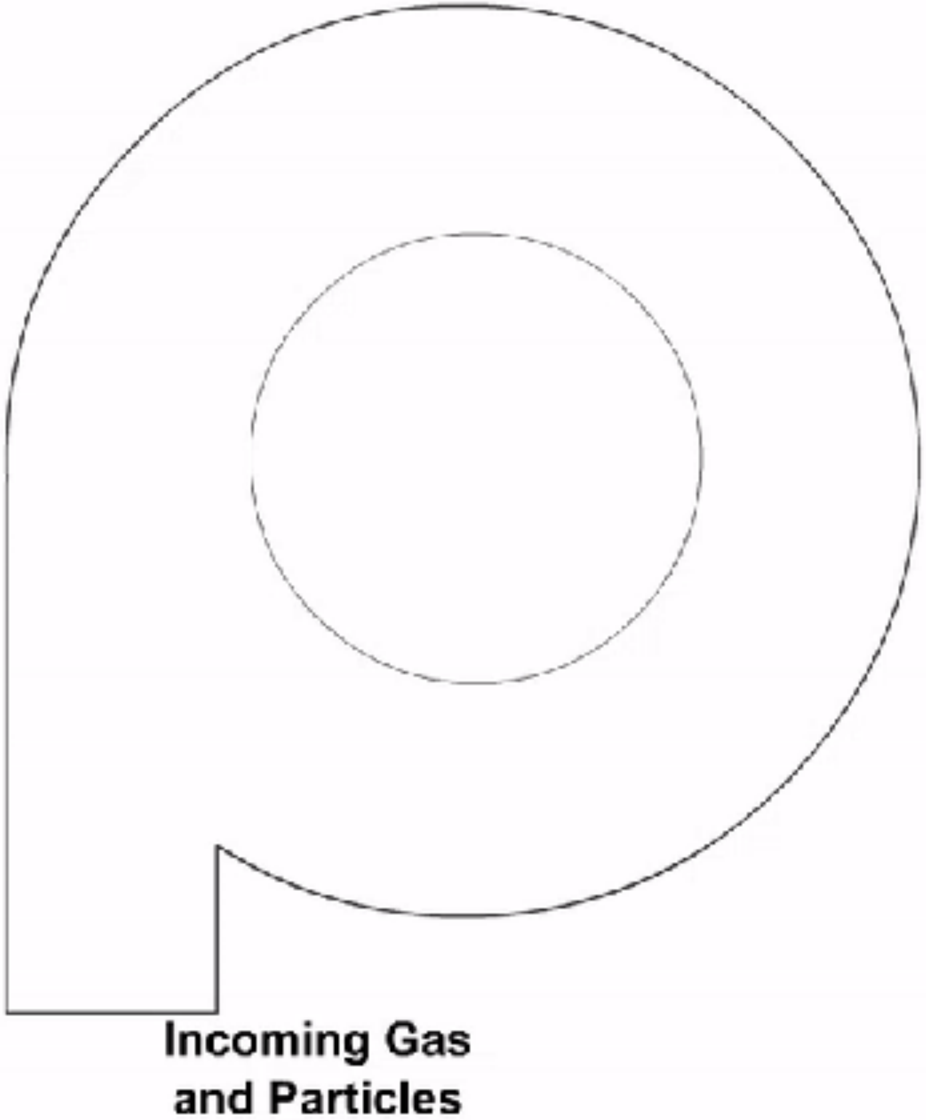


Gold Standard method for measuring PM mass concentrations. Flow rates correspond to specific size cutoffs or distributions (D50).

Manufactures should provide validation material the device (e.g. penetration curves)

Cyclones and Impactors select for particle sizes or distributions using particle dynamics in airstreams

Personal samplers often used as environmental samplers (size, flow rates, battery life)



http://aerosol.ees.ufl.edu/

Filter-based or gravimetric sampling

Active, integrated samplers

BGI Respirable /
Thoracic cyclone

SKC Personal
Exposure Monitor

SKC Cascade
Impactor

Filter-based or gravimetric sampling

New active, integrated samplers

UPAS

Weight of 1.5 iPhones
Quiet
~48h battery life
We'll use them soon!


61.50
9
26.55
43.95
26.55
52.93
43.65
52.93
101.60
Ø51.50
Ø8.20
128.15
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9.61
47.70
22.80


