Aerosol Research for Industrial Hygiene

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SEARCHING...

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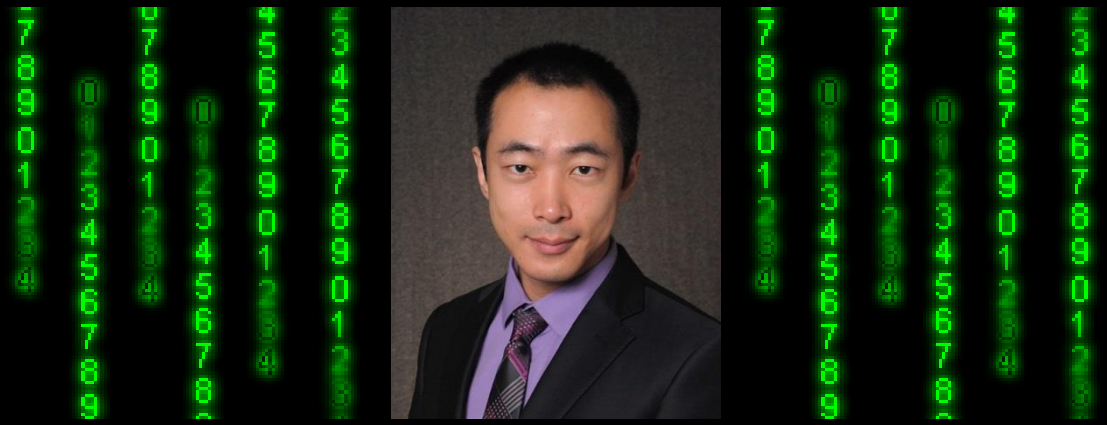


- Jae Hong Park, Ph.D., C.I.H.
- Assistant Professor of Health Sciences at Purdue University
- Born in Seoul, South Korea
- Industrial Hygienist, Aerosol Scientist, Mechanical Engineer
- Teaching
  - HSCI 346 IH Engineering Control
  - HSCI 348 IH Instrumentation Techniques
  - HSCI 552 Introduction to Aerosol Science

My background

1999 - 2003

B.S.
Mechanical Engineering

2003 - 2005

M.S.
Mechanical Engineering

2005 - 2010

Ph.D.
Mechanical Engineering

2010 - 2011

Postdoc.
Mechanical Engineering

2011 - 2016

Postdoc. and Research Associate
Department of Occupational and Environmental Health

2016 - Present

Assistant Professor
School of Occupational and Environmental Health Sciences

Contents

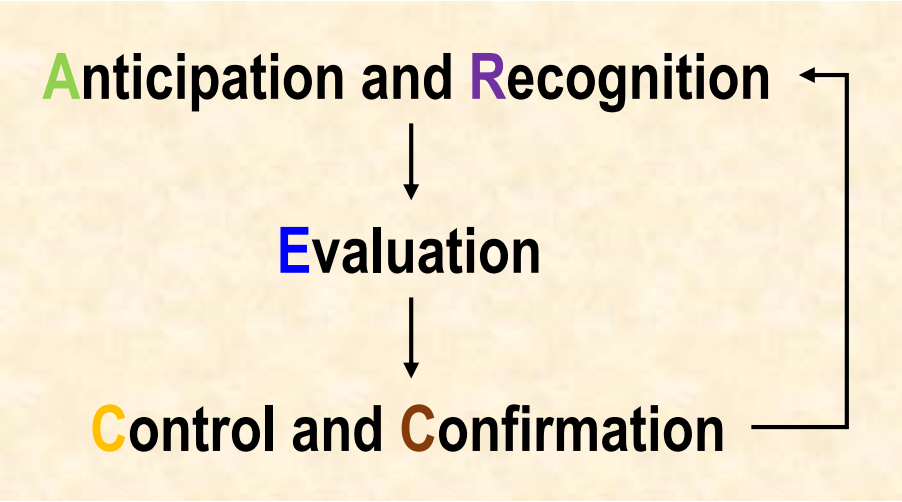
- **Introduction**

- **Aerosol research for IH**
  - Development of personal personal nanoparticle respiratory deposition (NRD) sampler
    Application in IH study – Welding fume sampling

- **Summary**

Industrial hygiene

- Also called Occupational Hygiene, Occupational Health, or Workplace Health
- Science dedicated to the anticipation, recognition, evaluation, control, and confirmation of environmental stressors in the workplace that may result in injury, illness, impairment, or otherwise affect the wellbeing of workers and community members

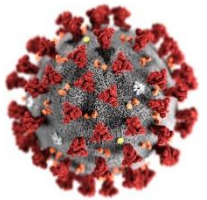


Stressors in the workplace

- **Chemical agents**
  - Example: asbestos in schools, pesticides in food, organic solvents in the workplace, lead in toys, aerosols, etc.

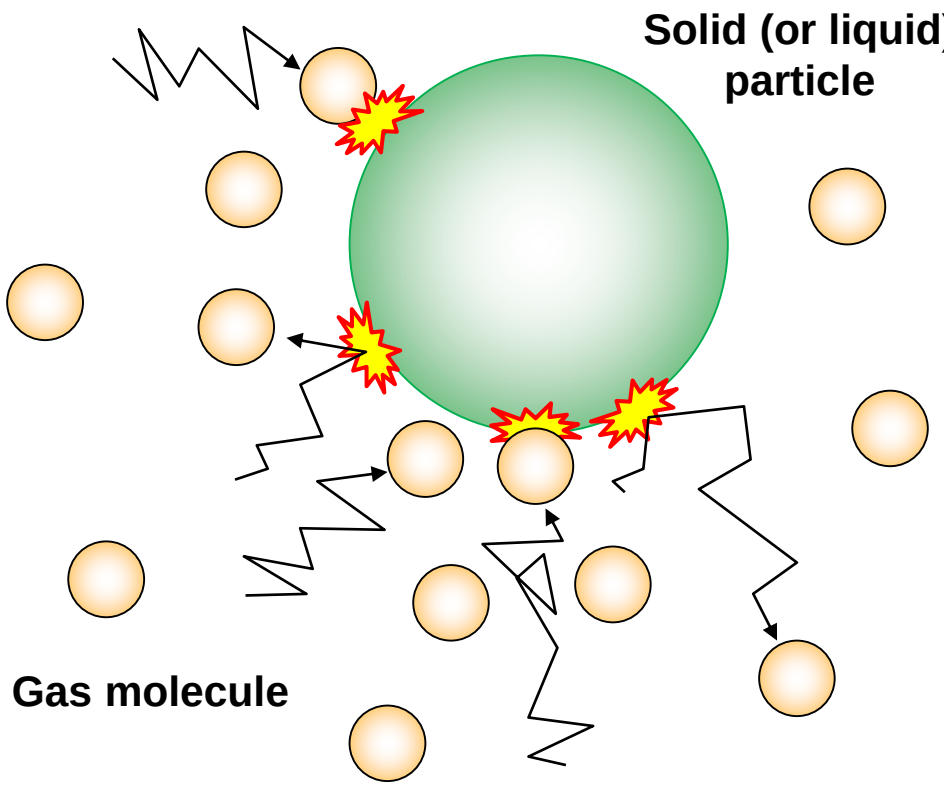
- **Physical agents**
  - Example: X-rays, noise, heat, etc.

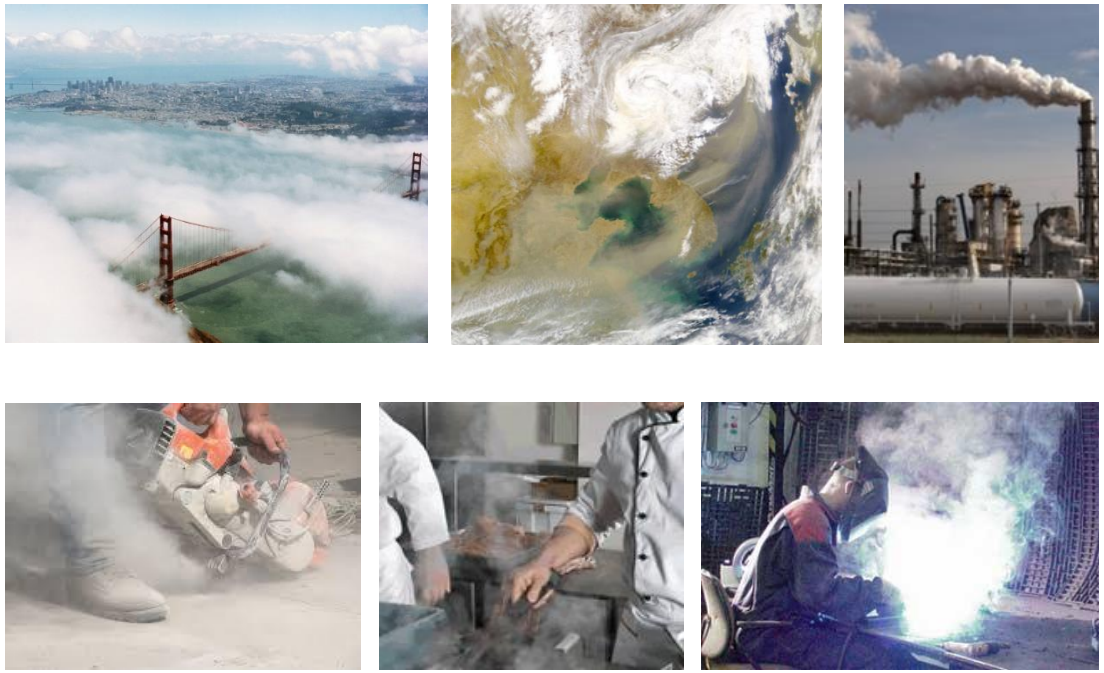
- **Biological agents**
  - Example: mold in damp offices, *E. coli* in water, blood borne pathogens, SARS-CoV-19, bioaerosols, etc.



