Pittsburgh Mining Research Division

Advanced real-time and field-based approaches for monitoring respirable dust and crystalline silica in workplaces.

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CDC - National Institute for Occupational Safety and Health

National Institute for Occupational Safety and Health

NIOSH

NIOSH Mining Program

Pittsburgh Mining Research Division

- Dust, Ventilation and Toxic Substances Branch (DVTSB)
- Electrical and Mechanical Systems Safety Branch (EMSSB)
- Fires and Explosions Branch (FEB)
- Ground Control Branch (GCB)
- Health Communications, Surveillance and Research Support Branch (HCSRSB)
- Human Factors Branch (HFB)
- Workplace Health Branch (WHB)

Worker exposure monitoring

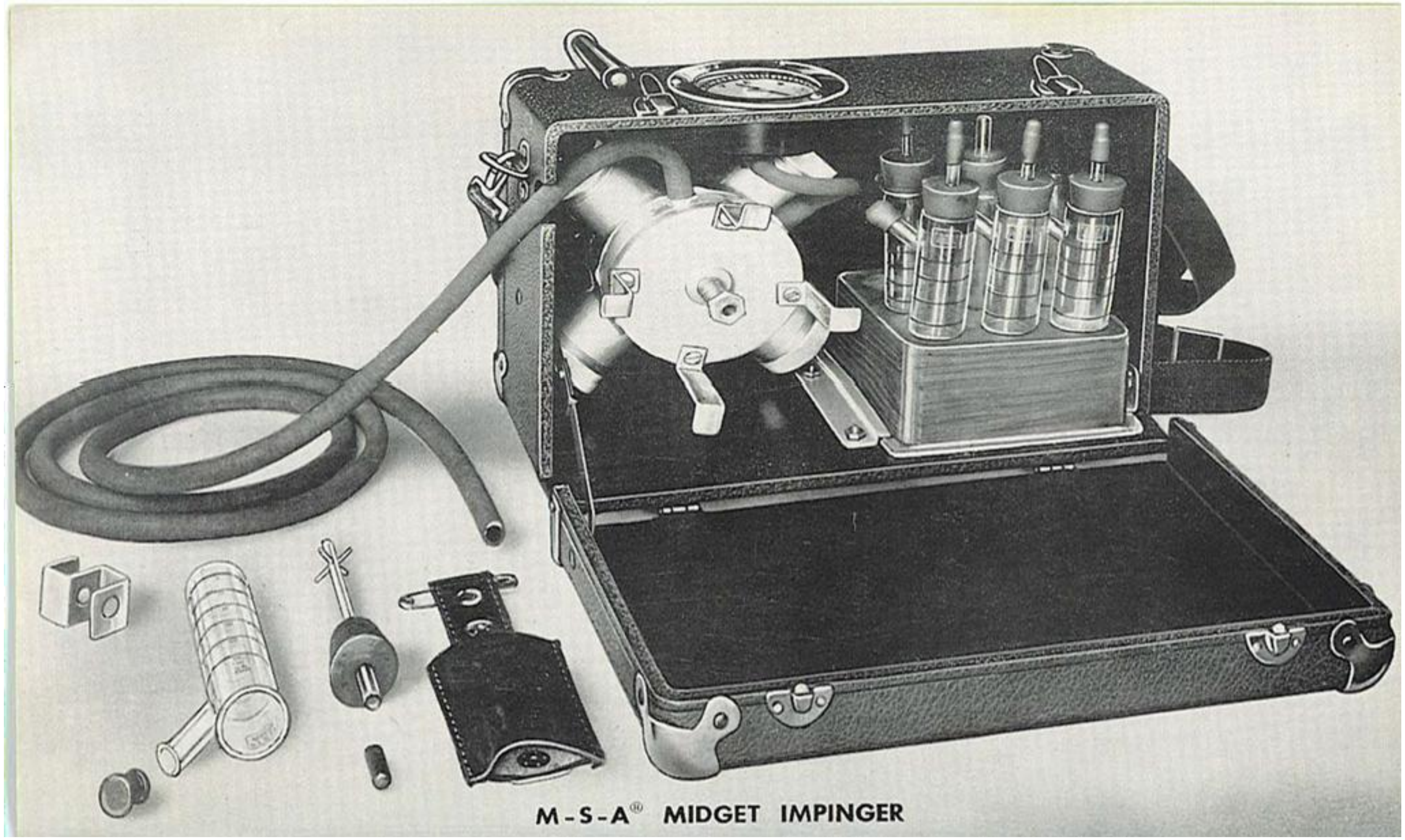
"One of the most important steps towards reducing the risk of impaired health resulting from inhalation of toxic chemicals is the measurement and evaluation of employee exposure to these chemicals."
NIOSH (1977) Occupational Exposure Sampling Strategy Manual

"Worker dust exposure assessments can be used for comparison with occupational exposure limits and as a measure of dose in epidemiological studies; other reasons include evaluating the effectiveness of engineering controls, changes in dust levels as a result of process changes, and the adequacy of personal protective devices such as respirators."
National Industrial Sand Association (NISA) (2010) "Occupational Health program for exposure to crystalline silica in the industrial sand industry"

Traditional personal exposure monitoring

Respirable dust and crystalline silica

Impinger Sampling - Standard procedure for sampling and counting dust – adopted by the ACGIH in 1942. Metric: *Millions of particles per cubic foot (mppcf)*



Ref: American Industrial Hygiene Journal; pg. 550, Nov – Dec 1967
Photo credit – Michigan Safety conference 2016

Traditional personal exposure monitoring

Respirable dust and crystalline silica

Key elements

- **Particle size selector** - aka cyclone or impactor. It is needed to prevent non-respirable particles from being collected

- **Collection media** – generally a filter.

- Personal sampling pump

- Analysis conducted in an accredited laboratory.

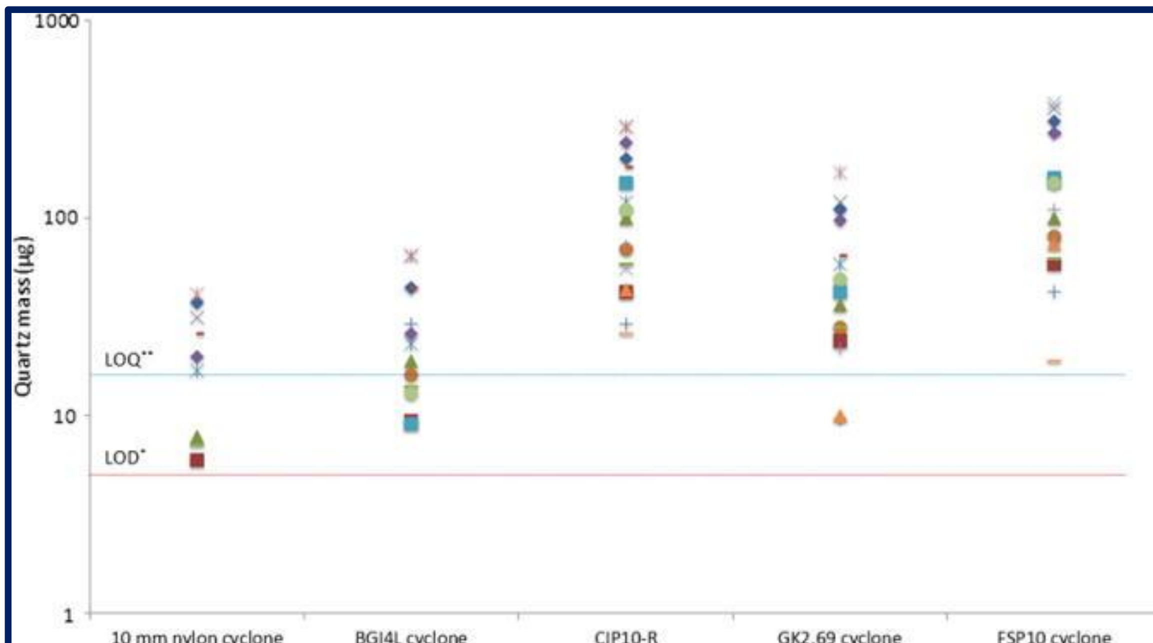
Photo credit - www.dcpolish.com

Personal exposure monitoring

Recent advancements

The use of high-flow rate respirable samplers have been investigated in recent years with success

- Benefit - sampling higher amount of volume (mass) in the same length of time.
- Benefit - short-time sampling – assessment of a specific task.
- More powerful personal sampling pumps can now handle higher flow rates.
- ***OSHA new silica rule*** – few high-flow rate samplers are included in the approved list.



Lee T, Lee EG, Kim S, et al. (2012). Quartz measurement in coal dust with high-flow rate samplers: laboratory study. Ann Occup Hyg; 56: 413–25

Personal exposure monitoring
Recent advancements

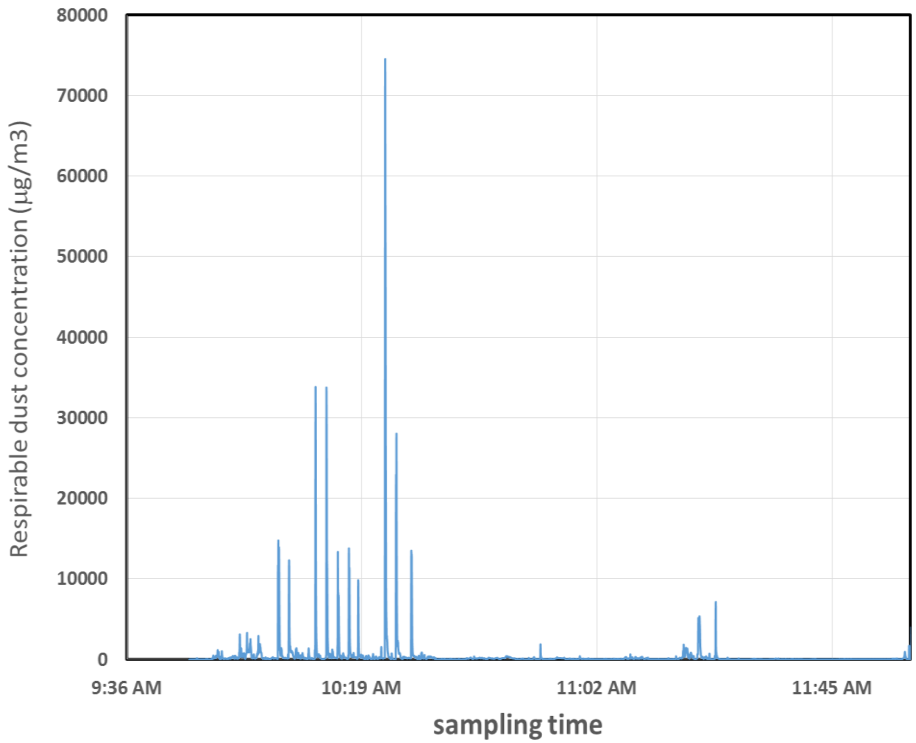
Real time dust monitors based on optical properties are not a new idea.

- Paul Baron (NIOSH) described them in great detail in the NMAM already in 1998.
- For most of them, the sensing process works via light scattering generated by the dust. The intensity of the scattering is affected by
    - *Refractive index of the dust – type of dust.*
    - *Size distribution of the dust particles.*
    - *Environmental conditions – primarily humidity.*

Best practice (if possible)
- Use a respirable sampler to define the particles monitored.
- Analyze the back-filter gravimetrically to calibrate the results.

Real time dust monitor

Dave: bagging operator



Traditional sampling

average dust concentration = 416 µg/m^3

Real time dust monitor

- Presence of several short episodes with dust levels up to 70 mg/m^3
- Specific adjustments – *work-practices or engineering control technologies* – should be considered to minimize the effect of the episodes.

What's missing?

The context !!!

What was Dave doing when those episodes happened? What kind of activity?

Helmet-CAM

Exposure Assessment Tool

Evaluation tool to identify "sources of exposure" and to assess "control technology effectiveness".

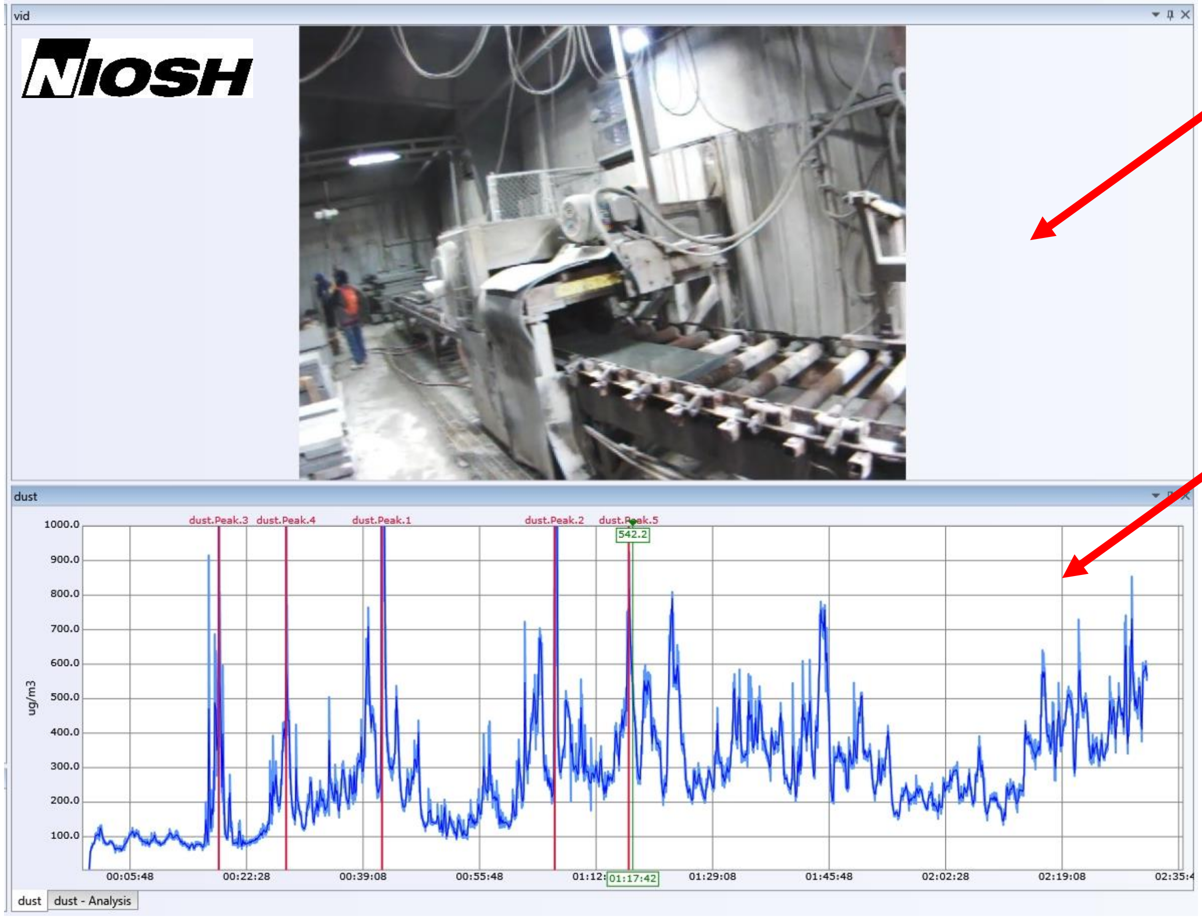
- Video of tasks performed by worker along with respirable dust exposure monitoring.
- Particularly suitable for mobile workers with multiple tasks.
- NIOSH designed software "EVADE" merges video and dust data in easy-to-use synchronized format.
- ***Goal*** - develop control technologies to minimize areas of elevated exposures.