1
CORAL

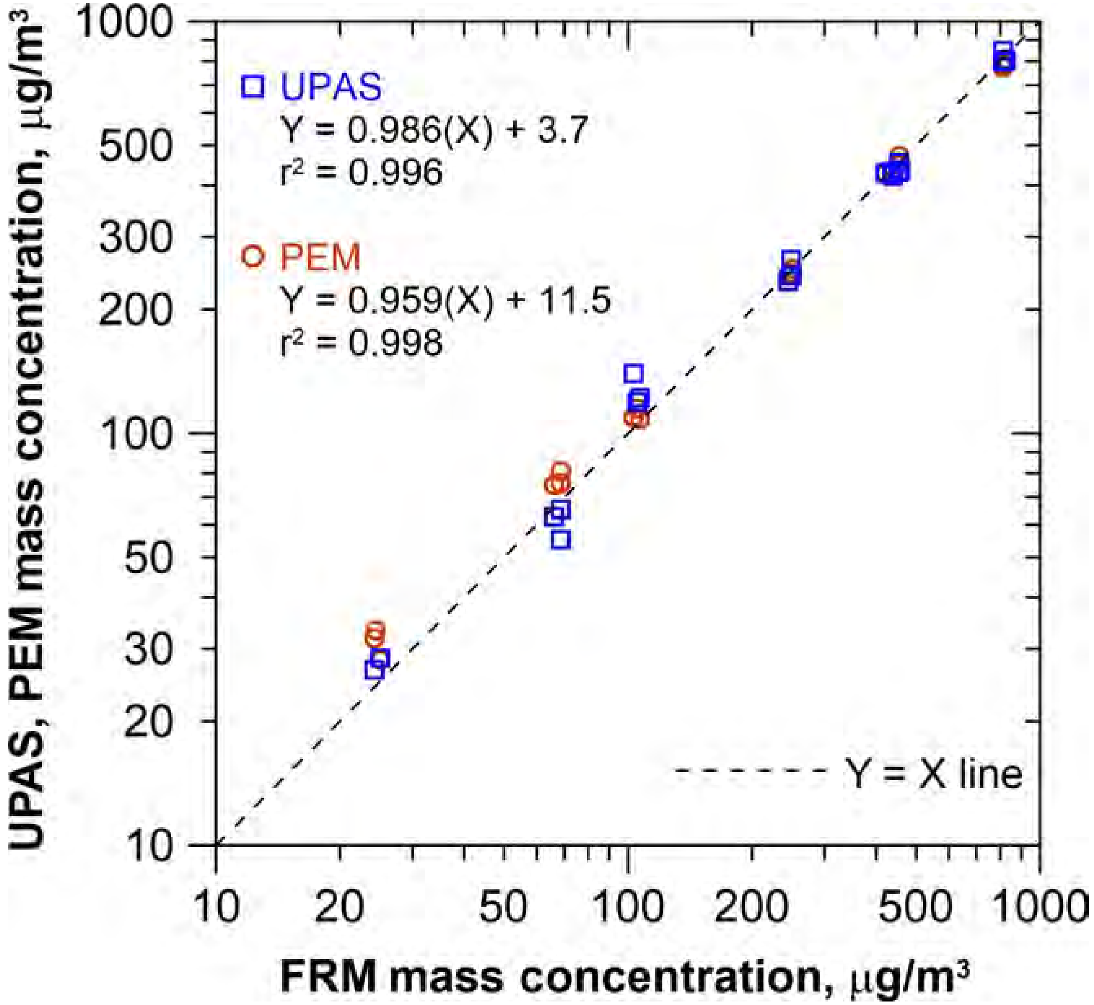


FIGURE 5 Performance of the ultrasonic personal aerosol sampler and a personal environmental monitor (PEM+XR5000 Pump, 2.0 L/min) relative to an EPA federal reference method (FRM) sampler for $PM_{2.5}$ mass

