Case Study Summary

Title: Use and Application of Real-Time Exposure Monitoring

Version:

Presented by:

Panel Advisor:

1. **Provide a few sentences summarizing the method illustrated by the case study.**

In September 2012, The National Research Council released its report on *Exposure Science in the 21st Century: A Vision and a Strategy*[1]. A major conclusion of the report was that new sensor methods and monitors will be an important driver for the future success of exposure sciences and exposure assessments.

The National Institute for Occupational Safety and Health (NIOSH) Center for Direct Reading and Sensor Technologies (NCDRST) was established in 2014 to coordinate research and to develop recommendations on the use of 21st century technologies in occupational safety and health. The objectives of the NCDRST are to:

- 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.

The assessment of exposures to potentially hazardous chemicals in the work environment is an essential tool of occupational safety and health. Since the publication of the *NIOSH Occupational Exposure Sampling Strategy Manual*[2], workplace exposure monitoring has relied on demonstrating that workplace exposures do not exceed occupational exposure limits. Although enforceable Permissible Exposure Levels (PELs), Short-Term Exposure Limits (STELS), and non-enforceable Recommended Exposure Levels (RELs) for workplace chemicals are well established, health protection is still difficult to demonstrate. Compliance measurements, i.e. the PEL/STEL are time-weighted averages (TWA) and are laboratory-based and often require complex sampling and analytical procedures. This typically results in a significant lag between sample collection in the field and analysis. Unfortunately, this does not reflect real-world workplaces where exposures are often intermittent and transient. While a momentary exposure may exceed a level of safety, the TWA concentration on a given day may be within exposure limits. These unrecognized acute exposures may lead to worker illness/injury that could be prevented.

To better assess worker exposures, real-time exposure monitoring may be used. Direct reading instruments are useful tools that traditionally have been used to:

- Detect and measure concentration of potential hazards in real time
- Alarm in the presence of unsafe conditions or hazardous atmospheres
- Aid in determining safety of confined spaces or other hazardous work locations
- Provide rapid reporting of increasing or decreasing concentrations of contaminants in air
- Assess performance of controls/safety equipment

Real-time instruments were critical in the investigation of nine worker deaths identified during 2010-2014 by a team of researchers consisting of occupational medicine physicians and experts from NIOSH and OSHA[3]. These fatalities occurred when workers were opening hatches on oil field production tanks for manual tank gauging or the collection of samples. Of these nine workers, only one was wearing a multi-gas, data logging monitor. The monitor worn by the decedent recorded low oxygen levels (less than six per cent) and flammable gas concentrations far in excess of the lower explosive limit (LEL). Ten percent of the LEL is defined as an immediately hazardous to life and health (IDLH) condition by NIOSH. Subsequent recreations of opening tank battery hatches found that these hazardous atmosphere conditions were typically encountered on high production shale oil and gas wells producing high gas:oil ratio-crude. The releases that produced the peak measurements were confined to a near vertical, high pressure plume for the initial release that lasted from under a minute to several minutes depending on tank size and numbers of tanks in a given battery. Traditional industrial hygiene sampling in this worker segment was primarily focused on aromatic hydrocarbons (benzene, toluene, ethylbenzene, xylenes-BTEX) and were based on TWA assessments. Some measurements were above the OELs (particularly the NIOSH benezene STEL) but, most samples were below the respective OELs. However, grab samples collected one meter from tank hatches detected hydrocarbon gas and vapor concentrations ranging from non-detect up to more than sixty percent by volume, one hundred percent LEL and oxygen as low as six percent. In some oil producing areas, a single worker may visit and open 20 hatches per day. Likewise, there may be hundreds of workers performing these same tasks and potentially exposed to the hazardous environment. Considering these findings, industry and regulatory agencies changed their work practices, methods and requirements for measuring oil and gas volumes, and many employers in the oil and gas industry are providing workers with data-logging multi-gas monitors and more importantly, are investigating alarms when they occur. These actions have identified several industry practices that could possibly lead to harmful exposures but have also led to corrective actions including engineering and administrative controls.