Aerosol?

- **Definition: solid or liquid particles suspended in a gas**

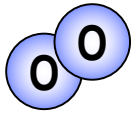




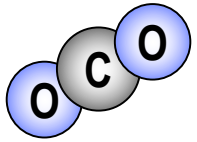
How small they are?

Aerosols size

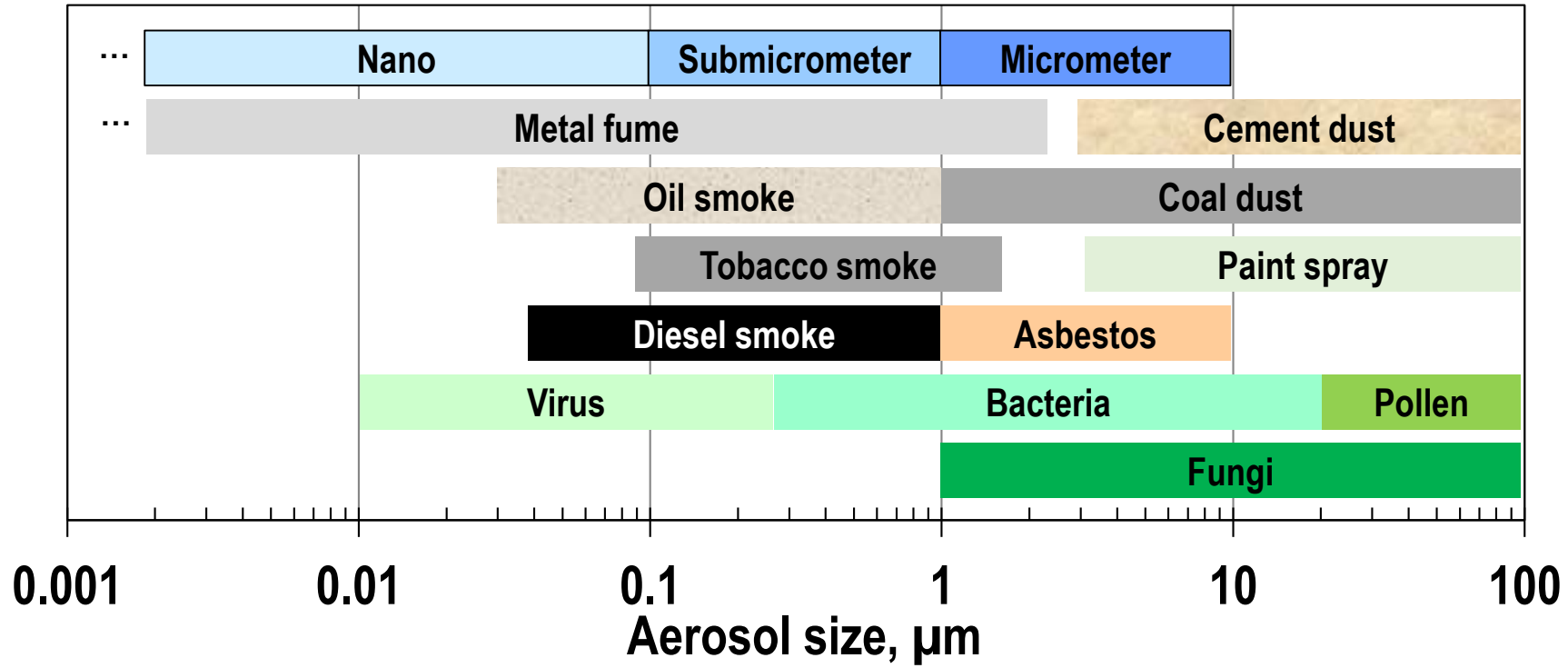
Gas molecules

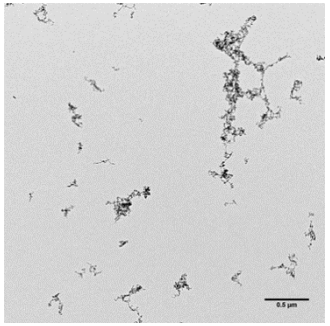


O_2: 0.0005 µm

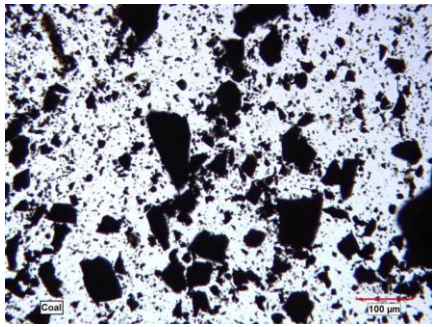


CO_2: 0.00065 µm

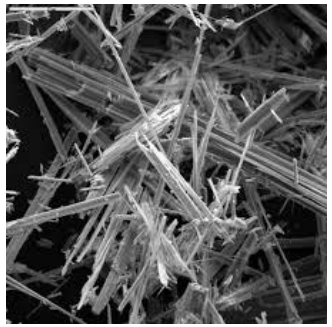




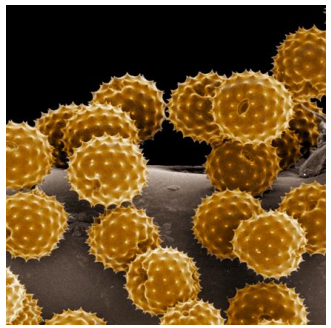
Welding fume



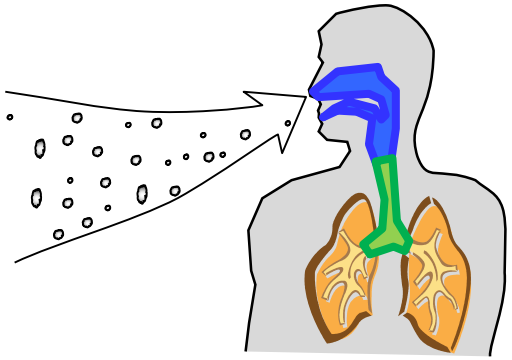
Coal dust



Asbestos



Pollen



Definitions of aerosols

- **Occupational**
  - Inhalable particles
    - Enter the nose and mouth during breathing and are deposited anywhere in the respiratory tract.
    - Inhalable size ≤100 μm
  - Thoracic particles
    - Pass the larynx and penetrate into the conducting airways (trachea, bifurcations) and the bronchial region of the lung.
    - 50% penetration at the size of 10 μm
  - Respirable particles
    - Penetrate to the deep lung where gas exchange takes place.
    - Respirable size ≤ 10 μm but having 50% penetration at the size of 4 μm

- **Environmental**
  - Particulate matter (PM)
  - PM10: Aerodynamic diameter ≤ 10 μm
  - PM2.5 (fine particles): Aerodynamic diameter ≤ 2.5 μm
  - PM0.1 (ultrafine particles): Aerodynamic diameter ≤ 0.1 μm
  - Nanoparticles: Size (at least one dimension) smaller than 100 nm

2.5 μm < coarse particles ≤ 10 μm

Occupational and environmental exposure limits

➢ Occupational Safety and Health Administration

- Permissible Exposure Limit (PEL) for respirable dust: 5000 µg/m^3 (TWA)

➢ U.S. Environmental Protection Agency

- National Ambient Air Quality Standards (NAAQS) for PM

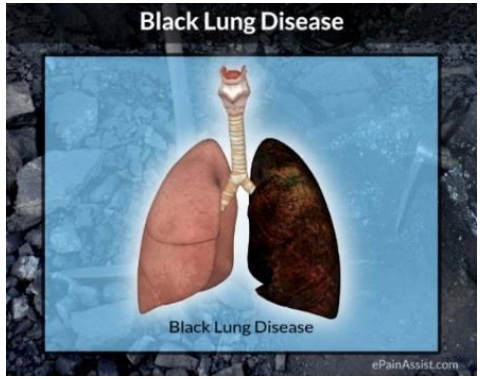
Primary/ Secondary	Indicator	Averaging Time	Level	Form
Primary	$PM_{2.5}$	Annual	12.0 µg/m^3	• Annual arithmetic mean, averaged over 3 years
Secondary		Annual	15.0 µg/m^3	• Annual arithmetic mean, averaged over 3 years
Primary and Secondary		24-hour	35 µg/m^3	• 98th percentile, averaged over 3 years
Primary and Secondary	PM_{10}	24-hour	150 µg/m^3	• Not to be exceeded more than once per year on average over a 3-year period

Primary standards provide public health protection, including protecting the health of "sensitive" populations such as asthmatics, children, and the elderly.
Secondary standards provide public welfare protection, including protection against decreased visibility and damage to animals, crops, vegetation, and buildings.