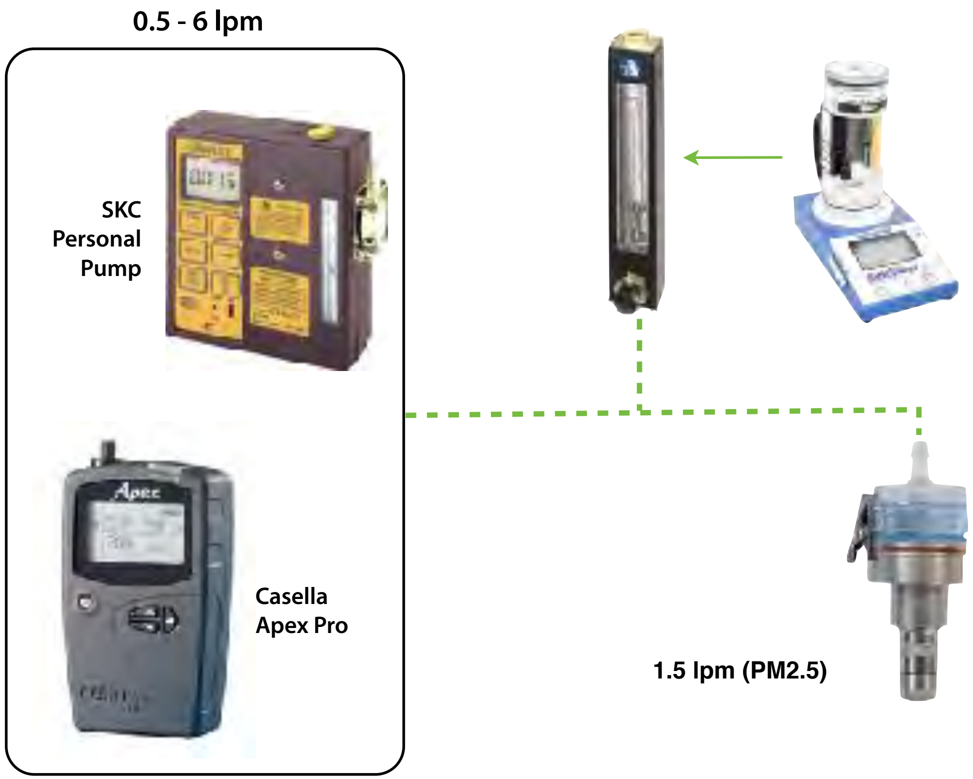
Volckens et al 2016

Filter-based or gravimetric sampling

Active, integrated and real-time sampler

Filter-based or gravimetric sampling

Active, integrated samplers - Workflow



Pump
Pulls air through cyclone and collects specific PM on the filter

Cyclone
Mechanically selects for PM smaller than a specific diameter cutpoint

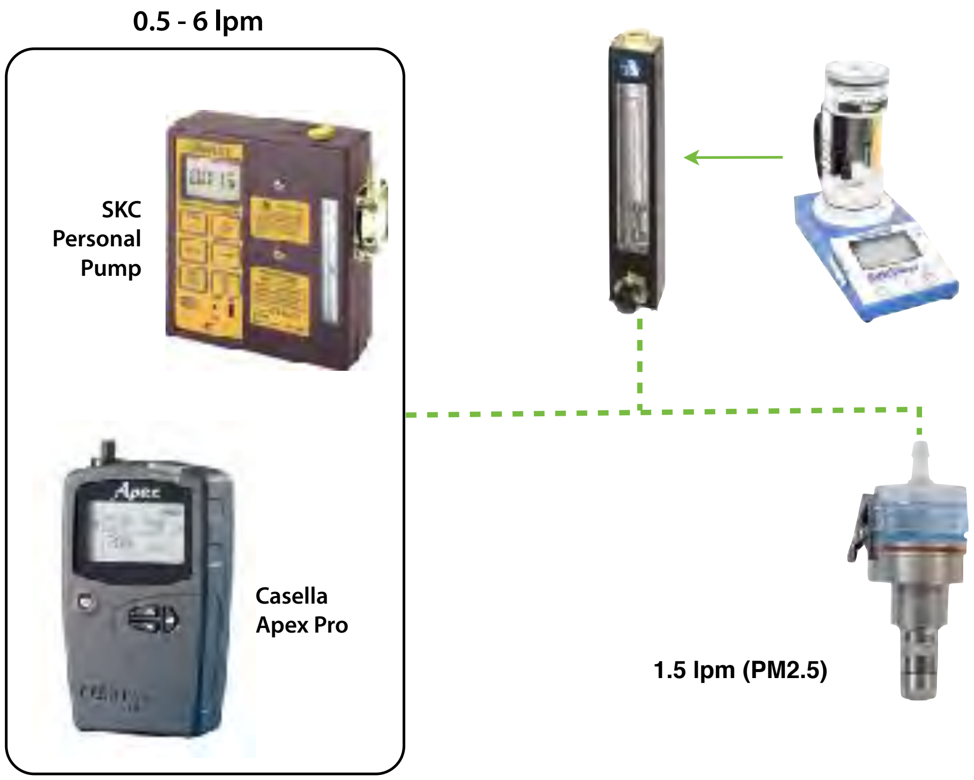
Filter
Captures pollution from the air sample

Primary Flow Calibrator
Gold-standard measure of flow rate used to directly calibrate pumps, or to calibrate non-primary-std. flow meters

Rotameter
Measures flow rate of pump; allows us to quantify and adjust flow through the cyclone and filter in the field

Filter-based or gravimetric sampling

Active, integrated samplers - Workflow



Filters and holders ($5-10 + labor), sampler ($350+), tubing (<$20), pump ($500+)

Flow calibration ($100s - 1000+)

Selecting Pumps - Battery life, flow rate requirements, and noise.

Flow compensation for consistent flow rate as filter loads and creates increasing resistance

Filter-based or gravimetric sampling

Workflow - Step by Step

PREPARATION

Equilibrate
Pre-Weigh
Prepare Cassettes

↓

Pre Mass (ug)
Sample + Blanks

SAMPLING

Leak Check Cassette
Pre/Post Flow rates
Sample Duration
Field Blanks
Transport

↓

Sample Volume (m3)
\+ Duration (hrs, days)

POST WEIGHING

Equilibrate
Post-Weigh

↓

Post Mass (ug)
Sample + Blanks

CALCULATIONS

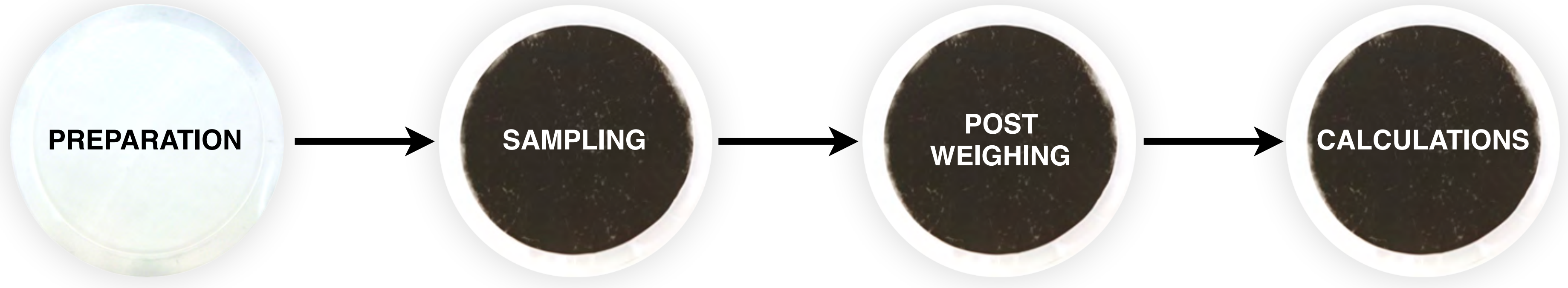
Adjust for blanks

$$C_{twa} = \frac{Post - Pre \pm Blank}{Volume}$$

↓

Mass
Concentration
(ug/m3)

A delicate process



Filter handling requires care and a well-maintained room with a microbalance.

