Respirable Crystalline Silica in the Workplace and NIOSH Studies on Engineering Controls

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National Institute for Occupational Safety and Health
Division of Field Studies and Engineering, Engineering and Physical Hazards Branch

What is Silica?

- Silicon dioxide (SiO_2)
  - Occurs in crystalline or non-crystalline form
- α-Quartz is the most abundant crystalline form
  - Most common mineral on Earth's continents
  - Found in sand, sandstone, shale and granite

Ampian SG, Virta RL [1992]. Crystalline silica overview: Occurrence and analysis. Washington, DC: U.S. Department of the Interior, Bureau of Mines, Information Circular IC 9317.

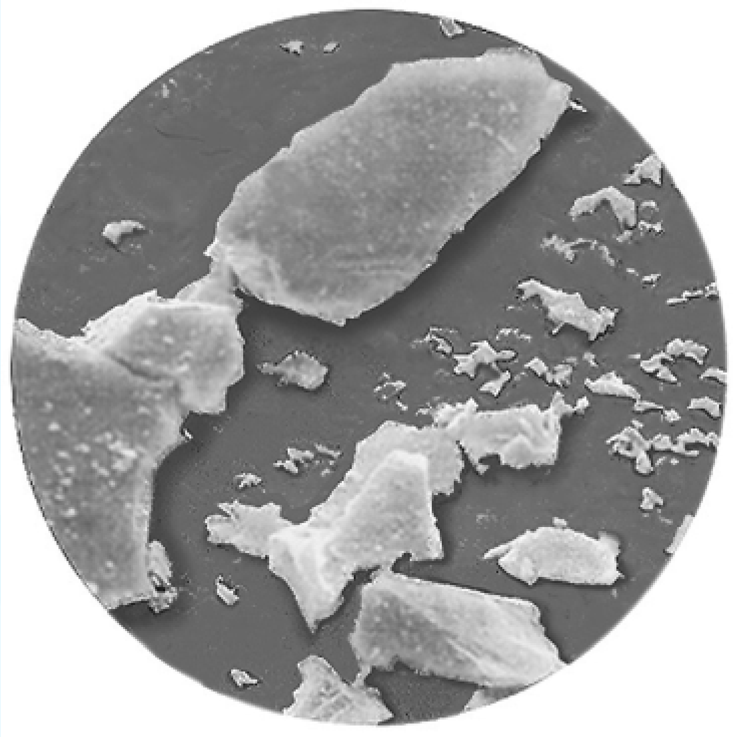
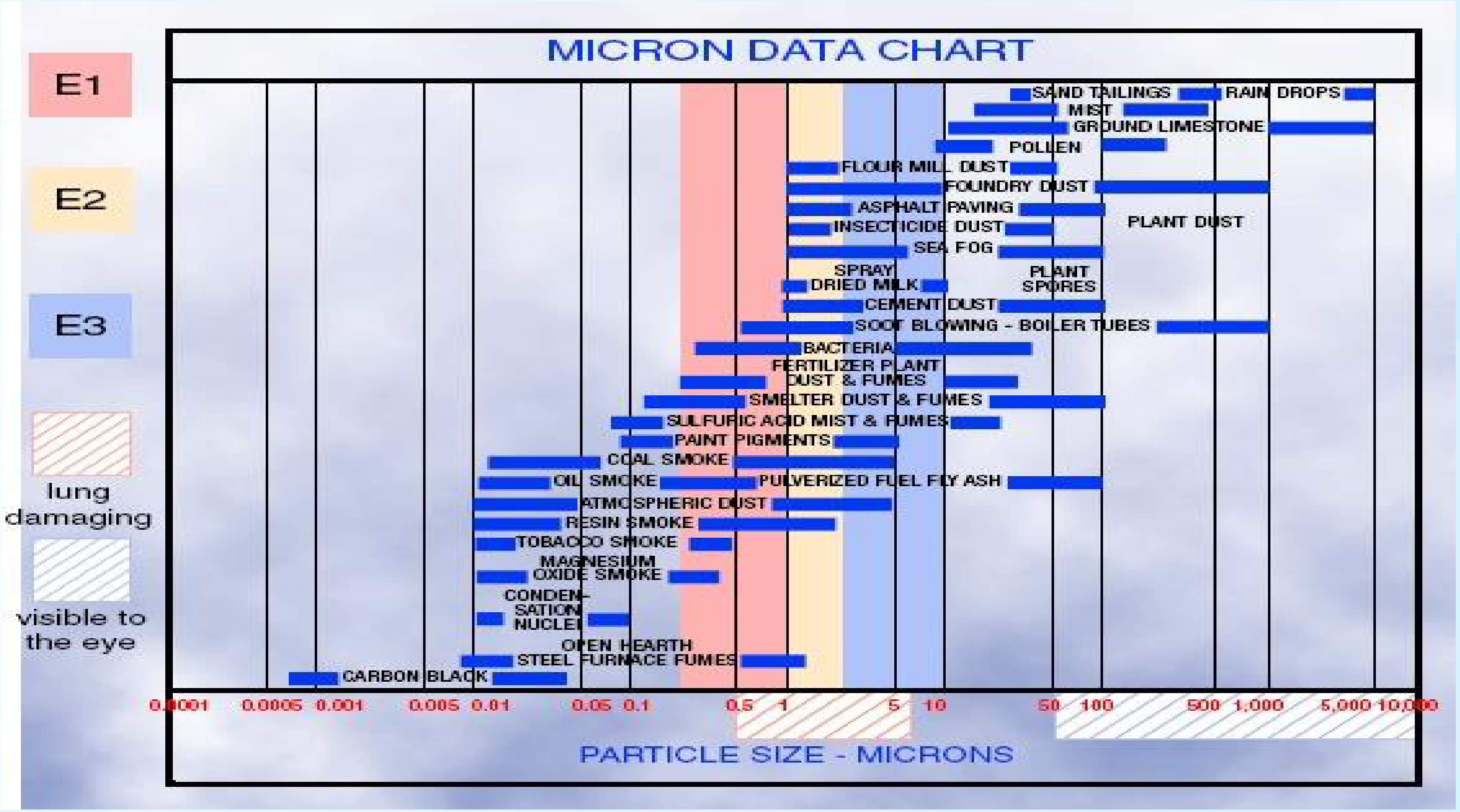


Photo from Silicosis: Learn the Facts!, NIOSH publication 2004-108.

What is Respirable Crystalline Silica (RCS)?



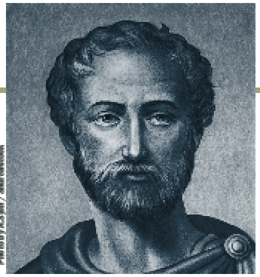
U.S. EPA AirKnowledge program

Silicosis is an Old Disease

MILESTONES IN RESPIRATORY PROTECTION

Pre-1800s

- Pliny the Elder (**23–79 AD**) used animal bladder skins to filter dust while crushing cinnabar
- Leonardo da Vinci (**1452–1519**) recommended the use of wet cloths over the mouth and nose



1800s–1919

- In **1877**, the English invented and patented the Nealy Smoke Mask
- United States Bureau of Mines (USBM) was established in **1910**
- USBM produced Schedule 13, "Procedure for Establishing a List of Permissible Self-Contained Mine Rescue Breathing Apparatus" in **1919**

1920–1949

- In **1920**, MSA Safety Company manufactured the Gibbs respirator, the first respirator approved by the USBM for industrial use
- The Hawk's Nest Tunnel Disaster in the early **1930s** expedited Schedule 21's standards for filter-type dust/fume/mist respirators

1950–1969

- Schedule 21B's expansion in **1965** provided further regulation and protection for industrial workers
- The **1969** Federal Coal Mine Health and Safety Act resulted in regulations governing the certification and use of approved respirators in the mining industry

1970–1999

- The Occupational Safety and Health Act of **1970** established both NIOSH and OSHA to protect the health and safety of American workers
- In **July 1995**, the respirator certification regulation, 30 CFR 11, was replaced by 42 CFR 84
- The necessity for respirators in healthcare became apparent with the outbreak of TB in the **1990s**

2000–2019

- Congress created the NIOSH National Personal Protective Technology Laboratory in **2001**
- The focus of respiratory protection for first responders shifted after the 9/11 terrorist attacks
- Public health emergencies like the **2009** H1N1 pandemic brought attention to the importance of respirators for healthcare workers

Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

100 Years of Respiratory Protection History, https://www.cdc.gov/niosh/npptl/Respiratory-Protection-history.html
September 2019

https://www.cdc.gov/niosh/npptl/pdfs/N95 -Timeline-508.pdf

Respirable Crystalline Silica Exposures

- OSHA estimates 2.3 million workers exposed to RCS in the workplace
  - Two million construction workers
  - Additional 300,000 in general industry and hydraulic fracturing
- "New" silica rule expected to protect workers
  - Save over 600 lives annually
  - Prevent more than 900 new cases of silicosis each year

What does the “New” Silica Rule Mean to Employers?

Table 1 excerpt—Specified Exposure Control Methods When Working With Materials Containing Crystalline Silica

Equipment/task	Engineering and work practice control methods	Required respiratory protection and minimum assigned protection factor (APF) ≤ 4 hours/shift	>4 hours/shift
(xii) Handheld grinders for uses other than mortar removal	For tasks performed outdoors only: Use grinder equipped with integrated water delivery system that continuously feeds water to the grinding surface	None	None
	Operate and maintain tool in accordance with manufacturer's instructions to minimize dust emissions		
	OR		
	Use grinder equipped with commercially available shroud and dust collection system		
	Operate and maintain tool in accordance with manufacturer's instructions to minimize dust emissions		
	Dust collector must provide 25 cubic feet per minute (cfm) or greater of airflow per inch of wheel diameter and have a filter with 99% or greater efficiency and a cyclonic pre-separator or filter-cleaning mechanism:		
	-When used outdoors	None	None
	-When used indoors or in an enclosed area	None	APF 10

Engineering Controls for RCS are not new

- Three choices to avoid exposure
  - Don't make RCS
  - Capture RCS with local exhaust ventilation
  - Suppress RCS with water spray

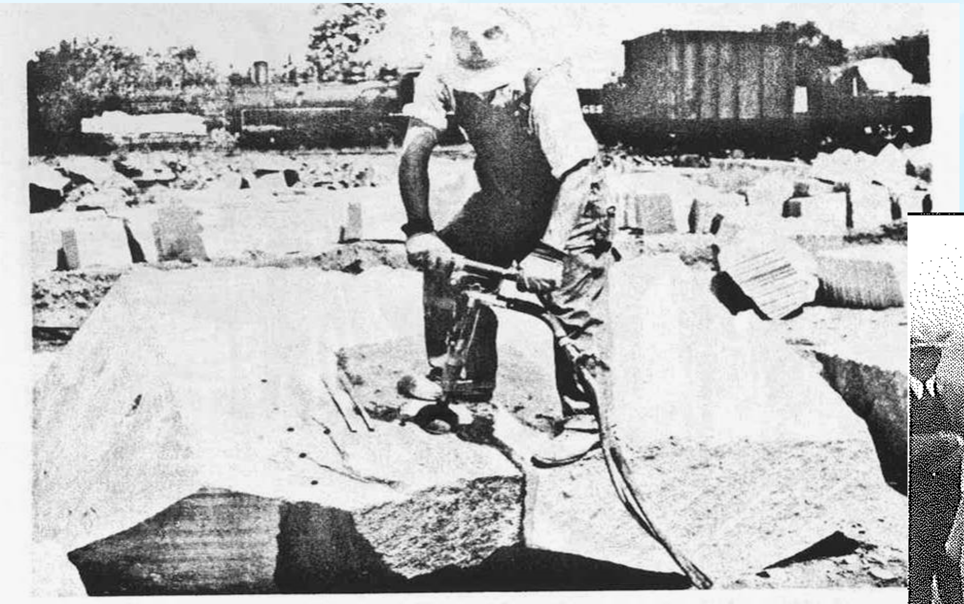


FIGURE 8. *Modern wet drilling with jackhammer in plug yard. Rubber cup preve... spraying operator with water. (Courtesy of Rock of Ages.)*

Photo from Control of Silicosis in the Vermont Granite Industry, HoseyAD, TraskoVM, and Ashe, HB, Washington, D.C.: U.S. Department of Health, Education, and Welfare, Public Health Service Publication #557, 1957.

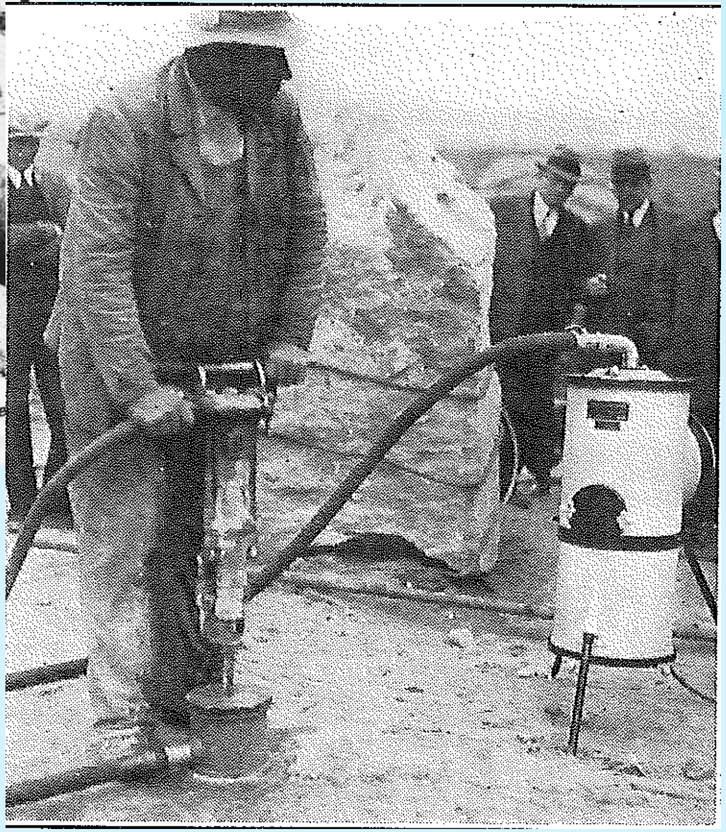
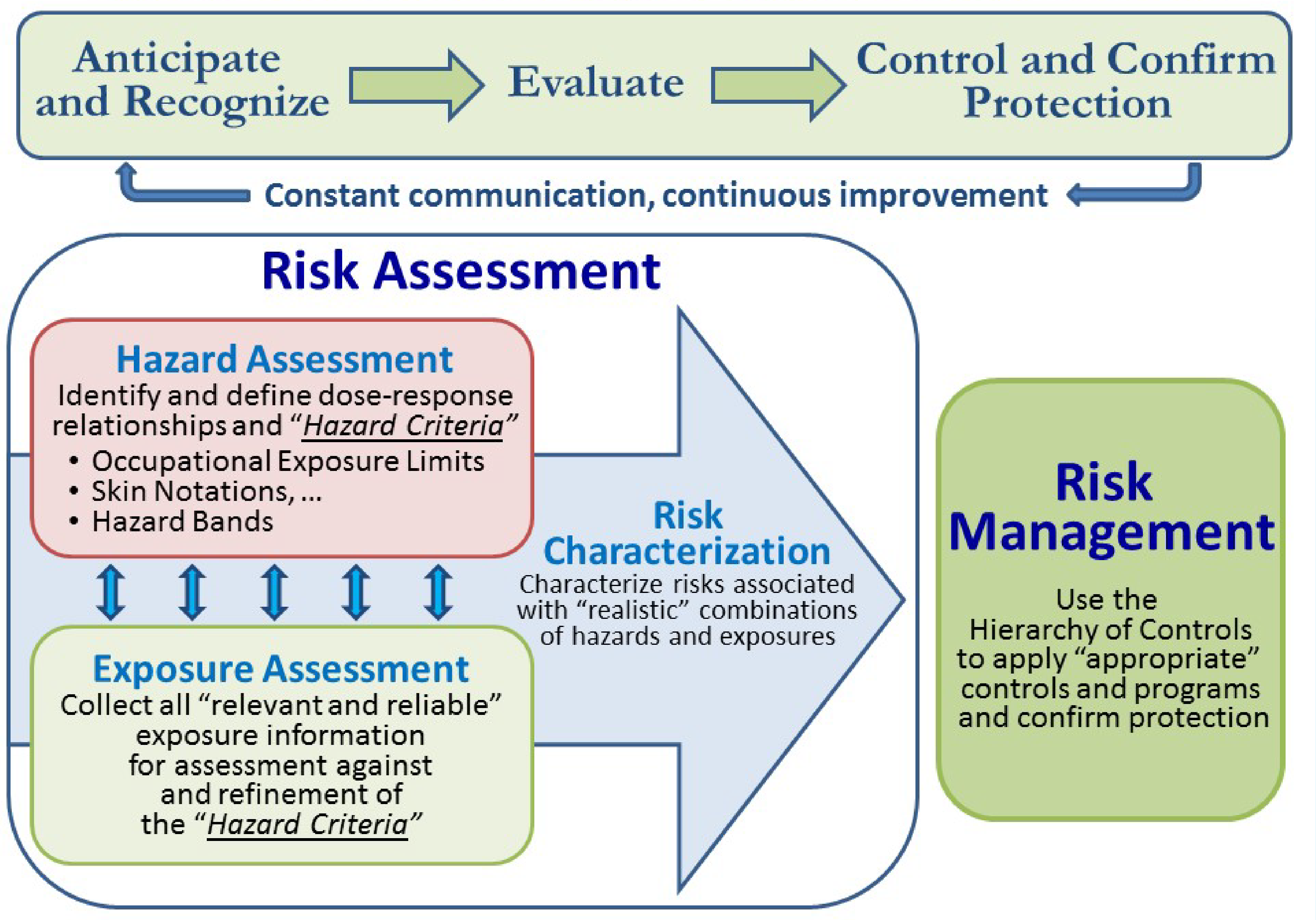


Photo from the files of Alan Echt

The Mission of an Industrial Hygienist is ARECC



From NIOSH [2017], NIOSH Exposure Assessment Program: Evidence Package for 2016

Many Occupations/Industries have a Risk of RCS Exposure

- Construction
  - Sandblasting and Jackhammering
  - Rock or concrete drilling, sawing, grinding, cutting, chipping or polishing
  - Brick or tile cutting and sawing and mortar removal (tuckpointing)
  - Tunneling
  - Demolition
  - Asphalt milling
  - Fabrication of stone countertops
  - Hardscaping
- Diatomaceous earth
- Pottery
- Foundries and work on linings of rotary kilns and cupola furnaces
- Mining
- Hydraulic fracturing

Exposures Vary for Different Work Tasks

- Content of crystalline silica varies
  - From trace amounts up to over 90% in engineered quartz stone
- Distance from the work to the breathing zone varies
  - From arm's length to floor
- Quantity of and size of material removed varies
  - Concrete breaking liberates less fine dust than grinding
- Task durations may vary
  - From minutes per day to all day long

Different Controls Function Better in Different Applications

- Dust capture
  - Relies on close contact between the capture hood and the source
  - May work best with rotary tools
  - Dust reservoir must be emptied periodically
  - May be best for indoors and at sub-freezing temperatures
- Water suppression
  - Can control dust over a greater distance
  - May work best with reciprocating tools such as jackhammers
  - Water may need to be contained
  - Dust may re-aerosolize when floors dry

The NIOSH Engineering and Physical Hazards Branch (EPHB) Researches Engineering Controls for RCS

- Ceramics manufacturing
- Cleaning foundry castings
- Jackhammering
- Concrete breaking, drilling, cutting, grinding, sanding, or polishing
- Masonry cutting, including bricks and roofing tiles
- Tuckpointing
- Stone countertop Grinding and Polishing
- Asphalt Milling
- Cutting Fiber Cement Siding
- Hydraulic Fracturing
- Hardscaping

Ceramics Manufacturing

Where exposures occurred:

- Dusting the molds with parting compound
- Wiping and scraping dry castings
- Poor housekeeping
- Spraying glaze in spray booths

Photo credit: Getty Images/lnzyx

Cooper TC, Gressel MG, Froehlich PA, et al. Successful reduction of silica exposures at a sanitary ware pottery. *Am Ind Hyg Assoc J.* 1993;54(10):600-606. 10.1080/15298669391355116.