Environmental and occupational aerosols

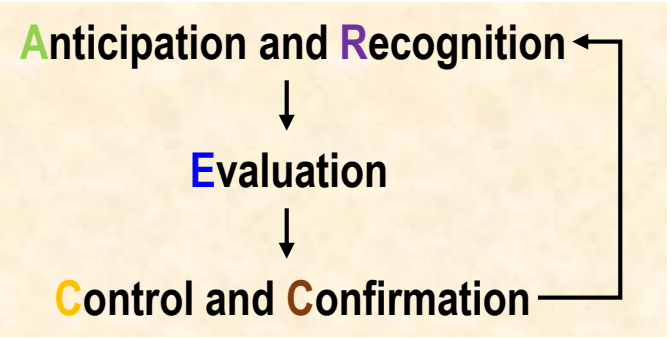
- **Workers are often exposed to high concentrations of aerosols.**
  - Sources of aerosols are close to workers.

- **Aerosols deposited in the respiratory tract can dissolve and/or translocate from the lungs, reach the bloodstream, and pass to other organs.**
  - Occupational exposures to aerosols are associated with a variety of adverse cardiopulmonary health effects such as asthma, pneumoconiosis, silicosis, cardiovascular disease, etc.



How to protect workers against aerosols?

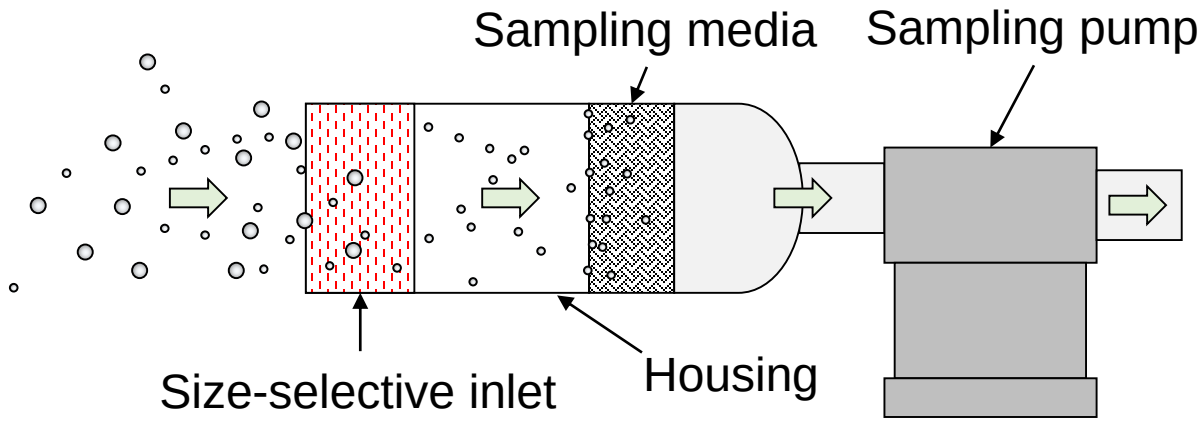
- **First step, "evaluation"**
  - Evaluate the exposure to aerosols
  - How much in the workplace?
  - Is it a problem? (compare the results to exposure limit)



- **Air sampling**
  - Collect aerosols on a filter using a **sampler**
  - Analyze samples using the standard methods
    - Gravimetric analysis to know the mass sampled
    - Inductive coupled plasma to analyze metal contents
  - Standard method to assess the exposure
    - E.g., National Institute for Occupational Safety & Health (NIOSH) 0600

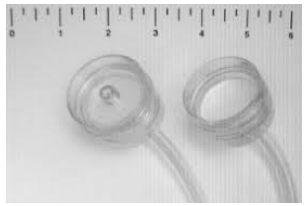
Aerosol samplers

- **Samplers generally consist of :**
  - Size-selected inlet to remove particles having unwanted sizes (e.g., cyclones and impactors)
  - Housing (cassette) to hold the sampling media
  - Media to collect aerosols (e.g., air filters)
  - Pump to pull the air through the size-selective inlet and sampling media

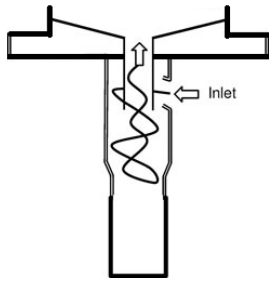


Size-selective inlets

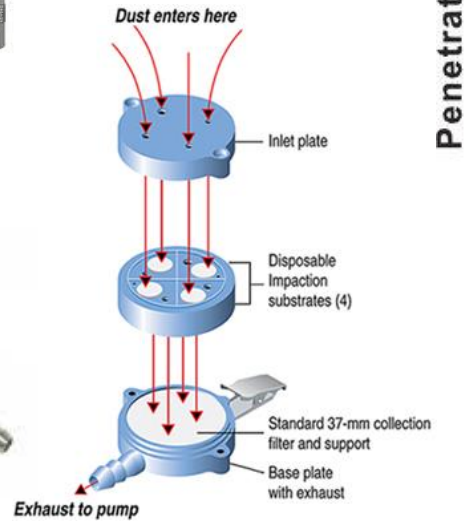
➢ Open or closed face cassette



➢ Cyclones

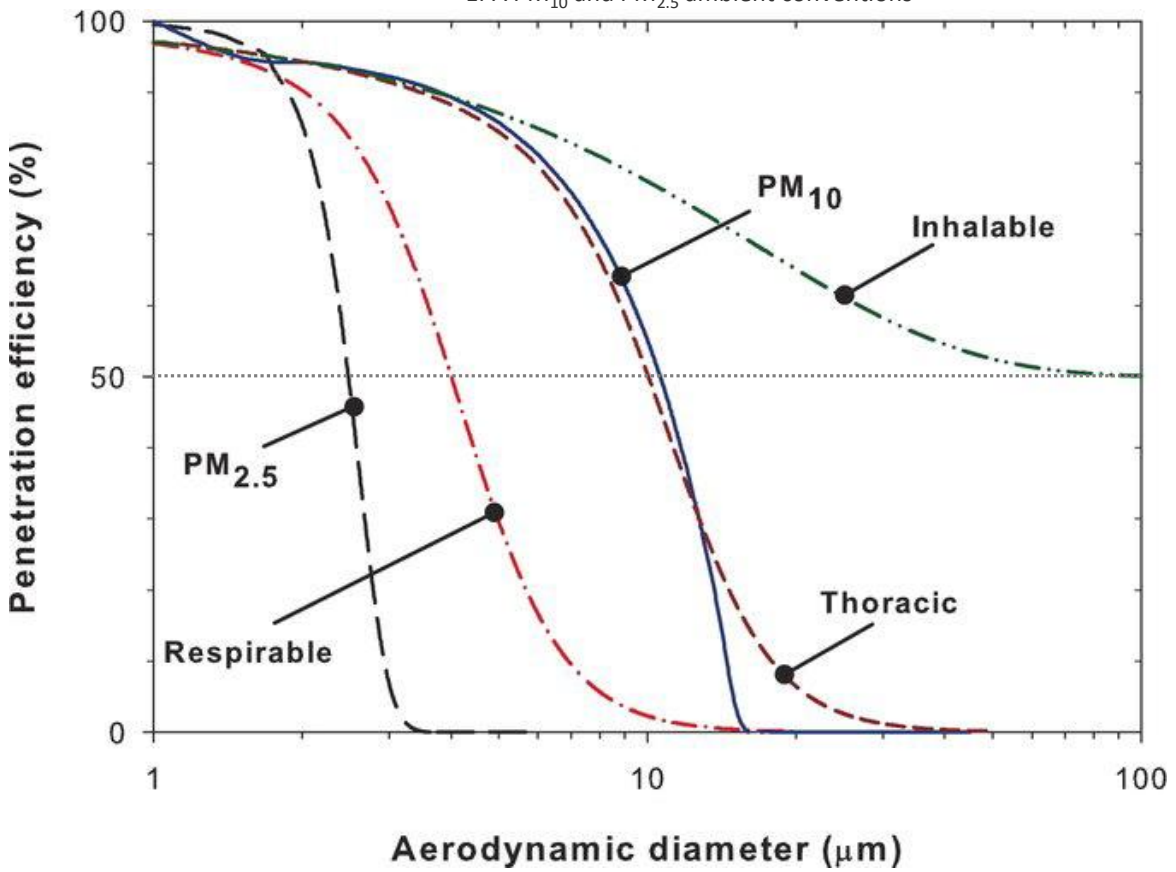


➢ Impactors



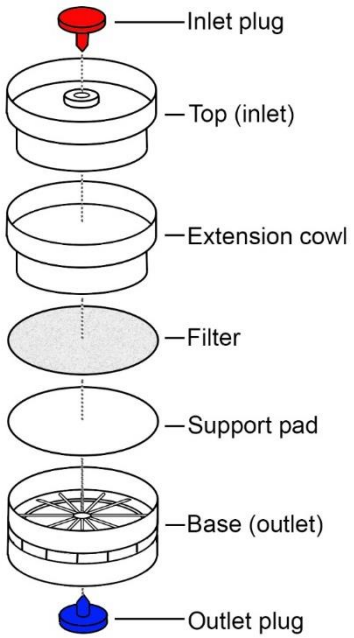
➢ Sampling conventions

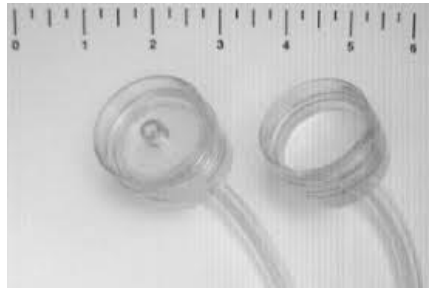
International workplace sampling conventions [ISO 1995]
EPA PM_{10} and $PM_{2.5}$ ambient conventions