Through its activities, partnerships, and collaborations, NIOSH intends to advance the development, validation, and application of these technologies to occupational environments. Many employers are using real-time instruments that were traditionally used as worker safety tools to alert the worker to unsafe conditions. These instruments now offer real-time measurements with remote reporting and data-logging. Health and safety managers are attempting to use these data to better protect workers from both acute and chronic hazards by using instrument data to identify locations and tasks that result in instrument alarms. Often these peak concentrations are of very short duration (seconds to minutes) but, may exceed established STELS and Ceilings by many times. Because the data are stored, they may be considered an exposure record by law, but there is little guidance on how to interpret these data.

The NIOSH CDRST has an active initiative called *"Right Sensors Used Right"*. The initiative aims to investigate, disseminate, and provide guidance for the selection and use of direct-reading and sensors technologies for health & safety environments. The objective is to promote the competent development, adoption, and interpretation of real-time monitors and direct-reading methodologies. Encouraging all involved individuals to consider the capabilities and limitations of a technology can improve the ability to address modern measurement challenges.

The *Right Sensors Used Right* 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 *Right Sensors Used Right* approach has its roots in the concept that every real-time monitor or direct-reading methodology has its own unique way of fitting into a generic life-cycle (Figure 2). The life-cycle for the development and application of direct-reading methodologies and sensor technologies shows key steps that are taken to ensure the relevance and reliability of measurements to protect workers. The cycle begins with identifying what needs to be measured, under what conditions it needs to be measured, and how well it needs to be measured. The life-cycle concept is well described in several publications[4-7] and presented in the AIHA Synergist article on Turning Numbers into Knowledge being used to meet all emerging sensor needs[8].

Each step of the life cycle is essential for the successful development of a new technology, for its adoption, and for transforming the data generated by the methodology into meaningful and useful information for occupational safety and health. Following the life-cycle process helps to ensure that the technology will work as intended under realistic conditions. For each technology, the life-cycle is continuingly active while improvements and adjustments are applied. Documenting the history of each life-cycle is essential.