Interventions Reduced Exposures

- Substituted silica-free parting compound for high-silica parting compound
- Moistened dry castings before wiping and scraping
- Housekeeping improved
- Repaired spray booths and increased ventilation rate
- Removed floor fans near spray booths

Respirable Crystalline Silica

	Initial Survey			**Follow-up survey**		
PERSONAL SAMPLES	Number of samples	% >REL	% >PEL	Number of samples	% >REL	% >PEL
Casting	15	100	95	24	29	8
Glaze Spray	18	100	100	20	25	5
Glaze Prep	6	100	83	6	83	50
AREA SAMPLES						
Slip House	6	100	83	9	0	0
Casting	7	88	88	12	0	0
Glaze Spray	6	66	17	6	0	0
Glaze Prep	3	100	66	6	0	0

Cleaning Foundry Castings

- Castings were produced in sand molds
- Final cleaning of castings was done by hand
  - Cup grinder
  - Cone grinder
  - Cutoff wheel
  - Pneumatic chisel
- The 12” exhaust duct was 6 feet away

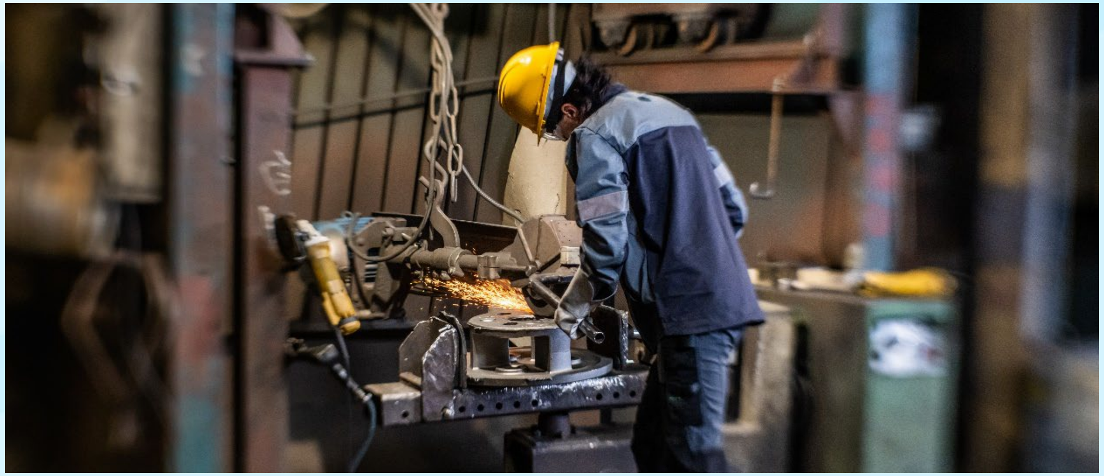


Photo credit: Getty Images/m

A Downdraft Table was Implemented to Control RCS

- Air flow rate was 3200 – 5600 cubic feet per minute
- Exposure reductions of 46% to 77% were measured
- Side benefit was improved housekeeping

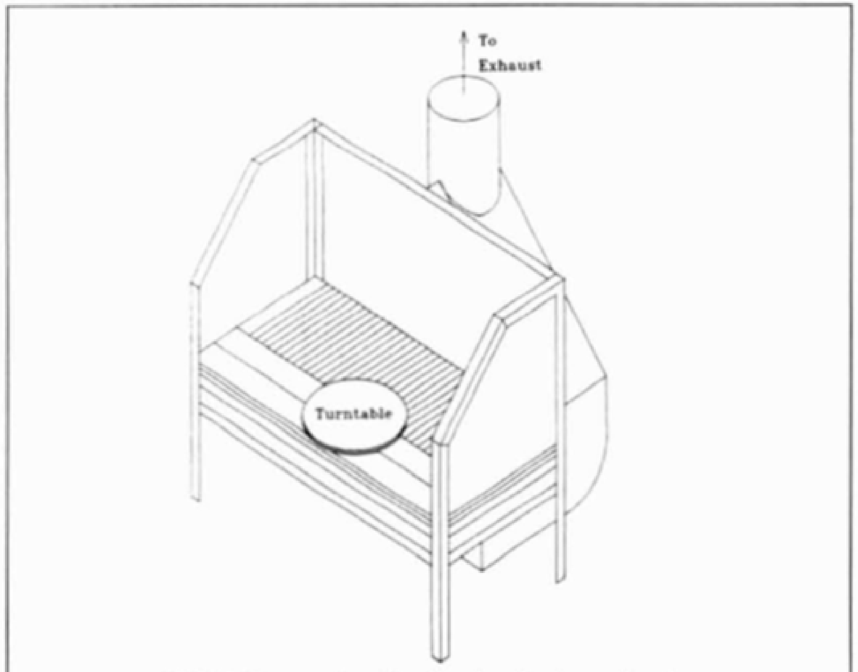


FIGURE 1. Diagram of ventilated casting-cleaning workstation

Gressel MG. An evaluation of a local exhaust ventilation control system for a foundry casting-cleaning operation. *Am Ind Hyg Assoc J.* 1997;58(5):354-358. 10.1080/15428119791012711.

Jackhammering and Concrete Breaking

Photo by NIOSH

Water Spray is the Recommended Control Method

- Water applied using a solid cone nozzle at a flow rate of 300 mL of water per minute resulted in a 77% reduction in quartz exposure
  - Could use the jackhammer 4 hours and 45 minutes in an 8-hour shift with no other exposures to quartz without exceeding the REL of 0.05 mg/m^3.

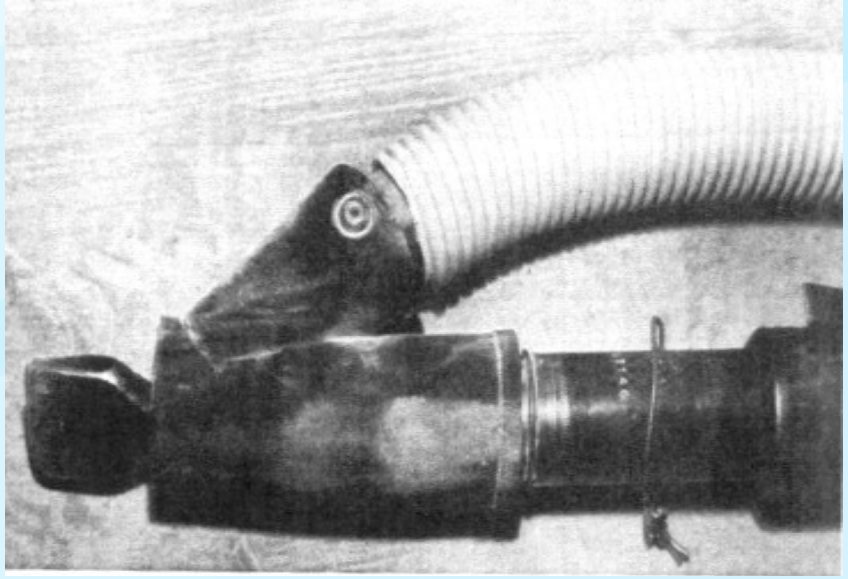
Equipment	Spray	Average Time (Minutes)	Average Water Flow (L/min)	Quartz (mg/m^3)		Notes
				Average	Range	
Jackhammer	Off (n=2)	57	---	0.38	0.32–0.43	Echt et al. [2004]
	On (n=2)	60	0.30	0.085	0.04–0.13	Echt et al. [2004]

Breaking Concrete

- Breaking concrete with drill hammers, breakers or scaling machines

Atlas Copco RRC 34

Atlas Copco RRC 12



Photos from Hallin, N(1983). Occurrence of quartz in the construction sector. The Construction Industry's Organization for Working Environment Safety and Health. Bygghalsan, Sweden. Report 1983-04-01.

Local Exhaust Ventilation Control

Test time (min)	Tool	Hood	Vacuum	PBZquartz (mg/m ^{3})	Notes
60	Hilti TE 60			2.26	Hallin et al. [1983]
60	Hilti TE 72			3.74	Hallin et al. [1983]
83,80	Hilti TE 72	Hilti bellows	Dustcontrol DC 3000	0.13, 0.21	Hallin et al. [1983]
120	Atlas Copco RRC 34	Hilti bellows	Dustcontrol DC 3000	1.33	Hallin et al. [1983]
60	Atlas Copco RRD 37	Dustcontrol bellows	Atlas Copco Sugkalla22	1.72	Hallin et al. [1983]
112	Atlas Copco RRD 57	Dustcontrol bellows	Atlas CopcoSugkalla22	0.55	Hallin et al. [1983]
60	Atlas Copco RRC 83	Dustcontrol bellows	Atlas Copco Sugkalla 22	2.03	Hallin et al. [1983]
55	Atlas Copco Tex 11 DCS	Dustcontrol bellows	Atlas Copco Sugkalla22	0.87	Hallin et al. [1983]
90	Atlas Copco RRC 12	Dustcontrol cover	Dustcontrol DC3000	0.28	Hallin et al. [1983]
30	Atlas Copco Super Tex 11	Dustcontrol bellows	Ermator Aermin DFL 200P	0.42	Hallin et al. [1983]
66	Atlas Copco RRC 12			3.24	Hallin et al. [1983]
63	Atlas Copco RRC 12	Dustcontrol cover	Dustcontrol DC 6000	0.11	Hallin et al. [1983]

Fiber Cement Siding

- **Replacement for recalled hardboard or pressboard siding**
- **Alternative to vinyl and wood siding**
  - Durable
  - Market share climbed from 1% to 13% from 1991-2010
  - The involved workforce is expected to be increasing

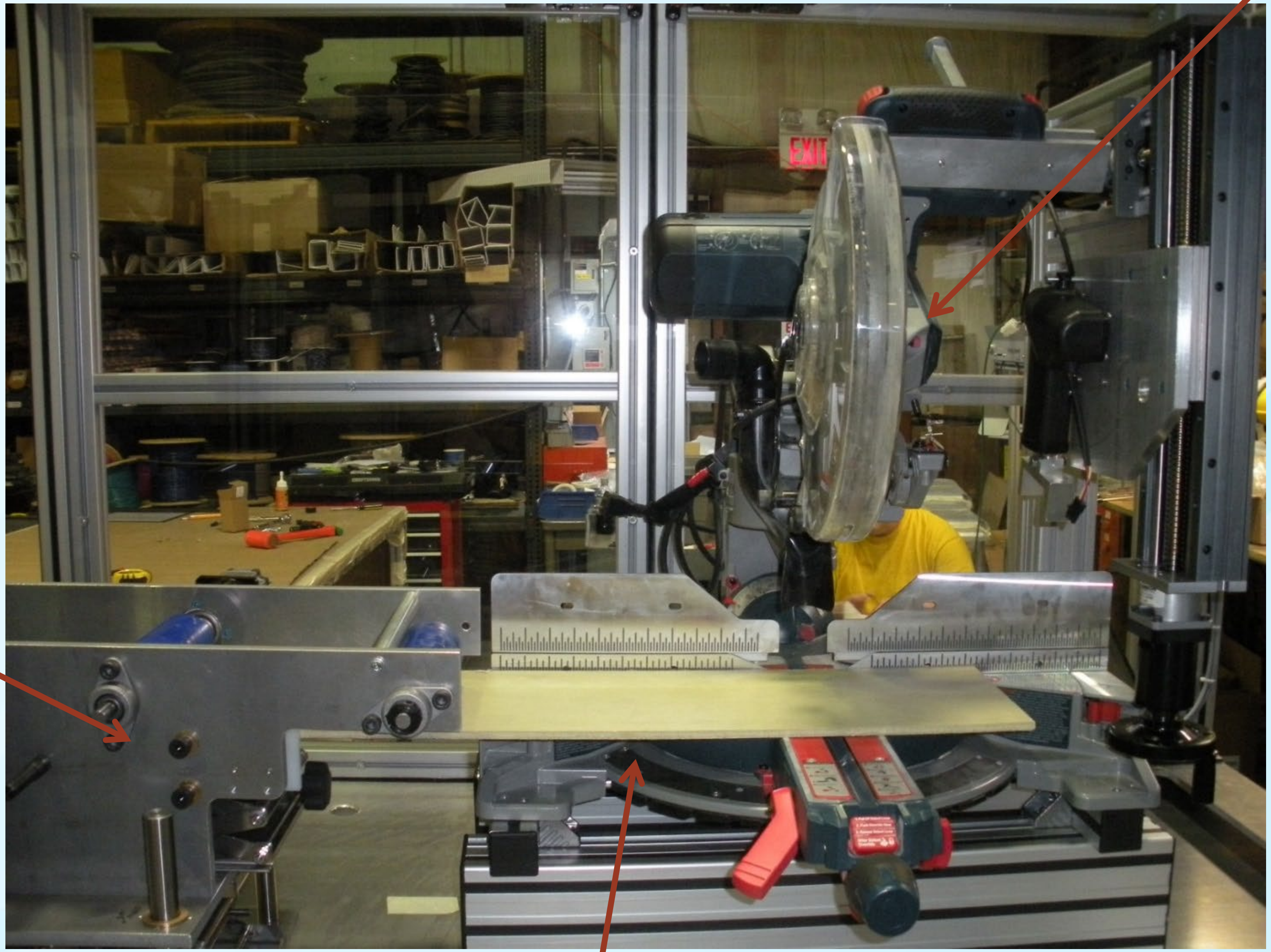
- **Major components**
  - Wood fiber, Silica sand, Cement
  - Contains up to 50% crystalline silica

Photo by NIOSH

Automated Test Chamber

Miter saw

Automatic feeding system with controlled speed



Fiber cement siding sample

Photo by NIOSH

Field Survey Results on Workers' Exposure to RCS with Control

Job	Sample type	Number of surveys	NIOSH REL (mg/m^3)	Geometric Mean (mg/m^3)	Lower 95% Confidence Limit (mg/m^3)	Upper 95% Confidence Limit (mg/m^3)	Geometric Standard Deviation	Notes
Cutters	TWA10	21	0.050	0.008	0.006	0.012	2.06	Qi et al. [2014]
Cutters	TWA8	21	0.050	0.011	0.008	0.015	2.06	Qi et al. [2014]
Installers	TWA10	12	0.050	0.004	0.003	0.006	1.67	Qi et al. [2014]
Installers	TWA8	12	0.050	0.005	0.004	0.007	1.67	Qi et al. [2014]

The upper 95% confidence limit of 10-hour TWA is only **24%** of the NIOSH REL for cutters, and 12% for installers

Masonry Cutting and Tuckpointing

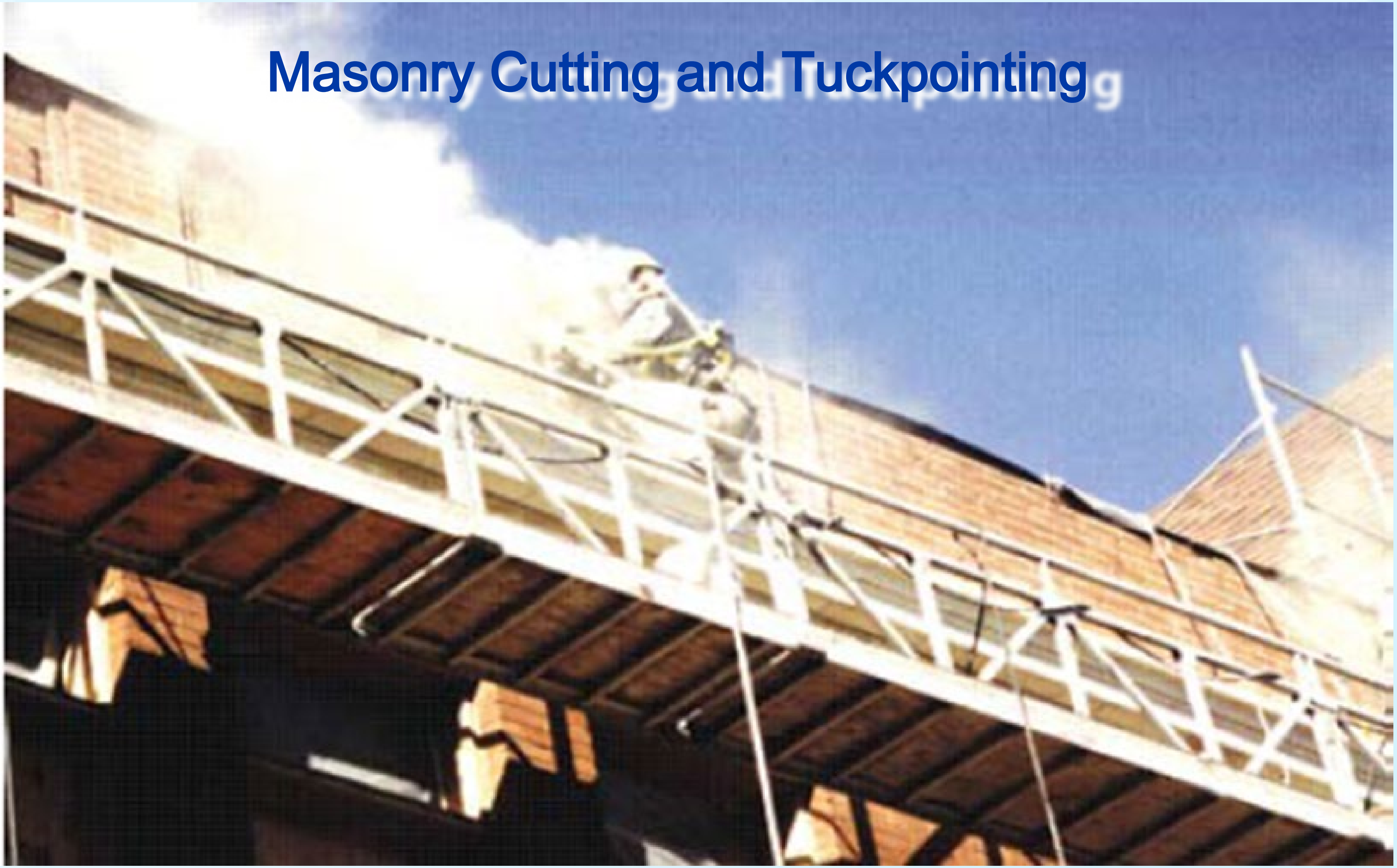


Photo by NIOSH

RCS Controls for a Portable Abrasive Cutter and Tuckpointing Grinder

	RCS Exposure		
Task	No Control	Control	Notes
Dry sawing concrete	0.09 mg/m^3		Shields [1999]
Block cutting	1.00–4.04 mg/m^3	<0.05–0.17 mg/m^3*	Meeker et al. [2009]
Brick cutting	0.45–1.58 mg/m^3	<0.05–0.15 mg/m^3*	Meeker et al. [2009]
Tuckpointing	3.06–25.8 mg/m^3	0.19–0.85 mg/m^3*	Shields [2000], Meeker et al. [2009]

