Use and Application of Real-Time Exposure Monitoring

John E. Snawder. PhD, DABT

jsnawder@cdc.gov

Co-Director of the NIOSH Center for Direct Reading and Sensor Technologies

National Institute for Occupational Safety and Health (NIOSH)

Center for Disease Control and Prevention (CDC)

Center for Direct Reading and Sensor Technologies

NIOSH has always been involved in direct reading methods and sensor technologies.

NIOSH began organized research on direct reading method in 2008 with the creation of the DREAM initiative - Direct Reading Exposure Assessment Methods.

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

John Snawder Director

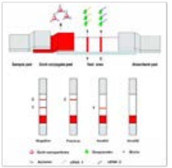
Emanuele Cauda Director

Pramod Kulkarni Center Coordinator

Strategic Plan

To coordinate research and to develop recommendations on the use of 21st century technologies in occupational safety and health.

- Sensor Strategies
- Sensor Development and Evaluation
- Outreach



FAST Field Analysis of Silica Tool

Center Objectives

- Coordinate a national research agenda for direct-reading methods and sensor technologies. Research on these technologies has been incorporated into the goals of the NIOSH Strategic Plan for fiscal years 2019-2023.
- 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.

Focus of the NIOSH Center for Direct Reading and Sensor Technologies

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

Center Vision

- Developing new direct-reading methods and sensors
- Sensor Life Cycle
- Right Sensor Used Right
- Selection of Sensors for Gases and Vapors
- Selection of Sensors for Gases and Vapors – Emergency Response
- Turning Numbers into Knowledge
- Framework for Ethical Sensor Use
- Sensor Use in Emergency Response NMAM Chapter on DREAM

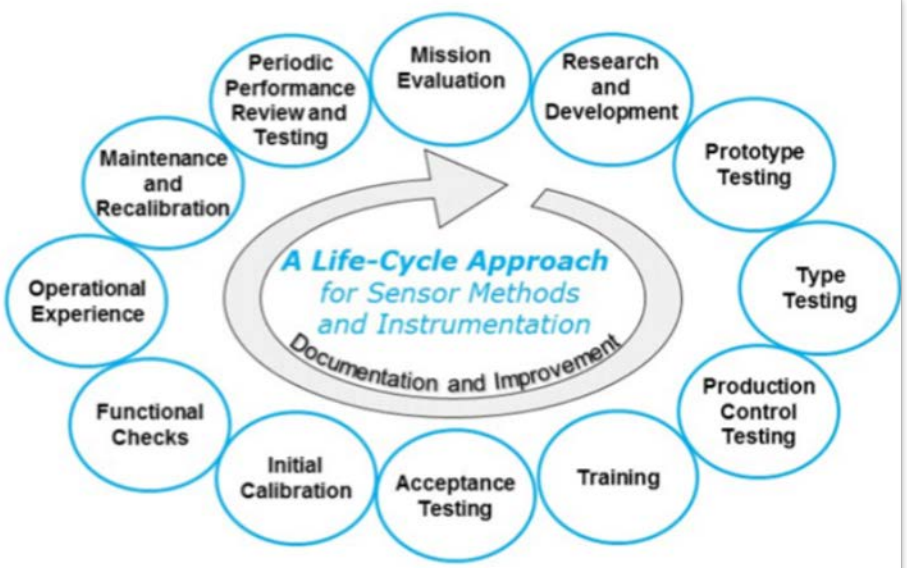


Figure 1. Life-cycle decision-making frame work and process for the effective selection and use of sensor methods and data.

Collaboration

- **Collaboration with Netherlands Organization for Applied Scientific Research (TNO) and UK Health and Safety Executive (HSE)**
- Memorandum of Understanding between HSE and NIOSH was Executed in July 2019
  - Covers many shared common interests including direct reading instruments
- Overarching Three-party Memorandum of Understanding was signed early February 2020
  - This is a very broad Memorandum NIOSH, HSE and TNO plan to cooperate to use their collaborative efforts and expertise to advance the protection of workers and to promote best practices to improve worker safety and health by applying the exposome concept on occupational health.
  - First effort is to develop protocols for evaluation of Direct Reading Instruments and Recommendations for their use.

Low Cost Sensor Projects

- Creation of a protocol/recommendations for systematic evaluation of low-cost sensors for gas/vapors and particulate matter
- Laboratory round-robin testing of low cost particulate sensors
- Field evaluation of low cost monitors by TNO, HSE and NIOSH in different workplaces

Collaborations

- American Industrial Hygiene Association
    - 2010-Present Real Time Detection Committee
    - 2015 Field Use of Direct-Reading Instruments for Detection of Gases and Vapors Body of Knowledge Working Group
    - 2016 Direct Reading Instrument Summit
    - 2017 AIHA Big Data Meeting
    - 2018 AIHA Sensor Accreditation Meeting
    - 2019 Direct Reading Instrument Body of Knowledge Working Group (Update and Revision)