Helmet-CAM

Hardware

Helmet-CAM

Software (*EVADE*)



POV VIDEO

SYNCED EXPOSURE DATA

NIOSH designed the EVADE software

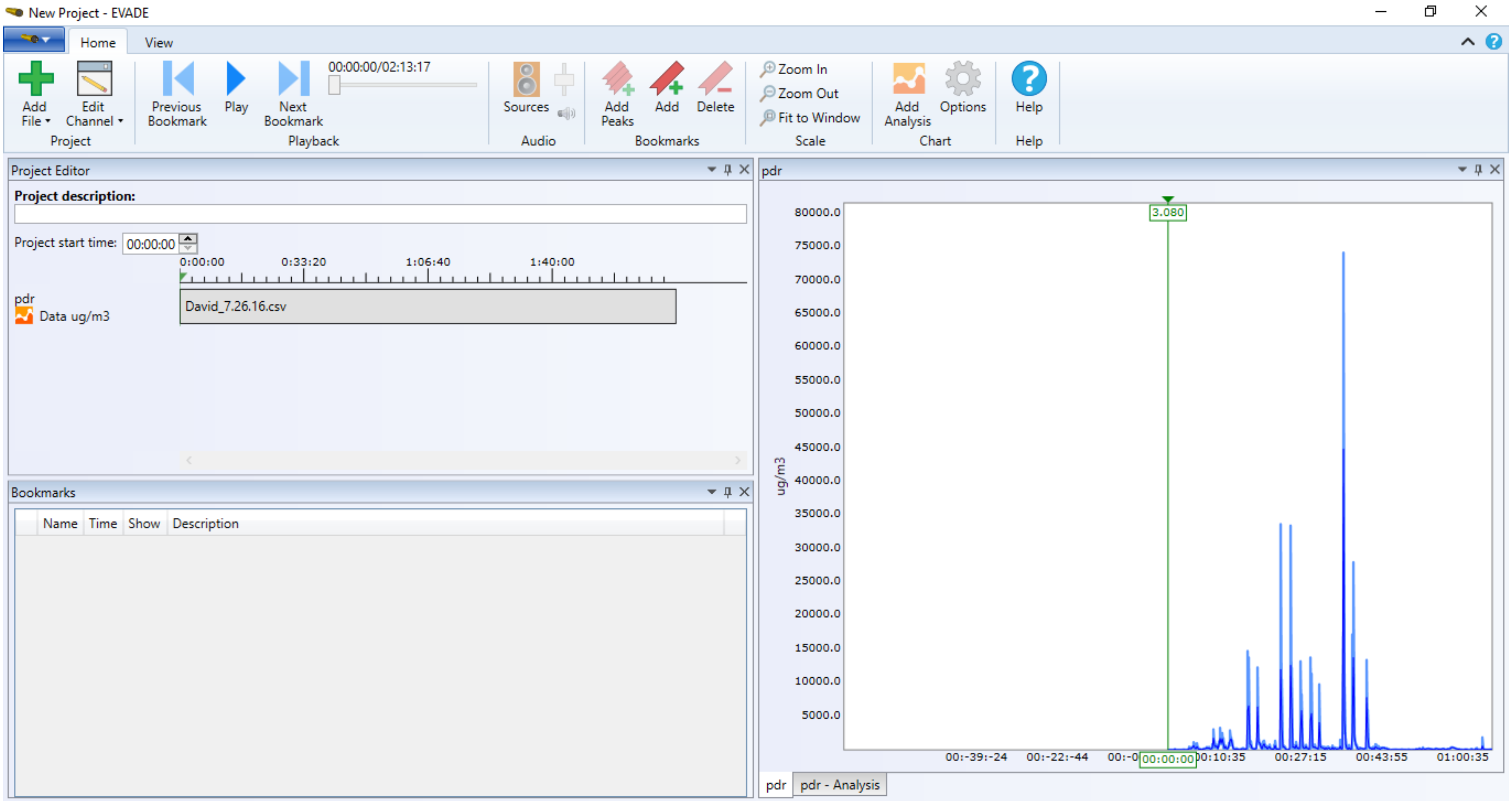
http://www.cdc.gov/niosh/mining/Works/coversheet1867.html

Elevated exposures working with bulk bags

Worker understands exactly when exposure is highest

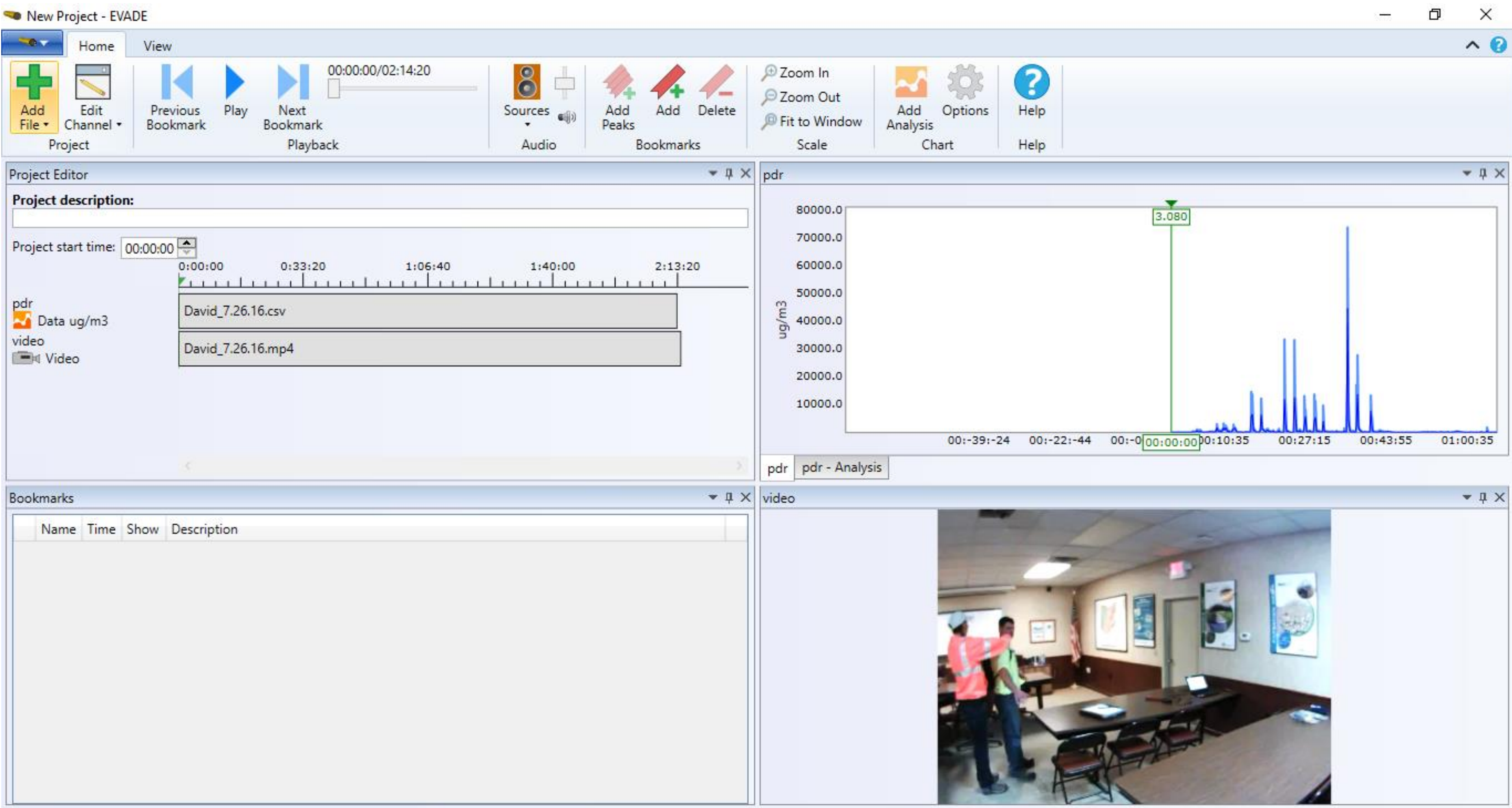
EVADE in action (1)

Upload dust monitor file



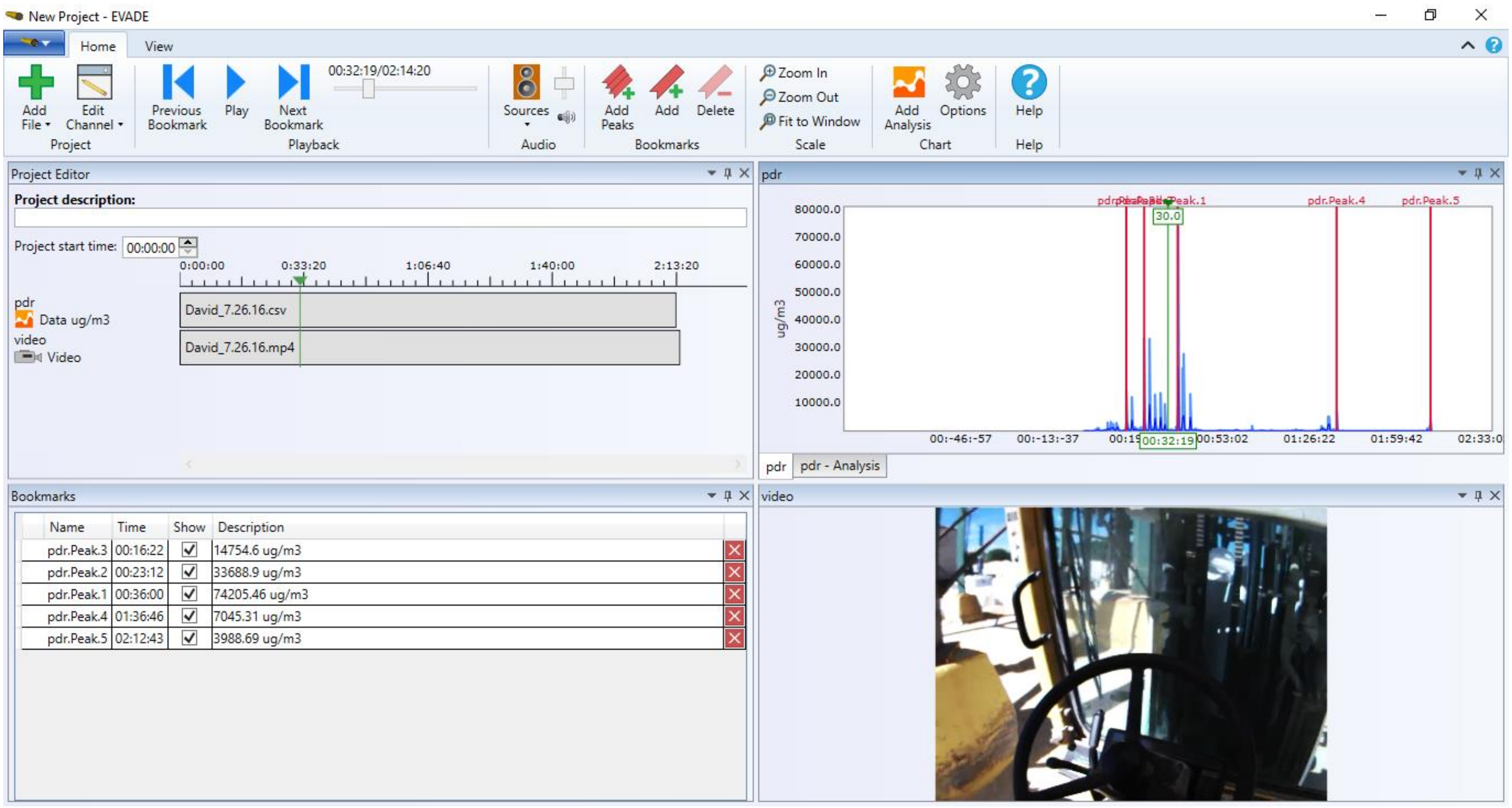
EVADE in action (2)

Upload camera file



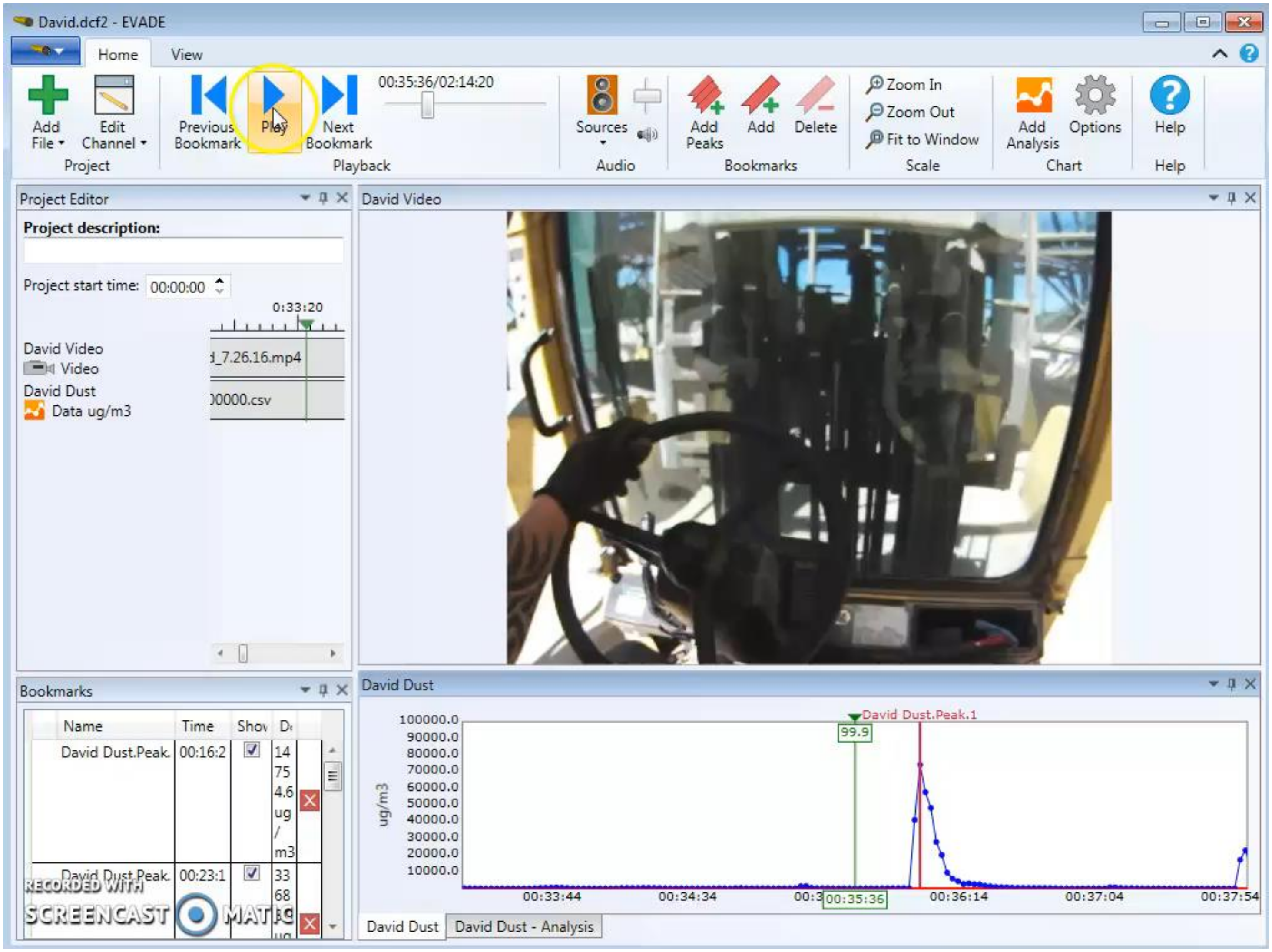
EVADE in action (3)