* With local exhaust ventilation

Local Exhaust Ventilation for RCS Control

- Tuckpointing grinder LEV systems reduced quartz exposures
  - 91% and 93% reduction in quartz exposures
  - 65 cfm and 97 cfm flow rates through vacuums (at start of tests)

	Mean mg/m^3 (range)	% Reduction	Notes
Bosch grinder	4.99 (3.06–7.24)		Meeker et al. [2009]
Bosch grinderwith Bosch LEV	0.47 (0.28–0.85)	90.6	Meeker et al. [2009]
Metabo grinder	10.9(5.25–25.8)		Meeker et al. [2009]
Metabo grinder with Dust Director LEV	0.33 (0.19–0.50)	93.4	Meeker et al. [2009]

GRINDING AND POLISHING CONCRETE

Photo by NIOSH

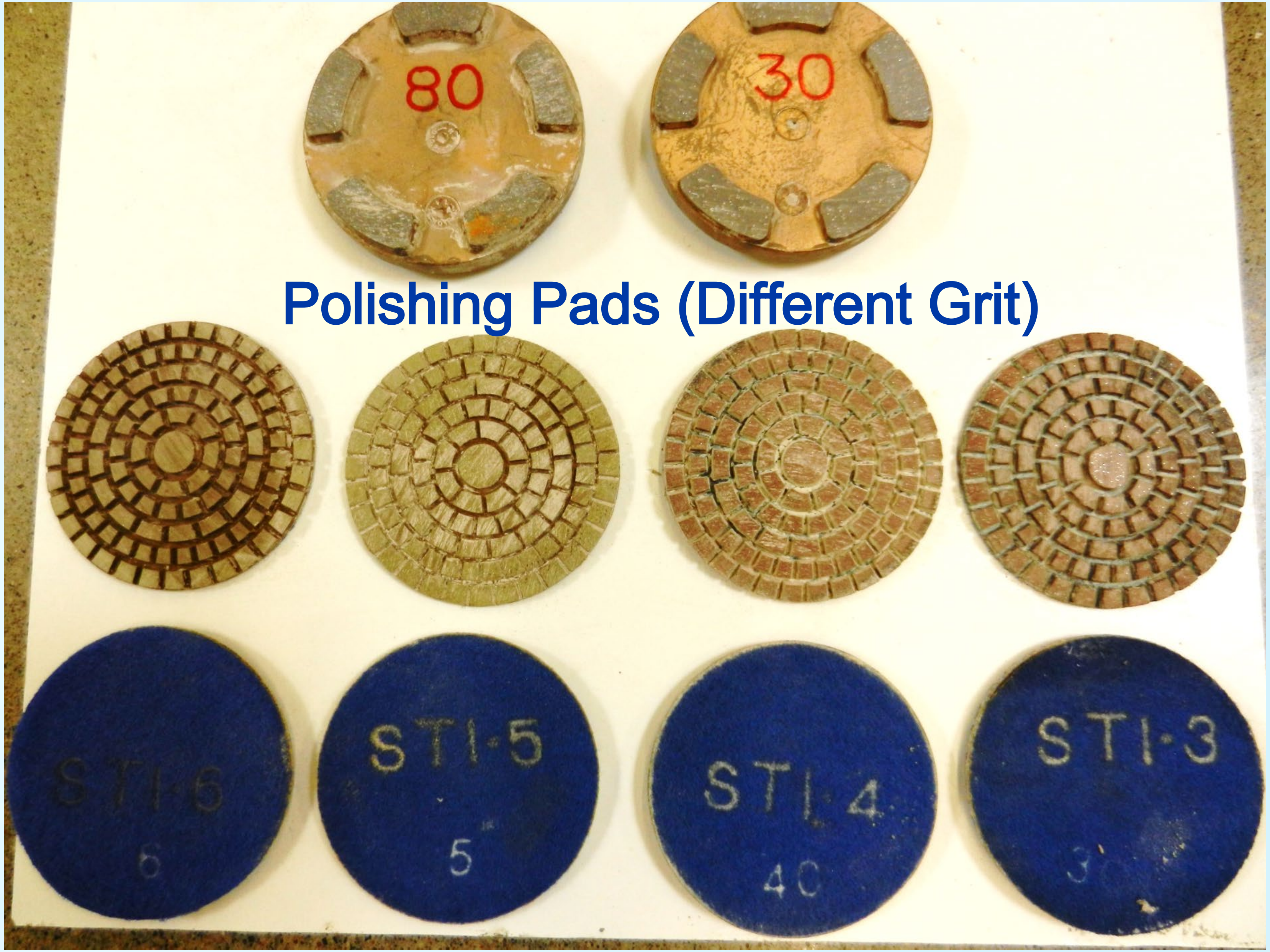
RCS Controls for Concrete Grinding

	RCS Exposure		Notes
Task	No Control	Control	
Grinding concrete	7.1 mg/m^3		Akbar-Khanzadeh, Brillhart [2002]
Grinding concrete	0.250 mg/m^3	0.034 mg/m^3*	Croteau et al. [2004]

* With local exhaust ventilation

Photo by NIOSH

Polishing Pads (Different Grit)



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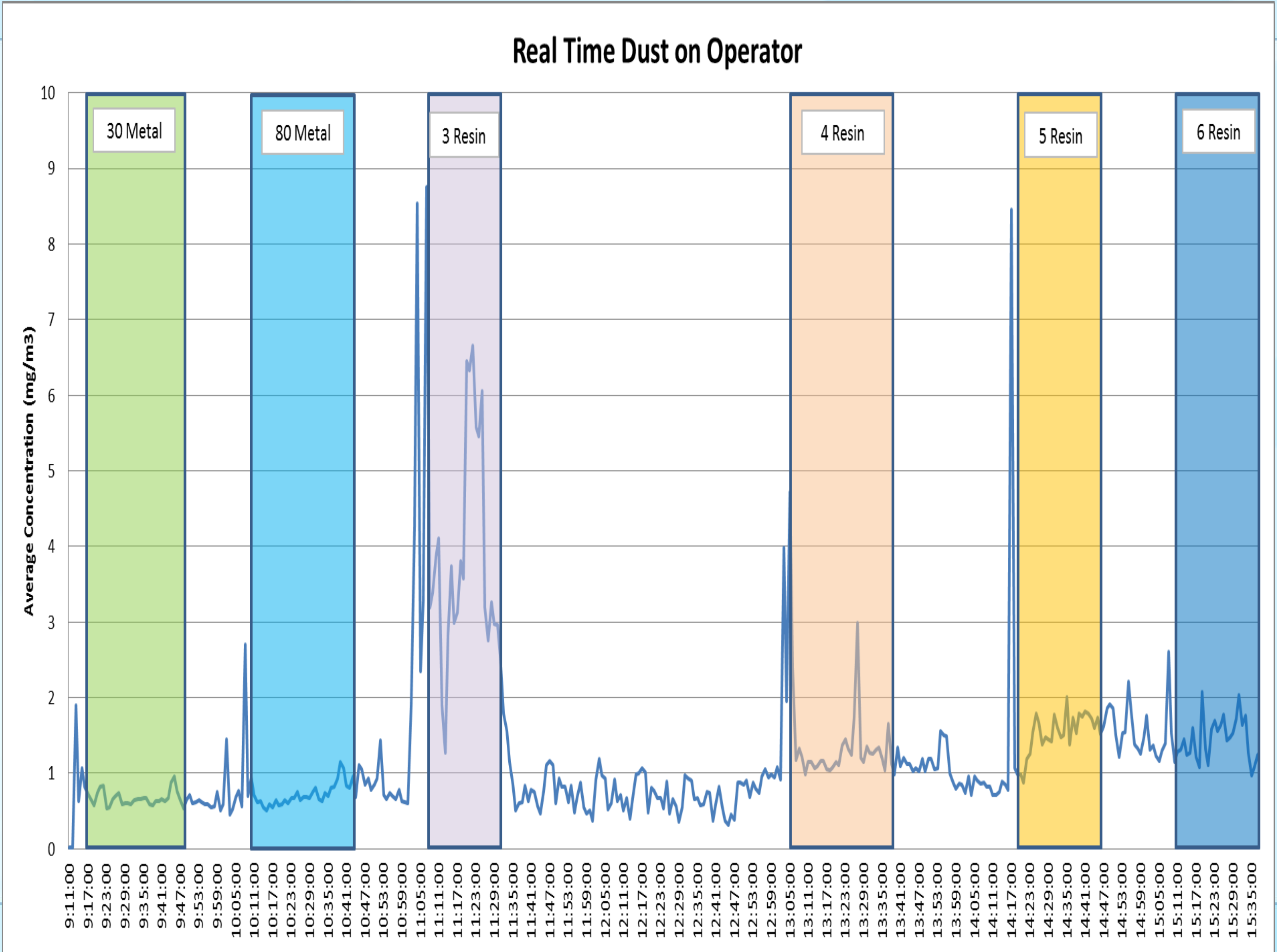

Real Time Dust on Operator
Average Concentration (mg/m3)
30 Metal
80 Metal
3 Resin
4 Resin
5 Resin
6 Resin
0
1
2
3
4
5
6
7
8
9
10
9:11:00
9:17:00
9:23:00
9:29:00
9:35:00
9:41:00
9:47:00
9:53:00
9:59:00
10:05:00
10:11:00
10:17:00
10:23:00
10:29:00
10:35:00
10:41:00
10:47:00
10:53:00
10:59:00
11:05:00
11:11:00
11:17:00
11:23:00
11:29:00
11:35:00
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Asphalt Milling LEV control field studies

rotating cutter drum to grind and remove the pavement to be recycled

Photo by NIOSH

Field Testing Results

Manufacturer	Control	% crystalline silica	PBZ RCS Concentration (mg/m ^{3})	Notes
A	Vacuum	7 - 23%	0.003 - 0.013	Hammond, Shulman, Echt [2016]
E	Wet drum	~14.5%	0.028 - 0.085	Hammond, Shulman, Echt [2016]
B	Local exhaust ventilation	5 - 12%	0.002 - 0.013 (except 1 day at 0.024 – partially clogged)	Hammond, Shulman, Echt [2016]

Summary – Asphalt Milling

- The LEV systems of manufacturers A and B have the potential to significantly reduce worker exposure to respirable crystalline silica during pavement milling operations.
- Following NIOSH recommendations, all manufacturers of half-lane and larger cold milling machines implemented dust controls that include local exhaust ventilation as a control for silica exposures by January 1, 2017.

Published Best Practices Document

- Describes 10years of collaborative research by labor, industry and government Partnership
- Highlights the most successful engineering controls to reduce silica exposures on asphalt pavement milling machines
- Published March 2015

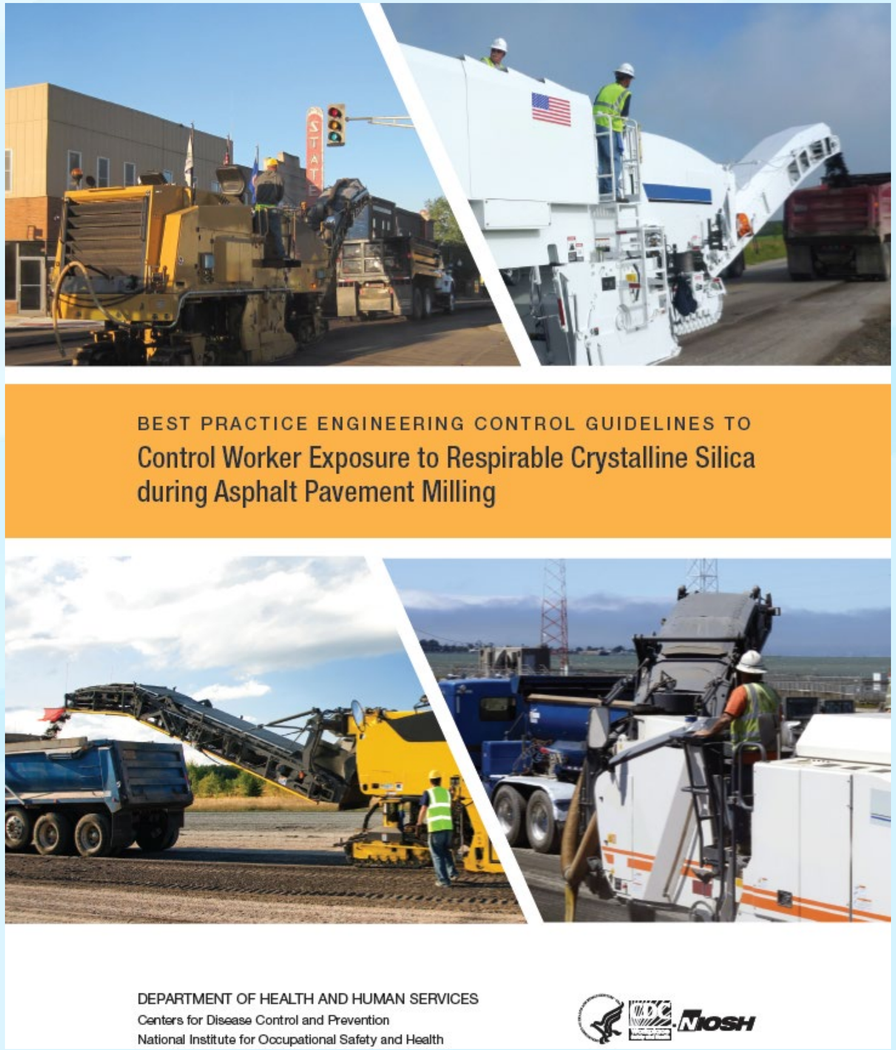


Photo by NIOSH

Photo by NIOSH

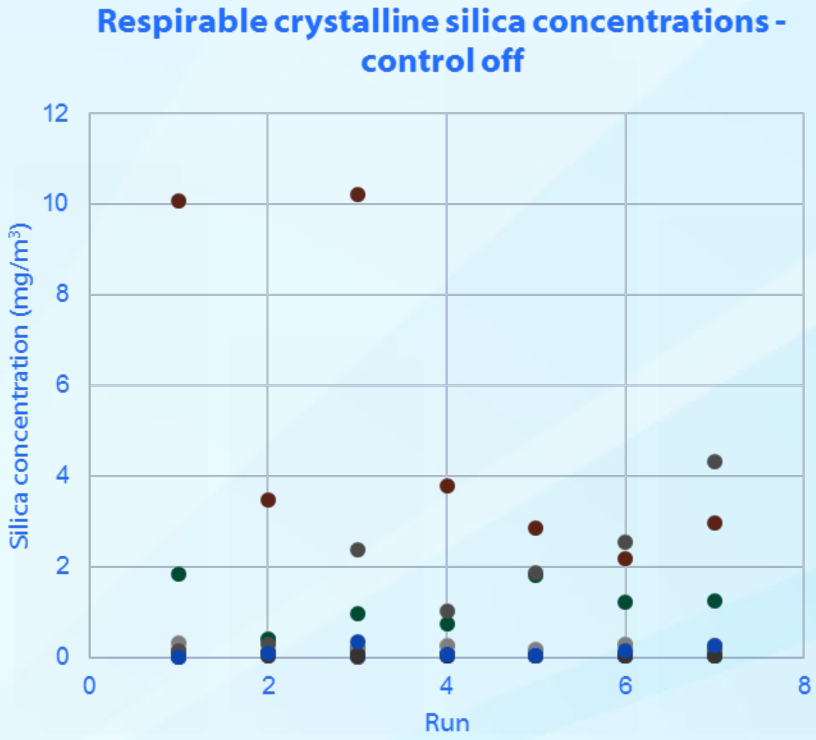
Hydraulic Fracturing Uses Tons of Silica Sand

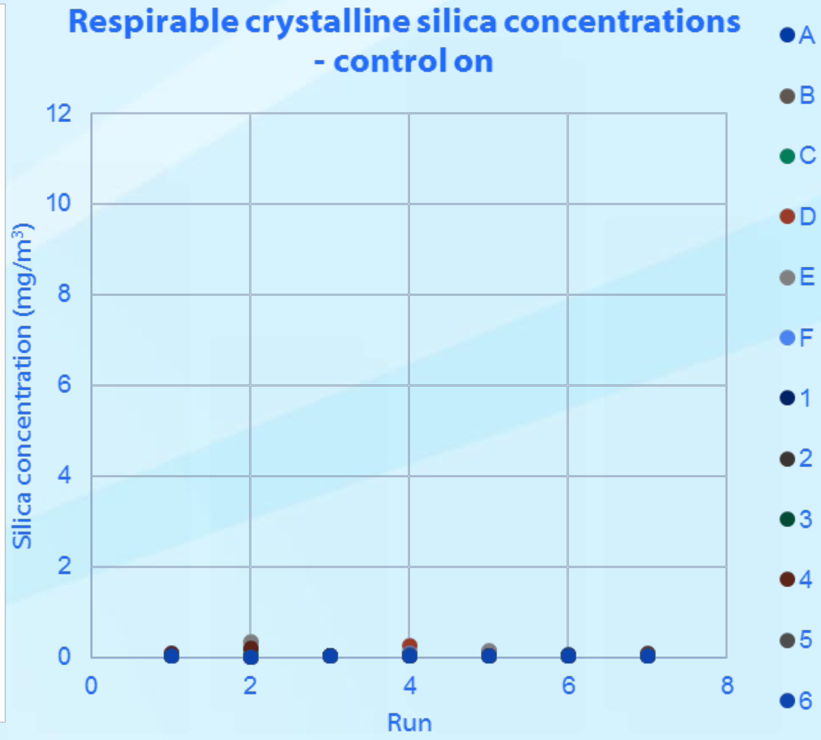
- NIOSH researchers were the first to systematically evaluate occupational exposures to workers at hydraulic fracturing sites [1]
  - Personal breathing zone air samples were collected for workers at 11 sites in 2010 and 2011
  - Out of 111 samples, 93 exceeded the "new" OSHA action level for RCS.
  - RCS exposures for sand mover operators/T-belt operators can be 10-50 times greater than "new" silica PEL