Research Partnerships

- Other Federal Agencies
  - Department of Defense-US Army Office of Research/US Army Research Institute of Environmental Medicine/US Army Corps of Engineers/US Navy/US Air Force
  - US Environmental Protection Agency
  - US Department of Agriculture-APHIS/ / Forest Service
  - US Department of Energy
  - US Department of Labor-Occupational Safety and Health Administration, Mine Safety and Health Administration
  - US Department of the Interior-Bureau of Land Management
  - US Nanotechnology Initiative
  - US Department of Justice/National Institute of Justice
  - ES 21

Fatalities Associated with Manual Gauging, Thieving, Fluid Handling

- **Nine (9) worker deaths where inhalation of petroleum hydrocarbons was likely factor**
  - All occurred at production tanks
  - All were working alone
  - 5 fatalities occurred during thieving (collecting a sample) by fluid haulers
  - One employee was wearing 4-gas monitor
  - One had sought medical evaluation for dizziness, etc. a few weeks prior

More information: www.cdc.gov/niosh/topics/ fog/data.html

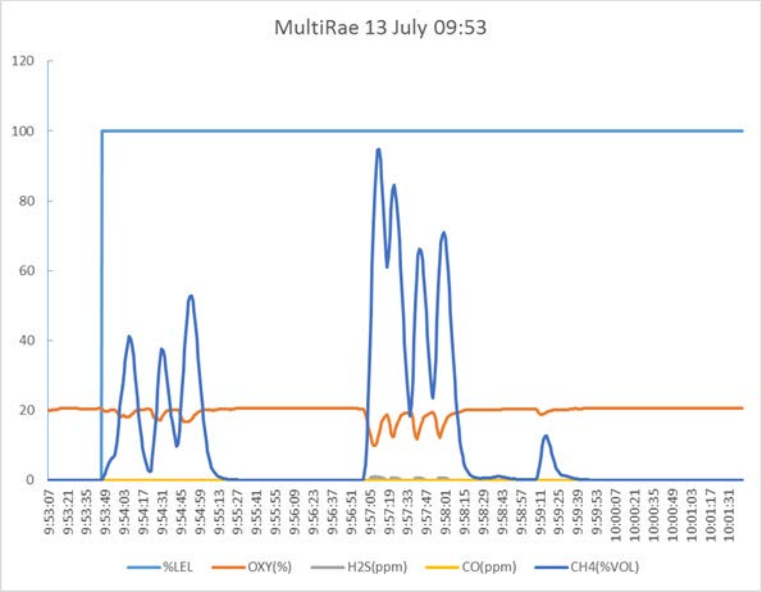
Opening Production Tanks

Worker Exposure Assessments: Methods Used

- Standard Industrial Hygiene Methods
  - NMAM (1500, 1501, 1550) and OSHA Methods (PV2010)
  - Personal and Area Samples (Full-shift, short term)
- Direct Reading Methods
  - Real Time Instruments, Meters and Monitors
  - Video Exposure Monitoring (FLIR GF 320)
- Whole air sampling
  - Evacuated containers (Entech Bottle-Vac)
  - Sample bags

Assessment

- Based on traditional IH sampling methods, exposure hazards of concern for benzene and other gas and vapors may be present
- Direct reading instruments demonstrate short-term hazardous atmospheres (flammable atmospheres, low oxygen, high levels of hydrocarbon gas and vapor) can occur when tanks are opened.
- ***<u>Standard methods are not always adequate to evaluate very high but, very brief exposures</u>***



Right Sensors Used Right

- In 2018 the Center launched a new initiative called "Right Sensors Used Right".

- The initiative focuses on

- **Right Sensors:** the **selection** of appropriate sensors/methodologies to meet mission objectives (*fit for purpose*).

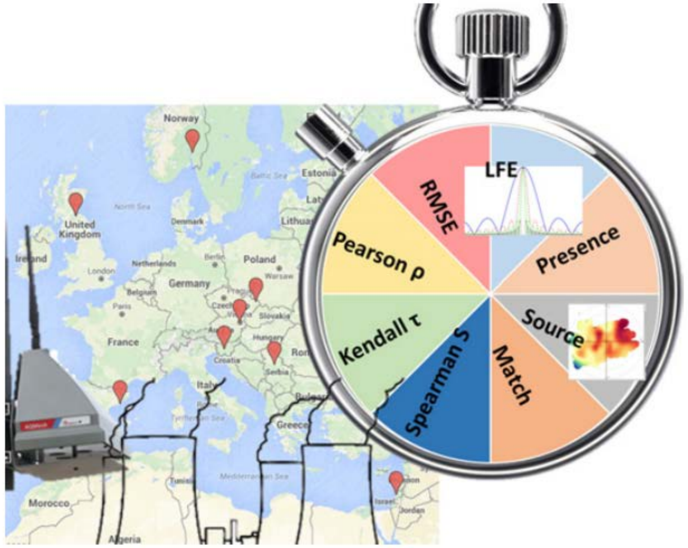
- **Used Right:** the **appropriate usage** of the sensors/methodologies to obtain the needed data quality.

- *The initiative is organized in specific tasks and activities.*

What about an holistic evaluation of the suitability and usability of (low-cost) sensors ??

Four possible schemes for evaluating sensors:
- Locate pollution sources
- Represent the pollution level on a coarse scale
- Capture the high temporal variability
- Reliability (precision?)