Identification of episodes



EVADE in action (3)

Investigation of episodes







Engineering Issues and Potential Modifications



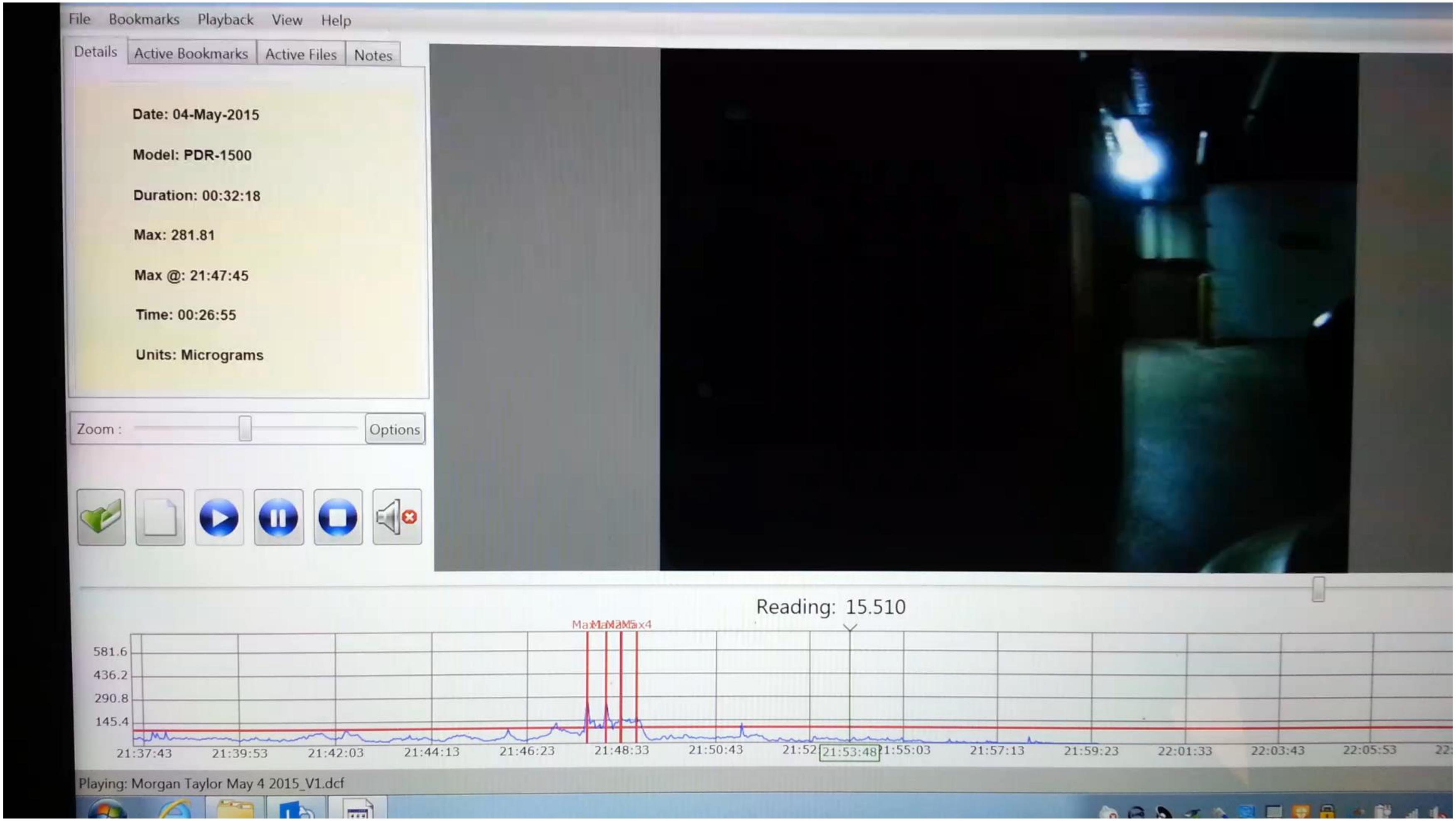

Elevated exposures in dry labs/splitter rooms

Example – Using splitter shack without fan

Increased awareness of respirable dust in splitter shack

Elevated exposures in dry labs/splitter rooms

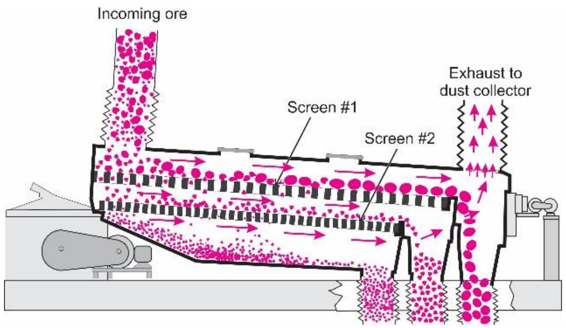
Using splitter shack with fan



Response: Improved filtration and pressurization systems for dry labs.

Screen Cleanings and Changes

Badger Mining Corporation



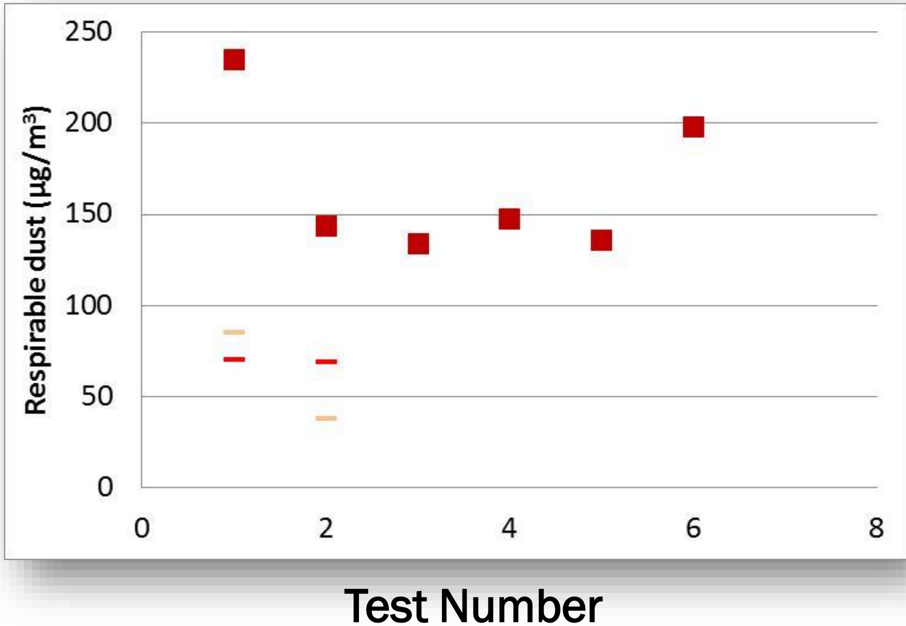
Rotex Global, LLC (Screening Manufacturer)

Using Helmet-CAM footage to determine possible control technologies and interventions to minimize respirable dust exposures

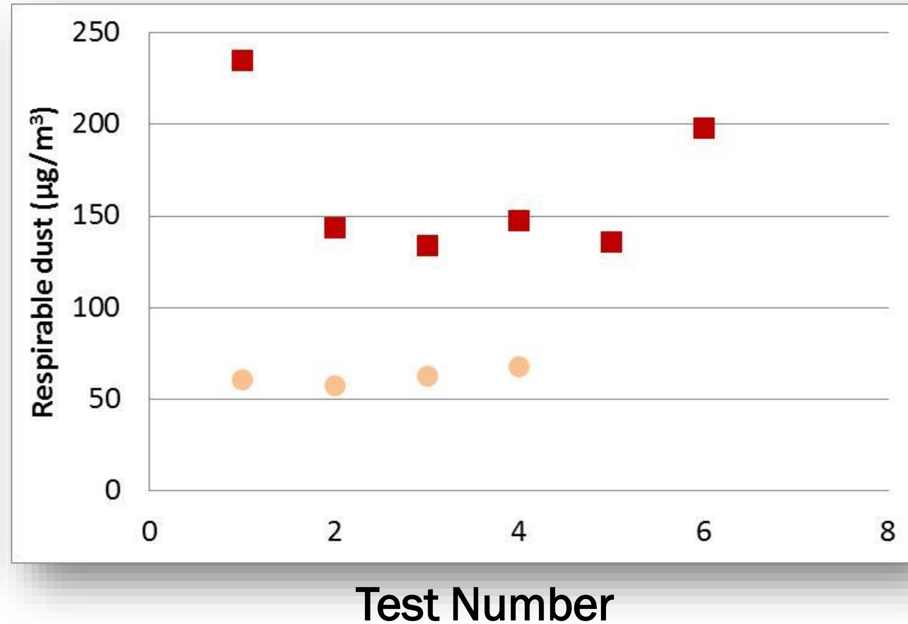
Traditional method

Results

Vacuuming



New Segmented-Panel Screen Design



Both modifications resulted in approximately a 60 pct. reduction in personal respirable dust exposure levels.

Minimizing Exposure During Emptying Hopper

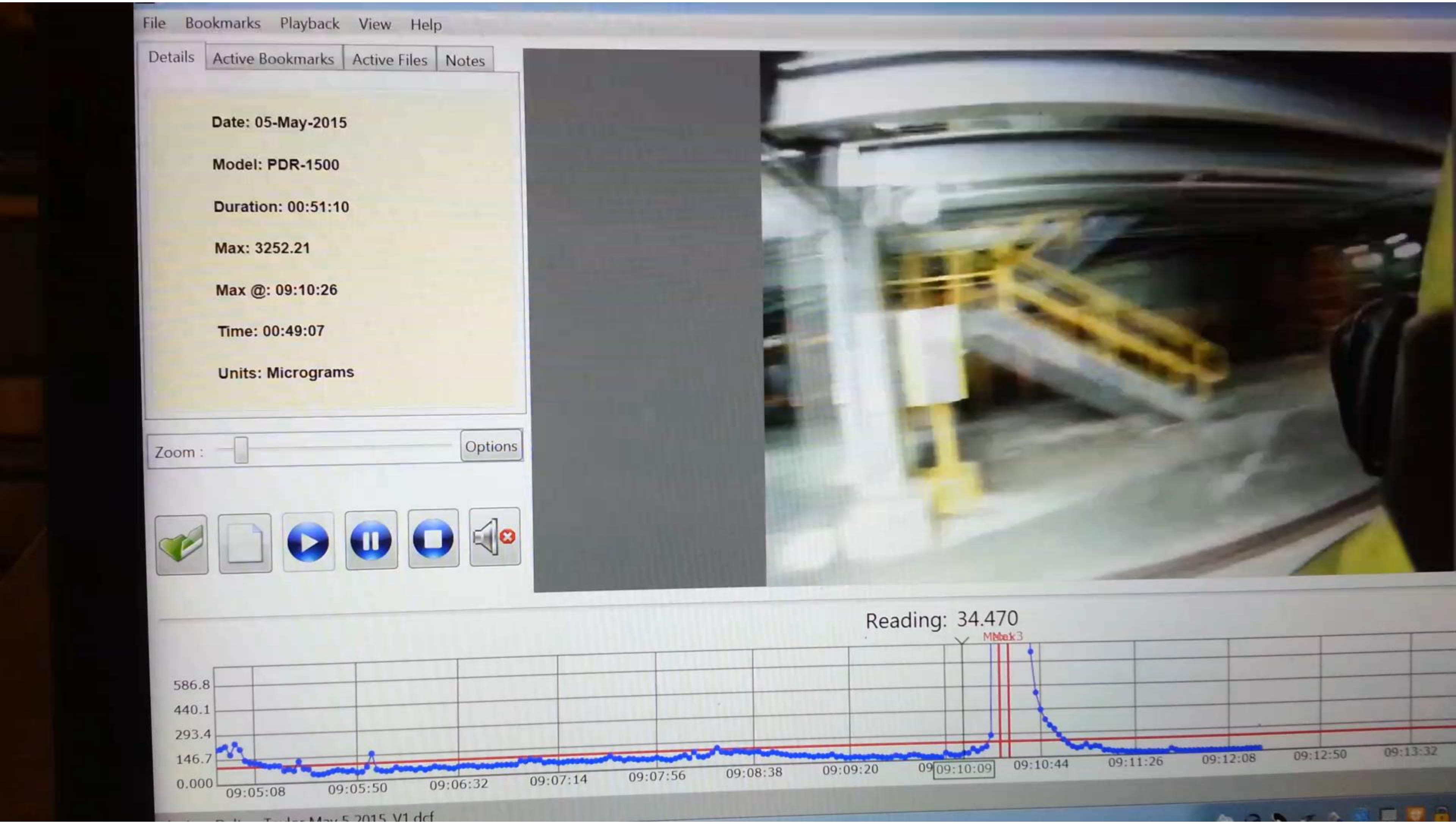
Flexible Intermediate Bulk Containers (FIBC)

Ground Level (5 trials): 1160 µ/m³ **Raised (7 trials): 240 µ/m³**

Approx. 80 pct. reduction with modification

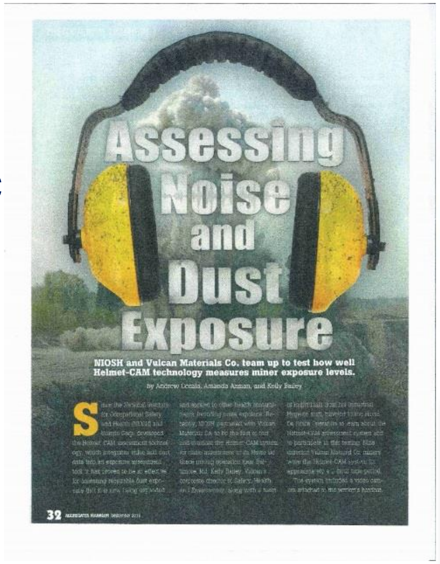
Example: Dusty/Dirty Clothes and Hands

Increased awareness of dust in soiled clothing



EVADE 2.0 Software

- Can interface with several real-time instruments (dust, DPM, noise, organic compounds)
- Can link with multiple cameras on same project.