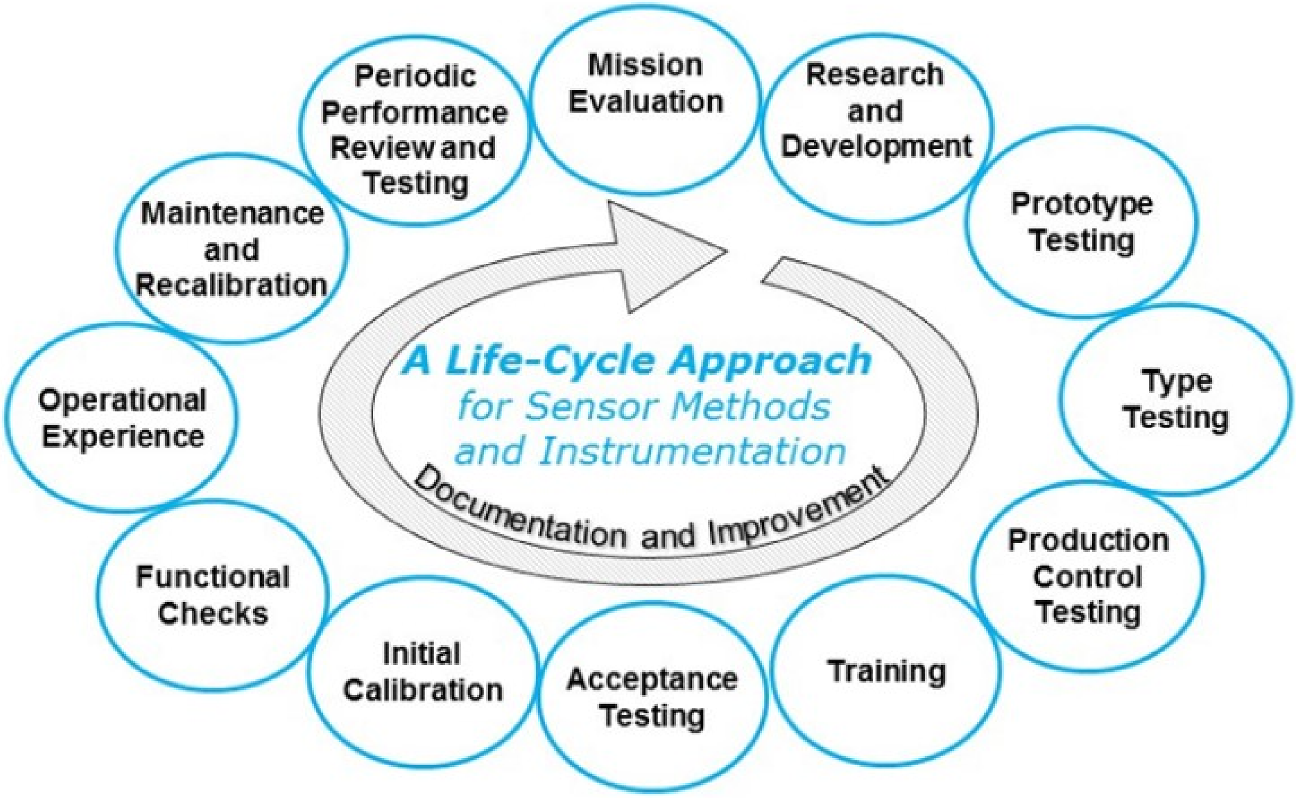


Figure 1. Life-cycle decision-making frame work and process for the effective selection and use of sensor methods and data.

The relative importance of the individual steps depends on the unique requirements of a given mission and specific real-time monitor or direct-reading methodology. Nevertheless, every step influences the capabilities and limitations of each technology.

Several individuals are engaged in the life cycle and they share roles and responsibilities. As illustrated in Figure 3, these individuals fit across four categories: ***customers, creators***, ***curators***, and ***analysts***. This division was first proposed in relation to sensor methods and data in nanotechnology[5]. In some instances, the same individuals may perform multiple roles. It may also be that many individuals must interact throughout the lifecycle process and their roles often extend over significant distances, organizations, and times, meaning that effective communication across the groups is essential. As the arrows in Figure 3 illustrate, there are six possible inter-categories interactions and they must work effectively in both directions.

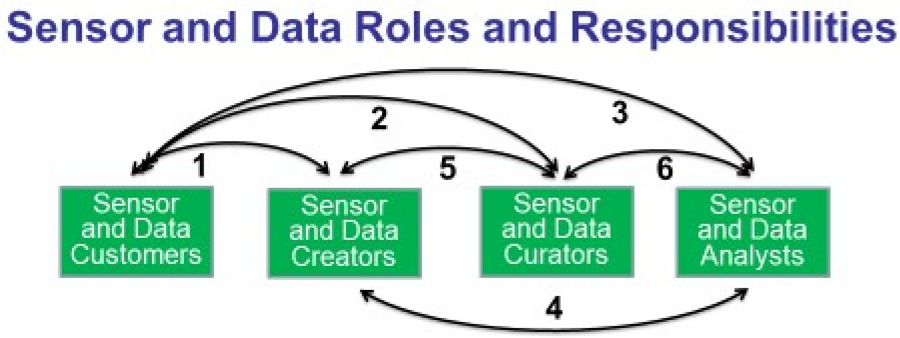


Figure 2. View of the roles and responsibilities for sensor and data customers, creators, curators, and analysts.

From the perspective of the *Right Sensors Used Right* approach:
Customers of real-time monitors and direct-reading methodologies and the resulting data include health and safety professionals, industrial/occupational hygienists, and anyone needing actionable information from the adoption of sensor technologies. Customers have a significant role in expressing the details of what sensor data will be needed and how it will be used. In some cases, customers have an opportunity to partner with a sensor developer to guide the development process. However, customers generally do not see new technologies until it is time for selection and implementation. From that moment on, customers are actively involved and responsible for the quality of the data generated by the technology.

Creators are individuals involved in the design and development of a real-time monitor or direct-reading methodology. The sensor creators will develop a technology from scratch, or they will repurpose and adapt an existing technology for a new application. Many different creators might be involved in one single life cycle: from an idea to a proof of concept, to a prototype, to production. The creators are mostly involved and responsible for the initial steps of the life cycle and typically include researchers at Universities, R&D teams at private companies, or developers in federal agencies. Once a monitor or method has been adopted, the users of the technology become the data creators.

Curators serve the critical role of maintaining and assuring the quality of the technology and data generated. The quality of the real-time monitor and direct-reading methodology and of the data generated by the technology is one of the most important factors related to use for health and safety. Curators can be institutions, associations, and manufacturers. The effects of the actions of curators can be present in every step of the life cycle from the production to the acceptance testing, to periodic performance review.