[1] Esswein, Breitenstein, Snawder, et.al,. *Occupational Exposures to Respirable Crystalline Silica in Hydraulic Fracturing* Jour. Occ. Env. Hyg. Vol. 10, Issue 7, May, 2013

Effectiveness of Mini Baghouse Retrofit Assembly

Generation 3 was Demonstrated





Effective Commercial Controls

- Non-silica proppant
- Sand treatments
- Gravity delivery of sand
- Boxed sand
- Dust capture

Stone Countertop Grinding and Polishing

Photo by NIOSH

Stone Countertop Industry

- **High silica content**
  - Granite: a worldwide average of 72.04% (Blatt and Tracy 1997)
  - Engineered quartz stone: 90+%
    - Caesarstone, Made in Israel
    - Silestone by Cosentino, Made in Spain
    - Corian® Quartz (formally Zodiaq®) by DuPont™, Made in Canada
    - Viatera® Quartz by LG, Made in USA
- **Silicosis outbreak**
  - Israel, 25 cases reported in 2012
  - Spain, 46 cases reported in 2014
  - Italy, a silicosis prevalence of 54.5% reported in 2011 (6 out of 11 workers)
  - USA, first silicosis case reported in TX in 2014; 18 cases reported in 2019*
  - Australia, 7 cases reported in 2018
  - Belgium, 2 cases reported in 2018

*Rose, C., et al. (2019). "Severe Silicosis in Engineered Stone Fabrication Workers - California, Colorado, Texas, and Washington, 2017-2019." MMWR Morb Mortal Wkly Rep **68(38): 813-818.**

Wetting Method – Center Water Feed vs Water Spray

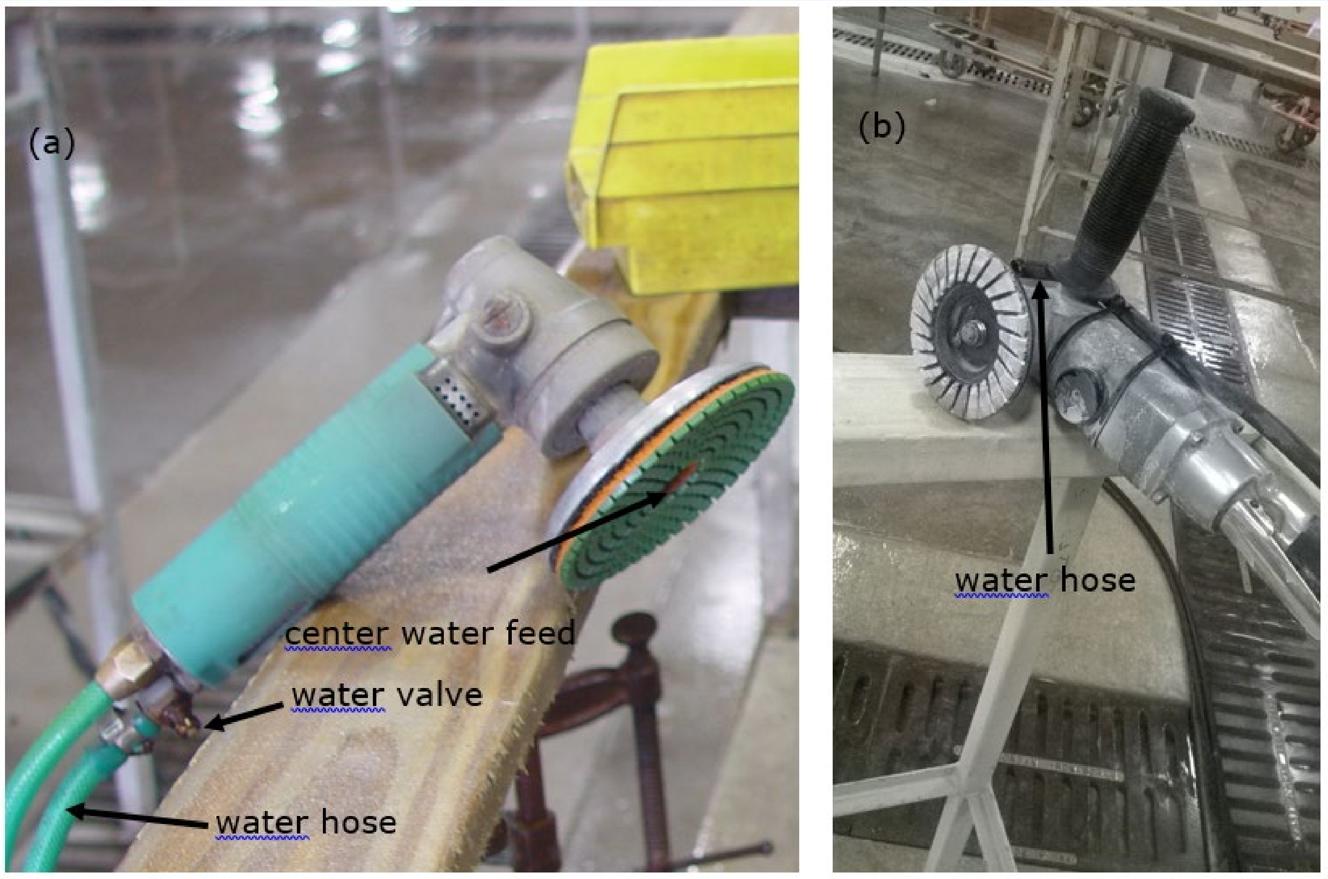


Photo by NIOSH

(a) A handheld pneumatic wet polisher used in the polishing process; (b) A handheld pneumatic wet grinder with a diamond grinding cup wheel used in the final grinding process..

Sheet-Water-Wetting

The TWA exposures from the 10 samples were 123.2±47.5 µg/m3 (mean± standard deviation) and 33.2±11.4 µg/m3 for respirable dust and RCS, respectively.

The mean TWA exposure to RCS was below the REL and PEL levels (50 µg/m3).

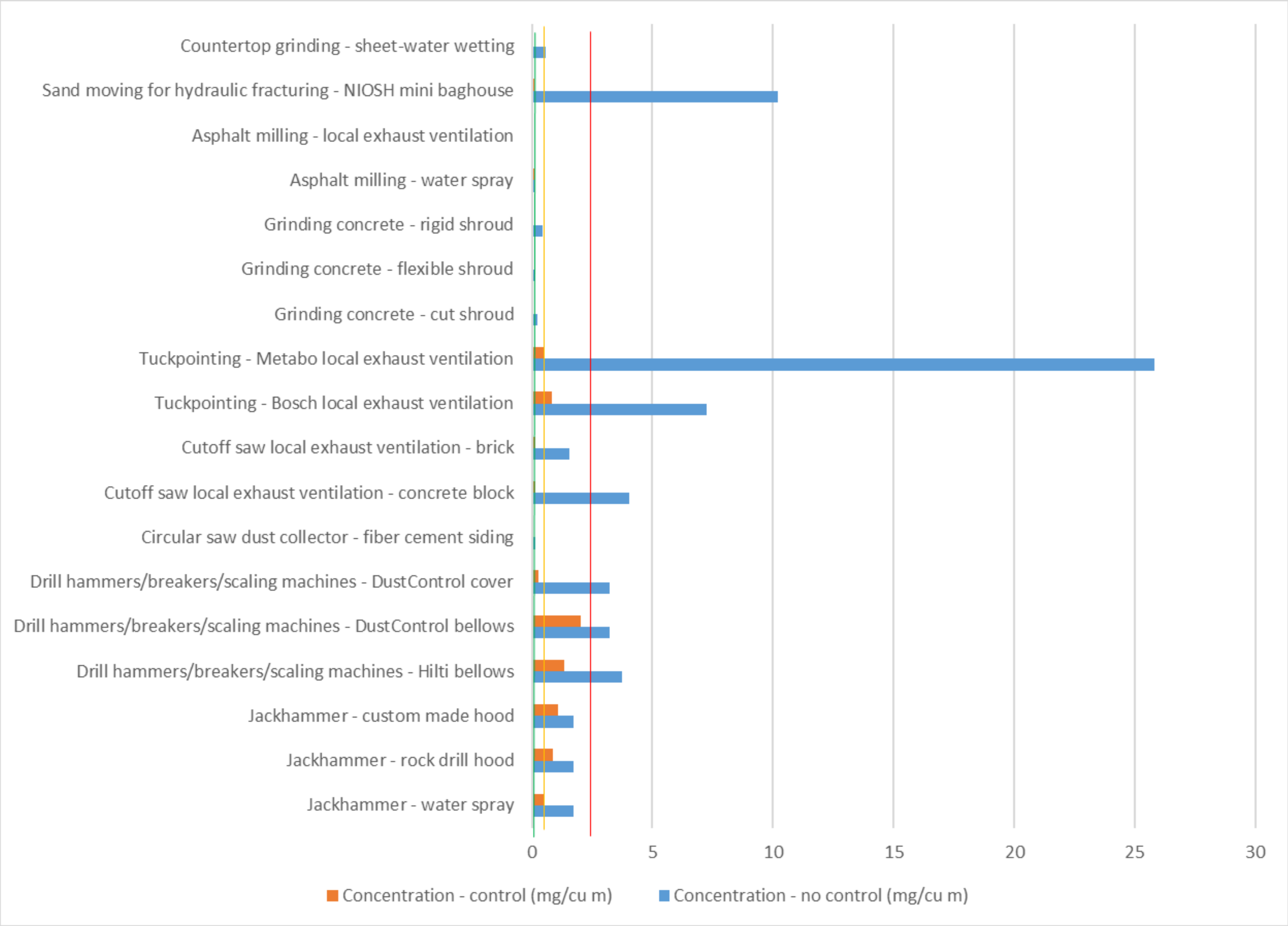
Video Credit: NIOSH

Engineering Controls Can Reduce Exposures

	RCS Exposure		
Task	No Control	Control	Notes
Quartz countertop grinding	0.11-0.58 mg/m^3		Qi and Echt [2019]
Quartz countertop polishing	0.021-0.14 mg/m^3		Qi and Echt [2019]
Mixed* countertop grinding	0.050-0.45 mg/m^3		Qi and Echt [2019]
Mixed* countertop polishing	0.0071-0.099 mg/m^3		Qi and Echt [2019]
Countertop grinding	0.79 mg/m^3	0.17 mg/m^3‡	Qi and Echt [2019]
Countertop grinding		0.033 mg/m^3^	Qi and Echt [2019]

* Quartz and granite ‡With dust control booth ^Sheet-water wetting method

Summary of RCS Levels



Consider partnering with NIOSH to:

- Help advance worker safety and health
- Share your knowledge
- Provide access to worksites for research purposes

Photo by NIOSH

Contact BAlexander@cdc.gov or HHERequestHelp@cdc.gov for further information

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1600 Clifton Road NE, Atlanta, GA 30333
Telephone: 1-800-CDC-INFO (232-4636)/TTY: 1-888-232-6348
E-mail: cdcinfo@cdc.gov Web: http://www.cdc.gov

Additive Manufacturing in the Workplace: Lessons from the Field

Eric Glassford, MS, CIH

Industrial Hygienist

32nd Annual Sustainability and Environmental Health & Safety Symposium; Workshop K
March 28, 2023

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The findings and conclusions in this presentation are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention. Mention of any company or product does not constitute endorsement by NIOSH, CDC.

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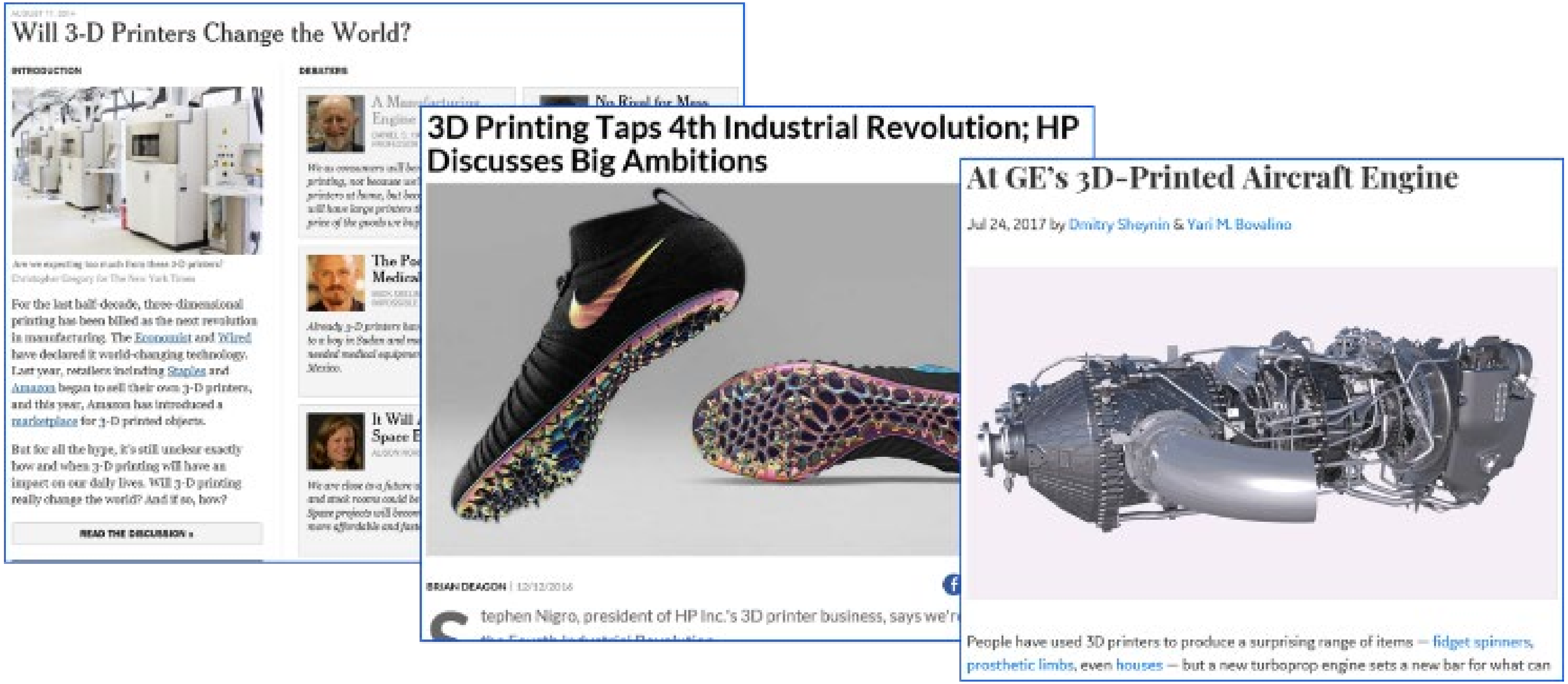
- A member of the Advanced Materials and Manufacturing Field Studies Team for the NIOSH Nanotechnology Research Center.
- Previously worked as an industrial hygienist at Sandia National Laboratories in Albuquerque, NM.
- Certified Industrial Hygienist and received Master of Science in Environmental Health and Industrial Hygiene from the University of Cincinnati.

What do we mean by additive manufacturing?

- Additive manufacturing - uses data computer-aided-design (CAD) software or three-dimensional (3D) object scanners to direct hardware to deposit material, layer upon layer, in precise geometric shapes
  - Also known as 3D printing
  - Form of advanced manufacturing
- Advanced manufacturing
  - Rapid transfer of science and technology into manufacturing products and processes

Additive manufacturing is changing the nature of industry…



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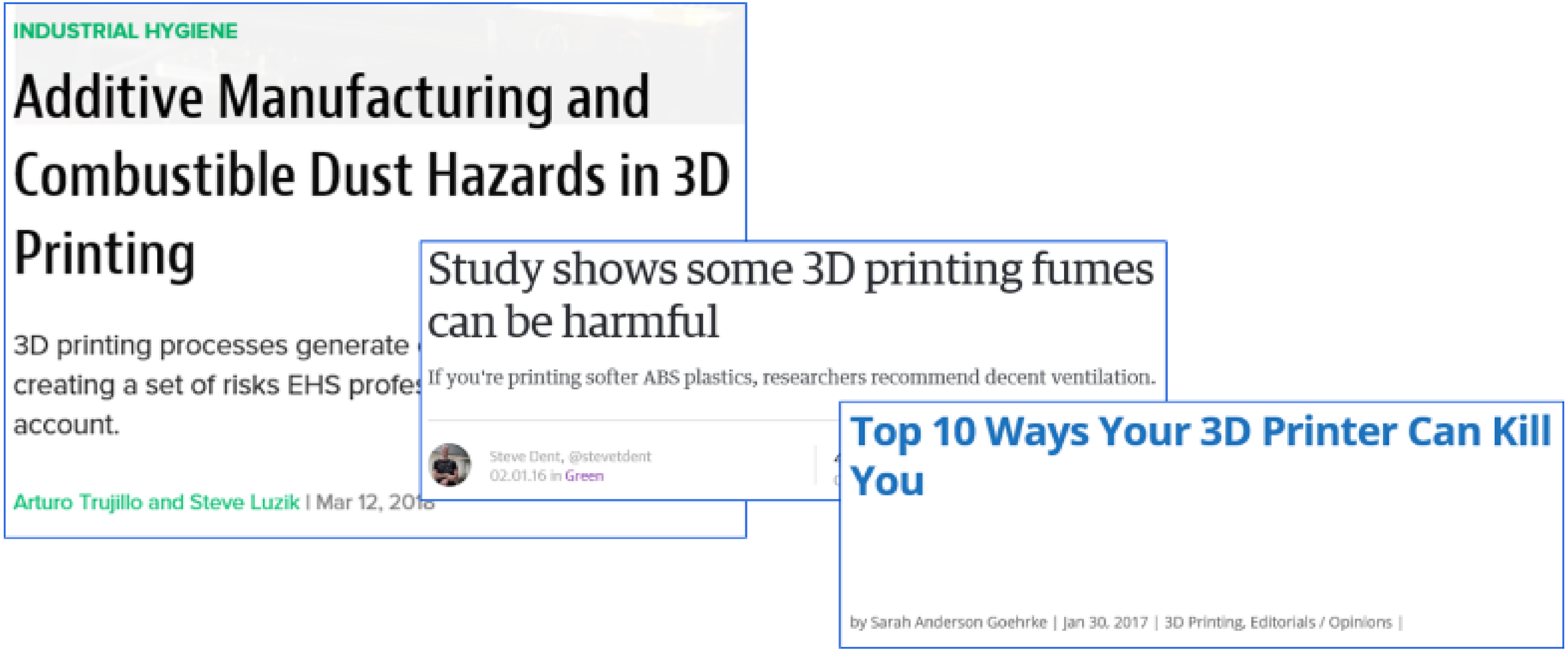
… while also raising safety and health concerns


INDUSTRIAL HYGIENE

Additive Manufacturing and Combustible Dust Hazards in 3D Printing

3D printing processes generate
creating a set of risks EHS profes
account.