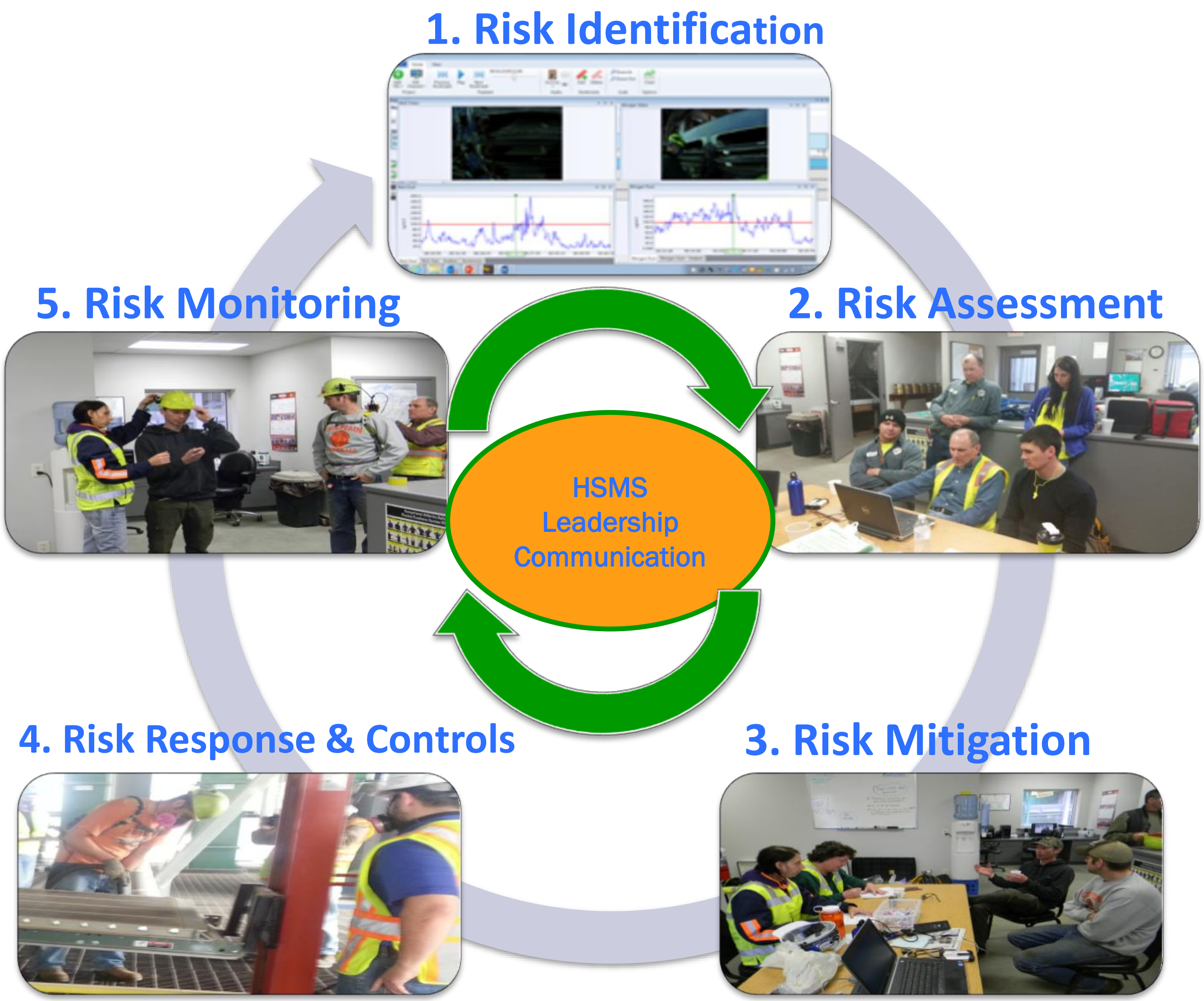
Assessing Noise and Dust Exposure

NIOSH and Vulcan Materials Co. team up to test how well Helmet-CAM technology measures miner exposure levels.

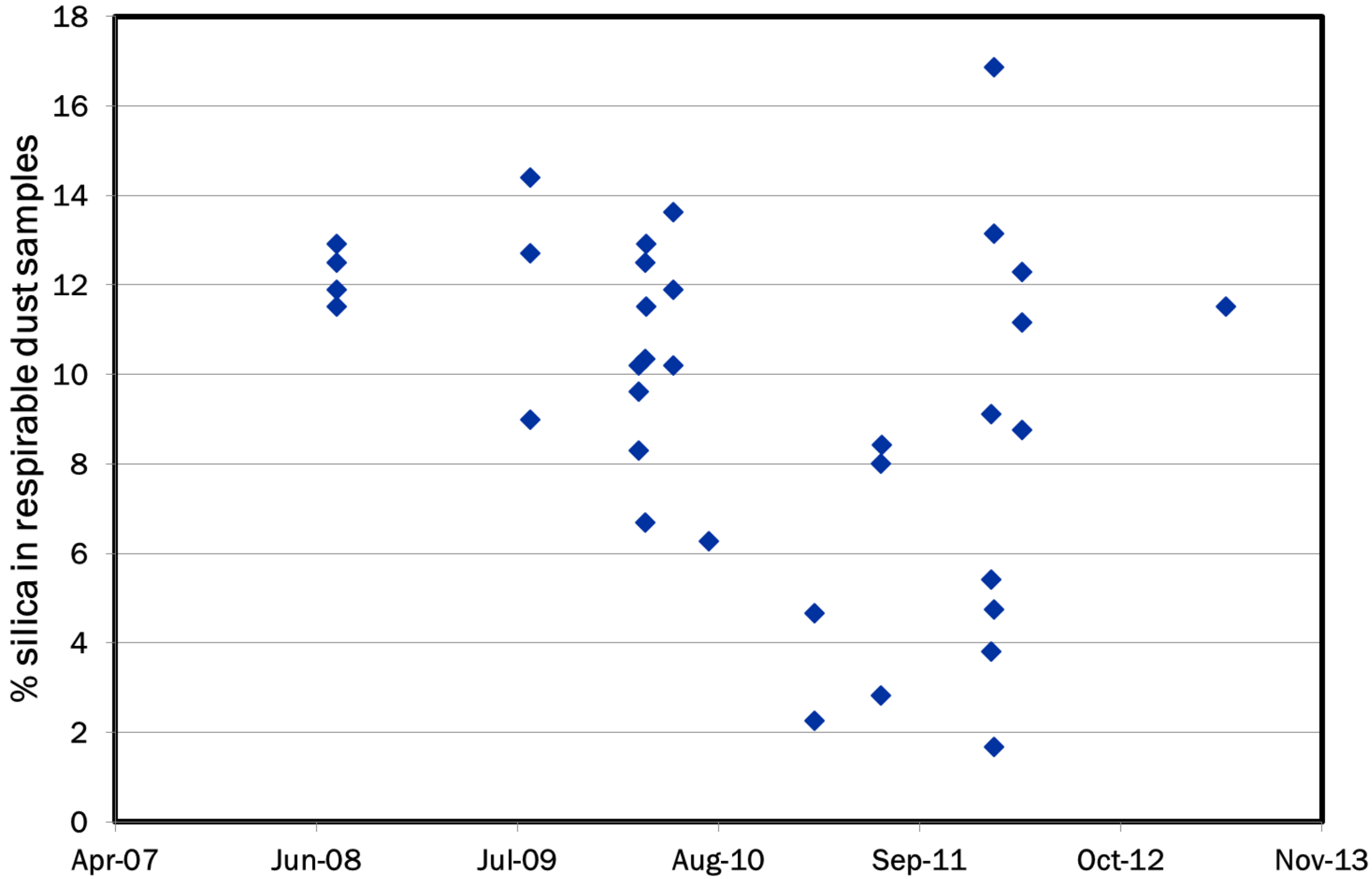
Available (free) here:
http://www.cdc.gov/niosh/mining/Works/coversheet1867.html

(search “NIOSH EVADE”)

Helmet-CAM as a H&S Risk Communication Tool

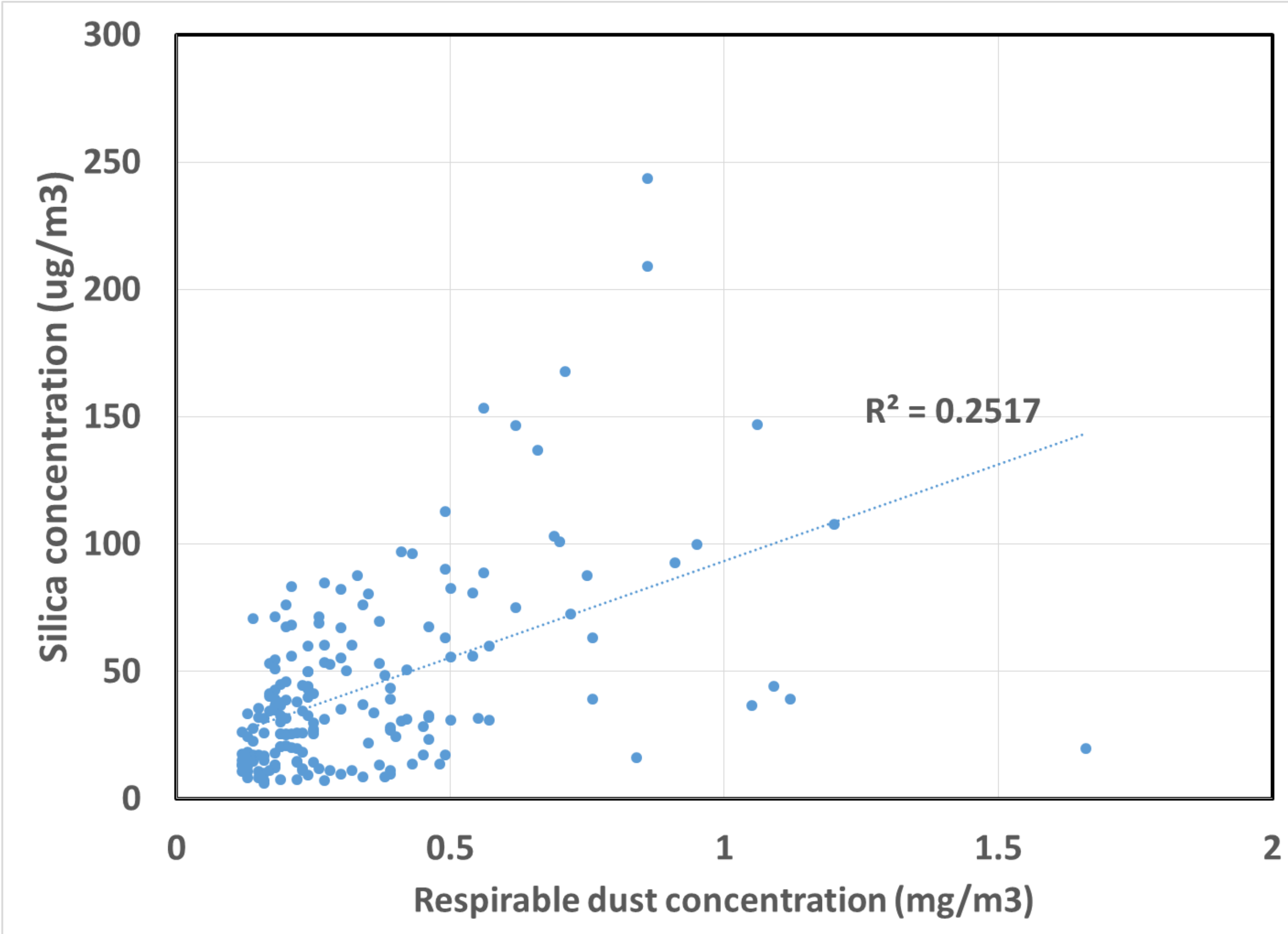


What about Respirable Crystalline Silica (RCS) ?



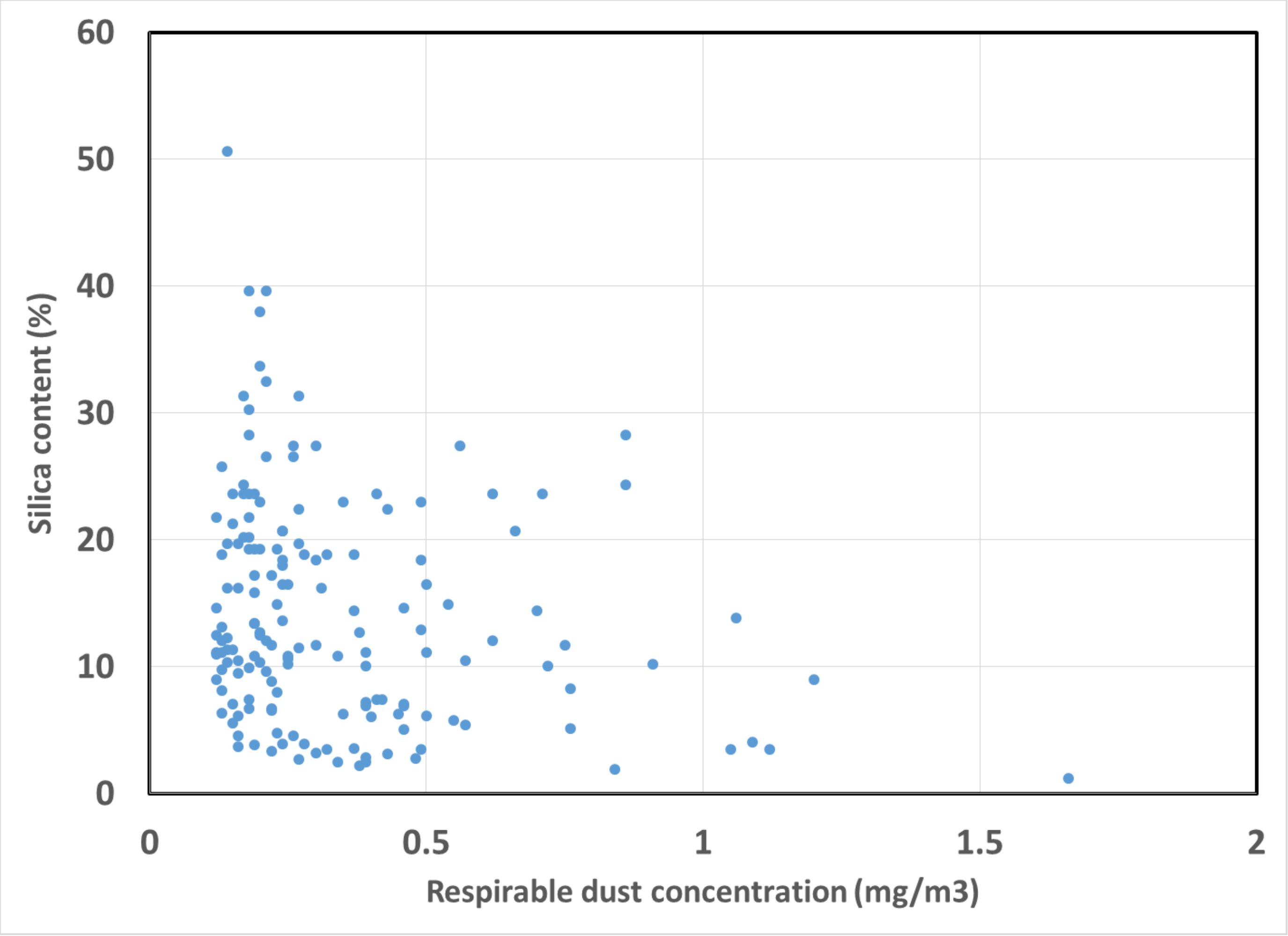
Samples collected by the Mine Safety and Health Administration (MSHA) in a single copper mine in Arizona 2008-2013.

What about Respirable Crystalline Silica (RCS) ?