Analysts "turn the numbers into knowledge" to enable the real-time monitor or direct-reading methodology data to be translated into information for decision making in terms of health and safety. This process can be quite simple and straightforward or more complex. In

both cases, the process is under the responsibility of one or more analysts. The analyst needs to be aware of the capabilities and limitation of the technology to generate data at the quality level assured by the curator in order to meet the need of the customer.
Sensor and data Customers, Creators, Curators, and Analysts should all be involved in adopting a *Right Sensors Used Right* approach in the identification and usage of real-time monitors and direct-reading methodologies.

The *Right Sensors Used Right* 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 *Right Sensor Used Right* approach is stepwise.
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.

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.

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 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. 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.

2. **Describe the problem formulation(s) the case study is designed to address. How is the method described in the case useful for addressing the problem formulation?**

Comparison of workplace concentrations of occupational chemicals to occupational exposure limits (OEL) is one of the primary means of evaluating the safety of workplaces. OELs, particularly PELs originally established by the US Occupational Safety and Health Administration (OSHA), may not always reflect the most current toxicologic knowledge of a given agent. To address incorporation of recent toxicology, risk assessment and occupational hygiene practices, NIOSH, along with outside experts, published a series of ten articles in The Journal of Occupational and Environmental Hygiene[2] focusing on the underlying principles for developing and interpreting occupational exposure limits.

Most NIOSH and OSHA occupational chemical exposure sampling and analytical methods are developed and evaluated with the purpose of assessing whether workplace concentrations do not exceed the OEL(s). Specifically, the goal of the method evaluation is to determine whether, on the average, over a concentration range of 0.1 to 2 times the exposure limit, the method can provide a result that is within ±25% of the true concentration 95% of the time. For some chemicals, especially those with STEL and Ceiling OELs, higher multiples of the exposure limit can be added if needed (e.g., 10 times the exposure limit). NIOSH methods published in the NIOSH Manual of Analytical Methods[3,4] typically provide guidance for peak, ceiling, and TWA determinations. The methods describe the operating range, precision, accuracy, limits of detection and minimum and maximum sampling times. Most methods in NMAM are not direct reading and typically require laboratory analysis which can limit their application to STELs and Ceiling measurements in a timely manner.

Real time/direct reading instruments can be useful in assessing worker exposures or to intervene immediately when workplace conditions become harmful. Government agencies such as NIOSH, OSHA, the US Environmental Protection Agency, the Mine Safety and Health Administration, Department of Energy and others as well as professional organizations such as the American Industrial Hygiene Association (AIHA) and the American Conference of Government Industrial Hygienists (ACGIH) have developed practical guidance and recommendations in the use and application of real time instruments for workplace exposure monitoring. As instruments have become more sophisticated with a wide range of sensors, simple user interface and time-stamped data logging, knowledgeable users can use data from these instruments to better characterize sources, characterize tasks and other operations for exposure hazards.

With the expanding availabilities of real-time instruments, “smart buildings”, remote monitoring, citizen science and cloud-based data management, there is a plethora of data related to atmospheric contaminants but, there is little consensus on how to interpret and act on this data. With increased use of real-time instruments with alarms and data-logging abilities, health and safety professionals are becoming more aware of short-term peak exposures that may exceed STELS, Ceiling and or IDLH values when workers are performing some tasks. NIOSH defines a STEL for a given chemical as a 15-minute TWA exposure that should not be exceeded at any time during a workday. A ceiling REL should not be exceeded at any time and may be defined as either an instantaneous value or 15-minute period. The IDLH is defined as "exposure conditions as that pose an immediate threat to life or health, or conditions that pose an immediate threat of severe exposure to contaminants...". The IDLH is based on effects that may occur with a 30- minute, unprotected exposure however, this is not meant to imply exposures less than 30- minutes will not cause harm. When IDLH conditions are encountered, protective actions should be immediate.