Arturo Trujillo and Steve Luzik | Mar 12, 2018

Study shows some 3D printing fumes can be harmful

If you're printing softer ABS plastics, researchers recommend decent ventilation.

Steve Dent, @stevetdent
02.01.16 in Green

Top 10 Ways Your 3D Printer Can Kill You

by Sarah Anderson Goehrke | Jan 30, 2017 | 3D Printing, Editorials / Opinions |

- Dent, Steve (2016). Study shows some 3D printing fumes can be harmful. Endgaget. URL: https://www.engadget.com/2016/02/01/study-shows-some-3d-printing-fumes-can-be-harmful/
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- Trujillo, Arturo and Luzik, Steve (2018). Additive Manufacturing and Combustible Dust Hazards in 3D Printing. EHS Today. URL: https://www.ehstoday.com/industrial-hygiene/additive-manufacturing-and-combustible-dust-hazards-3d-printing

Why is NIOSH Interested?

- The 3D printing market was valued at $10.6 billion in 2021
- Expected to grow to $50 billion by 2030

- Studies show workers are being exposed to emissions from 3D printing processes
- Studies report workers are experiencing health effects from occupational exposure to 3D printing emissions including ultrafine particulate(UFPs)

Forbes, 4/25/22:
https://www.forbes.com/sites/michaelmolitch-hou/2022/04/25/three-areas-holding-back-the-106b-3d-printing-industry/?sh=24faaa434935

What materials and process are used?

Solid plastics used in

Fused Filament Fabrication

Metal powders used in

Direct Metal Laser Melting, Powder Bed Fusion

Liquid resins used in

Stereolithography, Vat Polymerization

Potential occupational hazards of additive manufacturing

Category	Feedstock Materials	Feedstock Forms	Binding/fusing	Most prominent potential hazards
Material extrusion	Thermoplastics (may include additives)	Spooled filament, pellet, or granulate	Electrical heating, element-induced melting/cooling	Inhalation exposures to VOCs, particulate, additives, burns
Powder bed fusion	Metal, Ceramic, or plastic	Powder	High- powered laser induced curing	Inhalation/dermal exposure to powder, fume, explosion; laser/radiation exposure
Vat photopolymerization	Photopolymer	Liquid resin	Ultraviolet-light induced curing	Inhalation of VOCs; dermal exposure to resins and solvents, ultraviolet exposures
Material jetting	Photopolymer or wax	Liquid ink	Ultraviolet-light induced curing	Inhalation of VOCs; dermal exposure to resins and solvents, ultraviolet exposures
Binder Jetting	Metal, Ceramic, plastic, or sand	Powder	Adhesive	Inhalation/dermal exposure to powder; explosion; inhalation of VOCs, dermal exposure to binders
Sheet Lamination	Metal, ceramic, or plastic	Rolled file or sheet	Adhesive or ultrasonic welding	Inhalation of fumes, VOCs; shock, laser/radiation exposure

Gary A. Roth, Charles L. Geraci, Aleksandr Stefaniak, Vladimir Murashov & John Howard (2019). Potential occupational hazards of additive manufacturing. Journal of Occupational and Environmental Hygiene, 16:5, 321-328, DOI: 10.1080/15459624.2019.1591627

Note: Hazards in printing, post -processing, and support -processing activities

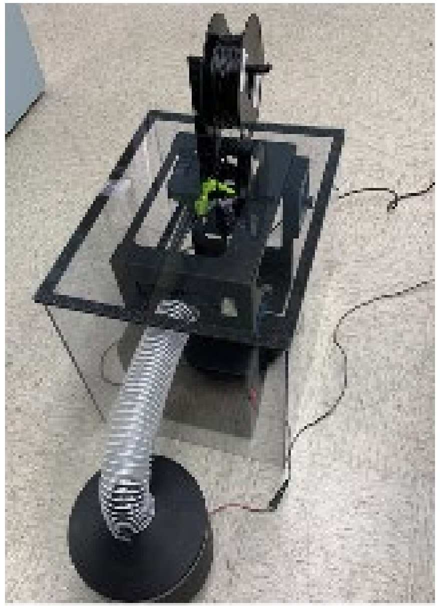
What is NIOSH doing?

- Assessing and characterizing potential exposures to additive and 3D printing emissions in a variety of settings
  - Field assessments have included printer manufacturing, aerospace additive manufacturing, universities and K-12 schools
  - Assessments include worker exposure to particles, metals, VOCs and emissions
- Assessing effectiveness of engineering controls to capture and remove emissions
  - Lab and field evaluations of controls have included the effectiveness of enclosures and custom designed extruder mounted LEV
- Developing risk assessment and management guidance for advanced material producers, users, and additive manufacturing users

Examples from the field

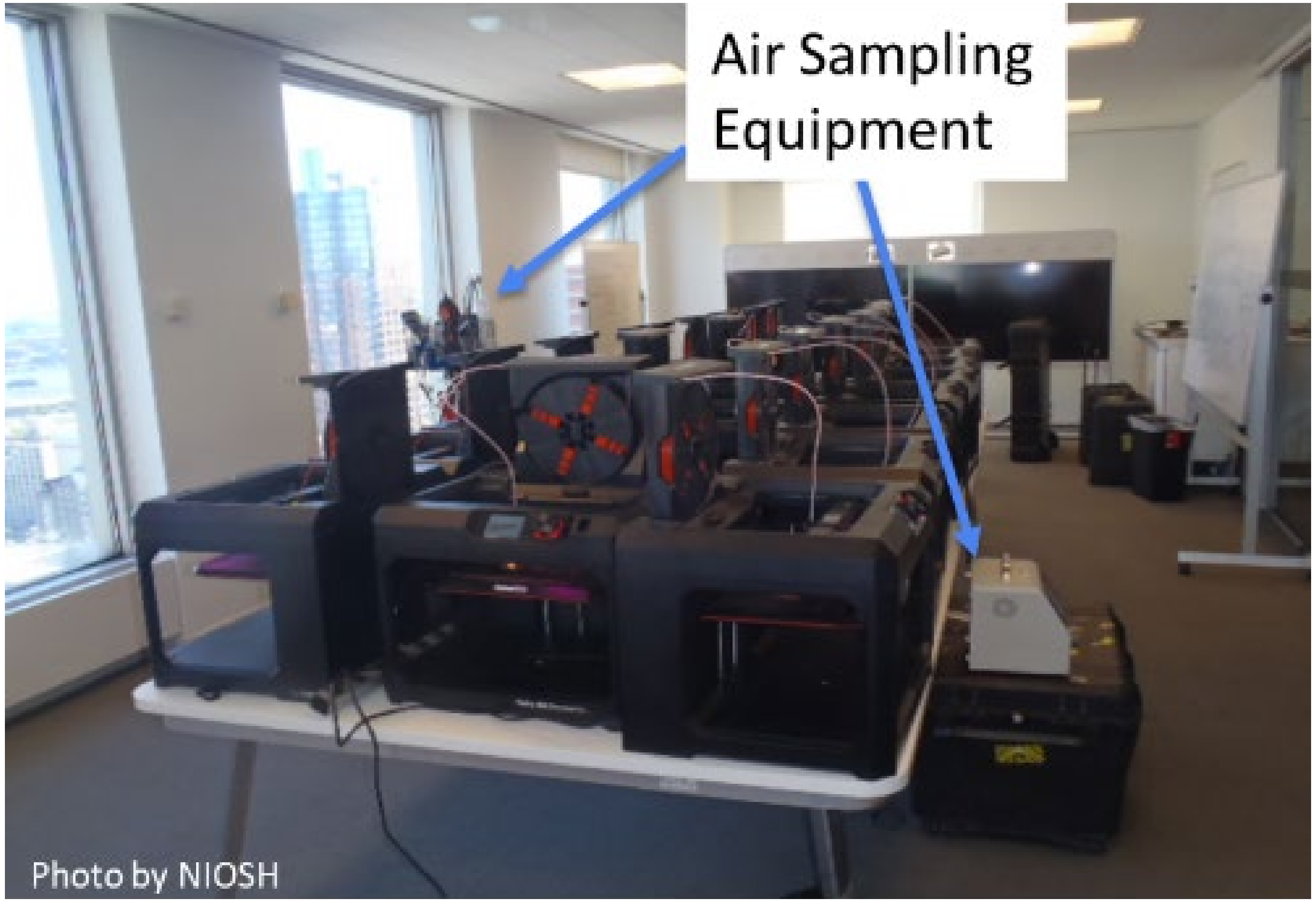
Controlling exposure to 3D printing emissions

- Assessed single and multi-printer ventilated enclosures—control efficiencies are greater than 99%
- NIOSH has evaluated several custom designed and built extruder-mounted LEV controls—control efficiencies are greater than 90%
- The 3D model for a local exhaust ventilation control has been published to the NIH 3D print site - Discover 3D Models | NIH 3D Print Exchange and assigned model #: 3DPX-015467
  - Dunn, K.L., Hammond, D., Menchaca, K., Roth, G., Dunn KH. Reducing ultrafine particulate emission from multiple 3D printers in an office environment using a prototype engineering control. J Nanopart Res 22, 112 (2020).

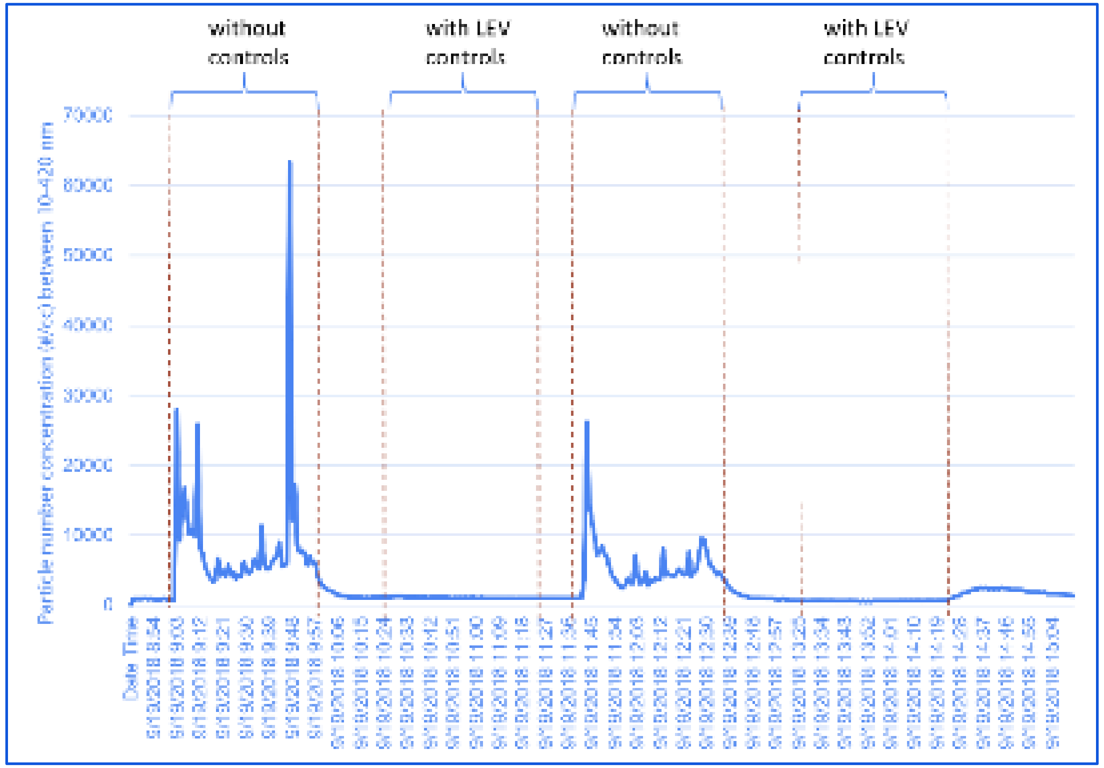


Photos by NIOSH

Collaboration with a major FFF Printer-manufacturer in June 2017, follow-up 2018



Evaluation of NIOSH-developed engineering controls to reduce emissions from 3D printers

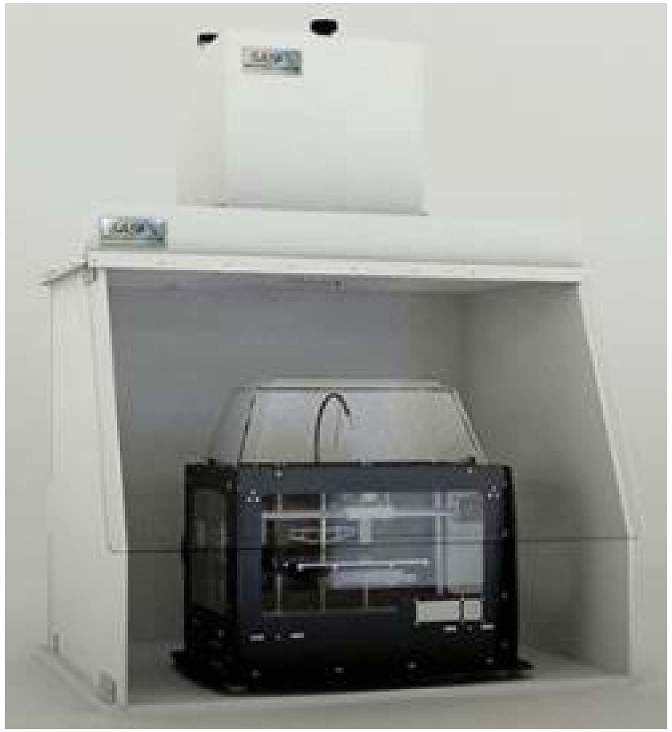


Assessment at a public university

- 5 separate locations across campus
  - Each location had multiple types of 3D printers used by teachers, student-workers, and students
  - Mixture of labs designed for makerspaces, traditional chemistry-type labs, and traditional classrooms
  - Printer types included filament, vat polymerization, and polyjet
- We detected chemical and particle emissions from 3D printers in the air
- Work practices and policies could result in unnecessary exposures

Selected recommendations

- Use engineering controls and increased ventilation to control 3D printing emissions
  - Enclose desktop printers with ventilation or use local exhaust ventilation
  - Keep doors to the 3D printer enclosures closed when possible
  - Connect local exhaust ventilation to exhaust ports of larger, industrial-style printers

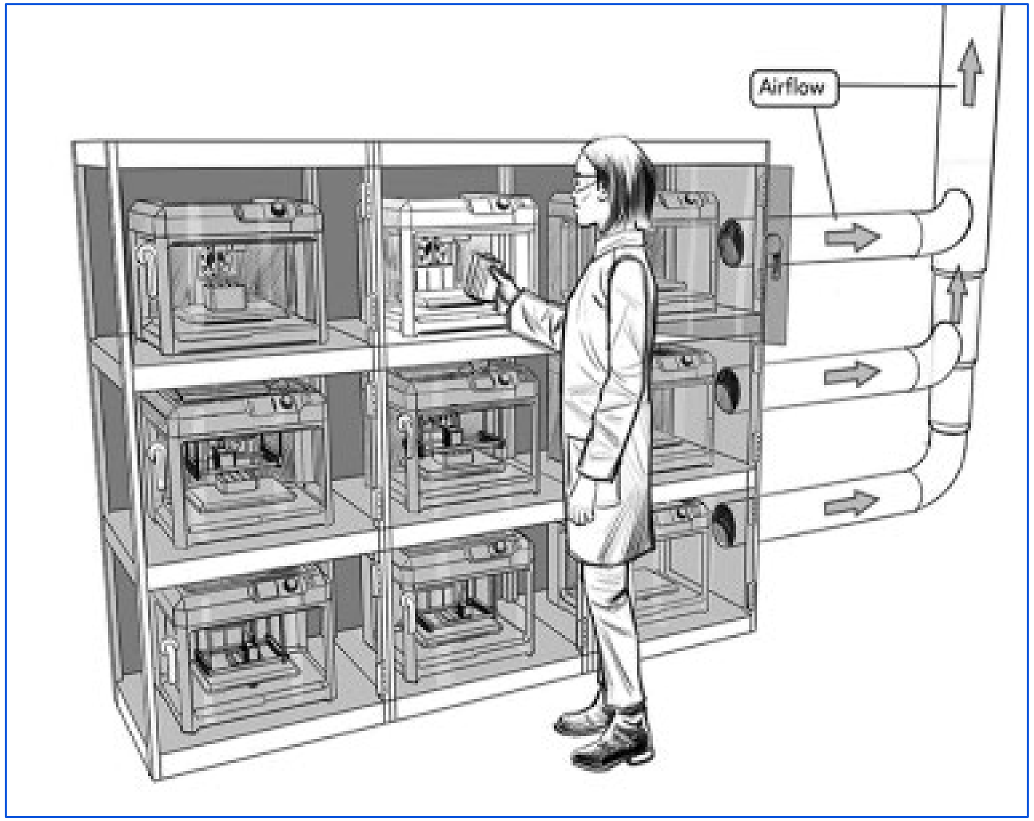


Example of a ventilated enclosure that contains and captures 3D printer emissions. Photo by NIOSH.

Selected recommendations (cont.)

3D printed pieces attached to a fan and HEPA filter

Attach to 3D printer head with hose



Example of a ventilated enclosure for multiple 3D printers. Each row of 3D printers is exhausted through the side of the enclosure. Image by NIOSH.

