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
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.”

“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.
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.

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/m³

Real time dust monitor
- Presence of several short episodes with dust levels up to 70 mg/m³
- 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)

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

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.

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

(search “NIOSH EVADE”)
Helmet-CAM as a H&S Risk Communication Tool

1. Risk Identification

2. Risk Assessment

3. Risk Mitigation

4. Risk Response & Controls

5. Risk Monitoring

HSMS Leadership Communication
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
Collection of respirable dust samples
Handling and shipping dust samples
Lab analysis and report generation

Limitations:
- Time lapse
- Per-sample cost
Collection of respirable dust samples

Handling and shipping dust samples

Analysis of data from the lab

Lab analysis and report generation
Collection of respirable dust samples

Handling and shipping dust samples

Intervention

Lab analysis and report generation

Analysis of data from the lab

- 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

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

Field-based estimation of silica in dust samples
- Time lapse reduced
- Per-sample cost eliminated

Assessment of the intervention(s)

Intervention

Analysis of data from the lab
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.

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<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td><strong>Limit of detection</strong></td>
<td>5 µg</td>
</tr>
<tr>
<td><strong>Limit of quantification</strong></td>
<td>16 µg</td>
</tr>
<tr>
<td><strong>Daily variability</strong></td>
<td>0.78%</td>
</tr>
<tr>
<td><strong>Intra-instrument variability</strong></td>
<td>1.65%</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th></th>
<th>Silica content in respirable dust samples (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>Min 10.4%</td>
</tr>
<tr>
<td></td>
<td>Max 18.7%</td>
</tr>
<tr>
<td>D2</td>
<td>Min 20.0%</td>
</tr>
<tr>
<td></td>
<td>Max 30.4%</td>
</tr>
<tr>
<td>D3</td>
<td>Min 16.2%</td>
</tr>
<tr>
<td></td>
<td>Max 24.8%</td>
</tr>
<tr>
<td>D4</td>
<td>Min 3.8%</td>
</tr>
<tr>
<td></td>
<td>Max 20.2%</td>
</tr>
<tr>
<td>D5</td>
<td>Min 9.6%</td>
</tr>
<tr>
<td></td>
<td>Max 35.5%</td>
</tr>
</tbody>
</table>
Preliminary results
Assessment of the field-based analytical technique

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

After first trip to each mine
Preliminary results
Assessment of the field-based analytical technique

After second trip to each mine
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**

<table>
<thead>
<tr>
<th>Phase analysis (%)</th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>D4</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂ (Quartz)</td>
<td>15</td>
<td>27</td>
<td>17</td>
<td>12</td>
</tr>
<tr>
<td>NaAlSi₃O₈ (Albite)</td>
<td>30</td>
<td>9</td>
<td>28</td>
<td>13</td>
</tr>
<tr>
<td>KAlSi₃O₈ (Microcline)</td>
<td>24</td>
<td>44</td>
<td>15</td>
<td>9</td>
</tr>
<tr>
<td>KAI₂(AlSi₃O₁₀)(F,OH)₂ (Muscovite)</td>
<td>10</td>
<td>16</td>
<td>19</td>
<td>43</td>
</tr>
<tr>
<td>(Mg₅Al)(AlSi₃)O₁₀(OH)₈ (Clinochlore)</td>
<td>11</td>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al₂Si₂O₅(OH)₄ (Kaolinite)</td>
<td></td>
<td>4</td>
<td></td>
<td>27</td>
</tr>
</tbody>
</table>

- 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 be 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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<td>9</td>
</tr>
<tr>
<td>K[AI₂Si₃O₁₀(H₂O)]₂ (Muscovite)</td>
<td>10</td>
<td>16</td>
<td>19</td>
<td>45</td>
</tr>
<tr>
<td>[Mg,Al]₂Si₃O₁₀(H₂O) (Chlorite)</td>
<td>11</td>
<td>12</td>
<td>14</td>
<td>27</td>
</tr>
</tbody>
</table>

Importance of collaboration with mining industry

PLSR model trained by NIOSH calibration samples

Calibration samples specific for mining sector

Adaptive model builds specific calibration for unique mineral mixture

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

**Accurate quantification of crystalline silica for each single sample**
Testing multiple commercially available portable FTIRs

<table>
<thead>
<tr>
<th></th>
<th>Bruker Alpha</th>
<th>Thermo</th>
<th>Perkin Elmer</th>
<th>Agilent</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Weight</strong></td>
<td>7 kg</td>
<td>10 kg</td>
<td>13 kg</td>
<td>4.8 kg</td>
</tr>
<tr>
<td><strong>Footprint dimensions</strong></td>
<td>12” x 8”</td>
<td>14” x 10”</td>
<td>18” x 12”</td>
<td>9” x 6”</td>
</tr>
<tr>
<td><strong>Battery capability</strong></td>
<td>Yes</td>
<td>No</td>
<td>Yes; battery is chargeable from car</td>
<td>No</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>$25K</td>
<td>$14K</td>
<td>$18K</td>
<td>$22K</td>
</tr>
</tbody>
</table>
Development of field-base silica monitoring

**Technology progress subtask**

**Silica monitoring cassette**
- 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.

**User friendly FTIR interface**
- 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

Dedicated End-of-shift Silica monitoring respirable 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

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

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.

Center Co-directors
- D. Gayle DeBord
  NIOSH DART
  Interim Division Director
- Mark D. Hoover
  NIOSH Exposure Assessment
  Program Coordinator
- John E. Snawder
  NIOSH DART
  Research Scientist Leader

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

### PMRD TEAM
- Emanuele Cauda
- Lauren Chubb
- Teresa Barone
- Andy Cecala
- Justin Patts
- John Organiscak
- Joe Archer
- Jeanne Zimmer
- Jason Pampena

### NIOSH Mining Support
- Arthur Miller (SMRD)
- Pamela Drake (SMRD)
- Eric Lutz (SMRD)
- Dust Control Team
- Human Factors Branch

### NIOSH Support
- Eric Esswein (NIOSH Denver)
- Max Kiefer (NIOSH Denver)
- Taekhee Lee (NIOSH HELD)
- Martin Harper (NIOSH HELD)
- Rosa Key-Schwartz (NIOSH DART)
- Barbara Alexander (NIOSH DART)

### External support

<table>
<thead>
<tr>
<th>University of Arizona Public Health</th>
<th>Patriot Coal Mine</th>
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<tr>
<td>Virginia Tech</td>
<td>Freeport McMoRan</td>
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<tr>
<td>Montana Tech</td>
<td>Unimin Corporation</td>
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<tr>
<td>Industrial Mineral Association (IMA-NA)</td>
<td>National Sand, Sand &amp; Gravel Association (NSSGA)</td>
</tr>
<tr>
<td>Vulcan Aggregates</td>
<td>CSIR (South Africa)</td>
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</table>
Questions?

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