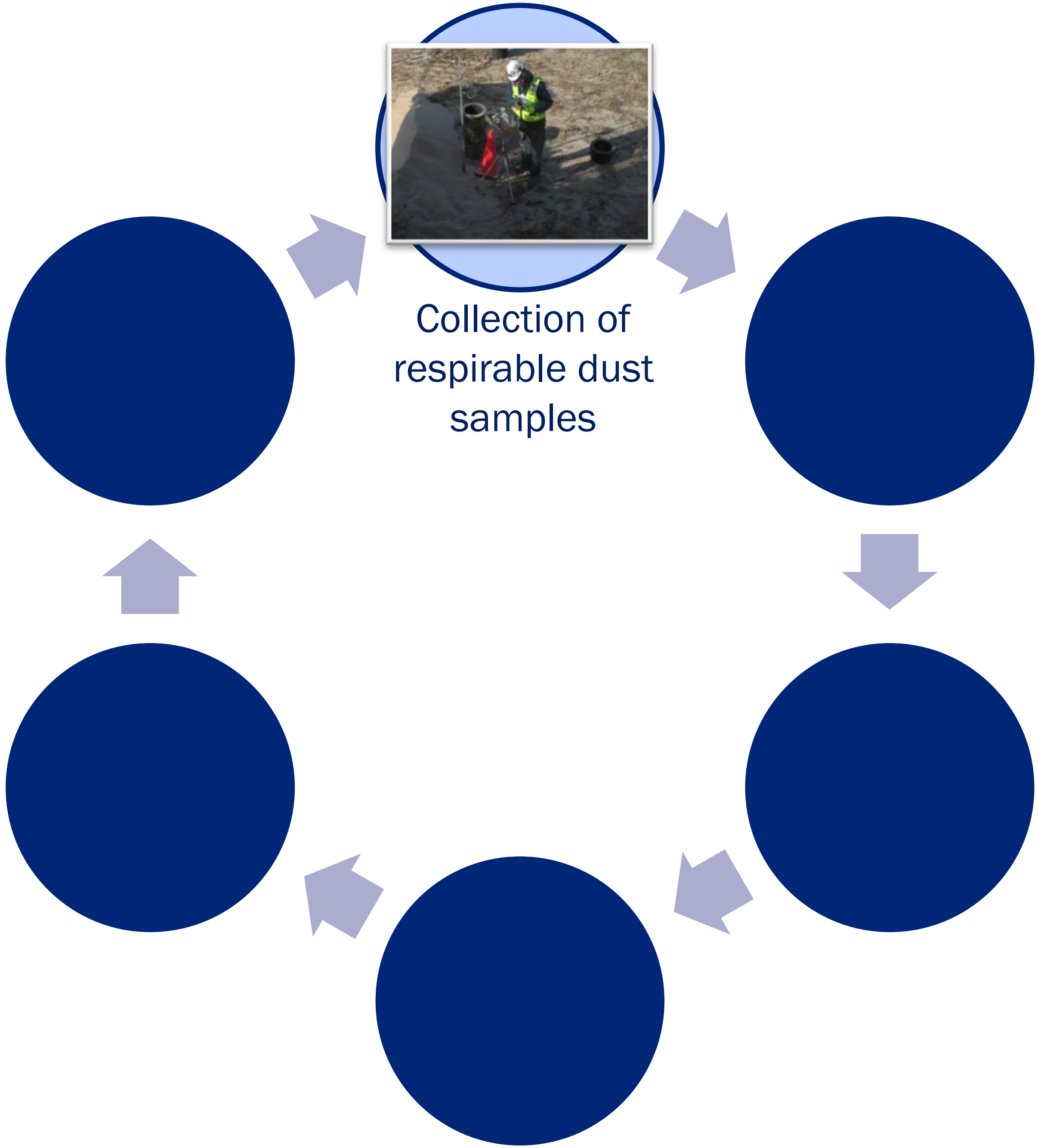


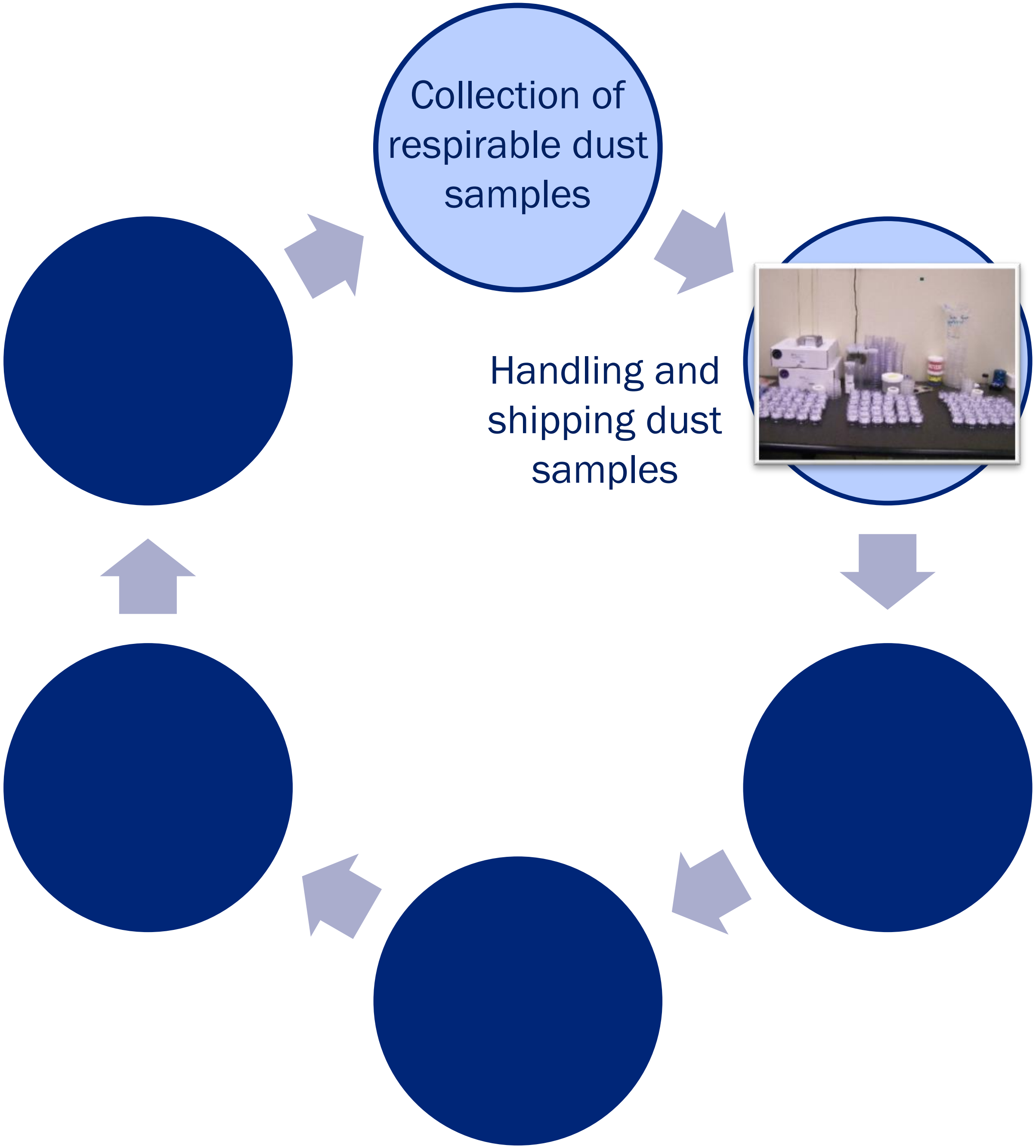
Samples (370) collected by MSHA in granite operations in Georgia, North Carolina, South Carolina (2008-2013).

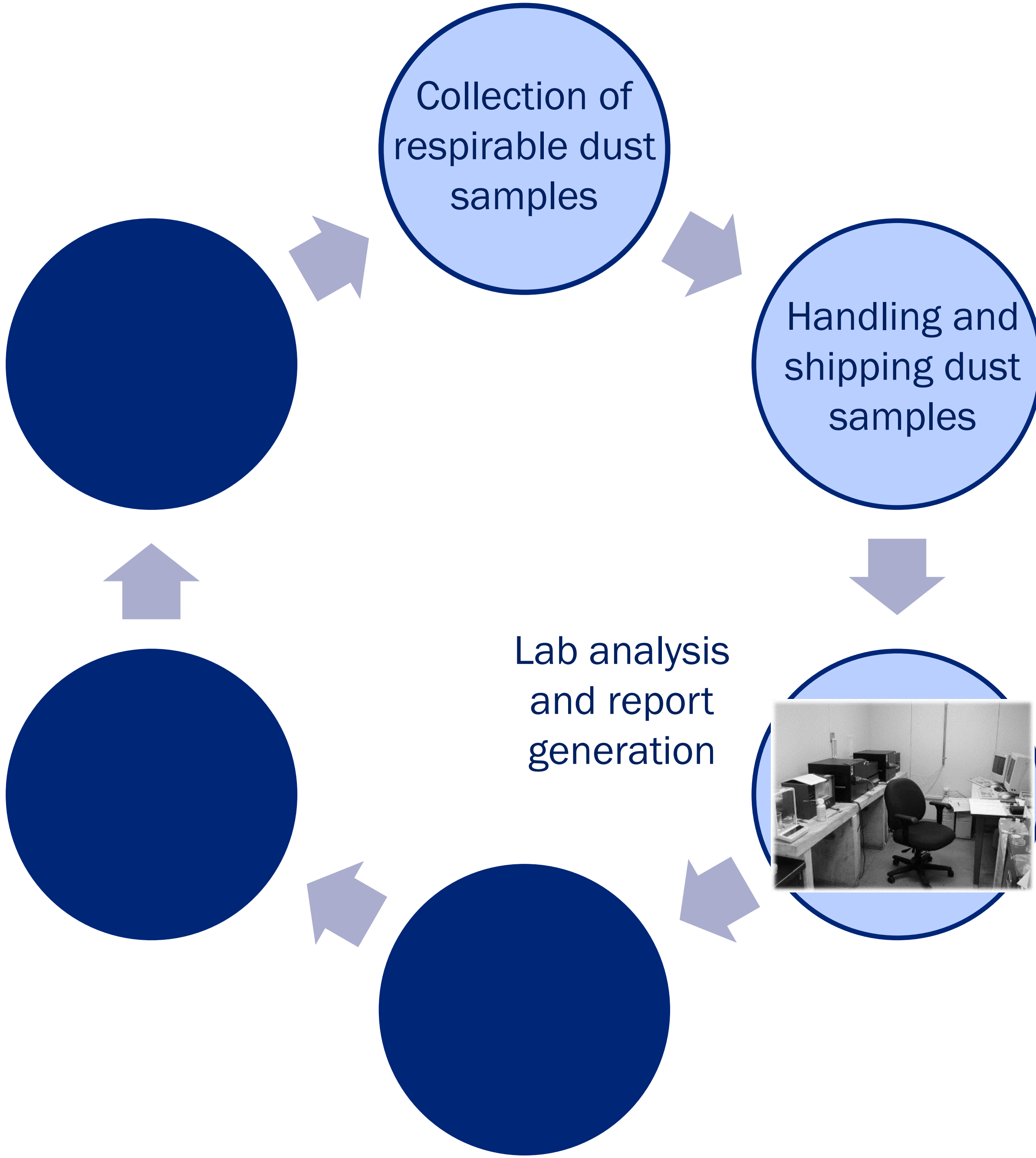
What about Respirable Crystalline Silica (RCS) ?



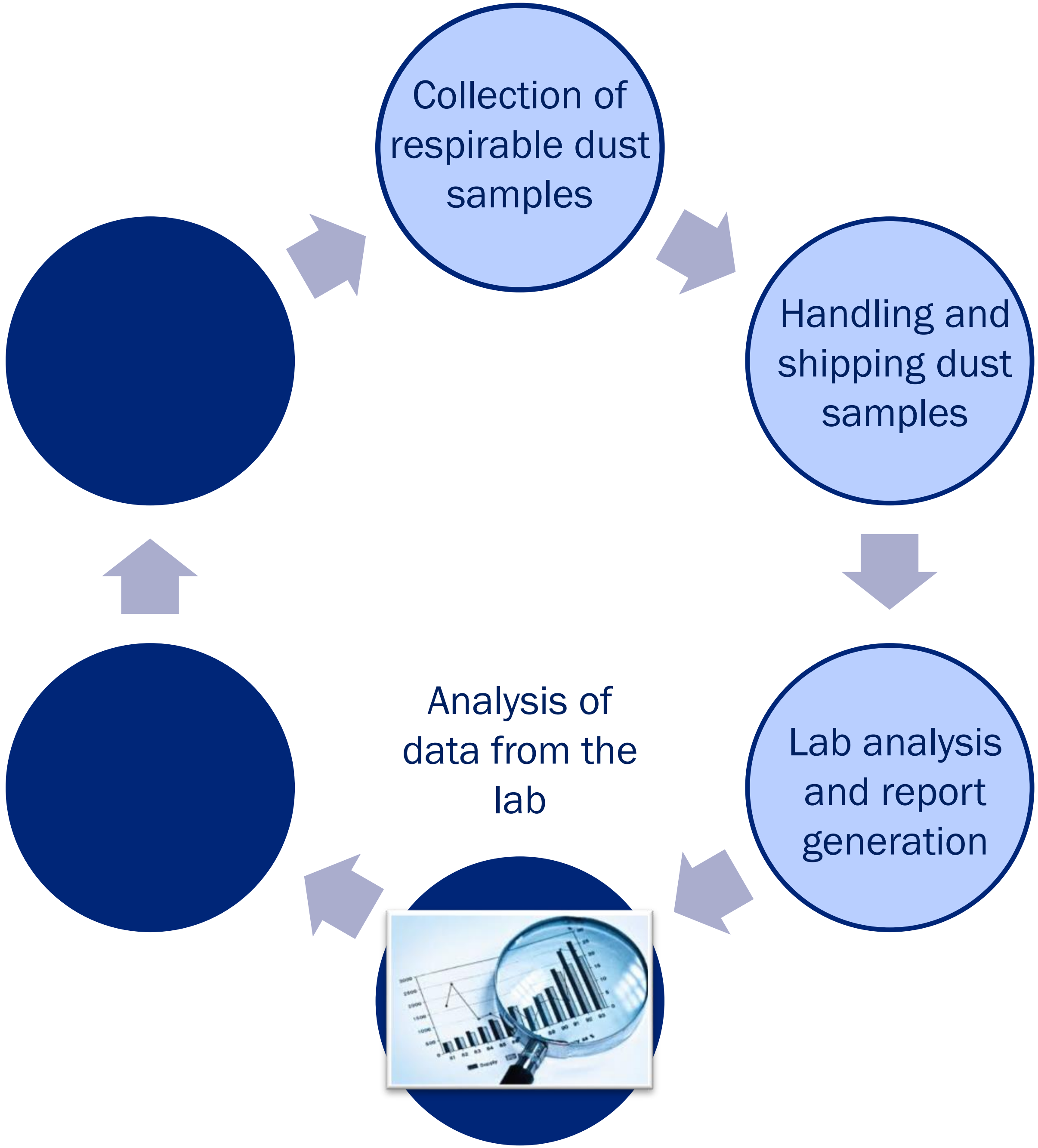
Samples (370) collected by MSHA in granite operations in Georgia, North Carolina, South Carolina (2008-2013).