Can these schemes for environmental monitoring be applicable for occupational hygiene?



Other schemes need to be included?

Fishbain et all. (2017). "An evaluation tool kit of air quality micro-sensing units." Science of the Total Environment **575**: 639-648.

Right Sensors Used Right Is a Stepwise Approach

- Step 1**. Define the Objective:** What is the purpose of using a real-time or direct reading method or monitor

- Step 2. **Select the Monitor/Method**: There are several important points to consider in assessing the suitability of a sensor for a given application, and these may be used to classify sensors. Selection is based not only on the capabilities of the monitor or method but, also the limitations of the monitor.

- Step 3. **Interpret Data, Define Actionable Data:** Based on the selected use, prior to deploying real-time instruments/methods a plan for the collection, use and interpretation of data should be carefully constructed and documented for all stakeholders

- Step 4: **Communicate**: Prior to deploying real-time instruments/methods a communication approach should be developed to transform processed data into usable information. The goal should be increasing situational awareness around exposures using the sensors and delivered to Customers, Creators, Curators and Analysts.

NIOSH/Partners Efforts to Date

- Step 1**. Define the Objective:** What is the purpose of using a real-time or direct reading method or monitor . Multiple collaborations covering when to use instruments
- Step 2. **Select the Monitor/Method**: There are several important points to consider in assessing the suitability of a sensor for a given application, and these may be used to classify sensors. Selection is based not only on the capabilities of the monitor or method but, also the limitations of the monitor.

  Multiple collaborations covering what to use, how to evaluate, how to calibrate, uses and limitations
- Step 3. **Interpret Data, Define Actionable Data:** Based on the selected use, prior to deploying real-time instruments/methods a plan for the collection, use and interpretation of data should be carefully constructed and documented for all stakeholders. Going beyond comparing to OELs, but interpreting data from an exposure standpoint, incorporating data into cumulative exposures or are they not relevant for that purpose.
- Step 4: **Communicate**: Prior to deploying real-time instruments/methods a communication approach should be developed to transform processed data into usable information. The goal should be increasing situational awareness around exposures using the sensors and delivered to Customers, Creators, Curators and Analysts. Collaborations in place to better communicate findings to all stakeholders. Not just reports.

RSUR to Date

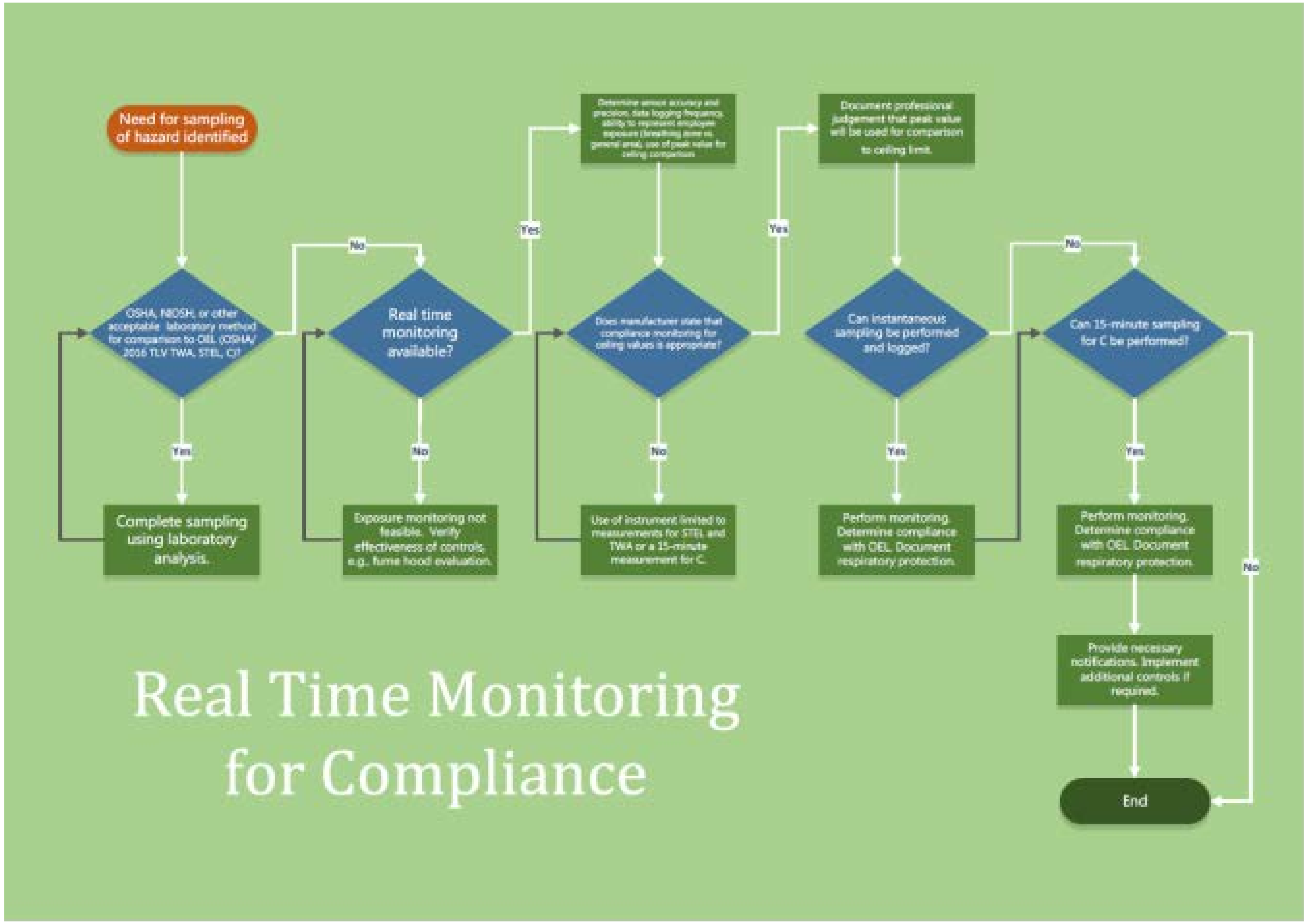
- At present, the CDRST uses subject matter experts (SMEs) knowledgeable in real-time monitoring, exposure assessment, toxicology and risk assessment. These SMEs work on a case by case basis with the requester and work through the steps of the Right Sensor Used Right process.