Flow rates are **extremely** critical: they allow you to calculate the volume of air that passed through the filter AND they determine the size distribution of particles collected on your filter.

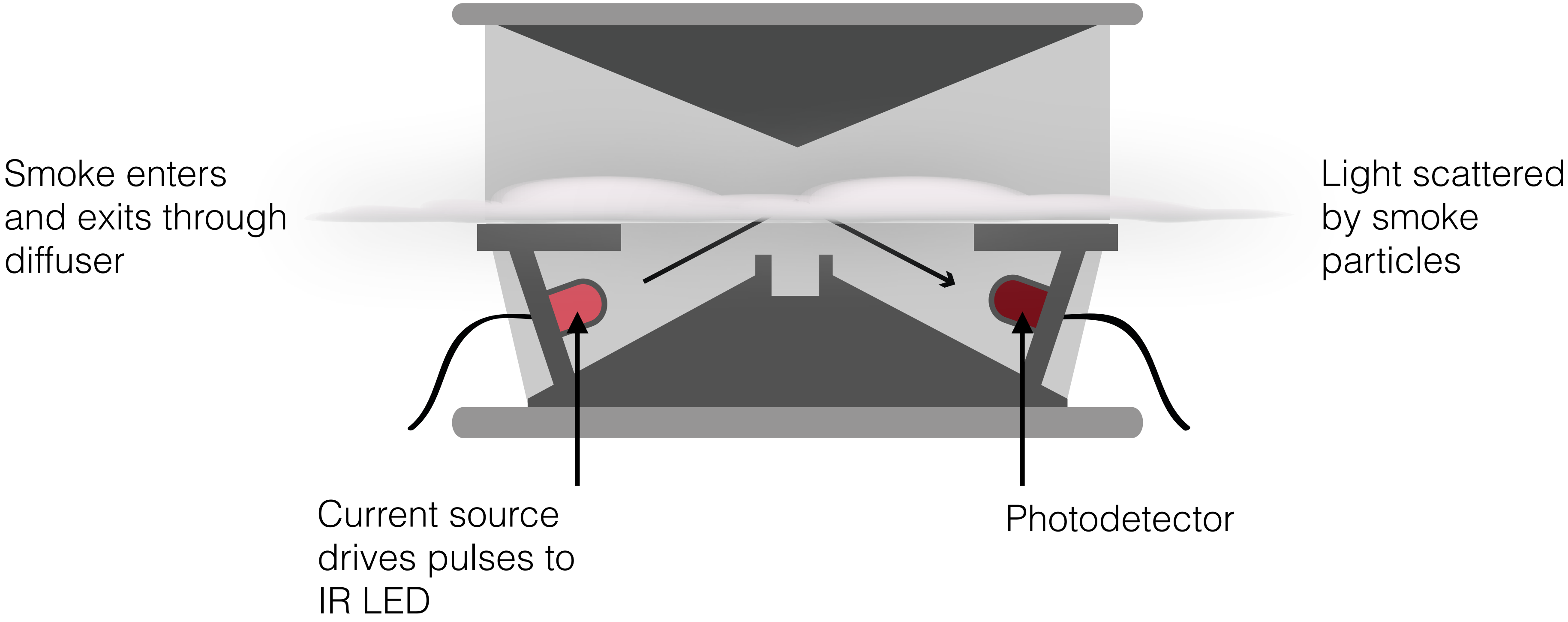
Blanks + duplicates

At minimum, 10% of total samples duplicated

10% of total samples as blanks (lab, field, travel)

Light Scattering Devices

UCB Particle Monitor



Light scattering is not a direct measure of mass concentration but can be related.

The relationship between scattering and mass concentration is affected by the aerosol and environmental conditions.

To obtain accurate mass conc. light scattering devices must be calibrated or co-located using filters, using the aerosol of interest, under field conditions.

Active, direct-reading instruments

Many on the market!