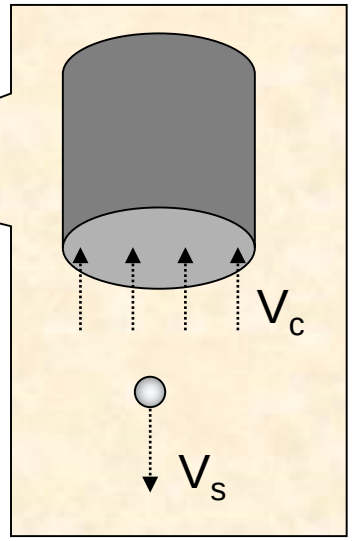


Filter cassettes

- **Holding filter media**
- **Size-selective inlet can be attached.**
- **Either open or closed face cassette can sample total suspended dust.**
  - Consider the capturing velocity (V_c) and particle settling velocity (V_s)

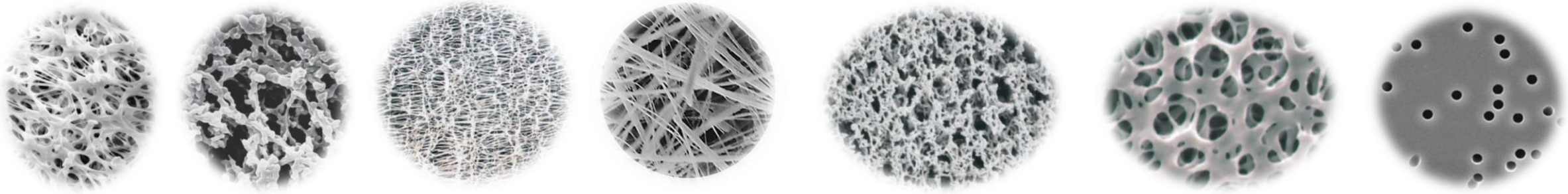






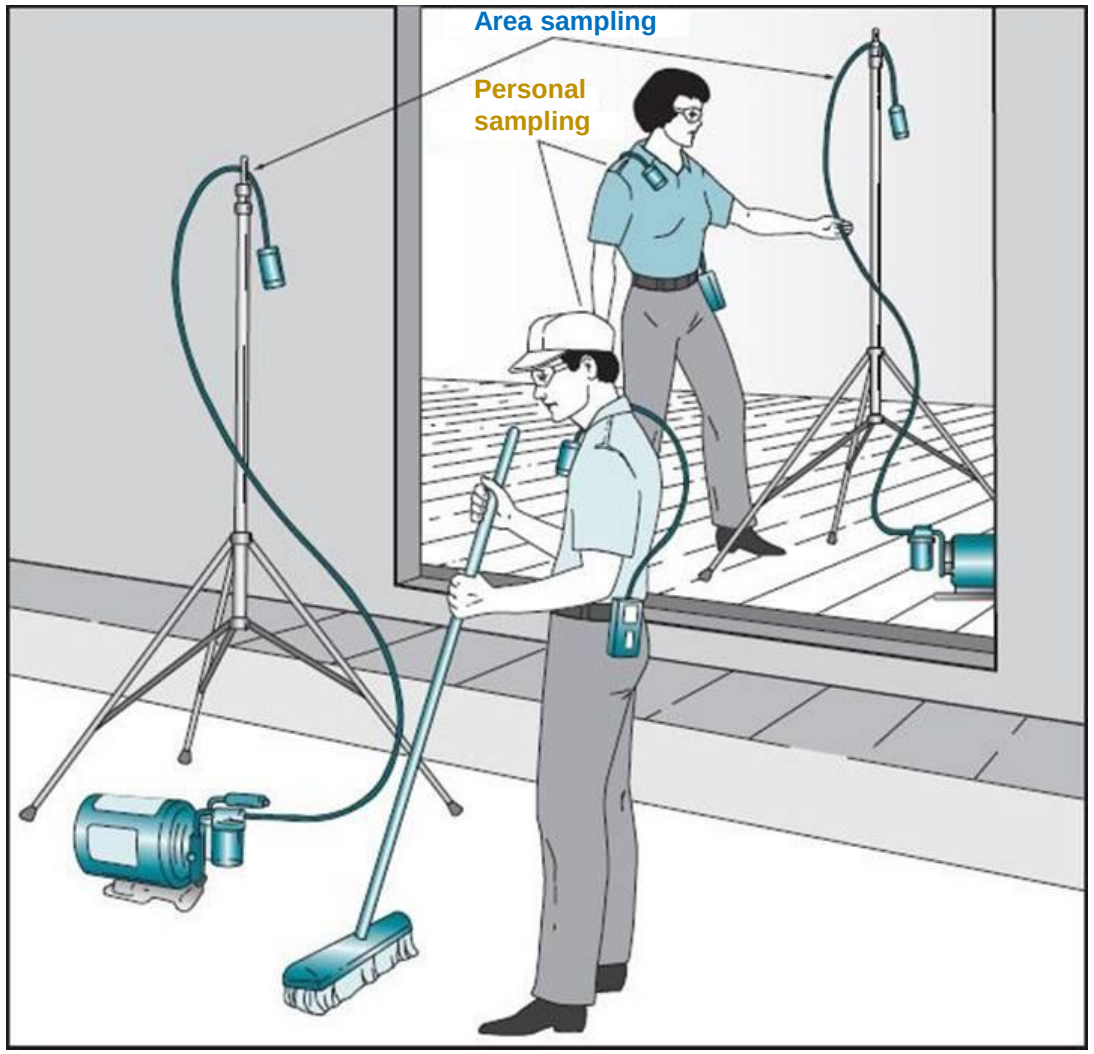
Sampling media – Air filters

- **Based on the objective of the sampling**
  - target chemicals, loading capacity, required sampling efficiency, cost, availability, and the type of analytical method
- **Most common types of filters**
  - polyvinyl chloride (PVC) and mixed cellulose ester (MCE)
  - polytetrafluoroethylene (PTFE), glass fiber, nylon, cellulose, polycarbonate, and glass fiber.



PVC **MCE** **PTFE** **Glass fiber** **Nylon** **Cellulose** **Polycarbonate**

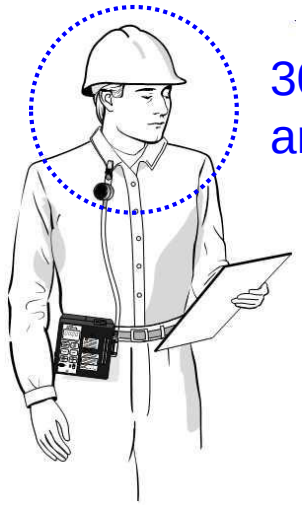
Air sampling pumps



Personal and area sampling

➢ Personal sampling

- Exposures are measured at the point nearest to the actual entry of airborne contaminants (breathing zone).
- Sampling system moves with the worker.
- Thus measurements are more likely to represent actual potential exposures.



30 cm hemisphere
around the nose and mouth

➢ Limitations of personal sampling

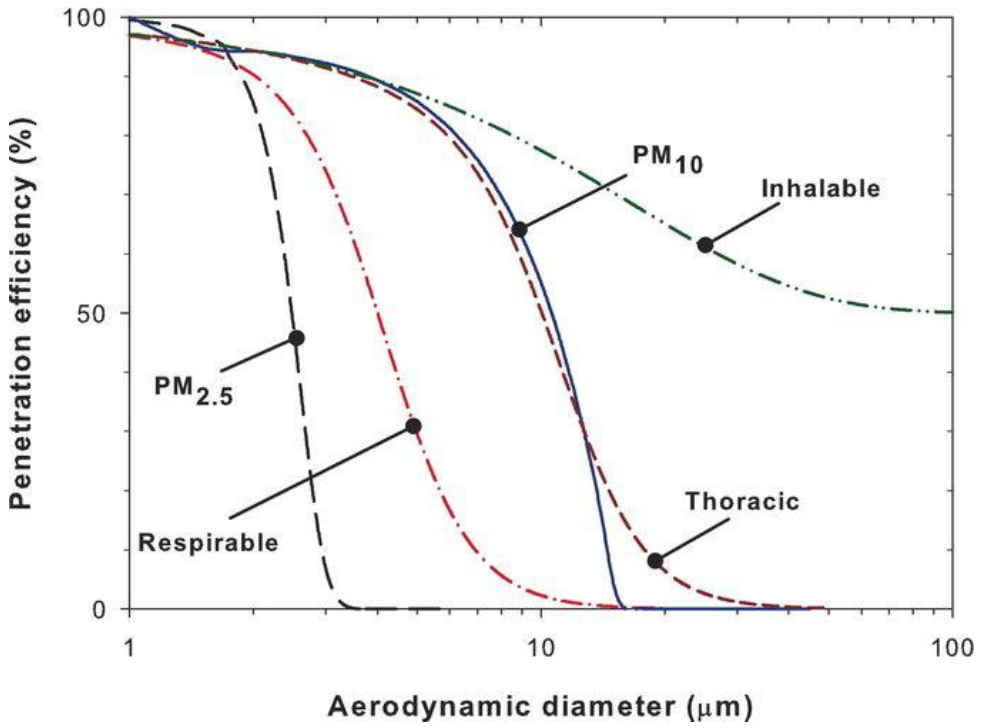
- The volume of air sampled is limited by the capacity of the battery-operated pumps used.
  - Difficult to trace contaminants
- Multiple samplers can't be installed in the worker's breathing zone.