- The goal of CDRST is to develop a tool or suite of tools for the *Right Sensor Used Right* approach to use real-time instruments to assess exposures and interpret the data from a toxicological and risk assessment point of view.

- A key question for the panel is how to integrate and utilize data from real time instruments into exposure/risk assessments. Exposure and risk assessors are challenged, to incorporate peak and task-based measurements (which can now be captured with new/improved measurement tools), into traditional exposure and risk assessments for acute and chronic effects.

- The CDRST is requesting review and suggestions on how best to present the tools for end users to design and conduct occupational exposure assessments using real-time instruments and more important, interpret data from these studies to better characterize risk, and finally communicate the findings to all stakeholders.

Decision Tree for Real-Time Monitoring



Evaluate the Hazard

Chemical Name			
CAS Number			
Exposure Effect	Measurement Time	OEL	Basis
Immediate	Instant	Ceiling/Peak	Irritant, Central Nervous System, Asphyxiant
Acute	Instant/Minutes	STEL/IDLH	Irritant, Central Nervous System, Organ toxicity
Subacute/Chronic	Shift TWA/Daily TWA	8-10h TWA	Systemic toxicity, Organ toxicity
Chronic	DailyTWA/Weekly TWA	8-10h TWA, Weekly	Systemic toxicity, Cancer, Organ toxicity

Select the Instrument

What is the Sampling Objective	Define why you want to test Define what you want to test Define how you want to test
Targeted Hazardous Agent	What are the hazards of concern, Gas/vapor? Particulate? Physical agents?
Proposed technology/selected instrument	What instrument(s) will be used? What level of specificity is needed? Class-level specificity acceptable?
Performance-Sensor/Monitor Response Time	What is the instruments T50? T90? How long does it take for the instrument to measure a step change?
Performance- Sensor/Monitor Range	Will the instrument measure the full range of potential concentrations?
Performance-Sensor/Monitor Accuracy at different concentrations: 0, 10, 50% and 100% of concentration of concern	Does the instrument have the level of accuracy needed for a given purpose?
Performance-Sensor/Monitor Precision at 0, 1%, 10%, 50% and 100% of concern.	Are instrument readings for a given concentration repeatable and reliable?
Data logging frequency	Does the instrument have enough storage capacity for, minutes, hours, days? Can the logging frequency be changed to match monitoring objectives? How easy is it to view or download data? Does it require special software?
Personal sample or area sample collection	How big is the instrument? How heavy is the instrument? Power requirements? Intrinsic safety?
Manufacturer recommended calibration, service, environmental capability	Can user calibrate? Special tools or standards? User serviceable? Environmental conditions for normal operations? Cold/Hot? Correction factors available?
OEL and basis 8-hour TWA: STEL: Ceiling: IDLH:	Can the user set custom alarms for each OEL? Can the user set custom time for peak alarms? Do instrument dead-bands interfere with interpretation? Does the instrument range cover all concentrations of concern?
Appropriate for Situation:	Yes/No

Ethyl Mercaptan

The OELS for ethyl mercaptan are NIOSH REL: 0.5 ppm ceiling (15-minutes), OSHA PEL: 10 ppm ceiling (15-minutes) and the ACGIH TLV: 0.5 ppm TWA. The revised NIOSH IDLH for ethyl mercaptan is 500 ppm based on acute inhalation toxicity data in animals.