With increasing use of logging real-time monitors in many workplaces as well as in emergency responses, NIOSH is receiving requests for assistance in interpreting the toxicological consequence of short duration peak instrument readings and how they should be interpreted as part of the overall exposure. Requestor concerns are both to protect worker health and safety but, also how to treat these readings in the context of a workplace exposure record. Usually, NIOSH replies in reference to the IDLH i.e. "*It is important to note that IDLH values are concentrations that may cause adverse effects, and thus, are not intended to be used as surrogates for occupational exposure limits (OELs).*" Additionally, NIOSH states that "*The IDLH values should not be used as comparative indices of toxicity or to infer a "safe" level for exposures to chemicals under routine occupational exposure conditions (see Section 2.3). A situation resulting in airborne concentrations at or near the IDLH value should be considered a non-routine event, and exposure duration should not exceed 30 minutes. All available precautions should be taken to ensure that workers exit the environment immediately if exposures are at or near concentrations equivalent to IDLH values"* (NIOSH, Current Intelligence Bulletin, 66[9]). Likewise, if there is a Ceiling (NIOSH, OSHA, or ACGIH) that value that may be referenced for guidance. However, many Ceiling values have a defined or implied 15-minute duration period based on detection methods other than a real-time monitor such as colorimetric tubes or sample collection and analysis. Even though the REL, IDLH and Ceiling values are based on adverse health outcomes from exposures this advice does not actually address the question, "if the worker does not show evidence of immediate harm, does the peak represent potential harm to the worker". From a strict interpretation of compliance from a regulatory standpoint, the workplace atmosphere was out of compliance as the Ceiling may have been exceeded. From a toxicological standpoint and assuming the monitor is accurate, a hazardous environment is clearly present for some period the worker(s) is in a location or performing a task what is not clear is, how should these peaks be interpreted.

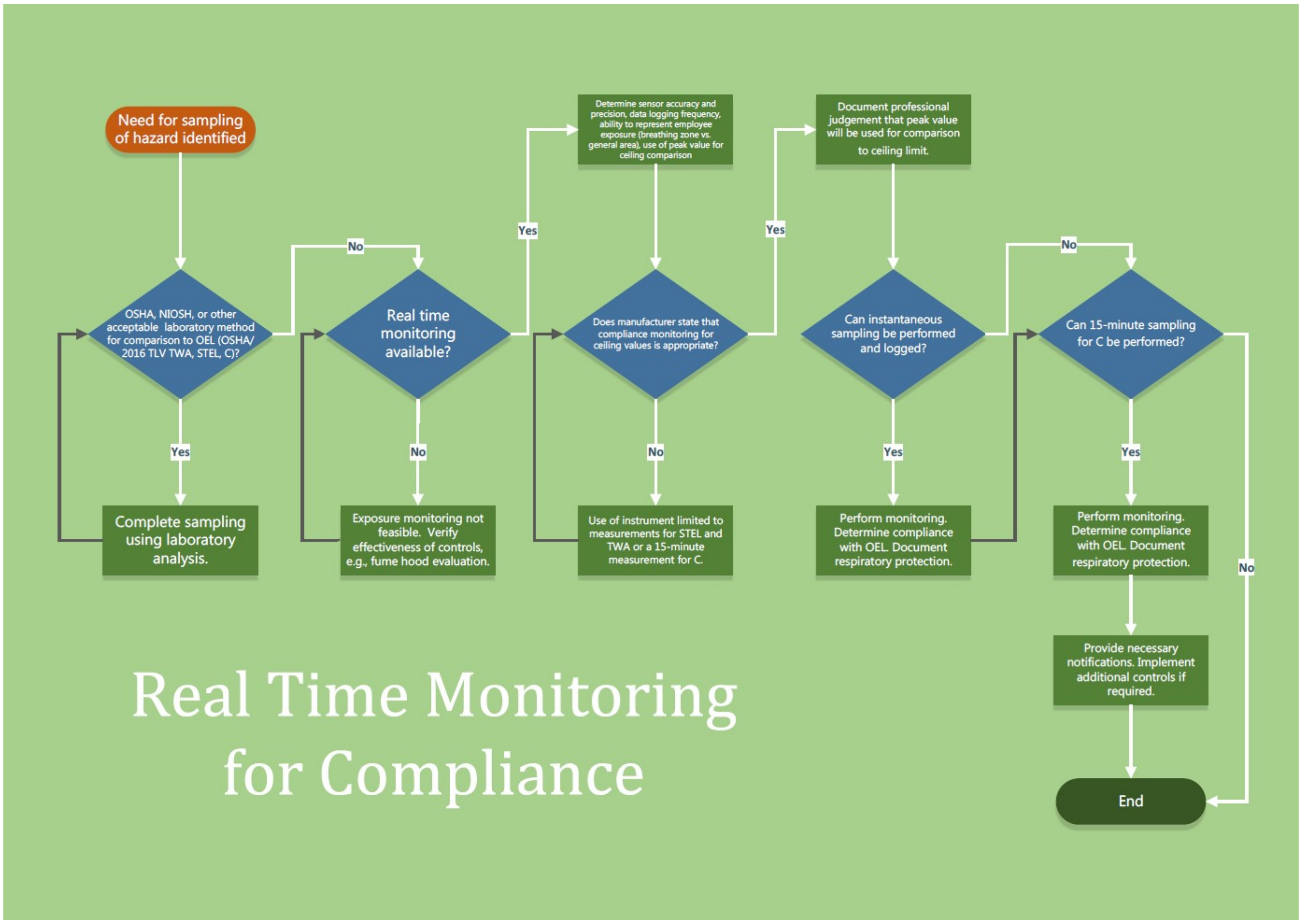
From an occupational hygiene practice standpoint, these short-term peaks are currently treated in two ways. First, they are an indication that a process or work-practice presents a danger to the worker to be corrected following occupational hygiene best practices and the hierarchy of controls[10]. Second, there are more and more data management tools and statistical analysis guidance such Bayesian, Monte Carlo and combinations of these to better manage the large amounts of data generated by modern data-logging instruments and hopefully better identify peak exposures values as well as integrate these into the TWA[11,12] .