TSI DustTrak
(~$8500)

TSI SidePak
(~$5000)

Thermo PDR
w/ cyclone
(~$4000)

Aprovecho
IAP Meter
(~$3000)

RTI
MicroPEM
(~$3000)

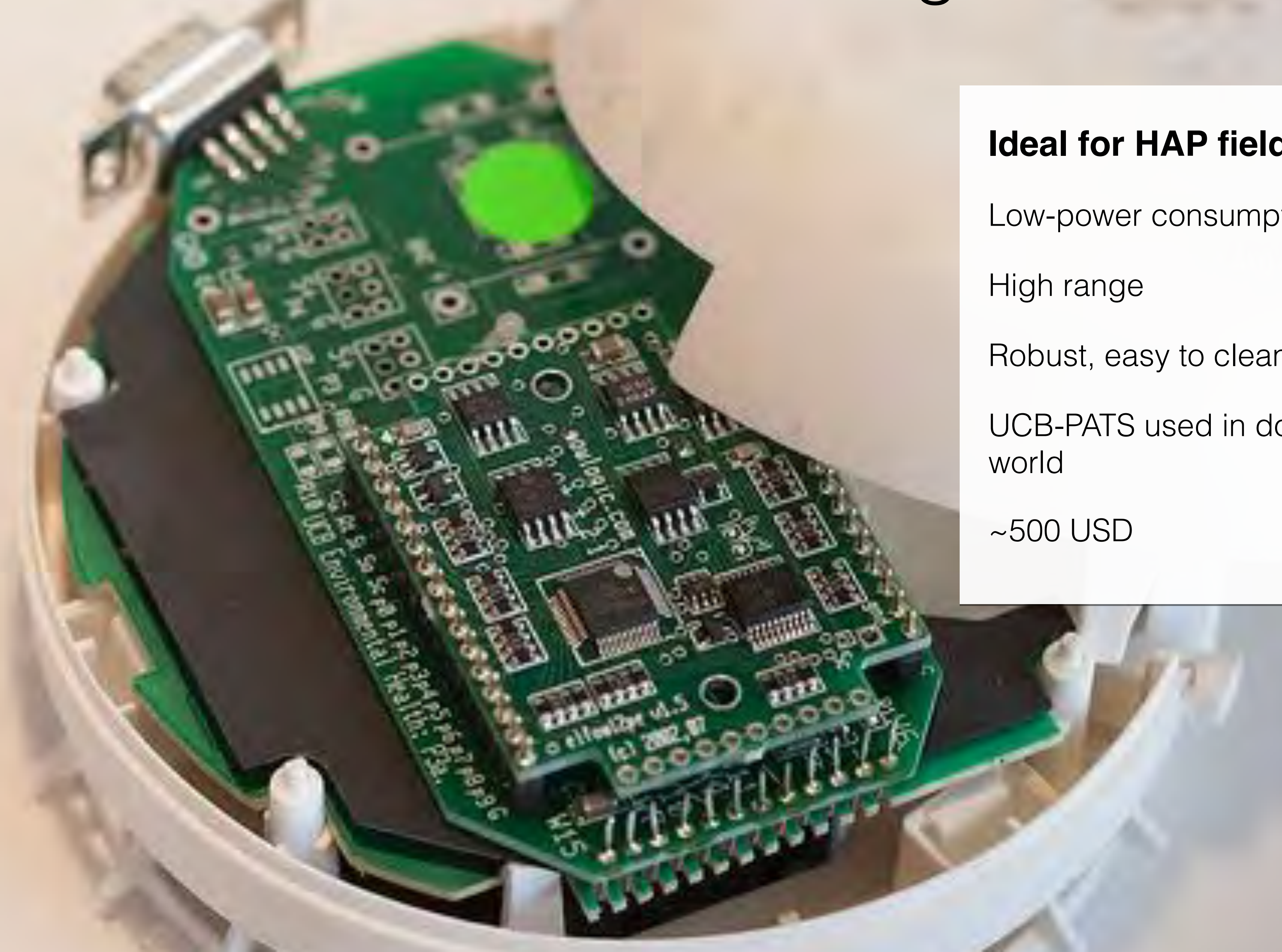
Devices vary by measurement range, size, cost, sensitivity, validation

Measure light scattering, not mass. Must be compared against filter-based measurements.

Aerosol mixtures pose adjustment challenges

Selection Considerations:
- Range of levels expected
- Duration of sampling (battery)
- Budget

Passive, direct-reading instruments



Ideal for HAP field studies

Low-power consumption

High range

Robust, easy to clean and service

UCB-PATS used in dozens of studies around the world

~500 USD

Passive, direct-reading instruments

PATS+

Wide dynamic range
10µg/m3 to 50mg/m3

Modern microelectronics
USB, SD card

Long-battery life - ~48h as pictured; 72+h
with new design

We'll use with them soon!


Berkeley Air
Monitoring Group
Pats+co
Battery
PM Sensor
CO Sensor

HAPEx Nano

Passive real time PM datalogger for exposure measurement

Main Features:

- Compact and light weight (100 gram, 5cm*7.5cm*2.5cm)
- very easy to use
- affordable: US$ 119 for bulk purchase
- very sturdy: one year world wide guarantee
- long run time: up to 2 years

Technical Specifications:

- measurement range: 10 $\mu g/m^3$ to 150 mg/m^3
- accelerometer for compliance assessment
- maximum number of log recorded: 11,712
- sampling rate: 20 seconds (2 seconds in calibration mode)
- log rate: 20 seconds to 1 hours

More at: http://www.climate-solutions.net/products/product/1-hapex-nano

All light-scattering, direct reading instruments must be calibrated
against the aerosol of interest

Adjust the response on the monitor

or

Ex post facto apply a 'calibration factor'