Chemical Name	Ethyl Mercaptan		
CAS Number	75-08-1		
Exposure Effect	Measurement Time	OEL	Basis
Immediate	Instant	Ceiling/Peak	Irritant, Central Nervous System, Respiratory paralysis
Acute	Instant/Minutes	STEL/IDLH	Irritant, Central Nervous System, Organ toxicity

Select the Instrument

What is the Sampling Objective?	Evaluate worker exposures to ethyl mercaptan. Evaluate potential sources, peak concentration and duration of releases
Targeted Hazardous Agent	Ethyl mercaptan vapor
Proposed technology/selected instrument	4-Gas Monitor (flammable gas, Oxygen, Hydrogen Sulfide, Carbon monoxide-) Photo Ionization Detector
Performance-Sensor/Monitor Response Time	With proper correction factor PID response is in seconds. Instrument is immediately responsive
Performance- Sensor/Monitor Range	PID, 0-2000 ppm, 4-Gas Monitor:0-400, Colorimetric tubes 1-160 ppm
Performance-Sensor/Monitor Accuracy at different concentrations: 0, 10, 50% and 100% of concentration of concern	Yes
Performance-Sensor/Monitor Precision at 0, 1%, 10%, 50% and 100% of concern.	Yes
Data logging frequency	**Does the instrument have enough storage capacity for, minutes, hours, days?** Yes **Can the logging frequency be changed to match monitoring objectives?** Yes **How easy is it to view or download data?** Yes. **Does it require special software?** No
Personal sample or area sample collection	**How big is the instrument?** 2x4 in. **How heavy is the instrument?** 12 oz **Power requirements?** Battery to 12 h **Intrinsic safety?** Yes
Manufacturer recommended calibration, service, environmental capability	**Can user calibrate?** Y**. Special tools or standards?** N **User serviceable?** Y **Environmental conditions for normal operations? Cold/Hot?** Acceptable **Correction factors available?** Y
OEL and basis : Irritant, CNS, Organ damage **8-hour TWA:** TLV 0.5 ppm **STEL: NA** **Ceiling:** 0.5 ppm NIOSH, 10 ppm **IDLH:** 500 ppm	**Can the user set custom alarms for each OEL?** Y **Can the user set custom time for peak alarms?** N **Do instrument dead-bands interfere with interpretation?** N **Does the instrument range cover all concentrations of concern?** Y
Appropriate for Situation:	**Yes**

Right Sensor Used Right Approach Followed

Step 1**. Define the Objective:** What was the purpose of using a real-time or direct reading method or monitor

- To alert the personnel for hazardous conditions
- Identify sources – i.e. mapping
- Qualitative survey to assess tasks and temporal variability
- Evaluate performance of administrative controls
- Evaluate performance of engineering controls
- Risk/Exposure assessment
- Compliance monitoring
- Training and continuous education

Right Sensor Used Right Approach Followed

- Step 2. **Select the Monitor/Method**: Several monitoring methods were chosen to evaluate exposures based on the defined objectives. The entire task was recorded with a digital camera, synchronized with the monitor internal clock. NIOSH EVADE Video Exposure Monitoring software was used to synchronize video with logged data.
- **To alert the personnel for hazardous conditions**: Multi-gas personal alarming monitors with Oxygen, Flammable Gas, Carbon Monoxide and Hydrogen Sulfide are always worn by workers. Hydrogen Sulfide sensor cross-reacts with Ethyl Mercaptan (correction factor =2)
- **Identify sources – i.e. mapping:** Multi-Gas monitors (area with pumps) were located in the work area. These were configured with photoionization detectors (PID; ethyl mercaptan ionization energy = 9.3 eV, correction factor 0.56). Workers also wore PIDs in their breathing zones.

Right Sensor Used Right Approach Followed

- **Qualitative survey to assess tasks and temporal variability**: Data logs from above monitors.
- **Evaluate performance of administrative controls:** Results from sampling compared to prior procedures.
- **Evaluate performance of engineering controls:** Results from sampling compared to prior procedures.
- **Risk/Exposure assessment:** Real-time measurements can document peak concentrations above a target value to be readily identified. Colorimetric detector tubes for ethyl mercaptan were used to estimate short-term concentrations. Data logging instruments can provide temporal information throughout the sampling period. Integrated sampling on collection media followed by laboratory analysis, provides information only about the average exposure across the full sample collection period.

Right Sensor Used Right Approach Followed

- **Compliance monitoring:** Examination of logged data from the selected instruments may be compared to the relevant OELs. Grab-sample peak concentrations from colorimetric tubes and traditional IH measurements for ethyl mercaptan using NMAM method 2542 to compare to relevant OELs.
- **Training and continuing education**: Real-time instruments and methods provide almost instantaneous results. Instruments were selected that electronically provided Peak, STEL, and TWA during and after the sampling period. Workers can be provided with real-time feedback on the effectiveness of engineering controls, behavior change and administrative controls

Right Sensor Used Right Approach Followed

- Step 3. **Interpret Data, Define Actionable Data:** Data log intervals, correction factors where appropriate, and alarms were set as appropriate. Because the task duration is less than two hours, data logging intervals were set for one second.
- Instrument alarms for the 4-gas monitor were not changed from routine settings: Oxygen Low = 19.5 %, Oxygen High = 24 %; Hydrogen Sulfide Low = 10 ppm;
- Carbon Monoxide Low = 50 ppm; Combustible Gas = 10 % LEL
- PID Alarms were Low = 10 ppm; High = 100 ppm Ceiling = 500 ppm

- The real time instantaneous plot provides actual worker exposure changes in concentration, worker actions can be matched through observation and video monitoring can reveal where peak exposures could occur.