The traditional role of most real-time monitors was to alert the user to a hazardous atmosphere. Typically, in the work environment this was defined as insufficient or elevated oxygen, a flammable or a toxic atmosphere. If the atmosphere was found to be hazardous, the user was expected to take corrective action. It is known, that brief, extremely high exposures do occur and sometimes result in fatal outcomes. In some cases, they can occur in what is assumed to be a "safe" or OEL compliant workplace as determined by traditional sampling and analytical methods. However, when real-time instruments are used to measure work-place air concentrations, short duration peak exposures may occur. Typically, these peaks occur and resolve more quickly than the minimal sampling time for most methods so confirmation may be impractical. Nevertheless, the worker may be exposed to concentrations that are immediately incapacitating.

NIOSH CDRST researchers are in the initial stage of developing tools for practitioners to follow a *Right Sensors Used Right* approach. Where possible, resources and guidance documents that are available and used in the normal practices of occupational health and safety professionals are incorporated in the approach. For example, NIOSH has documents for recommendation for the evaluation of real-time instruments[13], AIHA committees have produced documents on the available instruments[14], guidance for their use[15], and developed a standard specification format for manufacturers to report sensor performance and operational criteria[16],expert panels have developed high level guidance for interpreting data from real-time intstruments[17]. NIOSH is also developing checklists or worksheets for each step of the *Right Sensors Used Right* approach.

To start the *Right Sensors Used Right* decision process NIOSH has been evaluating the usefulness of approaches outlined in *A Practical Guide For the Use Of Real Time Detection Systems For Worker Protection and Compliance with Occupational Exposure Limits* prepared by the Energy Facility Contractor's Group (EFCOG) Industrial Hygiene and Safety Task Group and Members of the American Industrial Hygiene Association (AIHA) Exposure Assessment Strategies Group. Though the document is focused primarily on the use and application of real-time instruments for compliance assessments it provides guidance for selecting appropriate instruments for exposure assessments in accordance with current AIHA comprehensive exposure assessment practices[10]. The document provides matrices and decision trees that can aid in the decision to use real-time instruments for the hazard assessment task.

Figure 3. Decision Tree for Real-Time Monitoring

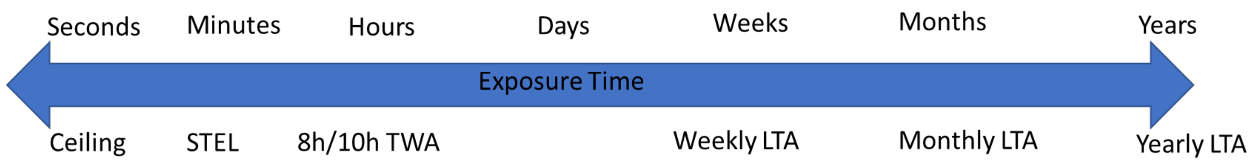


The decision matrix above has been applied to several *Right Sensor Used Right* studies with flammable and toxic gases, and with minimal changes may be easily adapted for case studies. Combined with NIOSH-specific worksheets for specific instruments and hazard characterization, health and safety practitioners may determine which monitor or combinations of monitors and traditional sampling and analytical methods to select and how best to evaluate, interpret and communicate results from these efforts to workers and management.