Photos by NIOSH

Metal powder printing assessments

- Multiple direct metal laser melting printers in segregated areas
- Site visit included:
  - Personal and area air sampling for particulates and subsequent analysis for aluminum, cobalt, chromium, copper, molybdenum, nickel, titanium
  - Direct Reading Instruments (particle counters) to measure process and non-process particulate emissions
- Additional personal and area air sampling during the building of printed parts using cobalt chromium blended powders

Full-shift personal air samples for cobalt

		Cobalt concentration ($\mu g/m^3$)
Day 1		
	Employee 1	10
	Employee 2	44
	Employee 3	5
Day 2		
	Employee 1	31
	Employee 2	30
	Employee 3	15
NIOSH REL		50
OSHA PEL		100
ACGIH TLV		20

REL=Recommended exposure limit
OSHA PEL=Occupational Safety and Health Administration Permissible exposure limit
ACGIH TLV=American Conference of Governmental Industrial Hygienist Threshold limit value

We saw dust escaping…

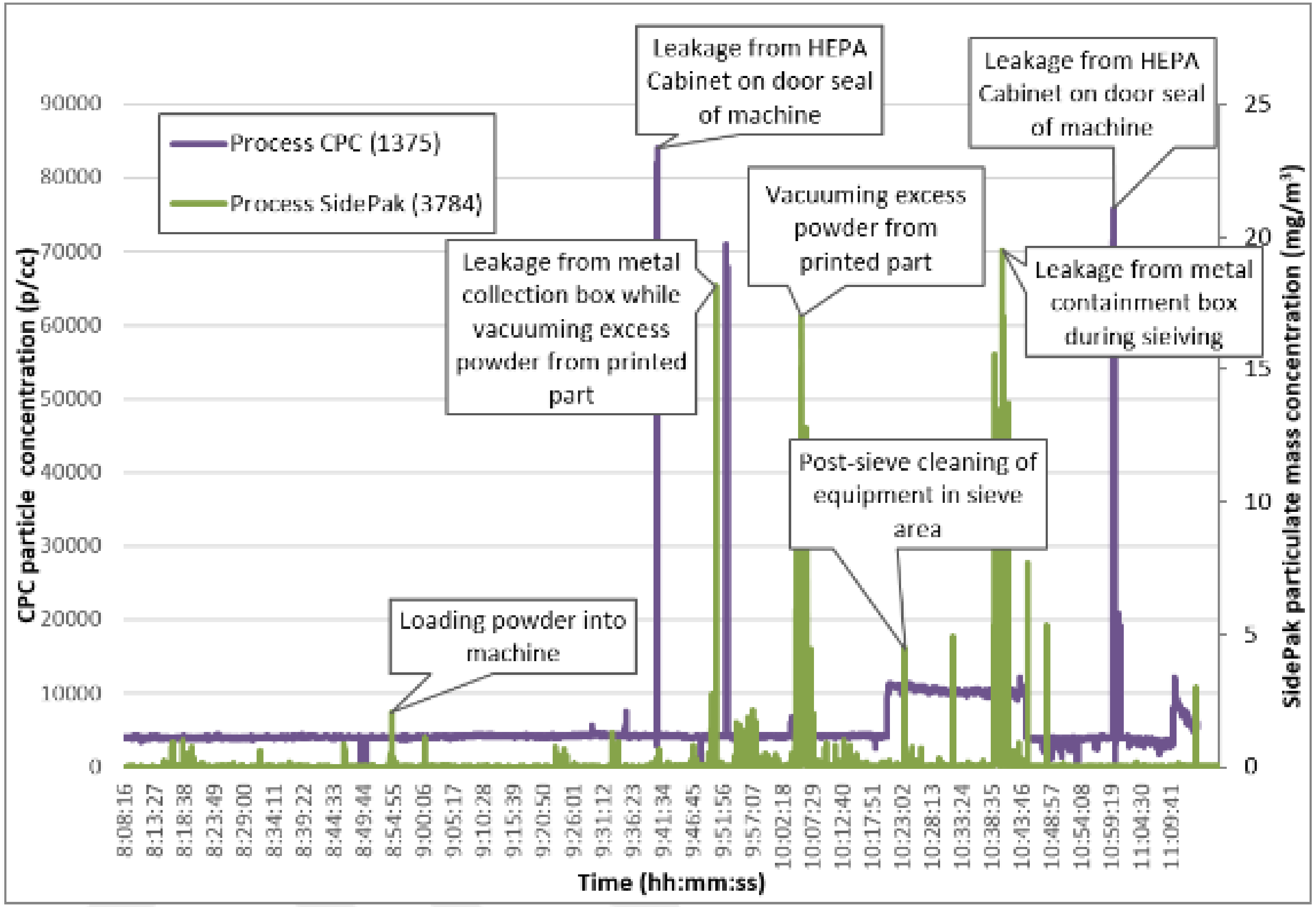
Powder handling

- Manually loaded powder into the printer
- Vacuumed powder from printer during unloading
- Manually scooped metal powder for transfer to containers

Maintenance and cleaning

- Manually cleaned the interior chamber of the printer
- Replacing the HEPA filters attached to the printers
- Emptied the HEPA vacuum waste containers

Identifying emissions during printing and powder handling



What did the AMMFT recommend?

Engineering Controls

- Install and/or improve seals on powder containing devices
- Replace seals on HEPA filtration units attached to machines when leaking
- Enclose the powder loading and unloading process and use LEV during powder transfers
- Use sticky mats at exits of processing areas

Administrative Controls

- Prohibit eating and drinking in processing areas
- Increase frequency of housekeeping and wet wiping equipment
- Limit access to essential personnel only, keep visitors and non-area employees out during powder handling

PPE

- Increase frequency of changing gloves
- Wear required respiratory protection when working near powder handling activities
- Leave used PPE like gloves in processing areas, and increase frequency of hand washing

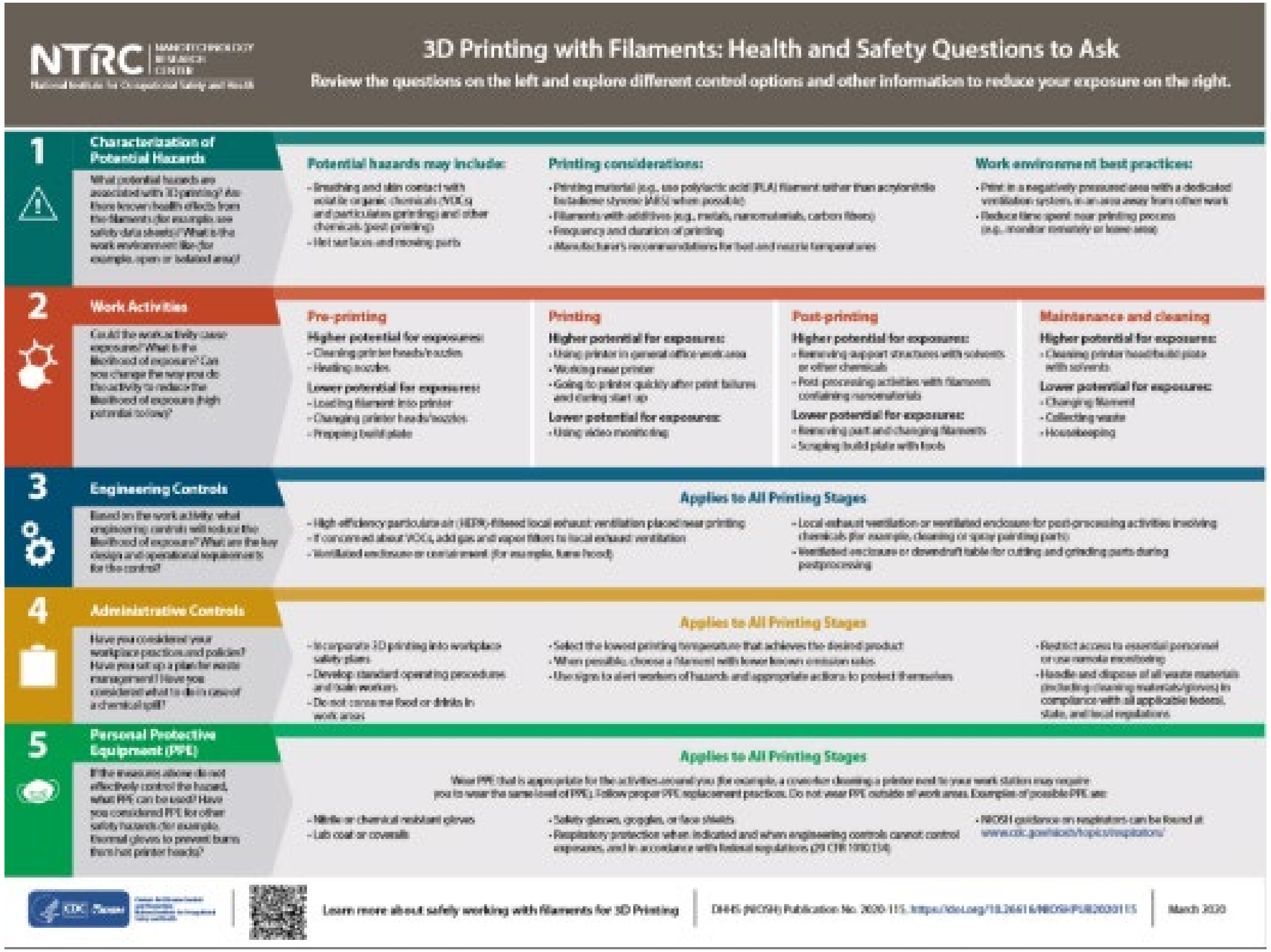
Enclosing the powder loading and unloading process

Example configuration that uses a clear panel to close out part of the opening of a metal powder printer. A high-efficiency particulate air-filtered vacuum could be attached to the panel to move powder plume away from the worker while loading or unloading powders. Image by NIOSH

NIOSH resources

NIOSH products related to 3D printing

- 3D Printing with Filaments: Health and Safety Questions to Ask
  - NIOSH Publication Number 2020-115
- Guides readers through health and safety questions to consider, and provide different control options and information to help reduce exposures



NIOSH products related to 3D printing

- 3D Printing with Metal Powders: Health and Safety Questions to Ask
  - NIOSH Publication Number 2020-114

NTRC Nanotechnology Research Center

National Institute for Occupational Safety and Health

3D Printing with Metal Powders: Health and Safety Questions to Ask

Review the questions on the left and explore different control options and other information to reduce your exposure on the right.

1 Characterization of Potential Hazards

Potential hazards may include:

Printing considerations:

Work environment best practices:

2 Work Activities

Pre-printing

Printing

Post-printing

Maintenance and cleaning

3 Engineering Controls

Pre-printing

Printing

Post-printing

Maintenance and cleaning

4 Administrative Controls

Applies to All Printing Stages

5 Personal Protective Equipment (PPE)

Applies to All Printing Stages

Learn more about safely working with metal powders for 3D Printing

March 2020

Publication and NIH 3D print exchange

- Dunn, K.L., Hammond, D., Menchaca, K., Roth, G., Dunn KH. Reducing ultrafine particulate emission from multiple 3D printers in an office environment using a prototype engineering control. J Nanopart Res 22, 112 (2020).

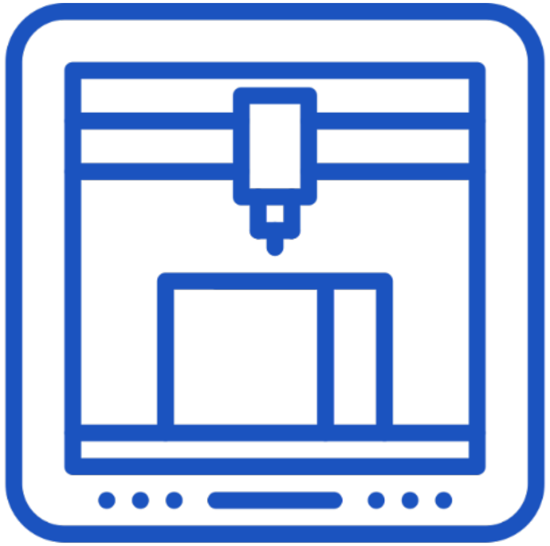
- The 3D model for the Local Exhaust Ventilation Control has been published to the NIH 3D print site - Discover 3D Models | NIH 3D Print Exchange and assigned model #: 3DPX-015467

Closing thoughts

- NIOSH researchers continue to collect occupational exposure data during advanced and additive manufacturing activities
- Our goal is to provide this data so that people can make informed health, safety, and environmental risk management decisions
- We hope to use laboratory and field-based research data to responsibly guide these rapidly developing technologies
- We do not yet know the “safe” or target exposure level for most of these materials. However, traditional IH safety, control, and work practice guidance are effective in reducing or eliminating exposures

With thanks and appreciation

- NIOSH Nanotechnology Research Center:
- Kevin L. Dunn: Advanced Materials and Manufacturing Field Team Leader
- Kevin H. Dunn: Engineering control technologies
- Duane Hammond: Engineering control technologies
- Aleks Stefaniak: Nano and Advanced lab and field research
- Gary Roth: Market surveillance & special projects
- Jessica Li: Industrial hygienist



Created by lastspark
from Noun Project

Special thanks to Kevin L. Dunn and Duane Hammond for work on projects featured in this presentation.

Thank you!

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For more information, contact CDC
1-800-CDC-INFO (232-4636)
TTY: 1-888-232-6348 www.cdc.gov

Exposure-Protection Integrated Communicator (EPIC) to Improve and Promote PPE Usages in Ohio Workplace

Jun Wang, PhD, PE, CIH, CSP, CHMM

Division of Environmental and Industrial Hygiene
Department of Environmental and Public Health Sciences
College of Medicine
University of Cincinnati
E-mail: jun.wang@uc.edu

Outline

- Project Team
- Background
- Device Development
- Testing Results
- Future work

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Project Team

- **Current project leadership**
  - PI: Dr. Jun Wang (DEPHS)
  - Co-PIs: Dr. Tao Li (EECS), Dr. Mingming Lu (CEE), Dr. Simone Balachandran (CEE)
- **Team members (graduate students unless otherwise noted)**
  - EPIC development: Chandra Choudhary, Tianshuo Wang, Sumedha Prabhu (post-doc)
  - Lab test: Michael Yermakov (Senior research associate), Xinyi Niu, John Singletary
  - Field test: Reshmasri Deevi, Alyssa Yerkeson
  - Data analysis: Rachel Tumbleson, Dexter Adams

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Background

- Inhalation exposure to particles in respirable and inhalable fractions is commonly seen in manufacturing and other sectors in Ohio.

Figure: (left) a welder exposed to welding fume (right) a granite countertop worker dry cutting a slab

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Background

- PPE against particles: respirators
  - Not mandatory: lack of awareness of hazardous environmental and personal exposure conditions.
  - Not effective: when respirators were used, the respirator is often not well fitted or loses protection during work.

Figure: a typical respirator fit test using a PortaCount

PortaCount is an instrument using a single particle counter and requiring alcohol to operate

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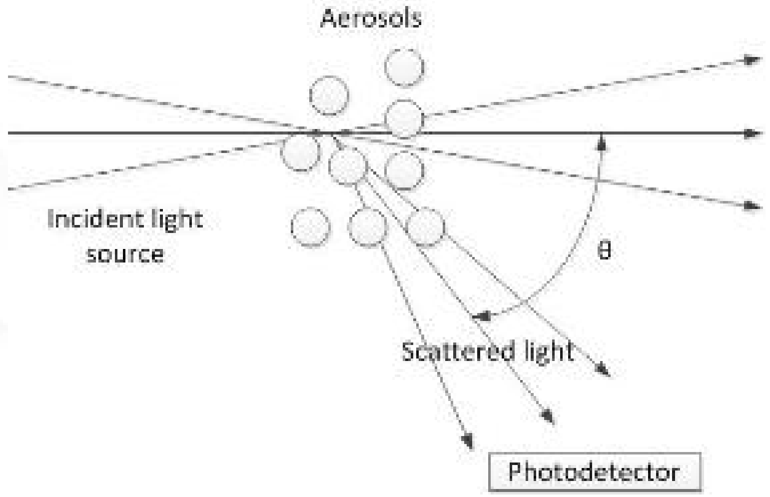
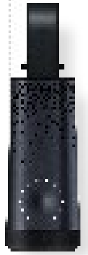
Background

- Emerging of low-cost optical based particle sensors



Performance of sensors depend on
- Optical properties of particle
- Size of particle
- Shape of particle
- Moisture content



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Background

- The work scope of this project is to develop a device called Exposure-Protection Integrated Communicator (EPIC).
  - EPIC comprises a series of sensors to monitor environmental concentration, personal exposure, respirator protection factor
  - A central processing unit that receives the data, compares them with occupational exposure limits (OEL) and assigned protection factor (APF), then notifies the workers through categorized status alarms.
  - Test EPIC in the lab and field to study its performance, accuracy, practicality and other potential issues.

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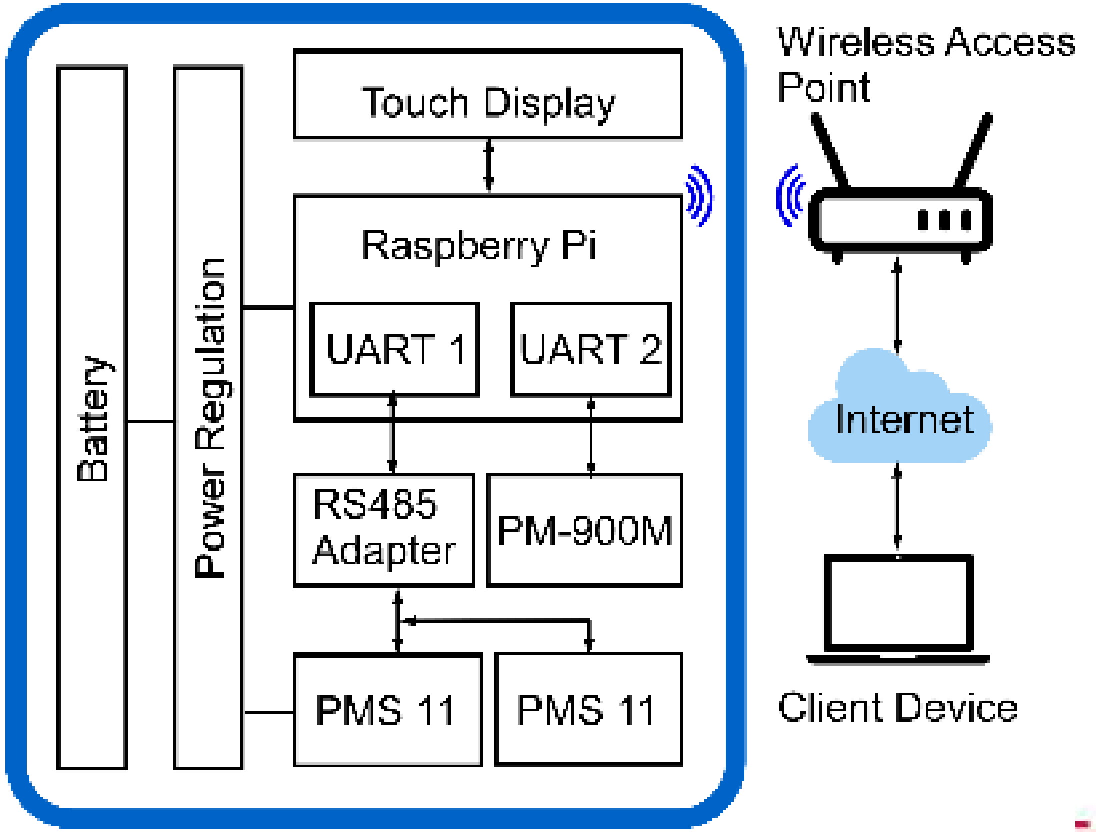
EPIC Development

- Fully packaged device with 3 integrated PM sensors.
- Integrated touchscreen with custom-built user interface.
- Sensor data wirelessly transferred to cloud through Internet, allowing remote data access and processing.