Right Sensor Used Right Approach Followed

Step 3. **Interpret Data, Define Actionable Data:** Data log intervals, correction factors where appropriate, and alarms were set as appropriate continued.

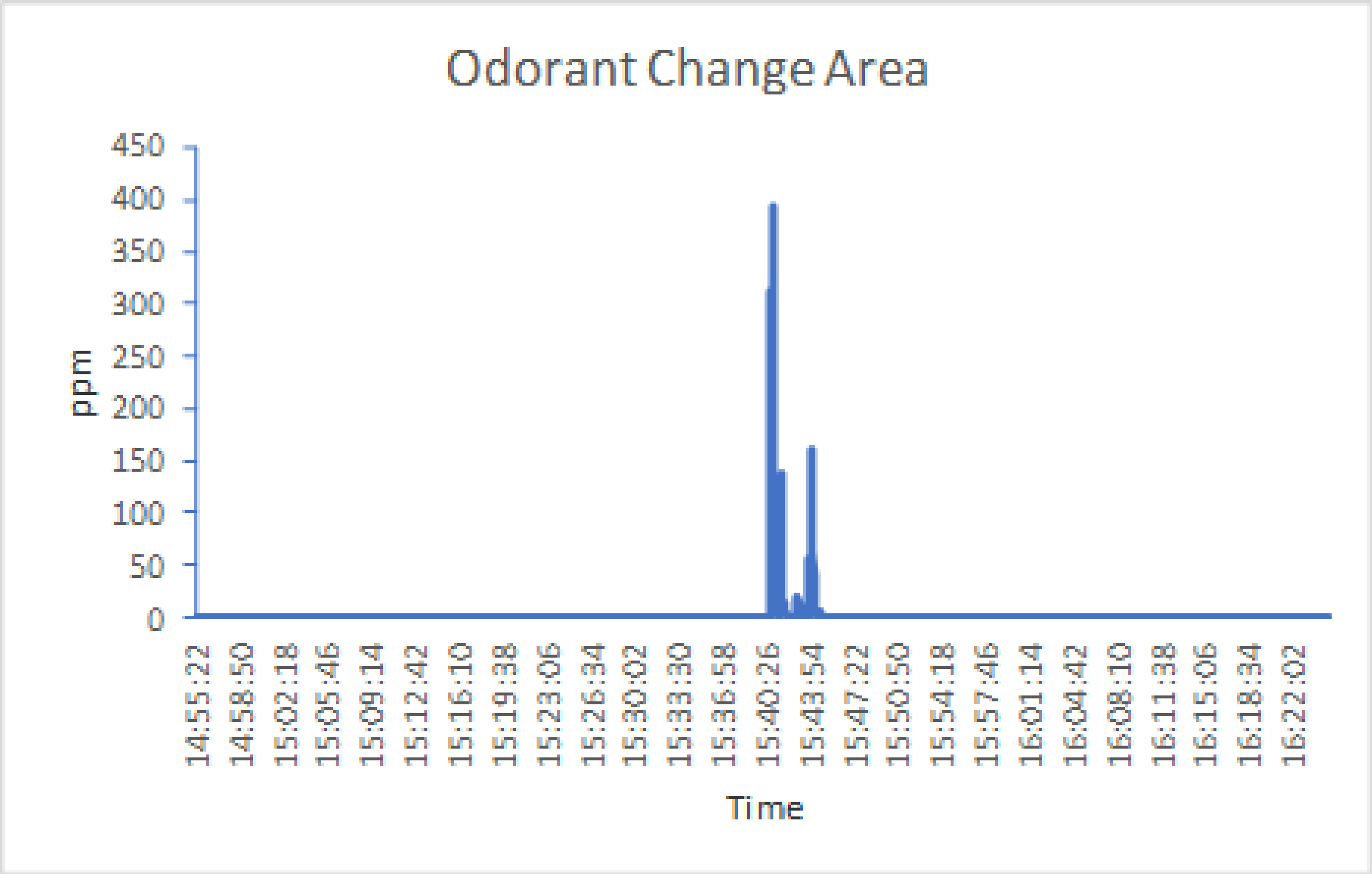
- All peak exposures will be evaluated based on concentration and time. Peak exposures greater that 500 ppm, regardless of duration will be considered an IDLH atmosphere and workers will either evacuate the area, or only perform the tasks associated with these peaks with supplied air respirators. Peak exposures l00 ppm up to 500 ppm will be treated as follows:
- 10 seconds or less: Recognized as a potential source and engineering or administrative controls should be used to mitigate. Concentration will be incorporated into Peak, Short-Term (15 min) and Task-Based TWAs
- 11 seconds to 10 minutes: Short-Term TWA will be determined and compared to the NIOSH (0.5 ppm) and OSHA (10 ppm) Ceilings. The instantaneous log will be examined, and the 15-minute Ceiling calculated such that the peak is bracketed by 7.5 minutes on either side to calculate the Ceiling concentration. If the calculated ceiling exceeds 10 ppm, tasks associated with these peaks will be performed with supplied air respirators.
- Regardless of the actual duration of the task, if the TWA calculated from the real-time instrument or NMAM 2542 exceeds the ACGIH TLV of 0.5 ppm, supplied air respirators should be worn until the task is mitigated.