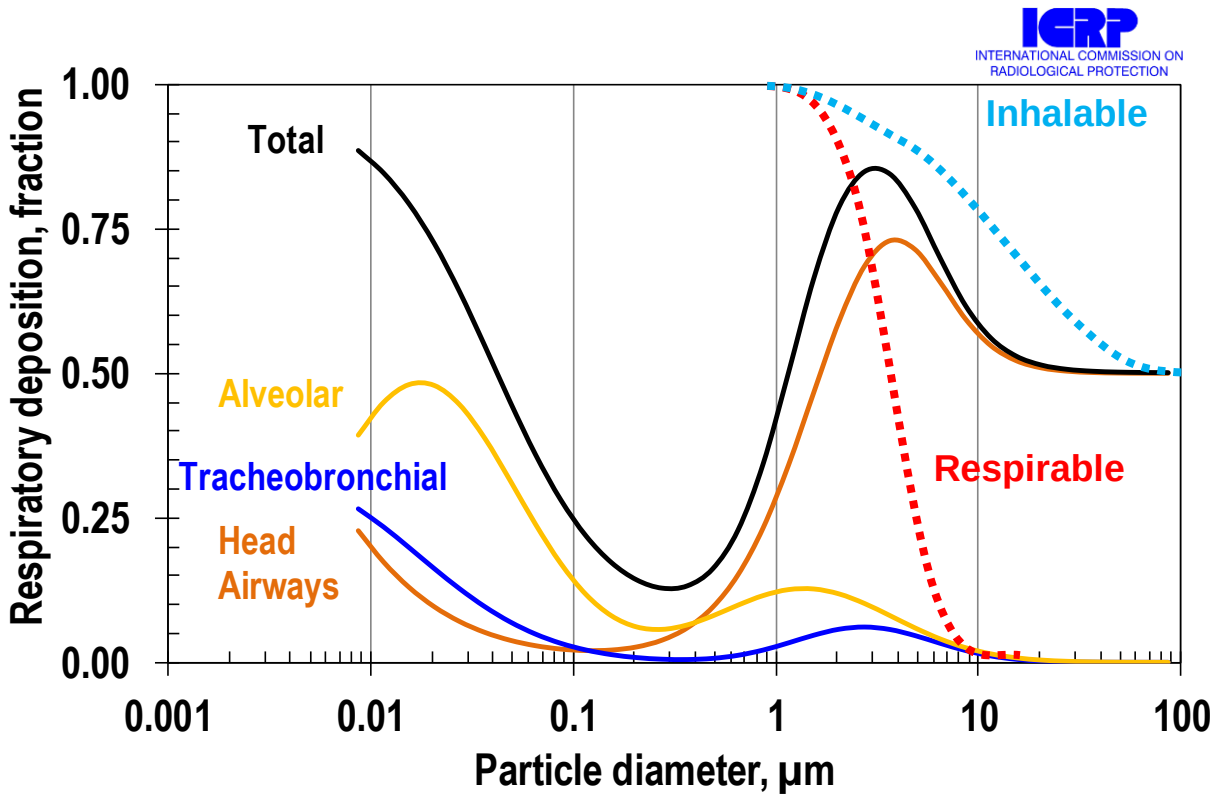
➢ Area sampling

- Fixed sampling station
- To measure
  - background concentrations
  - emissions from sources
  - concentrations in several areas simultaneously in order to evaluate the effectiveness of controls

Limitations of current size selective sampling conventions

➢ Collected ≠ Deposited





- Inhalable particles enter the respiratory system via the nose or mouth.
- Thoracic particles pass the larynx and penetrate into the conducting airways (trachea, bifurcations) and the bronchial region of the lung.
- Respirable particles enter the deepest part of the lung, the nonciliated alveoli.

New issue – nanoparticles

- The respirable sampler has limited usefulness in quantifying nanoparticle exposures.
- The mass measured from a sample collected using the respirable sampler can be dominated by particles larger than 100 nm, which are outside the range of nanoparticles.

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Research project

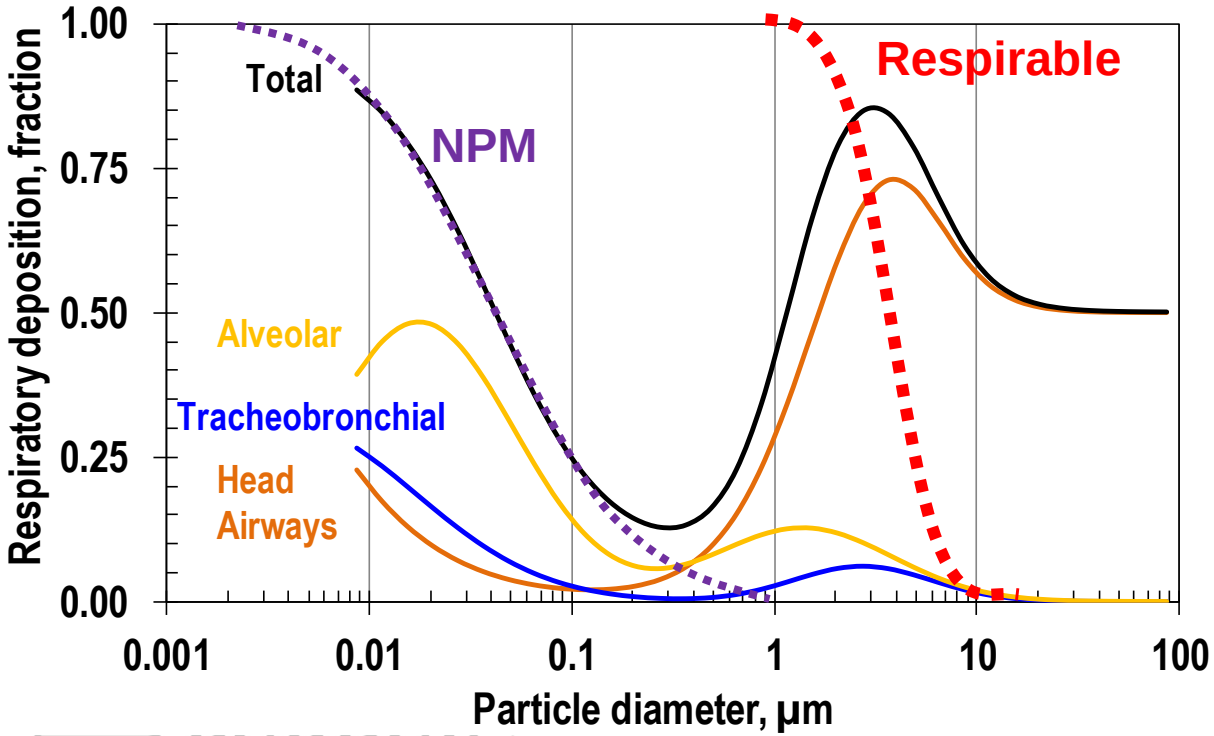
- **Development of personal personal nanoparticle respiratory deposition (NRD) sampler**

- **Application in IH study – Welding fume sampling**

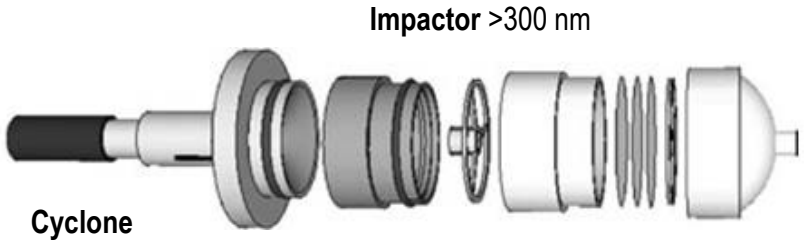
Nanoparticulate matter (NPM) criterion

➢ NPM criterion

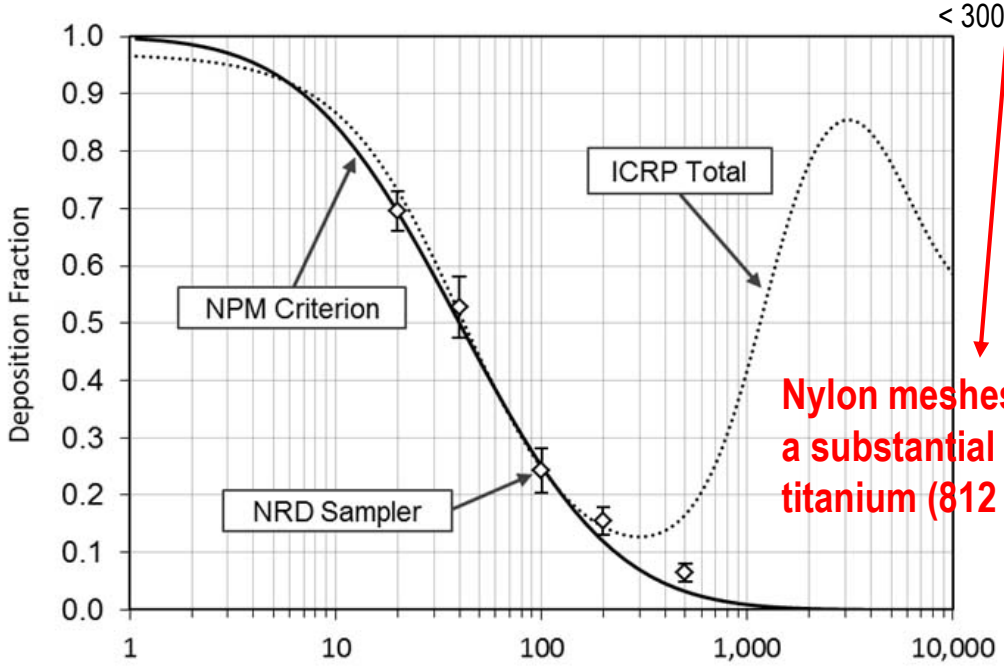
- Developed by Cena et al. (2014)
- Mimics the deposition of nanoparticles within the human respiratory track