Collection of respirable dust samples


Collection of respirable dust samples
Handling and shipping dust samples



Limitations:
Time lapse
Per-sample cost


Collection of respirable dust samples
Handling and shipping dust samples
Lab analysis and report generation
Analysis of data from the lab

Collection of respirable dust samples

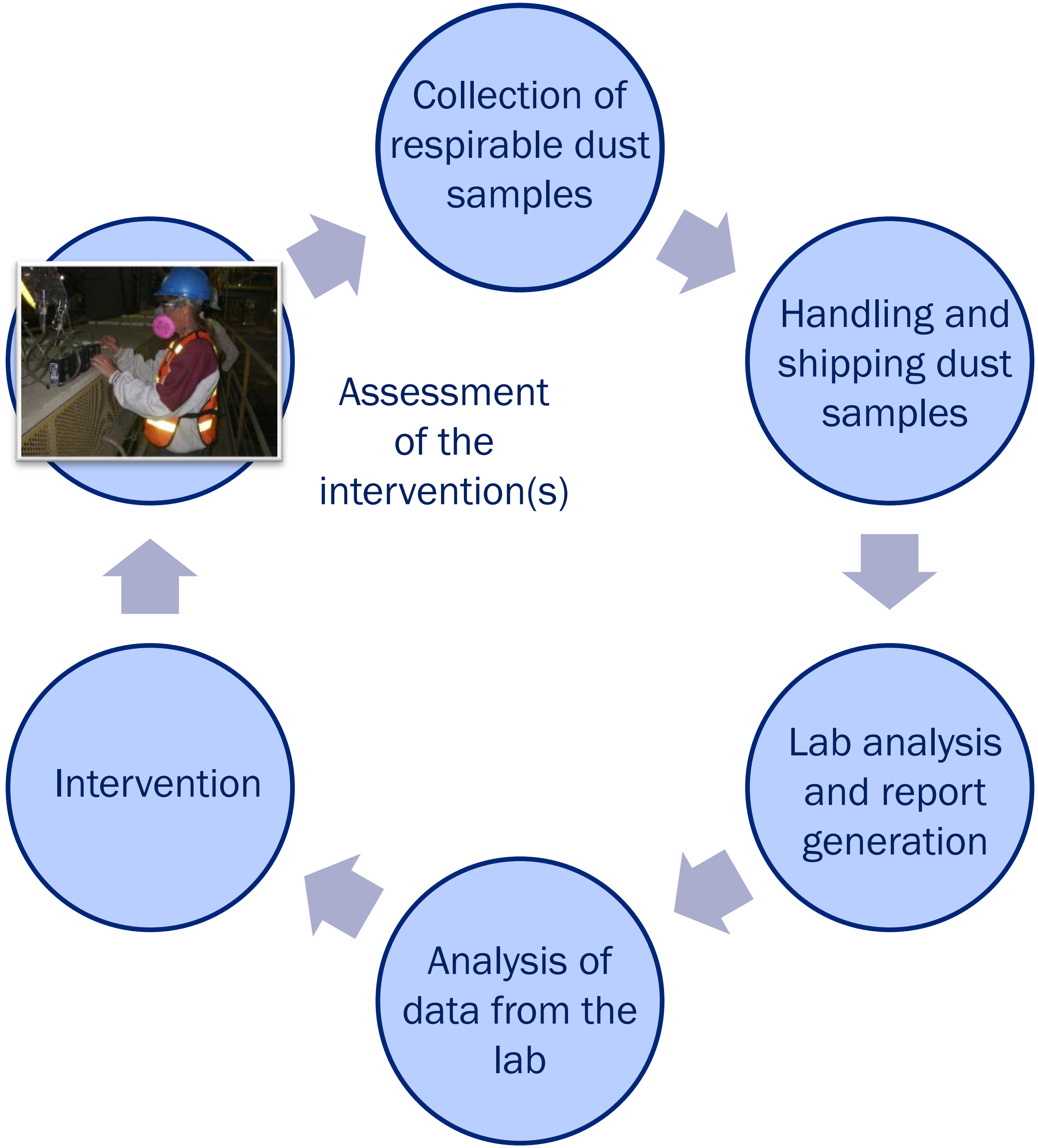
Handling and shipping dust samples

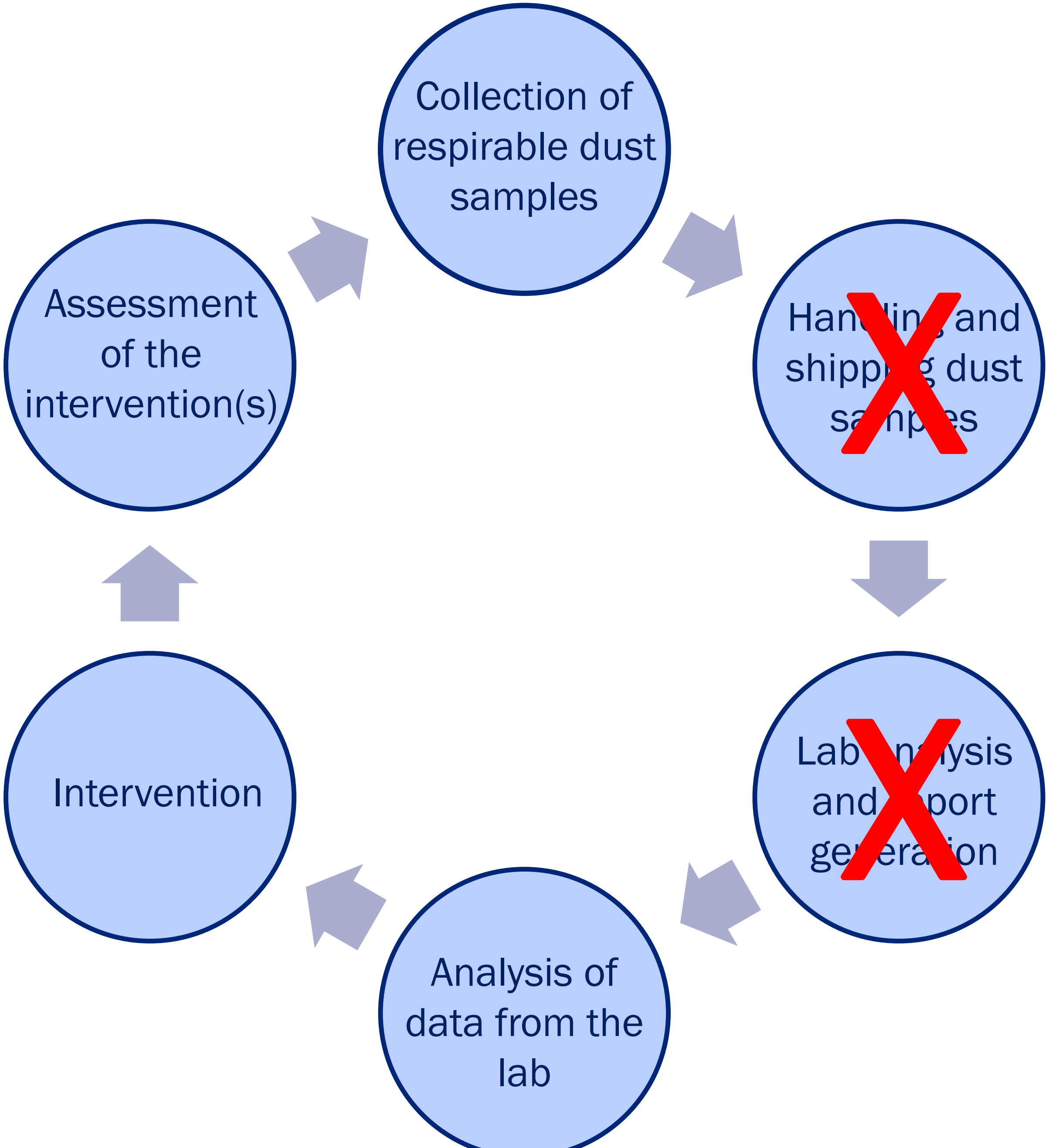
Lab analysis and report generation

Analysis of data from the lab

Intervention

- Optimize control tech
- New control tech
- Additional samples?


Collection of respirable dust samples
Handling and shipping dust samples
Lab analysis and report generation
Analysis of data from the lab
Intervention
Assessment of the intervention(s)


Collection of respirable dust samples
Han lin and shipp g dust sa np es
Lab n lysis and port ge era ion
Analysis of data from the lab
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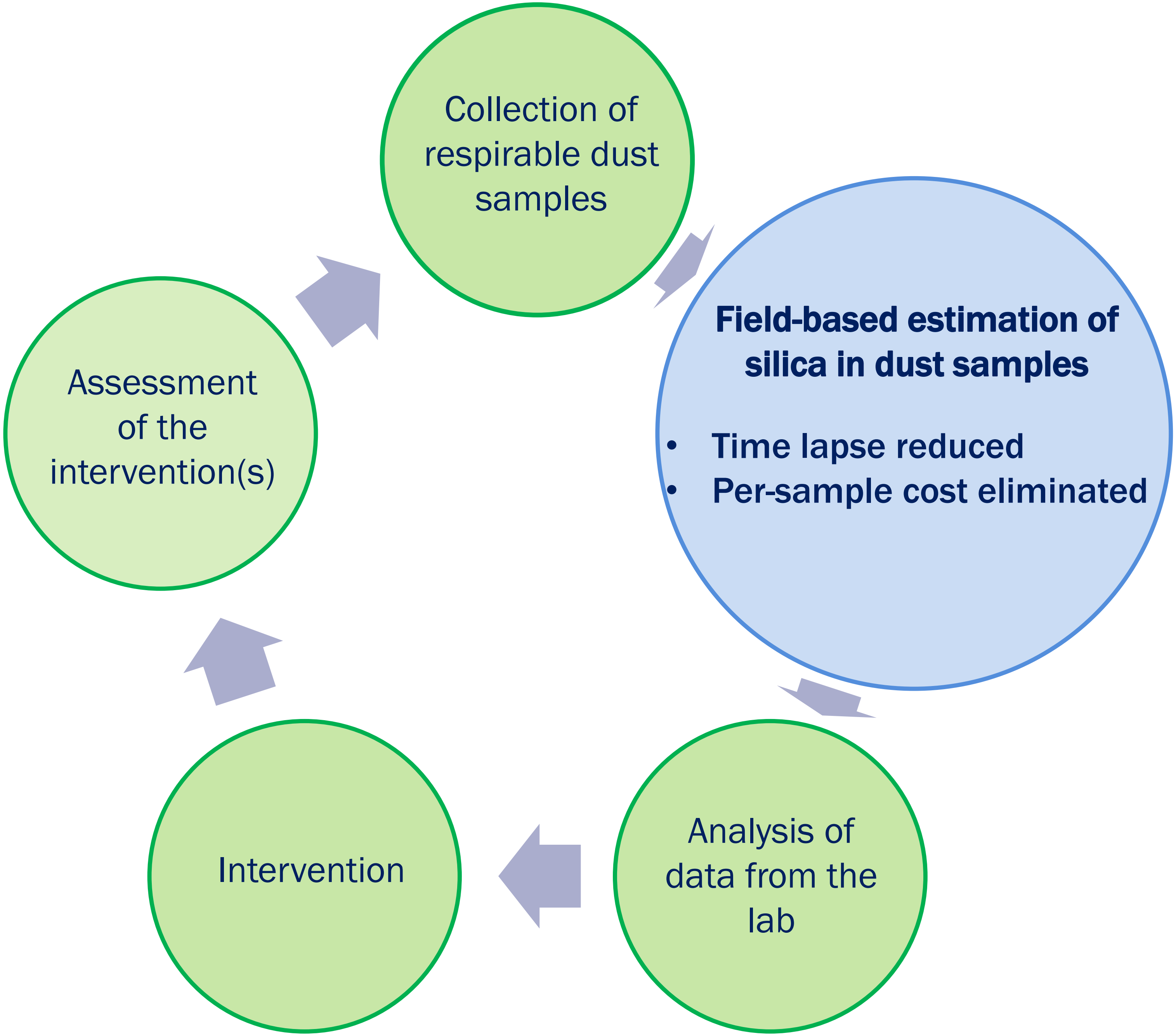

Collection of respirable dust samples
Field-based estimation of silica in dust samples
• Time lapse reduced
• Per-sample cost eliminated
Analysis of data from the lab
Intervention
Assessment of the intervention(s)

Field based silica monitoring

Requirements

- Specific to silica monitoring and not respirable dust monitoring.
- Accurate, precise, repeatable measurement.
- Field portable, small, "*relatively cheap*", and user friendly.
- To be used for self-assessment, engineering monitoring.

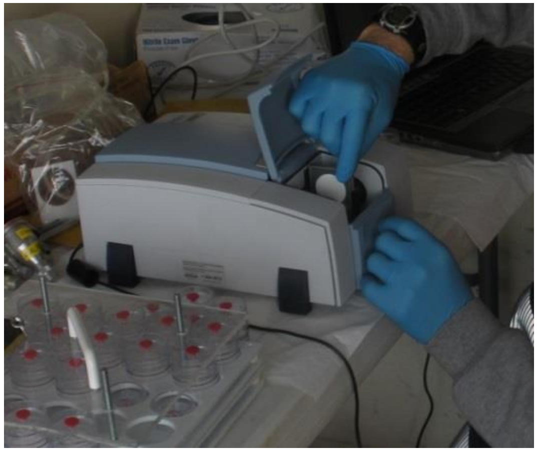
Benefits

- More timely silica monitoring – results in few minutes.
- More samples collected – no "cost per sample".
- More timely identification of overexposure cases.
- More timely assessment of efficacy of control technology.
- More control on the monitoring process

New responsibilities

- The analysis of the samples is deputed to the mine operator
- The H&S department might be in charge - Operator empowerment.
- The quality of the technique needs to be assessed at the mine site

Development of field-based silica monitoring approach



Analytical requirements

- Compatible with Direct-on-Filter approach
  - No pretreatment or removal of dust sample from the filter
  - Non destructive

Method selected: FTIR (in transmission mode)

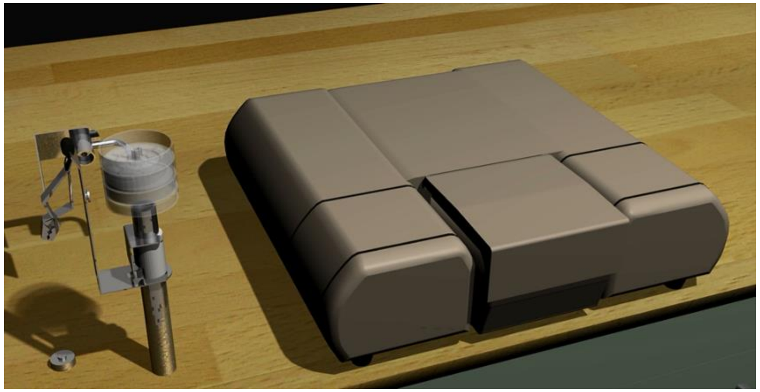
- Sample prep: None
- Portable instrumentation:
  - Small footprint (< 18 in by 12 in)
  - Easily lifted (< 30 lbs)
- Analysis time: 3 minutes

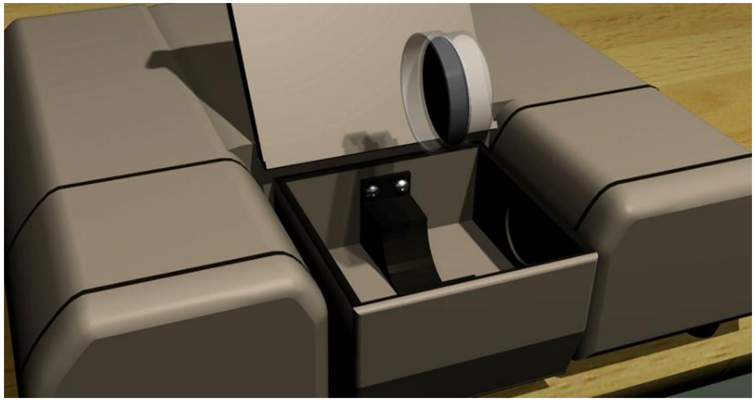
Preliminary findings

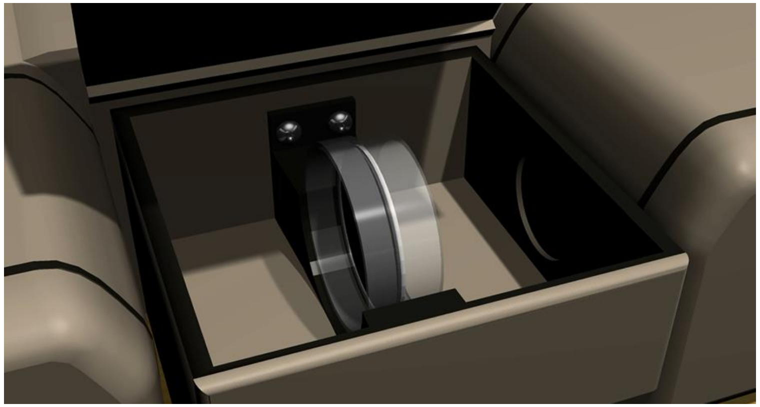
- Transmission FTIR can be used for dust samples collected in coal and non-coal mines.
- Bias of silica estimation might be affected by mineral confounders – especially for samples collected in non-coal mines.