Particle Calibrations

Once in the lab, at least once in the field

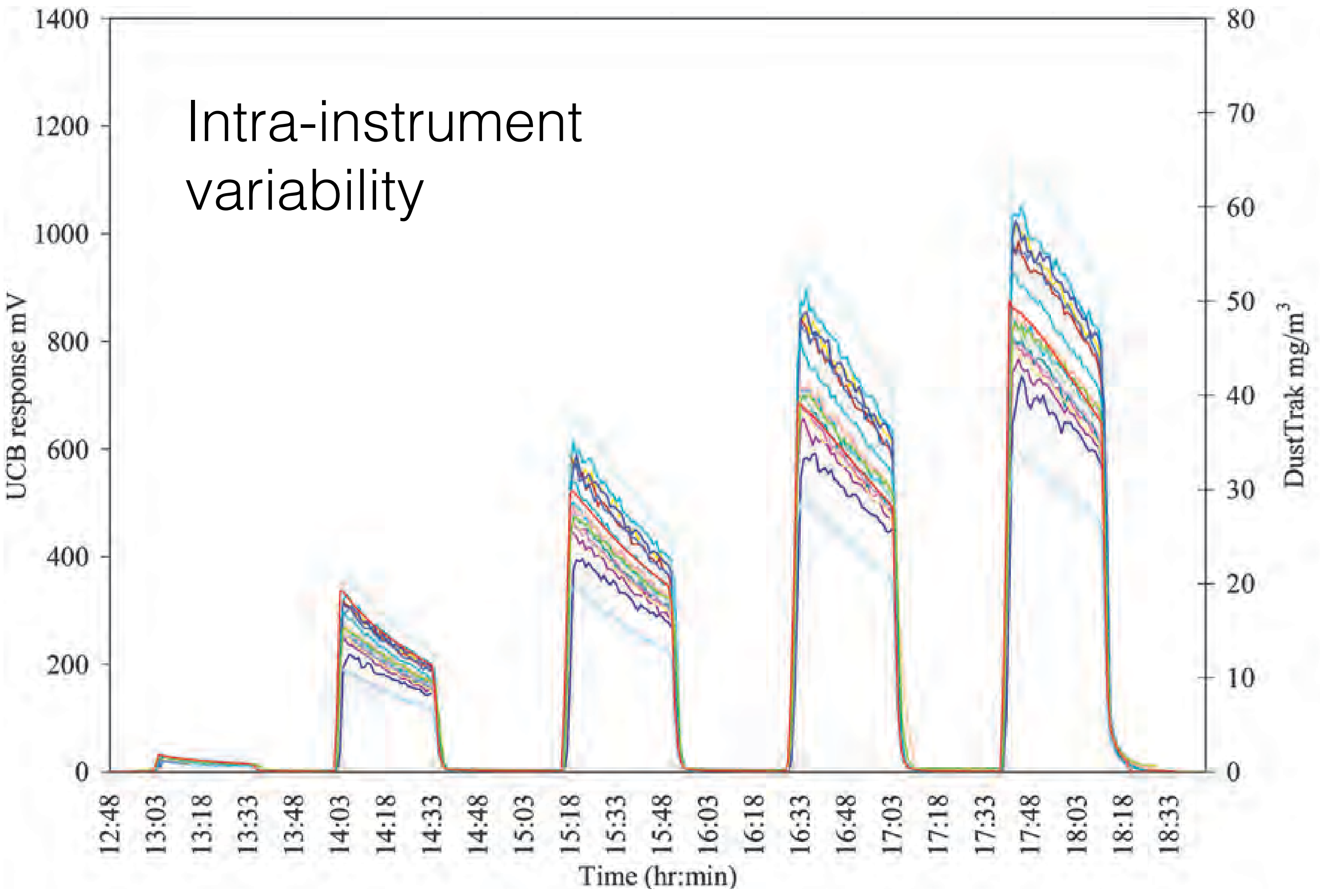
Light scattering devices should be calibrated against filter-based samples or filter-calibrated instruments.

Ideally, tests in lab first with aerosol of interest, then in-field co-locations to account for differences in aerosol mixtures.

Does not require complex chamber but is a critical step since intra-instrument variability combined with response can be a major source of error!