Right Sensor Used Right Approach Followed

Step 4. **Communicate**: Following completion of the exposure assessment activity a "hot-wash" was held. Once data was downloaded and examined, NIOSH SMEs and company HSE staff together developed communication approach for increasing situational awareness around exposures using the sensors, use EVADE and other visual tools to provide effective feedback to the research partners, workers and industry community.

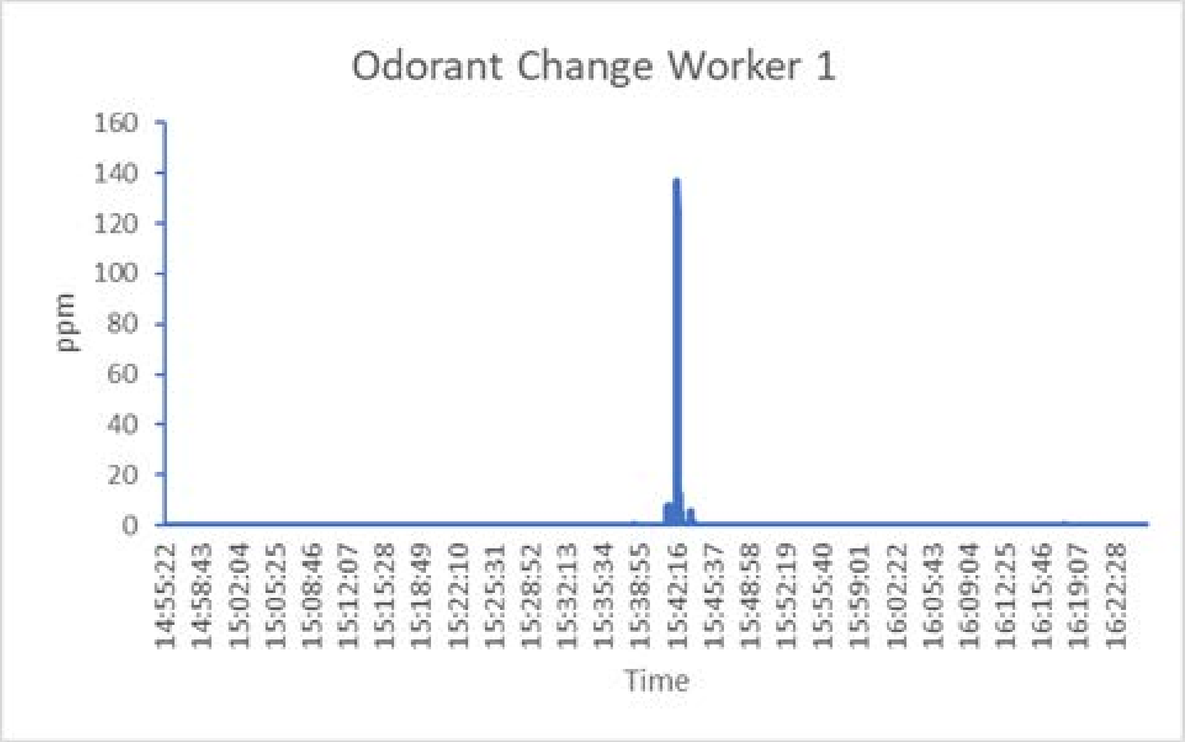
- Key information to be conveyed at Hot-Wash: What were the Peak concentrations observed, what was the concentration, duration, and what activity produced them. If audible alarms, what were they. How do any values relate to health and safety concerns related to OELs?
- Key information to be relayed during final reporting; What do the results mean, what technologies work, what do not? Communicate how the data will be used, how they are treated as an exposure record and what actions may be taken. Use video exposure monitoring to illustrate when exposures occur, highlight both predicted peaks and unexpected peaks regardless of concentration. Engage workers to help develop interventions and controls- they likely have a better idea when things occur and how to mitigate them.