Limit of detection	5 µg
Limit of quantification	16 µg
Daily variability	0.78%
Intra-instrument variability	1.65%

Development of field-based silica monitoring approach







Field study in surface copper mines in AZ/NM

In collaboration with Freeport McMoRan

Goal - assessment of the analytical technique with samples collected in copper mines

Methodology –

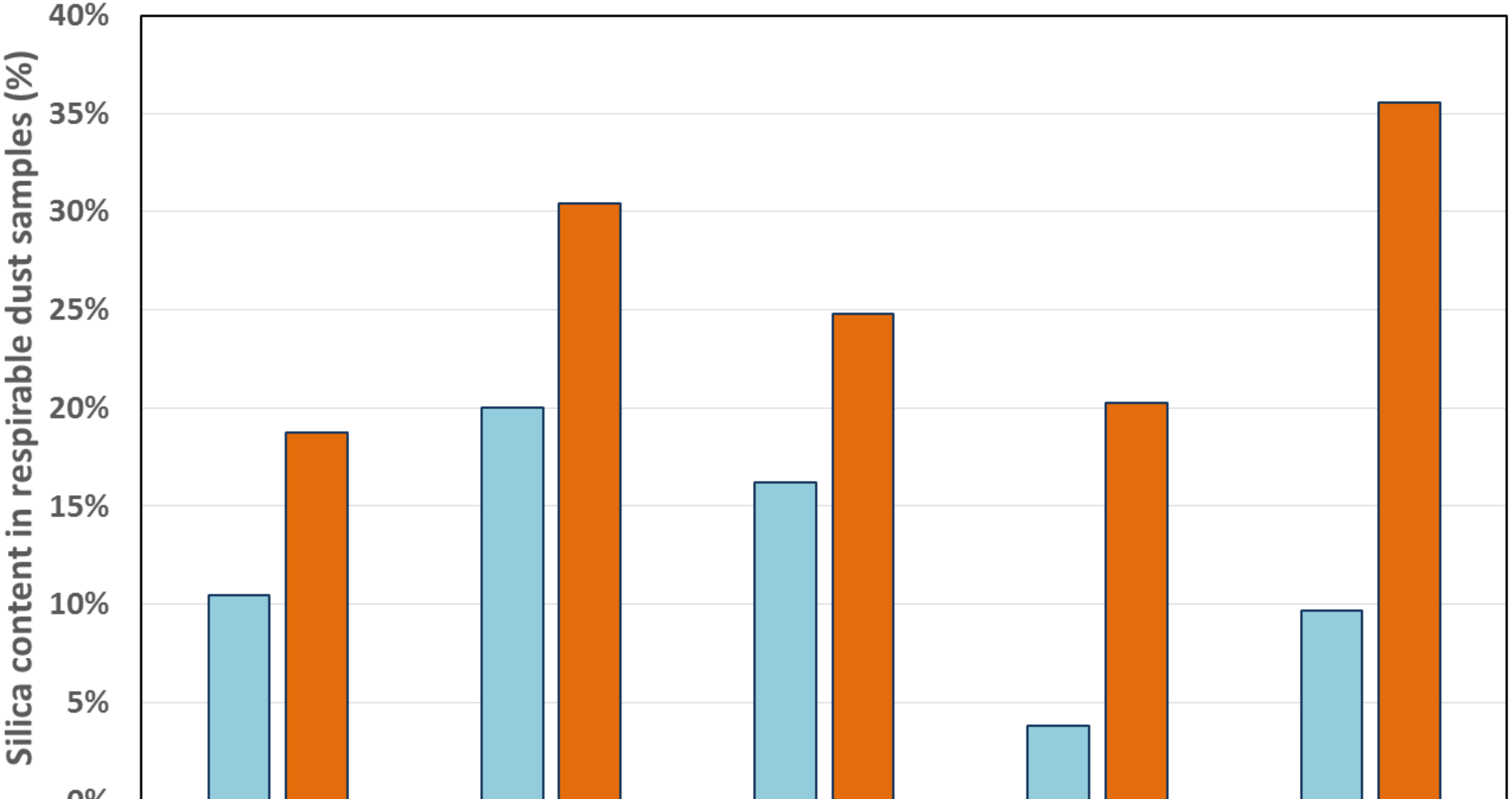
- Collection of 30-40 respirable dust samples in different area of a mine.
- Collection of settled bulk dust in sampled areas.

Analysis

1. Samples analyzed for respirable mass determination
2. Each sample analyzed in "Direct-on-Filter" with a portable FTIR for silica estimation.
3. The same samples then analyzed with the standard NIOSH7500 method.
4. The settled dust re- aerosolized and a respirable dust sample analyzed for minerals.

Preliminary results

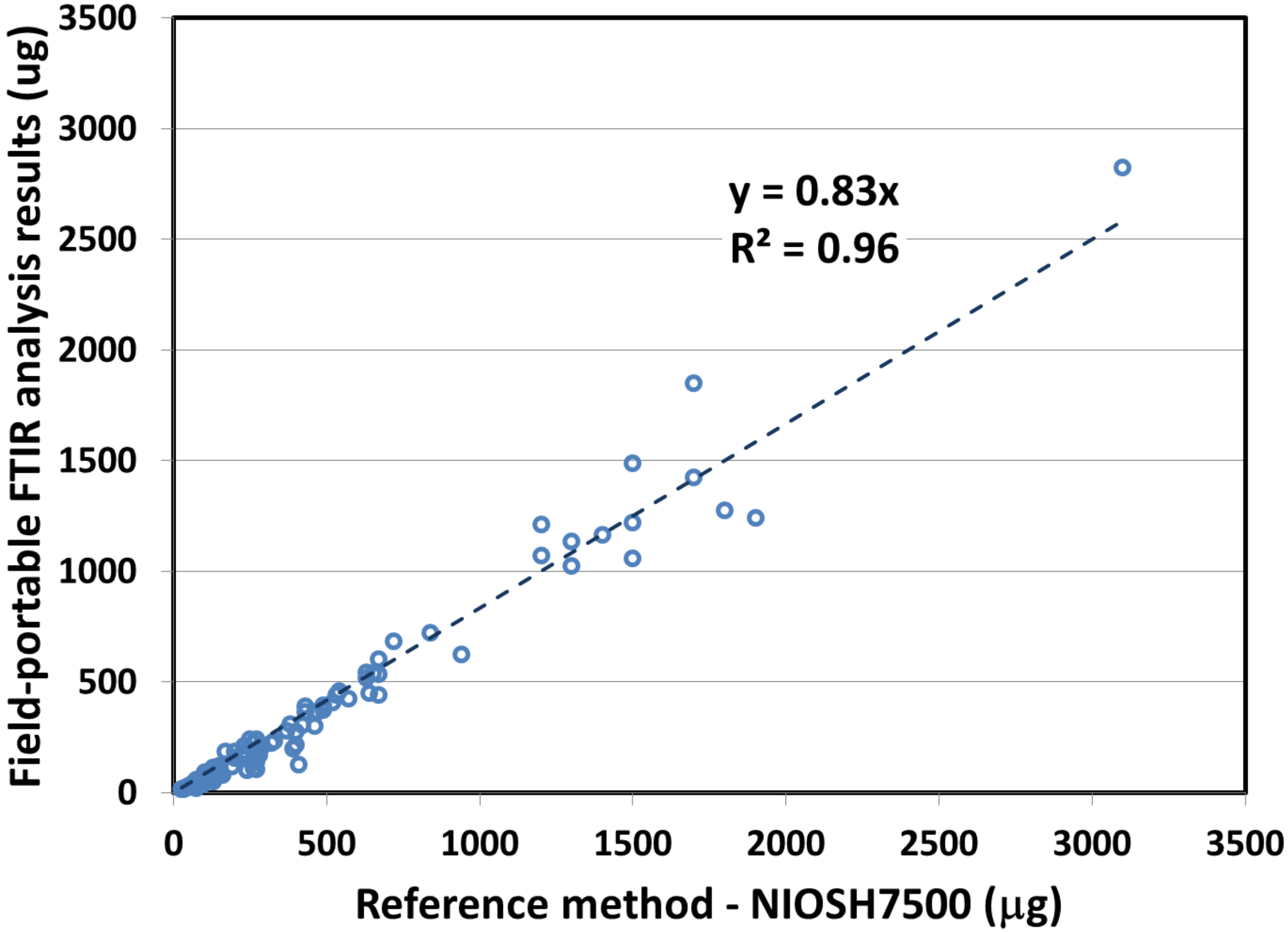
Silica content in the respirable dust



	D1	D2	D3	D4	D5
Min	10.4%	20.0%	16.2%	3.8%	9.6%
Max	18.7%	30.4%	24.8%	20.2%	35.5%

Preliminary results

Assessment of the field-based analytical technique



After first trip to each mine

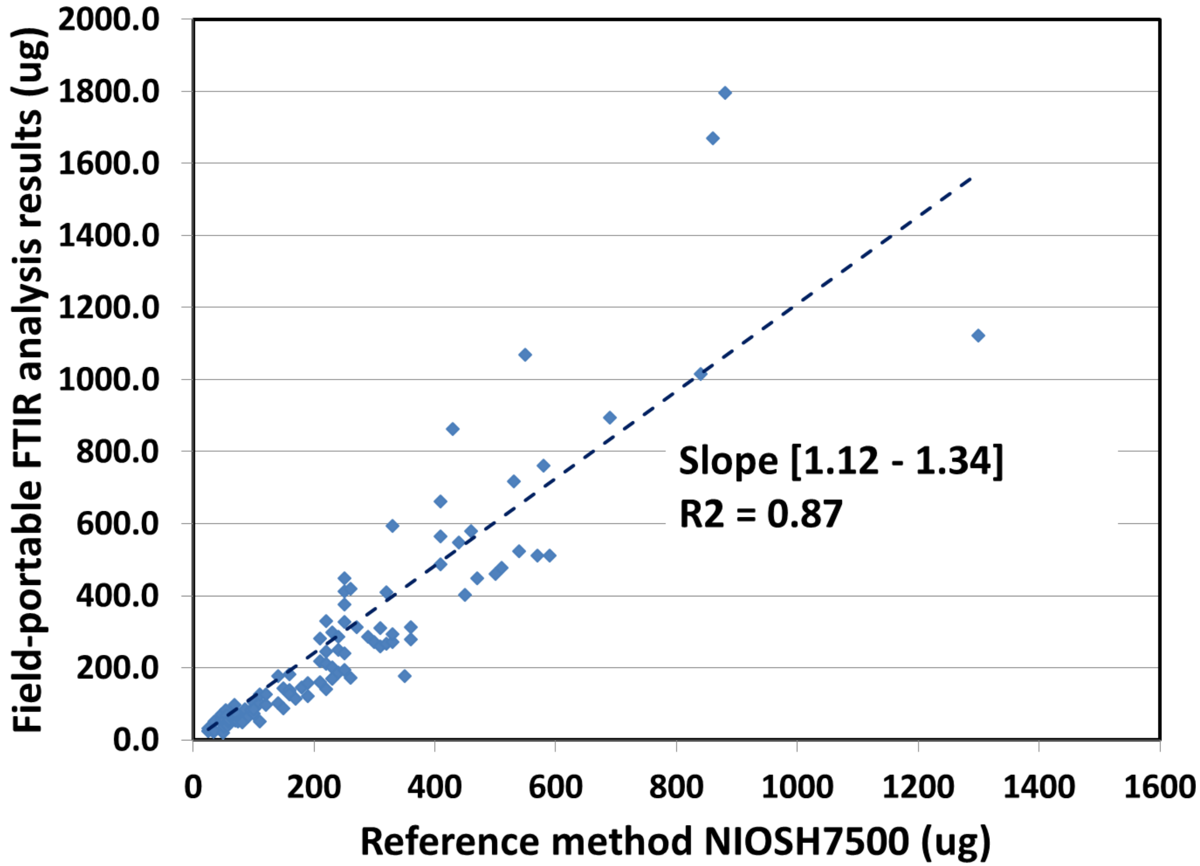
Average bias (relative difference field based method vs NIOSH7500) = -39%

Preliminary results

Assessment of the field-based analytical technique

<u>After second trip to each mine</u>

Quantification model adjusted mine by mine with information/knowledge accumulated during first trip



Average bias (relative difference field based method vs NIOSH7500) = 2.8%

Preliminary results

Mineral contents in respirable dust

	Phase analysis (%)			
	D1	D2	D3	D4
SiO_2 (Quartz)	15	27	17	12
$NaAlSi_3O_8$ (Albite) - anorthite - andesine	30	9	28	13
$KAlSi_3O_8$ (Microcline) -K Feldspar	24	44	15	9
$KAl_2(AlSi_3O10)(F,OH)_2$ (Muscovite)	10	16	19	43
$(Mg_5Al)(AlSi_3)O_{10}(OH)_8$ (Clinochlore)	11		12	
$Al_2Si_2O_5(OH)_4$ (Kaolinite)		4		27

- The respirable dust in different surface copper mines in Arizona/New Mexico is a mixture of: quartz, aluminum silicates of Na, K, and Mg.
- The intensity of each mineral is not constant mine by mine.
- It is foreseeable that the relative intensity of each mineral changes in time.

→ A "mine by mine" or sector (copper mines) calibration might be a partial solution.

Mineralogy data can provide general information on the quantification model that needs to refined for each sample.

Next step - Quantification of crystalline silica in complex dust mixtures

Partial Least Squares Regression (PLSR) Modeling

Collaboration with University of Ulm (Germany)

Relevant minerals determined from respirable dust field samples – PLSR model evolves as field data grows

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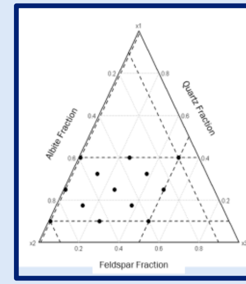
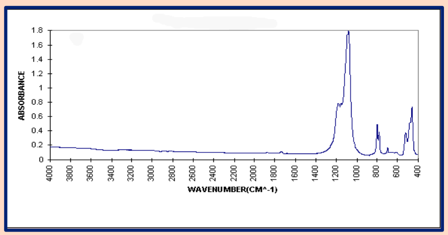
Importance of collaboration with mining industry

PLSR model trained by NIOSH calibration samples

Calibration samples specific for mining sector



The unique mineral composition of a sample will be considered for the analysis.