➢ Nanoparticle respiratory deposition (NRD) sampler



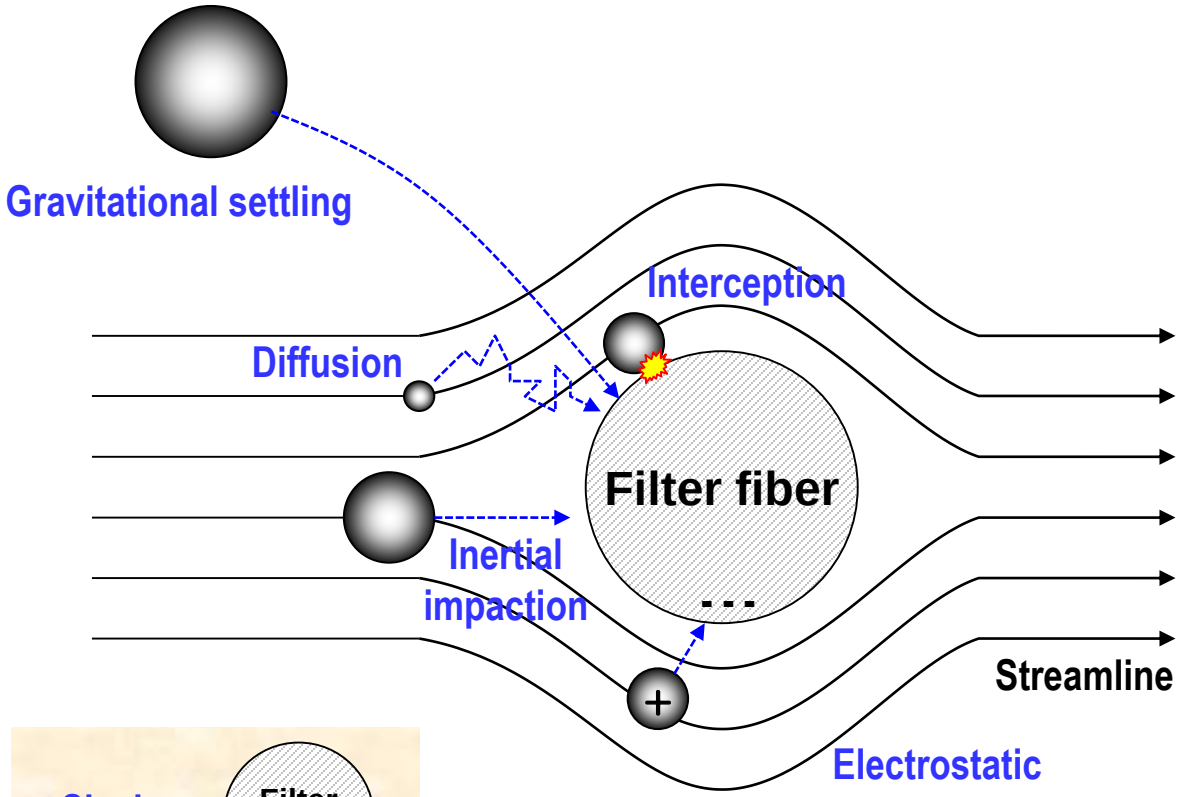
Nylon mesh
< 300 nm

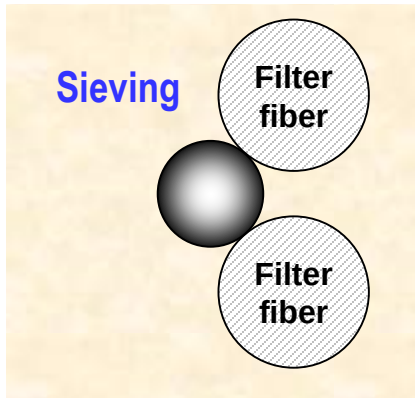


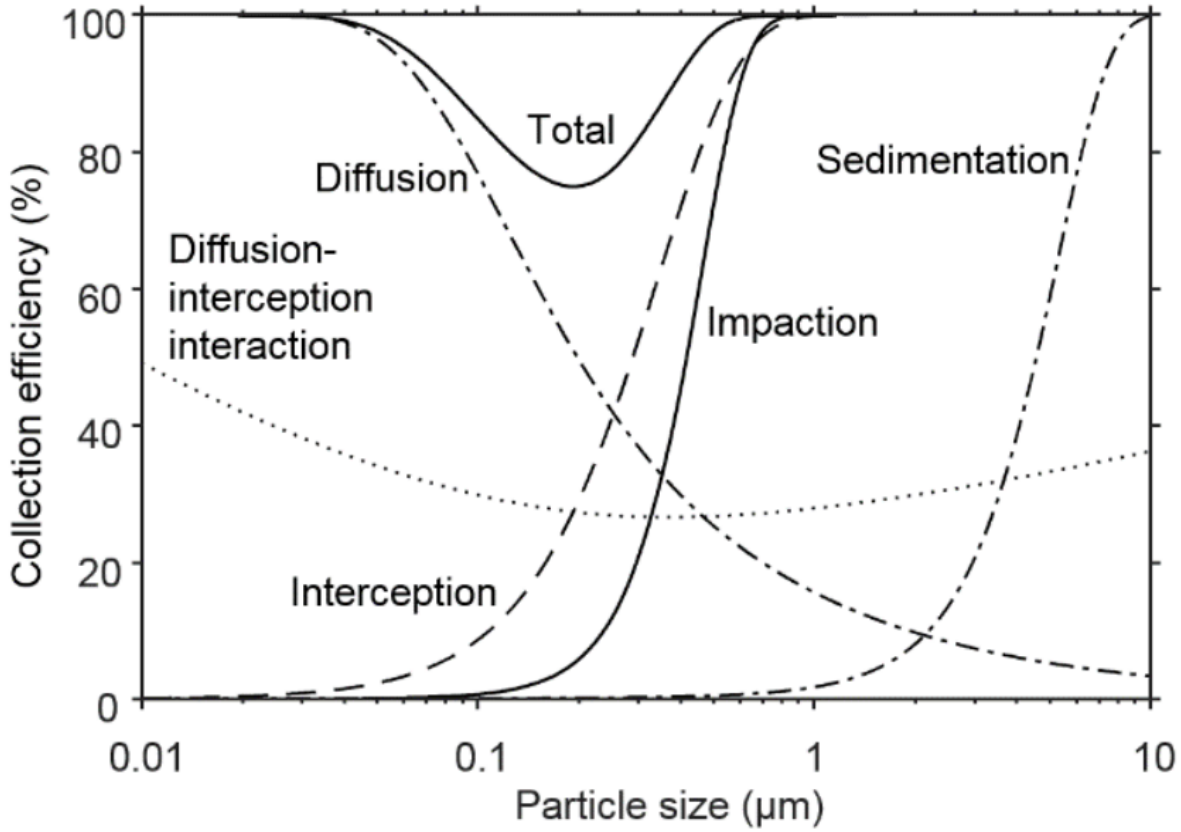
Nylon meshes contain a substantial amount of titanium (812 µg/g).

Cena et al. (2011). A personal nanoparticle respiratory deposition (NRD) sampler. *Environ. Sci. Technol.*, 45(15):6483–6490.