Particle Calibrations

Once in the lab, at least once in the field



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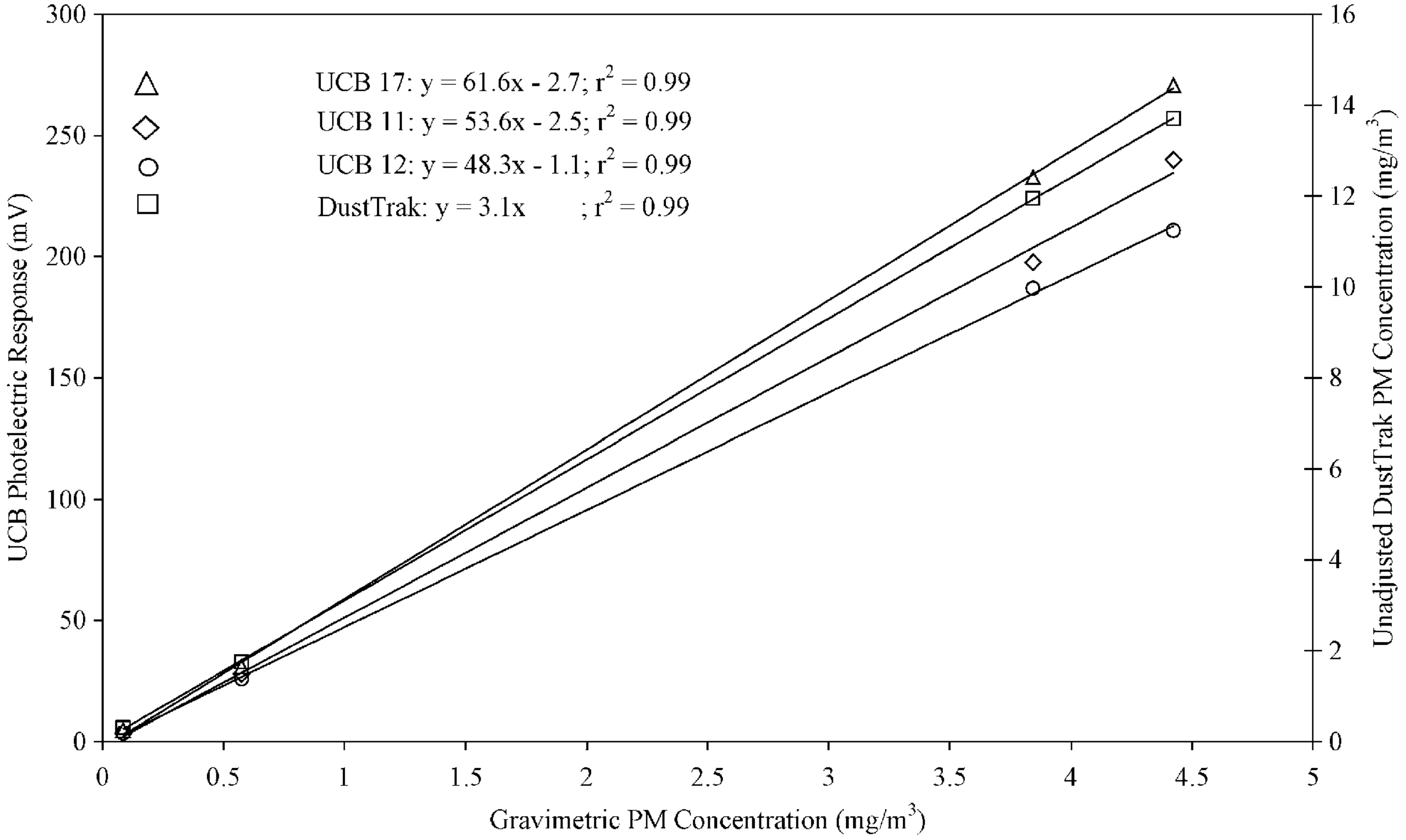

Particle Calibrations

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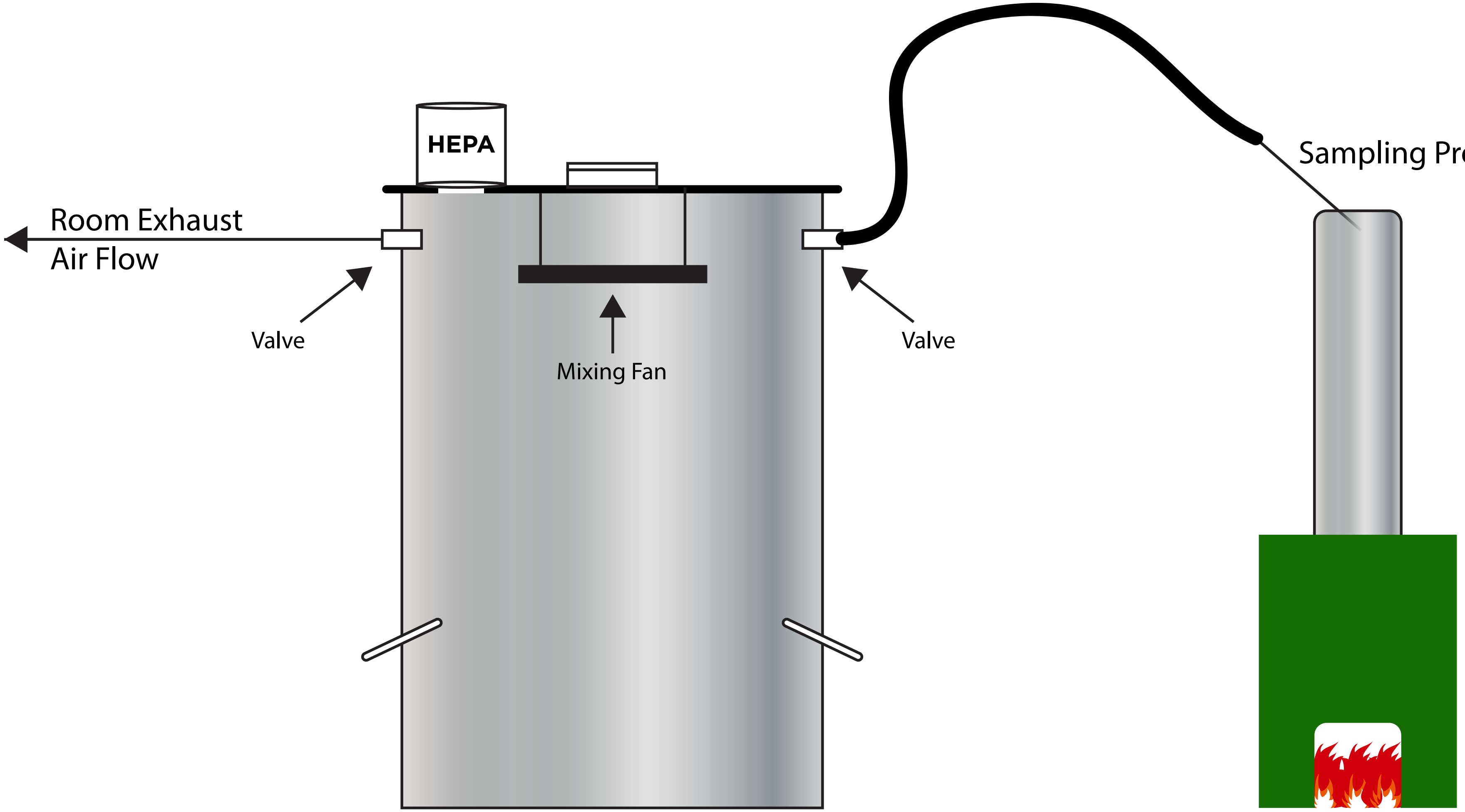