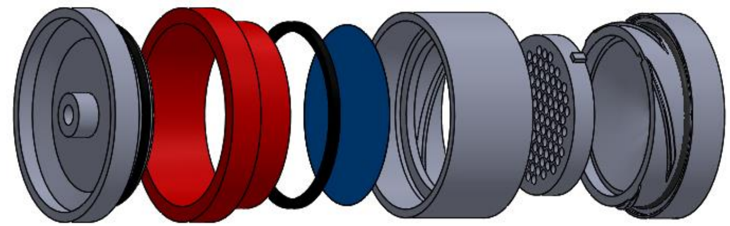
Adaptive model builds specific calibration for unique mineral mixture

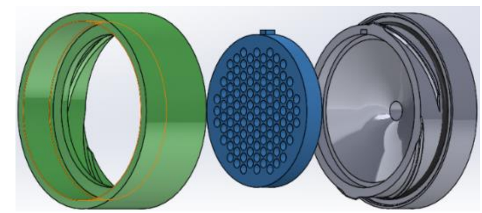
Accurate quantification of crystalline silica for each single sample

Testing multiple commercially available portable FTIRs

	Bruker Alpha	Thermo	Perkin Elmer	Agilent
				
Weight	7 kg	10 kg	13 kg	4.8 kg
Footprint dimensions	12” x 8”	14” x 10”	18” x 12”	9” x 6”
Battery capability	Yes	No	Yes; battery is chargeable from car	No
Cost	$25K	$14K	$18K	$22K

Development of field-base silica monitoring
Technology progress subtask



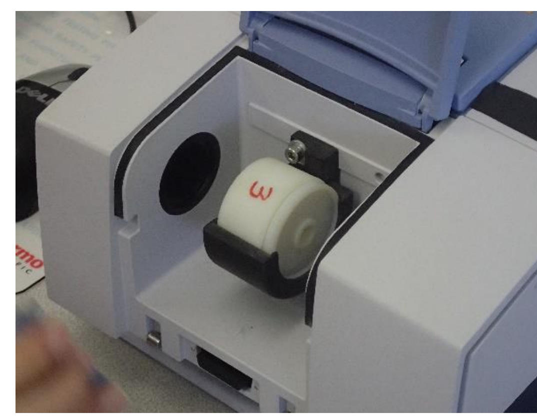


<u>Silica monitoring cassette</u>

- Shoot-thru cassette
- Compatible with existing cyclone(s)
- Simple to use on-site
- Compatible with the portable FTIR machine
- This is a project of a team of engineering students at **Gonzaga University.**
- **Commercial partner – Zefon.**

<u>User friendly FTIR interface</u>

- Software with optimized analytical protocol
- Data interpretation
- Protocol for periodic assessment of the technique.



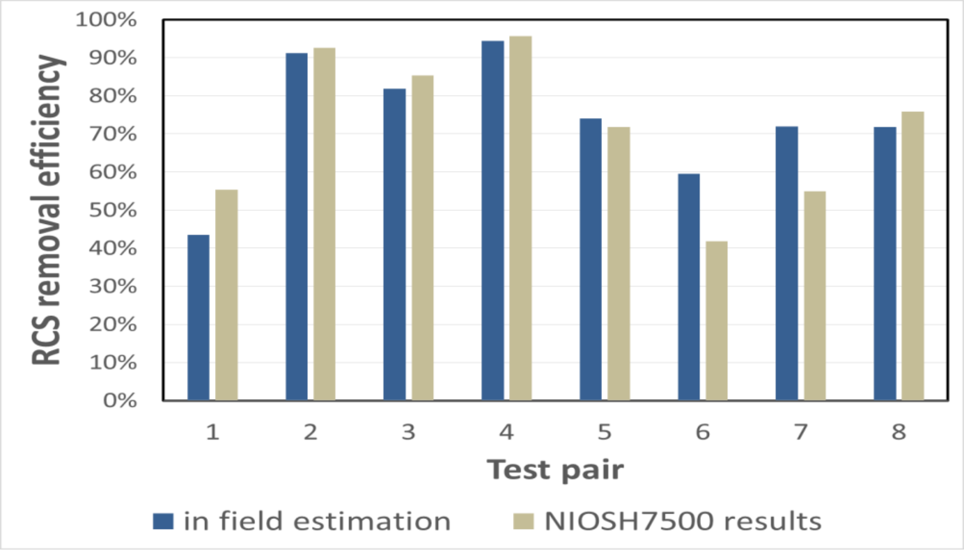
Beta testing

Field estimation of effectiveness of Mini Baghouse Retrofit Assembly

Evaluation of a mini bag house for the control of silica dust generated by a sand mover. NIOSH design.

Respirable dust concentration and RCS concentration levels were measured on and around the sand mover with and without the mini-baghouse.

- Analyzed the samples on site and estimated the silica concentration. Estimated efficiency of control technology on-site.
- The performance was then verified with the NIOSH7500 analysis results

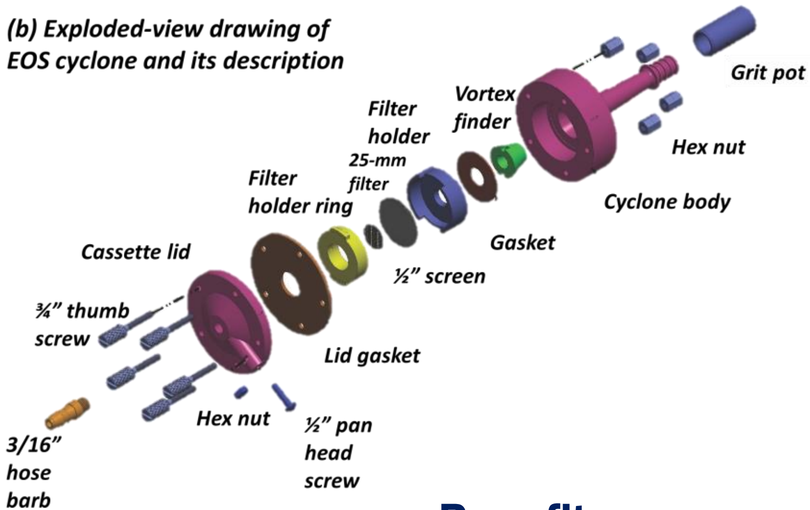


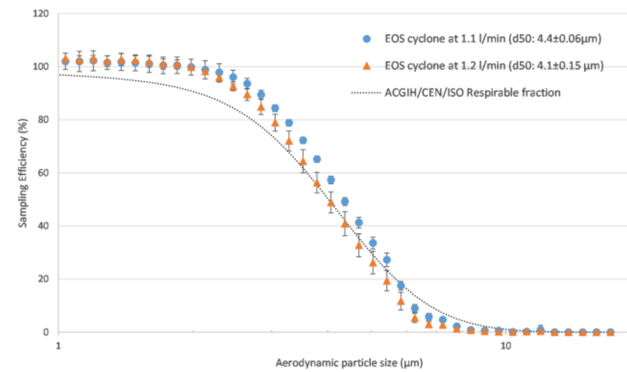
Alexander, B. M., E. J. Esswein, M. G. Gressel, J. L. Kratzer, H. Amy Feng, B. King, A. L. Miller and E. Cauda (2016). "The Development and Testing of a Prototype Mini-Baghouse to Control the Release of Respirable Crystalline Silica from Sand Movers." Journal of Occupational and Environmental Hygiene: 00-00.

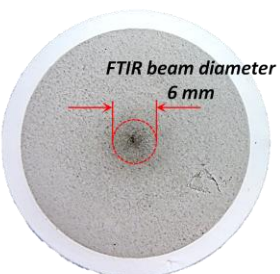
Dedicated End-of-shift Silica monitoring respirable cyclone

(a)Assembled EOS cyclone

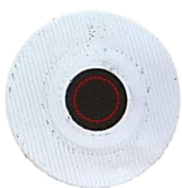
(b) Exploded-view drawing of EOS cyclone and its description







Coal dust on a
37 mm PVC filter
(10-mm nylon cyclone)



Coal dust on a
25 mm PVC filter
(EOS cyclone)

Benefits

- Specific filter holder for 25 mm filter optimized for Direct-on-Filter analysis
- Increased sensitivity for the crystalline silica quantification – possible LOQ ≈ 2µg

Status

Lee T, Lee L, Cauda E, Hummer J, Harper M. "Respirable Size-Selective Sampler for End-of-Shift Quartz Measurement: Development and Performance". J Occup Environ Hyg. (2016)

Field testing.

Helmet CAM – EVADE software

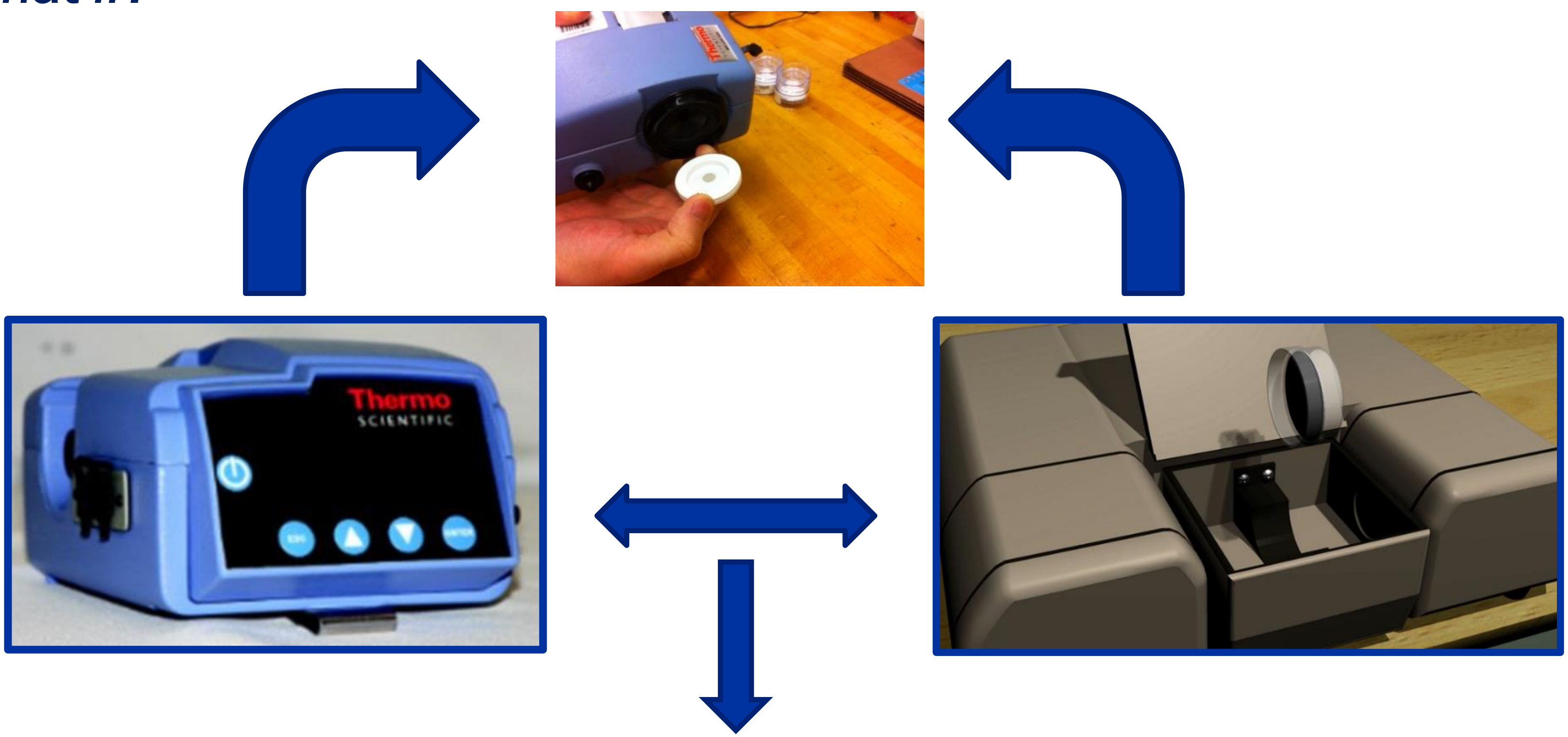
- Evaluation tool to determine “sources of exposure” and “control technology effectiveness”.
- Particularly suitable for mobile workers with multiple tasks.
- Concept applicable to other exposures – DPM, noise, chemicals.

Field-based Respirable Crystalline Silica (RCS) monitoring

- Specific to Respirable Crystalline Silica
- It is compatible with any sampler used by IH for respirable dust sampling
- Results in few minutes.

Helmet CAM + Field-based silica monitoring

What if?



Outcome:

- Real time respirable dust monitoring
- End of shift average respirable crystalline silica concentration monitoring
- *With modified filter holder* – higher sensitivity for silica quantification.

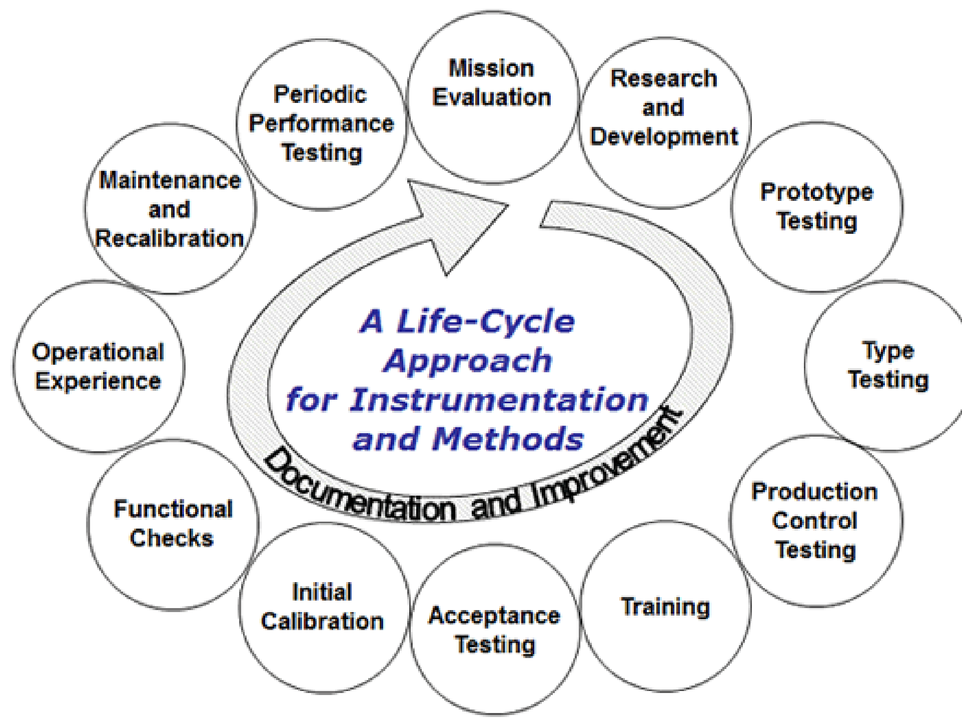
NIOSH Center for Direct Reading and Sensor Technologies

https://www.cdc.gov/niosh/topics/drst/

The Center was established in 2014 to coordinate research and to develop recommendations on the use of 21st century technologies in occupational safety and health. The NCDRST is a virtual center.

Goals

- Coordinate a national research agenda for direct-reading methods and sensor technologies;
- Develop guidance documents pertinent to direct-reading methods and sensors, including validation and performance characteristics;
- Develop training protocols; and
- Establish partnerships to collaborate in the Center's activities.



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Questions?

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