EPIC

System Concept Diagram

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Sensor Selection (respirator)

- Conducted broad investigation of commercially available PM sensors

Particle Sensor	PMS20	PMS10	PMS11	SN-GCJA5
Manufacturer	Temptop	Temptop	Temptop	Panasonics
Type	Particle monitor	Particle monitor	Particle counter	Particle monitor
Concentration Range	PM1.0: 0-10000 µg/m³ PM2.5: 0-10000 µg/m³ PM10: 0-10000 µg/m³	PM1.0: 0-2000 µg/m³ PM2.5: 0-5000 µg/m³ PM10: 0-5000 µg/m³	0-100000 #/cm³ in seven different channels	0µg/m³ – 2,000µg/m³ (UART)
Dimension (mm³)	223.6*120*70	113*88*38	113*88*38	37*37*12
Communication	RS485	RS485	RS485	I²C, UART
Power supply	12V	12V	12V	DC 5V/3.3V
Input current	3500mA	700mA	700mA	<100mA
Standby current	30mA	30mA	30mA	-
Response Time	10s	20s	6s	1s

- 2x PMS-11 selected for monitoring respirator protection factor
  - Includes integrated pump, measures particle count, lower response time

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Sensor Selection (environmental)

Particle Sensor	HPMA115C0-003	PMS6003	101020613 (HM3301)	PM-900M
Manufacturer	Honeywell	Plant Tower	Seed Technology Co. Ltd	Temptop
Type	Particle monitor	Particle monitor	Particle monitor	Particle monitor & counter
Concentration Range	0~1000ug/m^3	±10% @ 100~500μg/m^3 ±10μg/m^3@0~100 μg/m^3	1~500μg/m^3 (Effective range) 1000μg/m^3 (Maximum range)	0~999ug/m^3
Dimension (mm^3)	44*36*12	38*35*12	Not Available	47.9*36.8*11.8
Communication	UART	I^2C	I^2C	UART
Power supply	5V +- 0.2V	DC 5V	3.3V/5V	DC 5V+-0.1V
Input current	<80mA	<=100mA	-	100mA
Standby current	<20mA	<=200uA	-	-
Response Time	<6s	<1s (Single Response time) <10s (Total Response time)	-	<1s

PM-900M selected for environment monitoring

- Provides both particle count and concentration data,
- Small size and fast response

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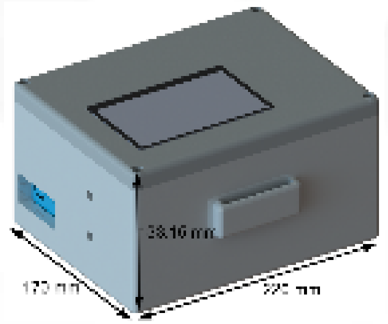
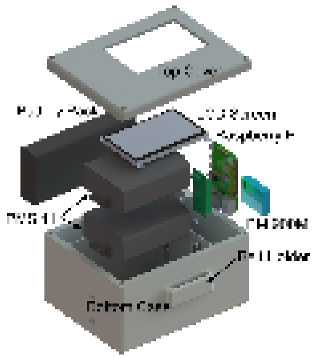
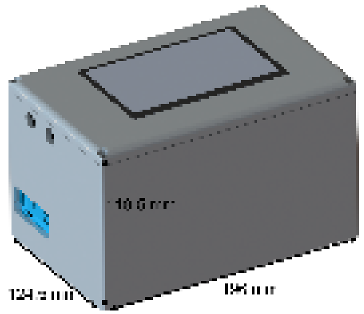
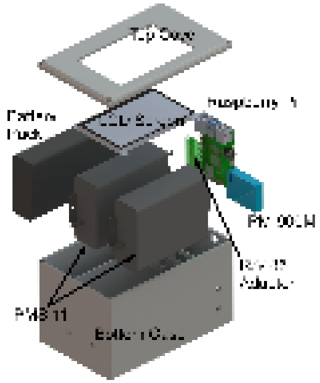
EPIC Design

	Assembled View	Exploded View	Size/Volume
Ver 1.2 (demo at OSC 2023)			L x W x H: 220 x 170 x 133 mm^3 Volume: 4975 cm^3
Ver 1.3			L x W x H: 220 x 170 x 133 mm^3 Volume: 3011 cm^3 (39% reduction)

New package size (V1.3) significantly reduced (by 39%) from V1.2 through improvements in component arrangement and integration method.

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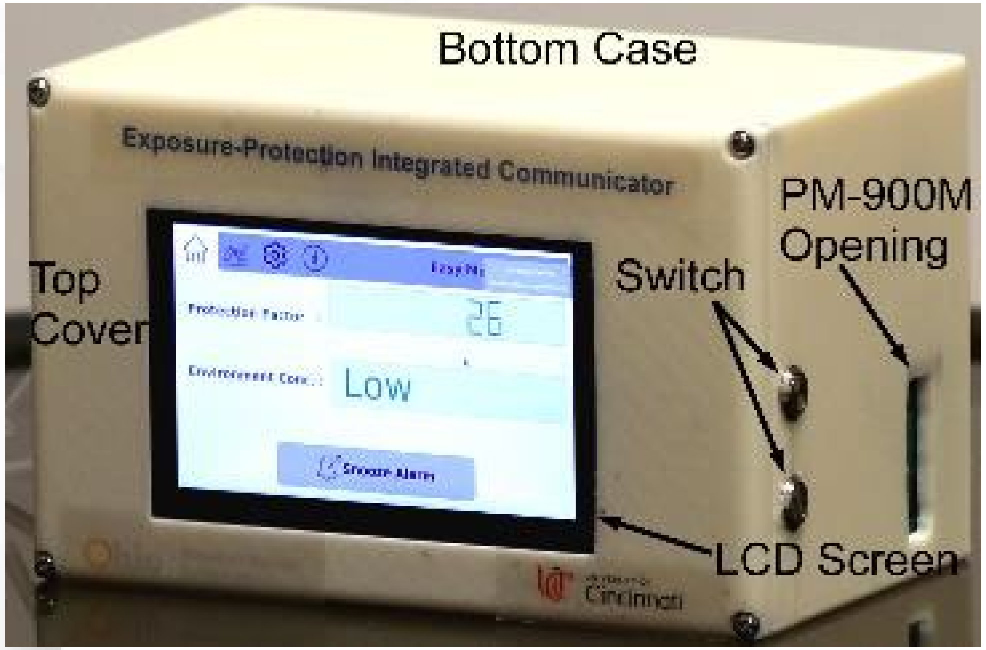
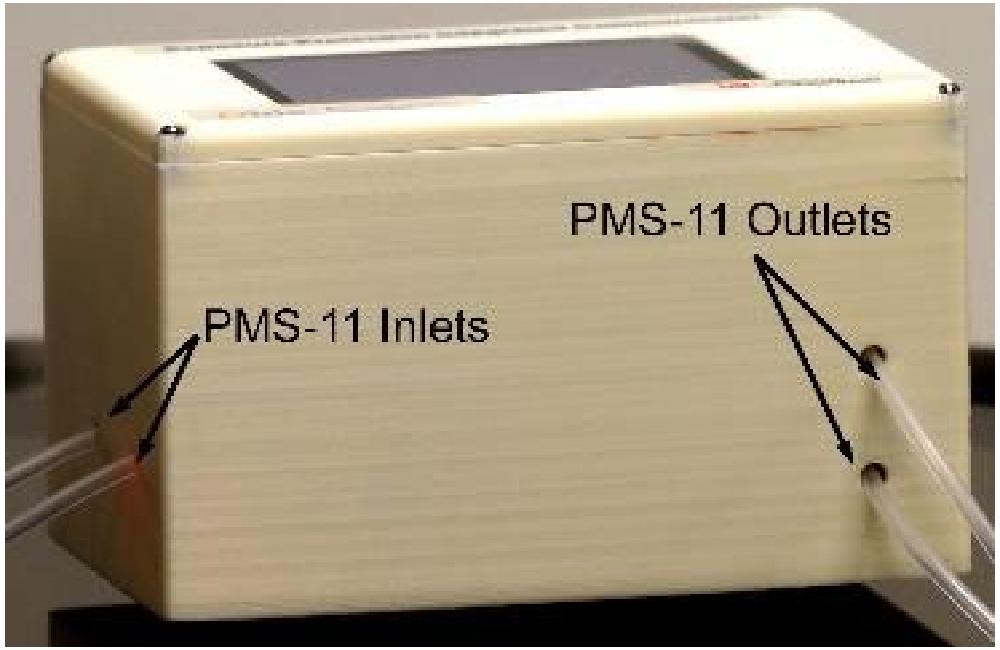
EPIC Fabrication

- 3D printed device package with all components integrated inside
- All planned functions implemented





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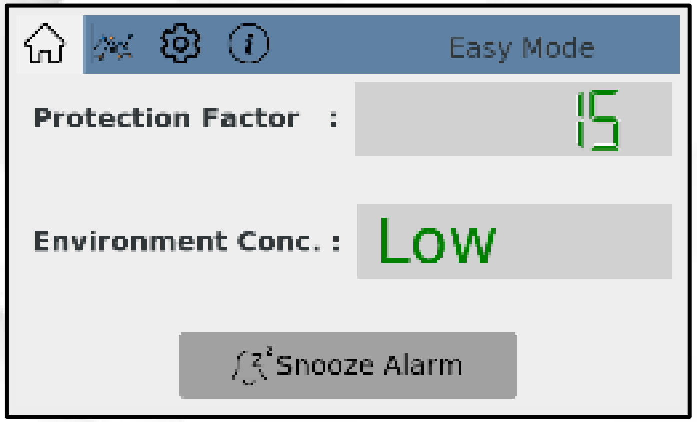
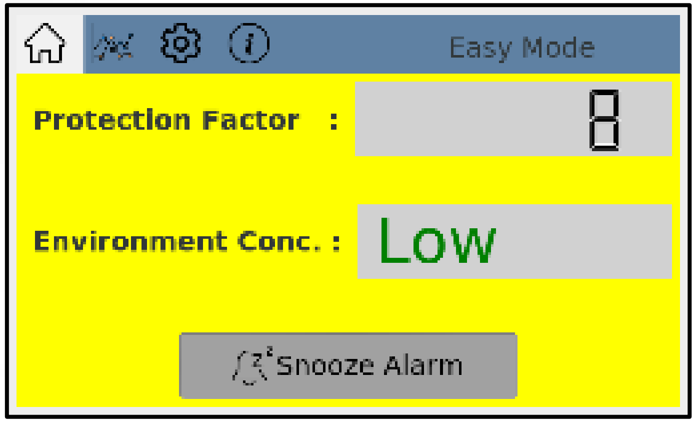
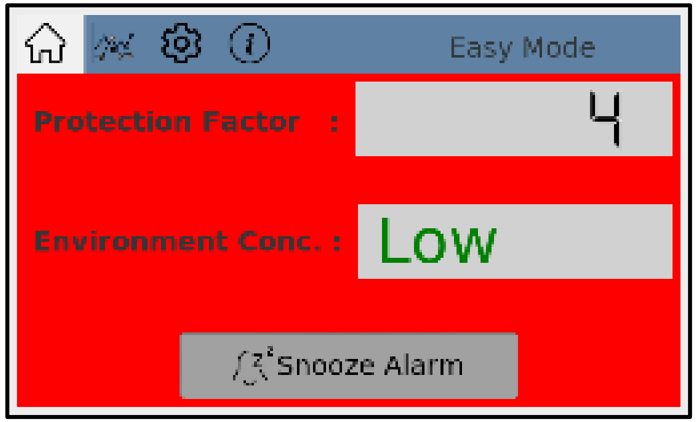
EPIC UI Design ("easy" mode)



Normal state (protection factor above high threshold)



Alarm triggered every 3 sec (protection factor between high and low thresholds)



Alarm triggered every 1 sec (protection factor below low threshold)

- 5" touchscreen for user interaction
- "Easy Mode" screen in default
- Screen flashes in yellow for medium level reduced protection factor, or in red for low level
  - Threshold adjustable in settings
- Provides audible alarm with color screen flashes, with option to snooze alarm

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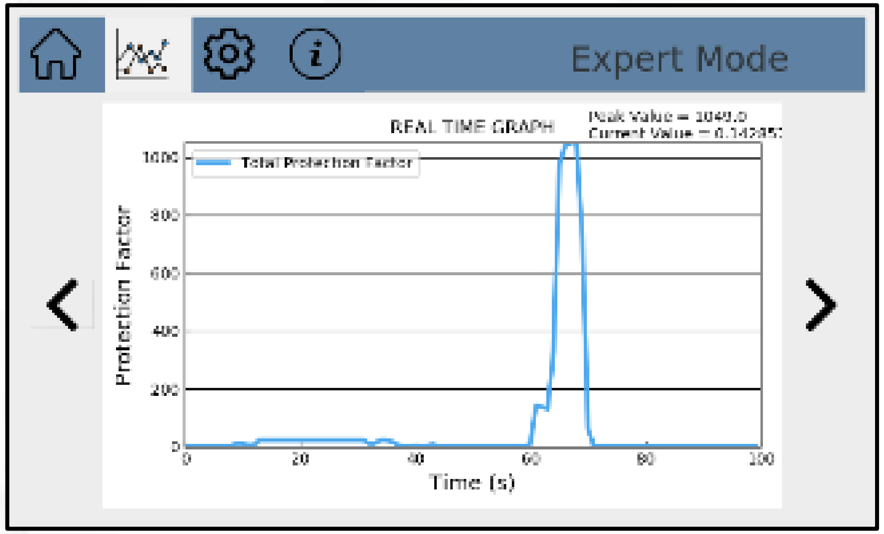
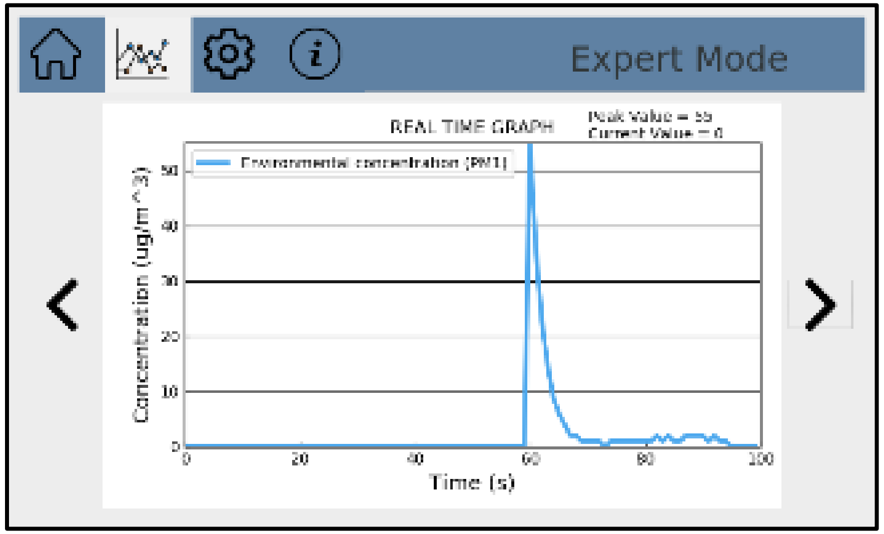
EPIC UI Design ("expert" mode)



(Example plot) Total protection factor in real time



(Example plot) Environmental concentration (PM1) in real time

Provides real time plots for various parameters over time, including:

- Total protection factor
- Protection factors for various ranges of particle sizes
- Total environmental concentrations
- Environmental concentrations of various ranges of particle sizes.