Why calibrate in the field?

PM size fraction (μm)	Open Fire		Patsari		Difference in β_1
	β_1 (mg m^{-3} per mv)	r^2	β_1 (mg m^{-3} per mv)	r^2	
TSP	0.037	0.69	0.066	0.63	**78%**
$PM_{2.5}$	0.035	0.70	0.055	0.67	**57%**

Field-based conversion factors calculated for Open Fire and Patsari stoves differed significantly

Using the Open Fire conversion factor for the Patsari would have resulted in **an underestimation of the PM concentration by ~57%.**

Fuel and stove type can influence light scattering response

In-field co-location with filter-based samples on subsample must be used for most accurate data.

Beta Attenuation Monitors

Tape advances at a set interval

Beta counts made before and after sampling on the tape

Relationship between beta attenuation and amount of mass on filter

Semi-continuous (reads 'clean' tape for ~2 minutes, samples air pollution for 8-9 minutes)

Federal equivalent method

Tapered element oscillating microbalance (TEOM)

Air is pulled into the device at fairly high flow rates (16.7 LPM)

The "tapered element" consists of a filter cartridge mounted on the tip of a hollow glass tube. The base of the tube cannot move, but the tip is free to vibrate at its natural frequency.

Particles that collect on the filter change its frequency. The electronic circuitry senses this change and calculates the particle mass from the magnitude of the frequency change.

Dividing the mass rate by the flow rate provides a continuous output of the particle mass concentration.

Ultrafine Particle Measurement

Very few field ready options available and none are capable of monitoring unattended for long durations (e.g. 24-48hrs)

Report count concentration (not size-resolved for field-ready devices)

Representative challenges - PM sizes may change depending on location in room, time in room

Upper limit of detection can be a concern in many household scenarios.

Measuring Particle Properties

MicroAeth

Sunset Labs OC-EC Analyzer

Quartz Fiber Filters

Growing interest in exposure to black carbon (BC) - (5-30% of PM by mass)

BC and elemental carbon (EC) often used interchangeably, although they differ in the method by which they are measured

Interpretation is a challenge for either method

Given field limitations, EC sampling which uses prepared quartz fiber filters would be the only real option (~24hr)

Personal Sampling: Considering costs

Various devices used to monitor micro-environmental concentrations can be adapted to monitor personal exposure

	Inexpensive	Moderate	Expensive
Particulate Matter	Low Cost Light Scattering	Filter-Based	Sensitive Light Scattering; Combined with Filters
Gas	Indicator Badges	Passive Diffusion Tubes and Badges; Electrochemical	Adsorbent Tubes; Electrochemical

Integrated and non-reusable devices (e.g. passive diffusion tubes) can quickly become expensive, however, if large number of samples are needed. Can also be difficult to analyze.

Colorimetric Badges (~$5-10ea)

Passive Diffusion Tube (~$10ea)

Lascar CO (~$100)

Really Inexpensive, inconspicuous, light-weight, no alarms, sensitivity issues

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Industrial Scientific GasBadge Pro (~$375)

Drager Pac 7000 (~$450)

Inexpensive (1ppm resolution), light-weight, concealable, alarms can be dealt with

---

Langan CO T15n ($1500)

Passive Badge Sampler (~$40 + Processing)

Most sensitive but expensive or flexible

Available for various gases

UCB PATS ($500)

PATS+ ($ TBD)

Direct Reading Low Cost

Pump and Filter
~$1200 full setup +
$10/filter

Integrated

TSI SidePak
(~$5000)

Thermo PDR w/ cyclone
(~$4000)

RTI MicroPem
(~$2000)

Direct Reading Sensitive & Integrated