Results



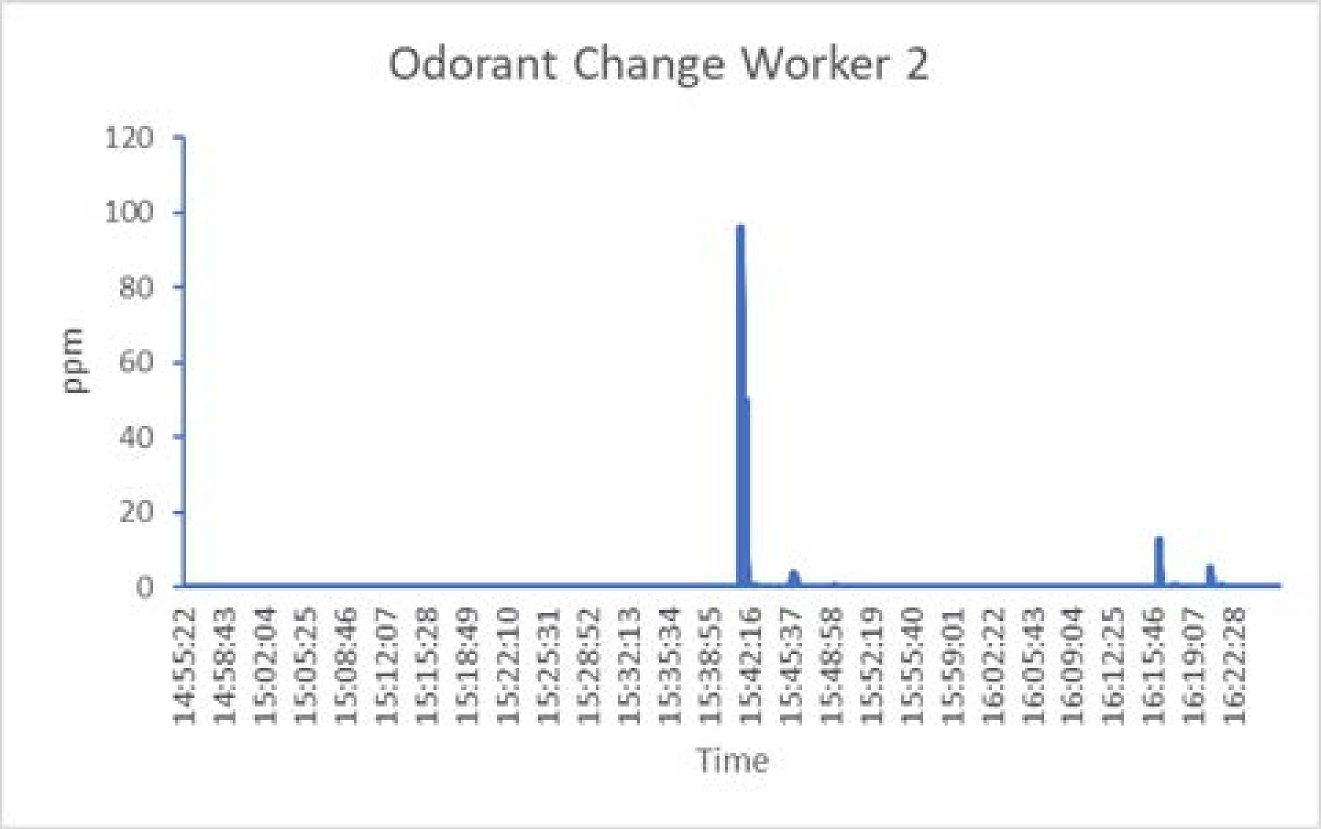
Odorant Change Area
ppm
450
400
350
300
250
200
150
100
50
0
14:55:22
14:58:50
15:02:18
15:05:46
15:09:14
15:12:42
15:16:10
15:19:38
15:23:06
15:26:34
15:30:02
15:33:30
15:36:58
15:40:26
15:43:54
15:47:22
15:50:50
15:54:18
15:57:46
16:01:14
16:04:42
16:08:10
16:11:38
16:15:06
16:18:34
16:22:02
Time

Results



Odorant Change Worker 1
ppm
160
140
120
100
80
60
40
20
0
14:55:22
14:58:43
15:02:04
15:05:25
15:08:46
15:12:07
15:15:28
15:18:49
15:22:10
15:25:31
15:28:52
15:32:13
15:35:34
15:38:55
15:42:16
15:45:37
15:48:58
15:52:19
15:55:40
15:59:01
16:02:22
16:05:43
16:09:04
16:12:25
16:15:46
16:19:07
16:22:28
Time

Results



Odorant Change Worker 2
ppm
120
100
80
60
40
20
0
14:55:22
14:58:43
15:02:04
15:05:25
15:08:46
15:12:07
15:15:28
15:18:49
15:22:10
15:25:31
15:28:52
15:32:13
15:35:34
15:38:55
15:42:16
15:45:37
15:48:58
15:52:19
15:55:40
15:59:01
16:02:22
16:05:43
16:09:04
16:12:25
16:15:46
16:19:07
16:22:28
Time

Results

The results demonstrate that momentary excursions above established chemical short-term exposure limits detected with the PID are not observed or may be underestimated with the TWA method. The estimated ethyl mercaptan concentration at the source (vent trap) for the entire task was 0.45 ppm as measured by NMAM 2542 (both workers were non-detect). Calculated Ceilings for the Peak concentrations for the source was 1.1 ppm, which does exceed the NIOSH Ceiling. Calculated worker ceilings were 0.1 ppm for both workers. Without the PID indication of high transient peak concentrations, it would be assumed that worker exposures were likely compliant when compared to the OELs. In this case, the health and safety (HS) professional supervising this task had anticipated that peak exposures may exceed certain OELs.

Final considerations

- Sensors, real-time monitors, and direct-reading methodologies are part of the workplace
- Sensing technologies have been part of occupational hygiene for quite some time
- An optimized integration of advanced sensing technologies and traditional methodologies can be the contribution to Occupational Hygiene
- We need still better technologies, better data management and processing systems, proper communication of finding and ethical evaluation
- The entire OH community should embrace the "**Right Sensors Used Right**" mindset and responsibility