Filtration mechanism

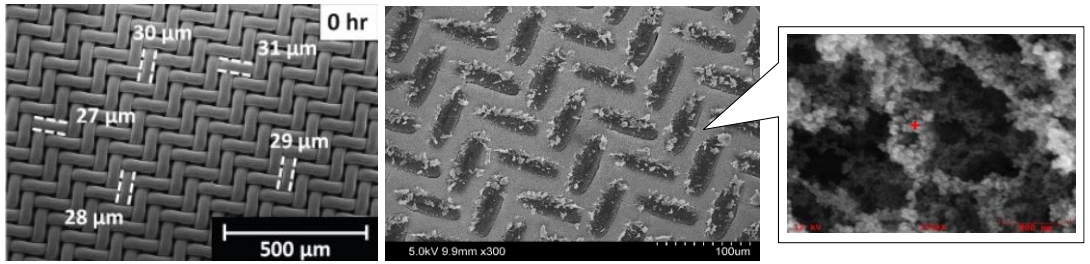






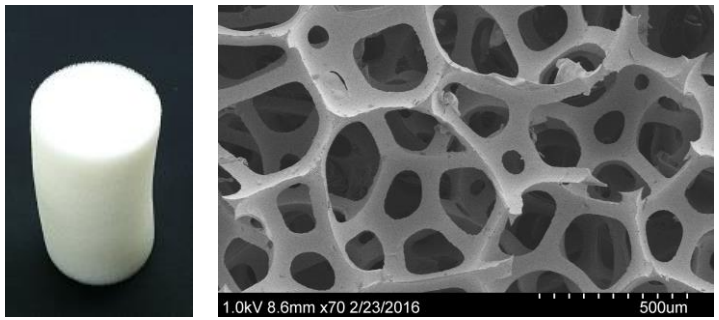
Advanced NRD sampler

- **Used the polyurethane foam to mimic the lung structure**



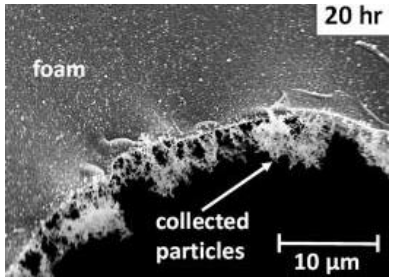
Nylon mesh (original)

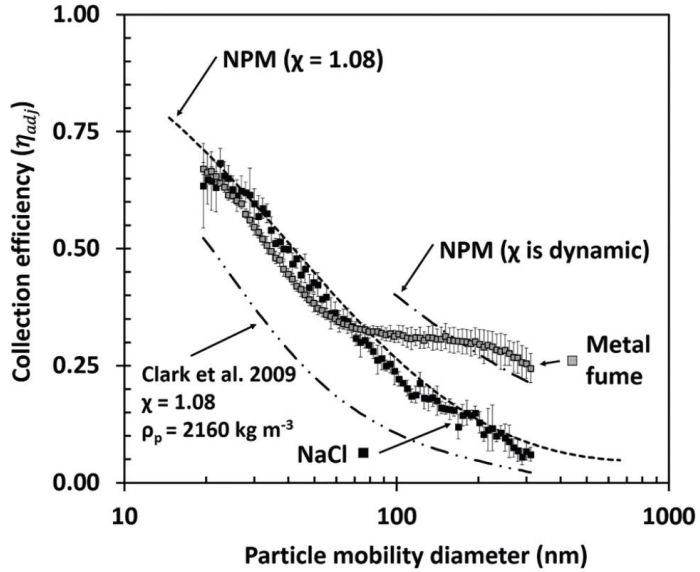
Vs.



Polyurethane foam (advanced)

- **Results**





- Matched well with NPM
- Less metal contents
  - Titanium content measured using an ICP-optical emission spectrometry
    - Foam: 0.23±0.221 µg/g
    - Nylon mesh: 812±141 µg/g

Mines et al. (2016) Porous polyurethane foam for use as a particle collection substrate in a nanoparticle respiratory deposition sampler, *Aerosol Science and Technology*, 50(5):497-506.

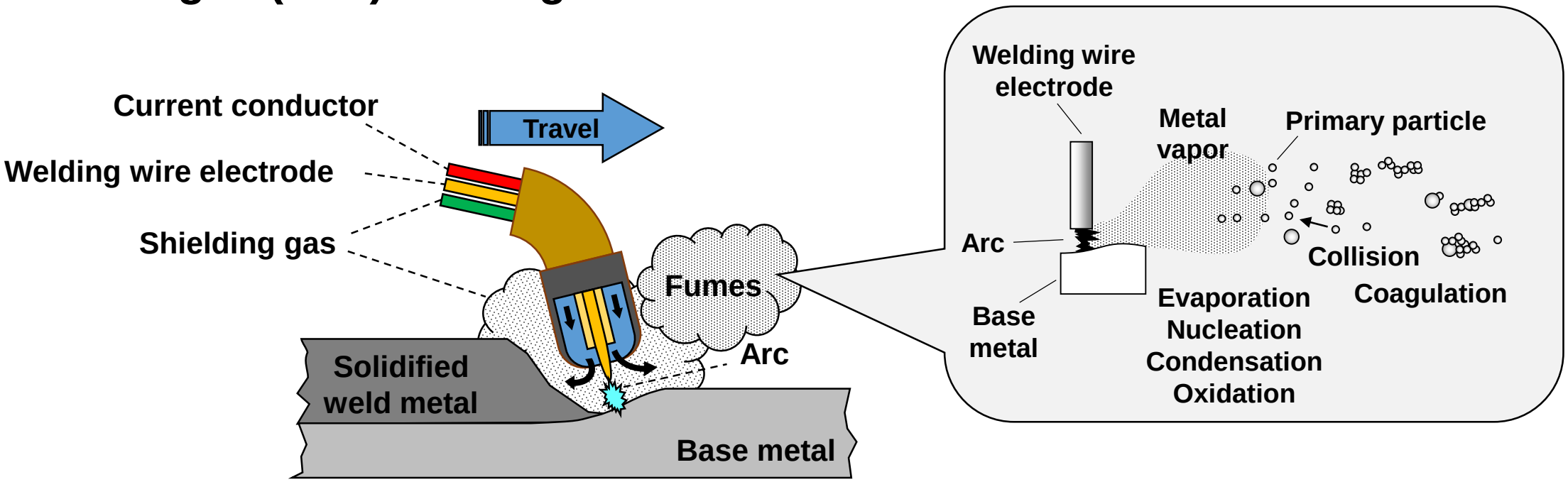
Application of NRD sampler

- **Welding fume sampling**
  - What are welding fumes?
    - Mixture of metal oxide particles and gases
    - Mainly iron (Fe) oxides
    - Contains hazardous metals: manganese (Mn), copper (Cu), Zinc (Zn), etc.
    - Chronic or acute adverse health effects, metal fume fever, lung disease, etc.

- **Mn in welding fumes**
  - Mn in welding fumes
  - Condition associated with slower reaction time, hand tremor, and Parkinson's-like symptoms (Manganism).

Particles in the welding fumes

➢ Metal inert gas (MIG) welding



➢ Size of particles in welding fumes

- 0.005 - 20 μm
- Less than 10–30% of the fume mass is larger than 1 μm.

Methods for welding fume sampling

➢ Study population

- Inclusion criteria
  - > 18 years old.
  - Must have been welding at the facility for at least one year.
- Exclusion criteria
  - Prior diagnosed neuro or psychological disorder
  - Known drug use
  - Pregnancy
  - Exposure to chemicals
  - Inability to undergo MRI examinations

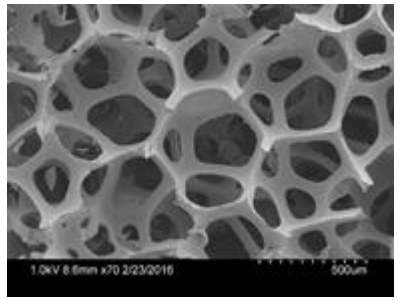
➢ Sampling location

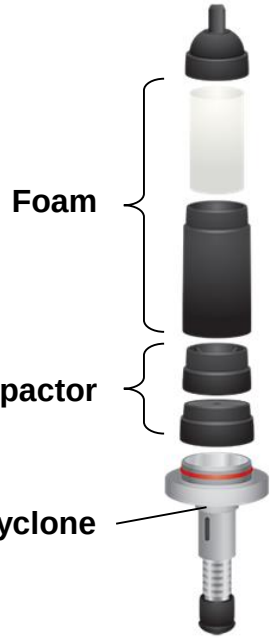
- Semi-truck trailer manufacturing facility in Lafayette, IN.

Methods for welding fume sampling

NRD sampler

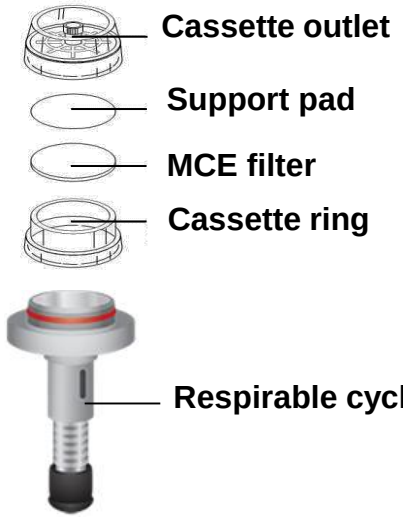
- **Foam sampling media mimics structure and deposition frequency of human lung.**

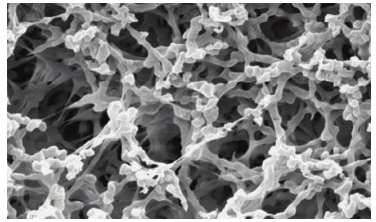




Respirable sampler

- **Current occupational standard method**
- **Mixed cellulose ester (MCE) sampling media**