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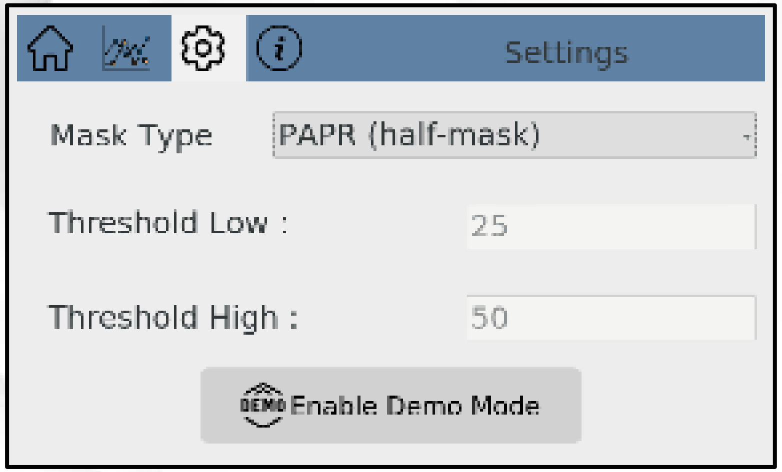
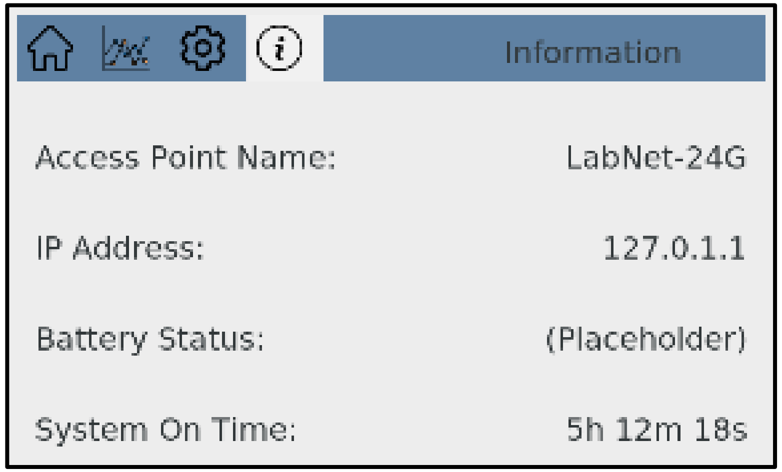
User Interface Settings



- Settings page:
  - Presets included for various common mask types
  - Includes an option to set custom thresholds



Mask Type	Threshold High	Threshold Low
N95	5	10
PAPR (half-mask)	25	50
PAPR (full-face)	500	1000
SAR (half-face)	25	50
SAR (full-face)	500	1000
SCBA (full-face)	5000	10000
Custom	Custom	Custom

- Information page:
  - Displays system information including wireless parameters, system on time, and battery status (pending)

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EPIC Design Highlights

- Advantages of EPIC design over traditional PPE/IH approach
  - Field portable, no need for liquid
  - End user friendly, simple alerts and alarms
  - Can be configured by IH with custom values
  - Can give protection factor for each size ranges
  - Modular design with future upgrades and applications (cloud, AI, ML)
- Performance of optical-based sensors need to be validated

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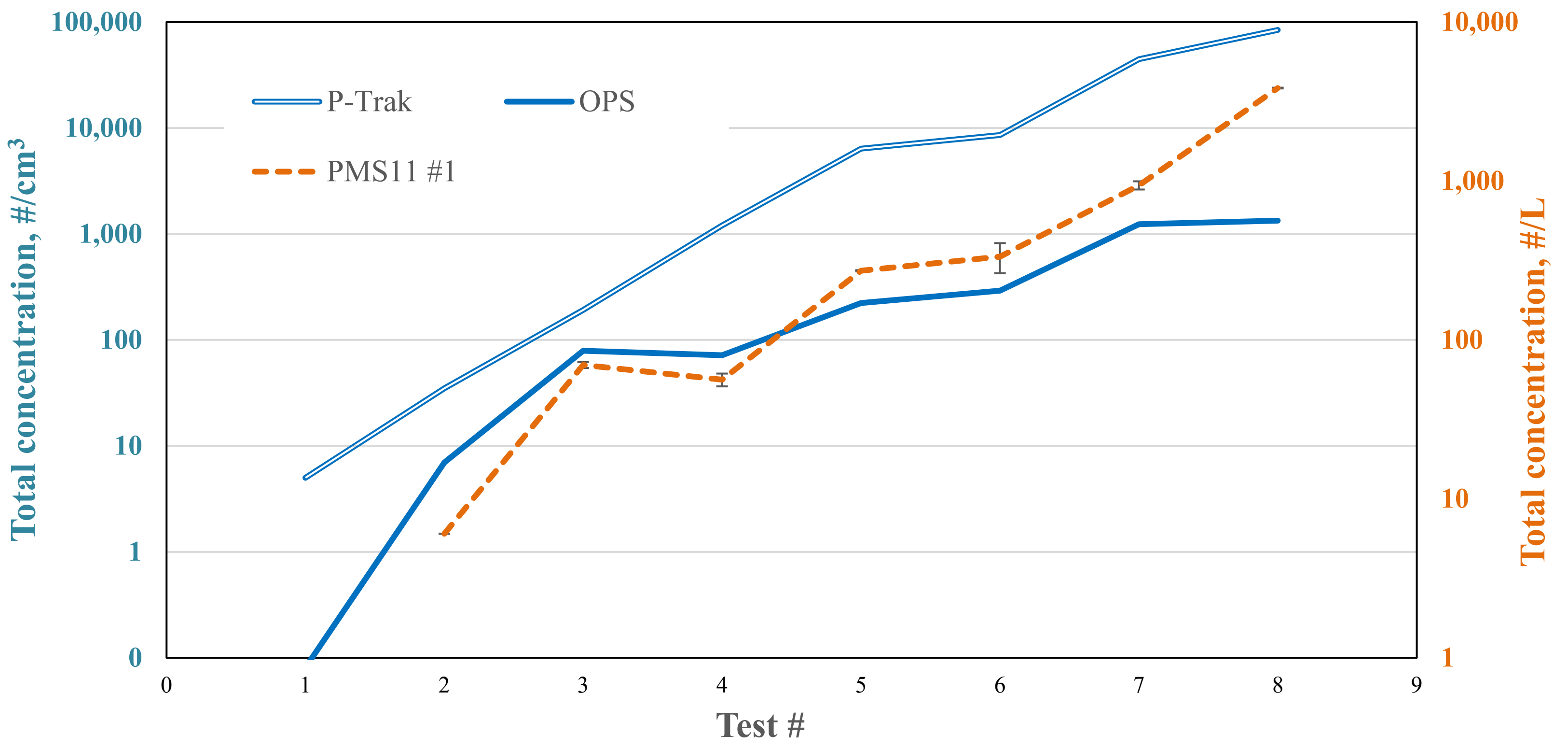
Lab Results

- Comparison of 3 instruments (P-trak, TSI OPS, PMS)
  - NaCl aerosol generated by 6-jet Collison nebulizer with wind tunnel dilutor



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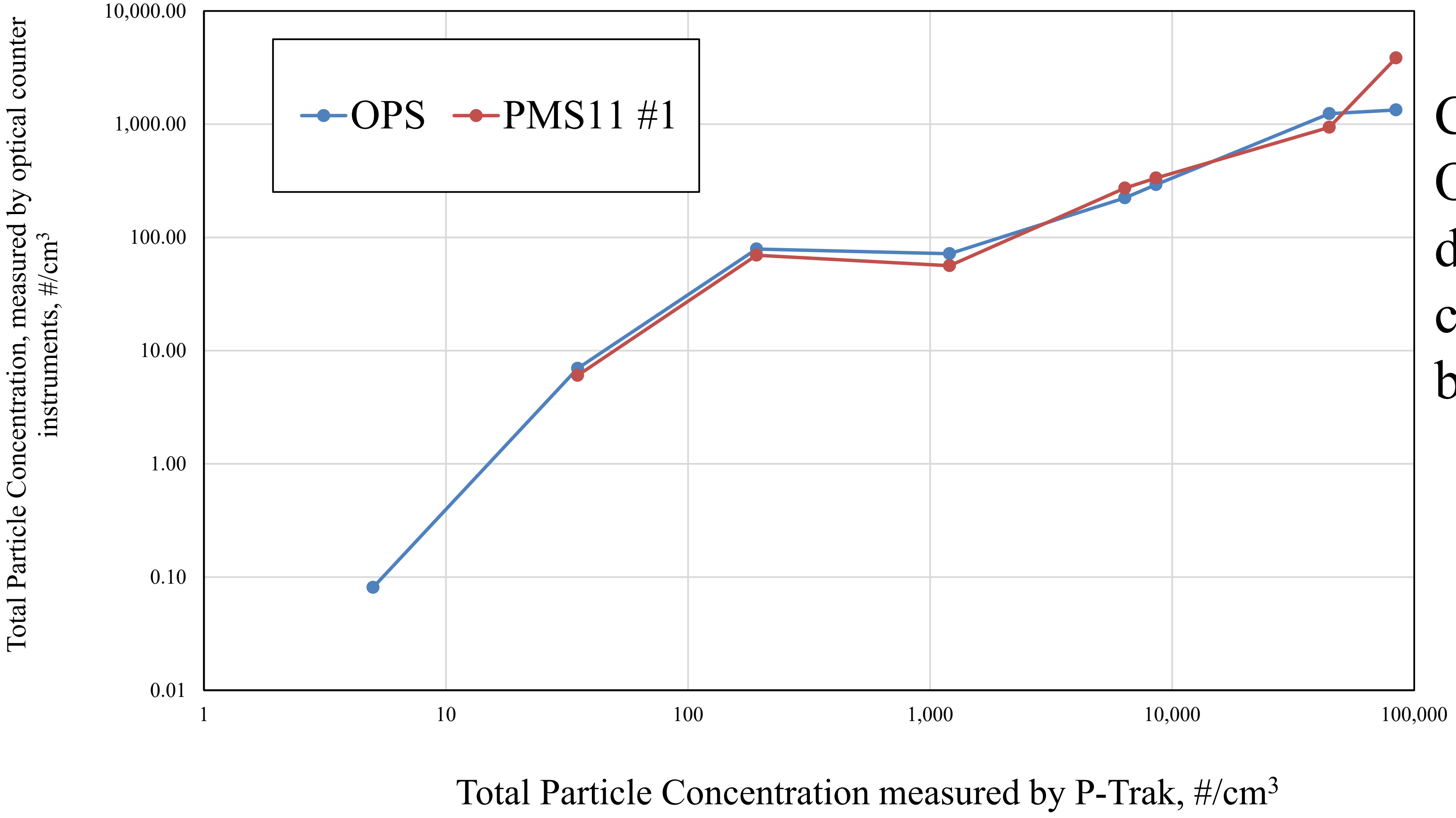
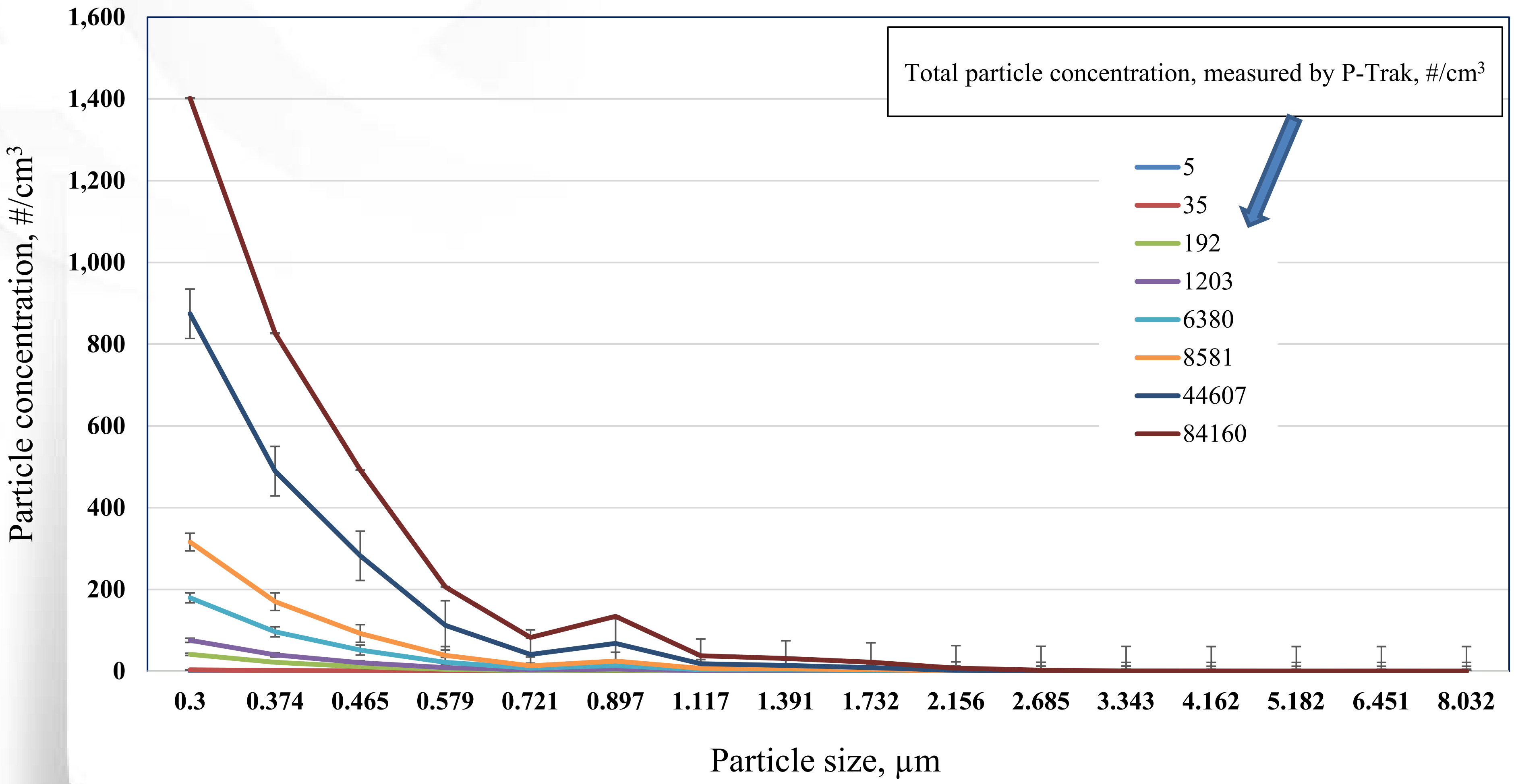
Lab Results



Correlation between TSI OPS and PMS11 depending on total particle concentration measured by P-Trak.

Lab Results

- Particle size distribution measured by TSI OPS



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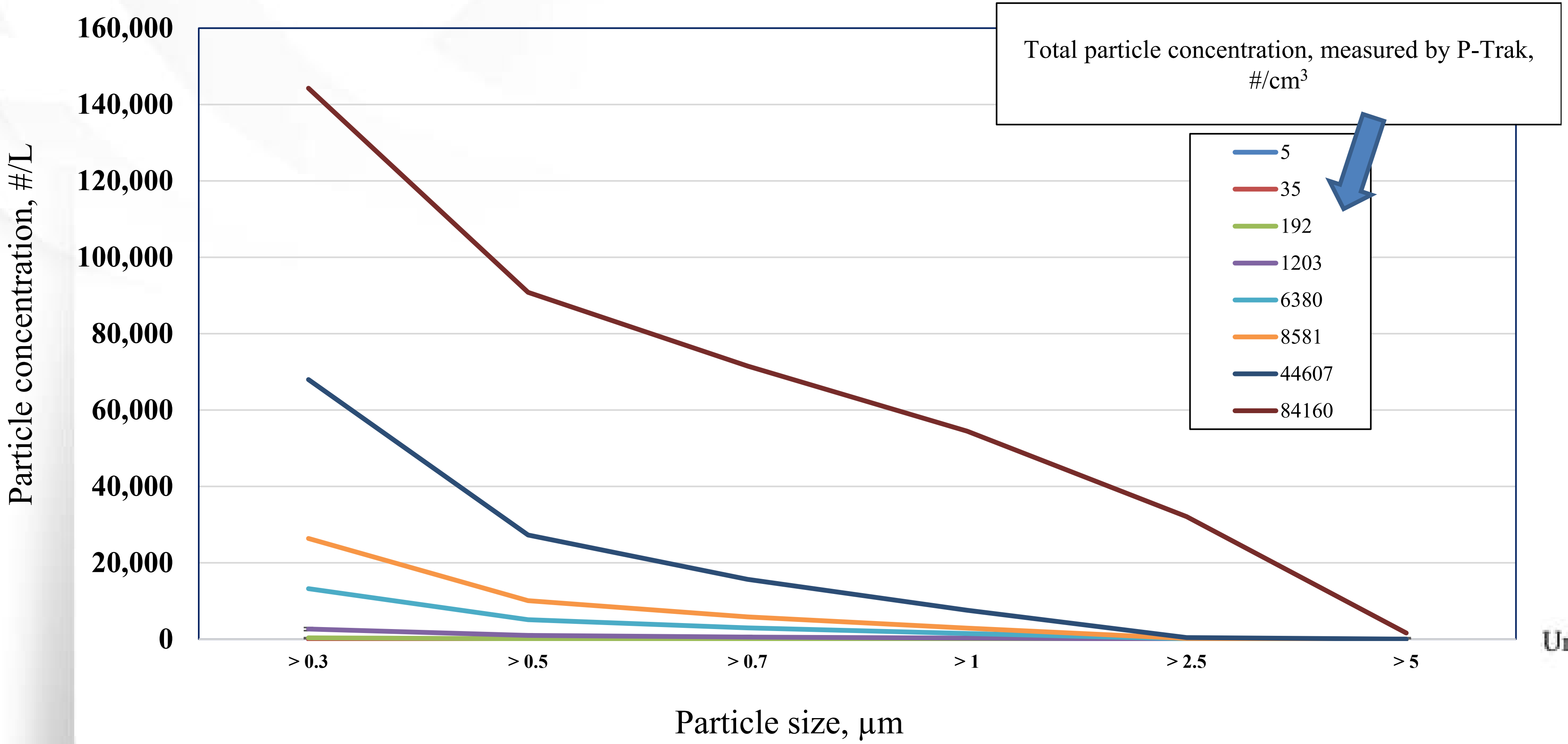
Lab Results

- Particle size distribution measured by PMS-11



EPIC Sensitivity

- Preliminary sensitivity: minimal environmental concentration for reliable EPIC usages

Name of FFR and FF threshold	*Minimal Total Conc., #/cm^3*
N95: 5, 10	Close to the clean room conditions
PAPR (half-mask): 25, 50	≥250
PAPR (full-face): 500, 1000	≥5000
SAR (half-face): 25, 50	≥250
SAR (full-face): 500, 1000	≥5000
SCBA (full-face): 5000, 10000	≥50000

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Future work

- **EPIC hardware improvement**
  - New sensors, miniature, robust, UI design, battery consumption, prototyping

- **EPIC software improvement**
  - Train algorithm for reliable operation, incorporating correction factor for different ranges,

- **More testing scenarios**
  - Broad range of occupations and environments, adapt to different respirators

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ANY QUESTIONS?

Biographical Information

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Barbara Alexander has worked for NIOSH for 9 years in the Engineering and Physical Hazards branch. She has a Ph.D. in Chemical Engineering and a Master's Degree in Environmental and Industrial Hygiene, and she is a Professional Engineer and Certified Industrial Hygienist. Before coming to NIOSH, she worked in the nuclear industry and in the chemical industry. At NIOSH, she has been involved in the responses to Ebola and to COVID-19. Her projects have included measuring exposures and developing engineering controls for the oil and gas extraction industry, developing and testing dry decontamination systems for firefighters and for mass casualty events, investigating exposures to peracetic acid, and researching health and safety for landscapers and grounds management professionals. She has authored seven articles on her NIOSH research in the peer-reviewed literature and has presented her research at multiple national conferences.

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Eric Glassford has been at CDC/NIOSH since 2015. He is an industrial hygienist and works in the Health Hazard Evaluation program in Cincinnati, OH. He is also a member of the Advanced Materials and Manufacturing Field Studies Team for the NIOSH Nanotechnology Research Center. He previously worked as an industrial hygienist at Sandia National Laboratories in Albuquerque, NM. He is a Certified Industrial Hygienist by the American Board of Industrial Hygiene and received his Master of Science in Environmental Health and Industrial Hygiene from the University of Cincinnati.

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