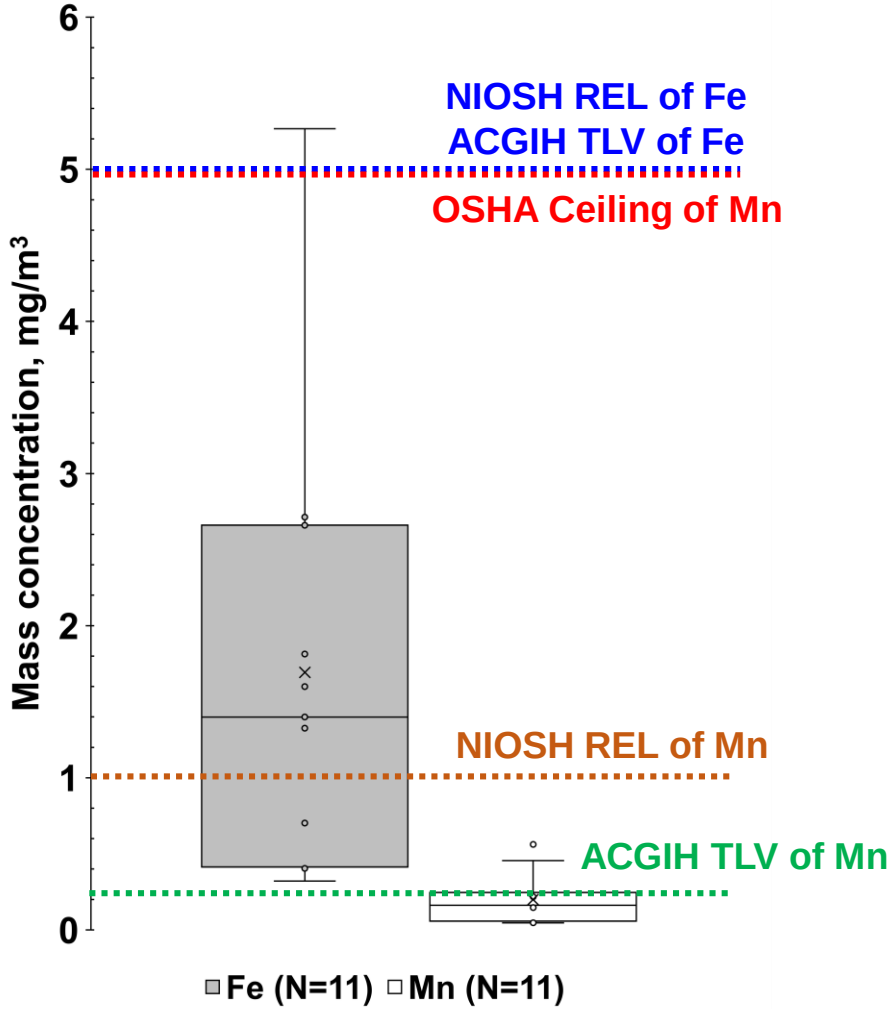




- Standard methods were used.
  - NIOSH 0600 for sampling respirable particles
  - NIOSH 7302 for ICP-OES analysis
    - Metal contents of sampled aerosols were measured.

Results

➢ Respirable Mn in welding fumes



➢ Respirable vs. NPM

	Average mass concentration of metals, mg/m³			
	Fe	Mn	Cu	Zn
Respirable particles (n = 11)	1.7 ± 1.5	0.20 ± 0.17	0.04 ± 0.03	0.02 ± 0.03
NPM (n = 10)	0.745 ± 0.792	0.086 ± 0.091	0.018 ± 0.016	0.010 ± 0.013
NPM / Respirable	0.44	0.43	0.48	0.41

- Ratios of Fe:Mn were 8.5:1 for respirable particles and 8.7:1 for nanoparticles, respectively.
- The fraction of specific metal nanoparticles within respirable metal particles ranged from 0.41 – 0.48.

Conclusion

- **Worker exposures to respirable particles in welding fumes were assessed and compared.**
  - Personal exposure level was higher than background level.
  - Average exposure levels were lower than OSHA PEL but higher than action level.
  - A substantial portion of respirable particles were nanoparticles.
    - Further emphasizing the need for the development of regulations for nanoparticle exposure.
  - Personal protective equipment (respirators) were in use by study participants.

- **Study provides evidence that use of NRD sampler is an effective method for nanoparticle assessment.**

- **Future research includes:**
  - Analyze metal contents in the brain and toenails.
  - Test from different types of welding, such as shielded metal arc welding and tungsten inert gas (TIG) welding.

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    - T42 OH008455
    - T03OH008615

Other aerosol research in IH

Anticipation and Recognition

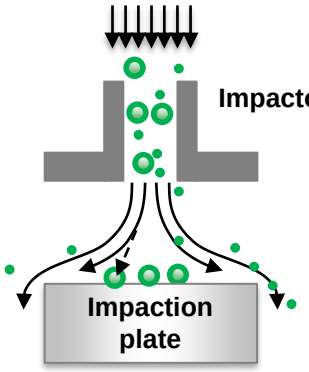
↓

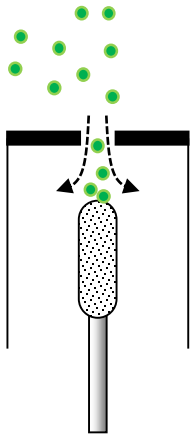
Evaluation

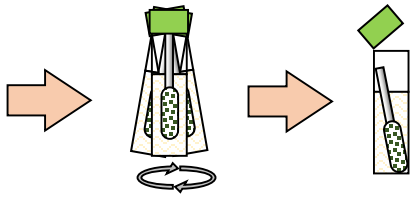
↓

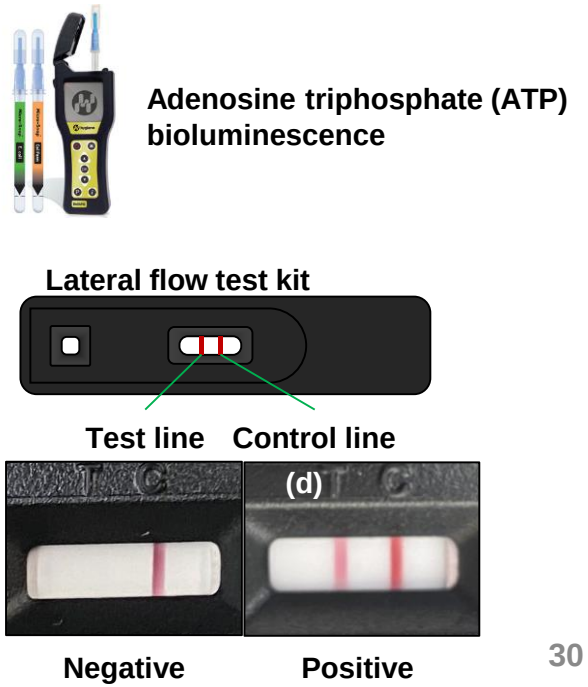
Control and Confirmation

- **Bioaerosols**
  - Aerosols of biological origins
    - E.g., airborne virus, bacteria, fungi, etc.
- **Bioaerosol samplers**
  - Combined with non-culture based methods



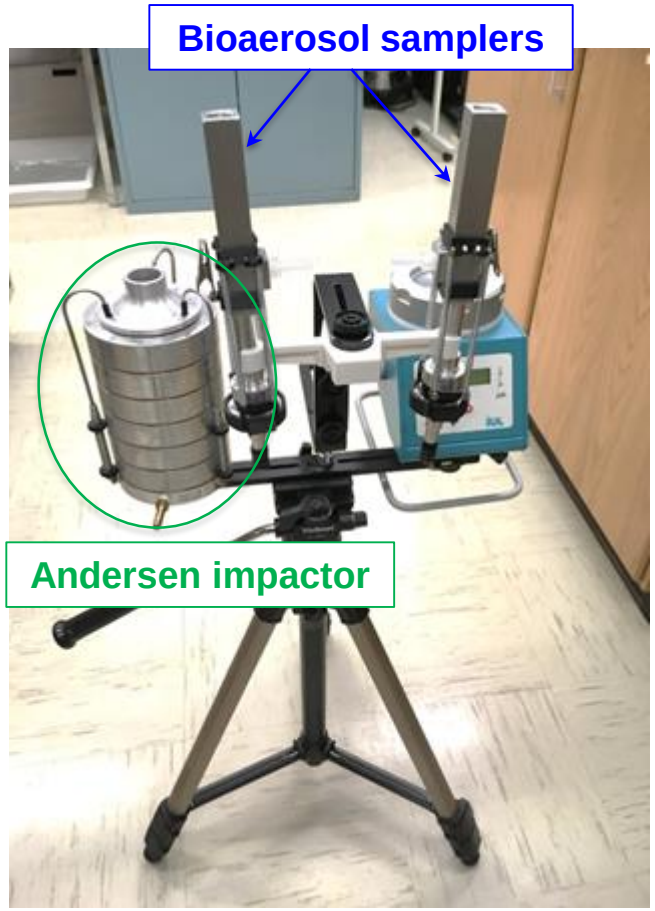






Field sampling

- **Sampling station**



- **Liao et al. (2019) A size-selective bioaerosol sampler combined with an ATP bioluminescence assay to measure the total bioaerosol concentration,** *Environmental Researc*h, Vol. 194, 110615 https://doi.org/10.1016/j.envres.2020.110615
- **Patent: Personal sampler combined with ATP bioluminescence method for rapid quantification of bioaerosols, Appl. No. 16/558,361, Pub. No. US 2020/0110008 A1 (Apr 09, 2020)**

Summary

- Industrial hygiene to protect workers health
- Aerosols are liquid or solid particles suspended in a gas.
- Aerosols can be inhaled, deposit in the respiratory system, and cause adverse health outcomes.
- Concentration of aerosols: Occupational > Environmental
- Exposure assessment: first step to protect workers health
- Air sampling to collect aerosols: Personal vs. Area
- Size-selective samplers
- NRD sampler developed for sampling nanoparticles

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Questions?