The *Right Sensors Used Right* strategy relies on the assumption that the workplace hazard, whether chemical, particulate, biological or physical is known. It is intended to use real-time monitoring tools to better define the nature of exposures. It can be used to document: where exposures may occur, what are the patterns of exposures, and who may be exposed. Logging of instantaneous concentrations provides data that can characterize when peak exposures do occur their magnitude, duration and resolution resulting in better characterization of exposures.

Application of a Relevant Toxiciy Time Frame in selection of real-time instruments can guide instrument selection and is key in making more informed decisions in interpreting data, determining the importance of peak exposures and their contribution to worker safety and health. Knowledge of the mechanism of toxicity, target organ(s), local versus systemic toxicity, exposure route, the interaction of exposure concentration and eposure duration on adverse effects, and whether adverse effects are immediate, acute, subacute, subchronic or chronic. A knowledge of why and how OELs are developed and assigned is important in selecting the instrument(s) and how one interprets and takes action based on logged data.

Figure 4. Relevant Toxicity Time Frame



Chemical Assessment Worksheet

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

INSTRUMENT SELECTION WORKSHEET

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**

Based on the selected use of real-time monitoring instruments and a sampling strategy is defined, a plan for the collection, use and interpretation of data should be carefully constructed and documented for all stakeholders prior to deploying real-time instruments/methods. The technical basis for instrument selection, data collection parameters, the data processing approach, reduction of the data (instantaneous concentration or time weighted averages for specified periods) and most important, how these data will be incorporated into the exposure assessment process should be transparent. Treatment of instantaneous peaks should be documented and how they are integrated into the overall exposure assessment should be defined as well as readings that approach or exceed STEL or IDLH values for periods shorter than 15 minutes. In some cases where traditional IH sampling and analytical methods require a minimum sample time or analytical limit, these may be reported as non-detect despite real-time readings greatly exceeding an OEL. In all cases the underlying toxicological mechanisms that cause harm to workers should be incorporated into how peaks are addressed.

The final step of the *Right Sensors Used Right* strategy is to develop a communication strategy to present the results to workers and management. The communication approach should be designed to communicate large amounts of data into usable, actionable information to increase situational awareness of potential exposures for those parties using the sensors. The basis for how instantaneous peaks (many times relevant OELs are treated should be described as well as short excursions at or near Ceilings, STELS and IDLH values.

To evaluate the usefulness of the *Right Sensor(s) Used Right* approach for using real time technologies to evaluate worker exposures NIOSH worked with an industry partner to evaluate potential exposures during a specific task.

NIOSH was approached by an oil production company to assist in the evaluation of worker exposures performing a task involving ethyl mercaptan. In response to a safety audit, the company revised their work practices and was hoping to evaluate potential exposures as well as determine the effectiveness of work practices and controls.

The company wanted to assess potential worker exposures to ethyl mercaptan during a task to transfer ethyl mercaptan odorant from a nurse tank to a tank used for the metered injection of the odorant to propane being loaded to rail cars. The company had concerns about peak exposures as well as compliance with relevant OELs. NIOSH assisted the Health and Safety Professional to use the Right Sensor(s) Used Right Approach to conduct the assessment.

As illustrated by the figure below the goal was to assess worker exposures to ethyl mercaptan. Exposure concerns were the primary exposure source (an activated carbon vent trap) and workers operating the tank valves on the nurse tank and the metering tank. Typically, the entire task could be performed in under one hour and the actual period where exposures could occur was under 5 minutes when the line connections were purged and ethyl mercaptan was routed to the vent trap.

Figure 5. A) Photograph of the work area where the ethyl mercaptan tank transfer was performed. a) Vent trap for nurse and metering tank. b) Nurse tank. c) Metering tank

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 Assessment Worksheet

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

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(s) 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

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.

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**.**

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

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.

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.

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.

Case study results

Figure 5 B). Time vs. Concentration Plot of PID Readings from the Area Monito

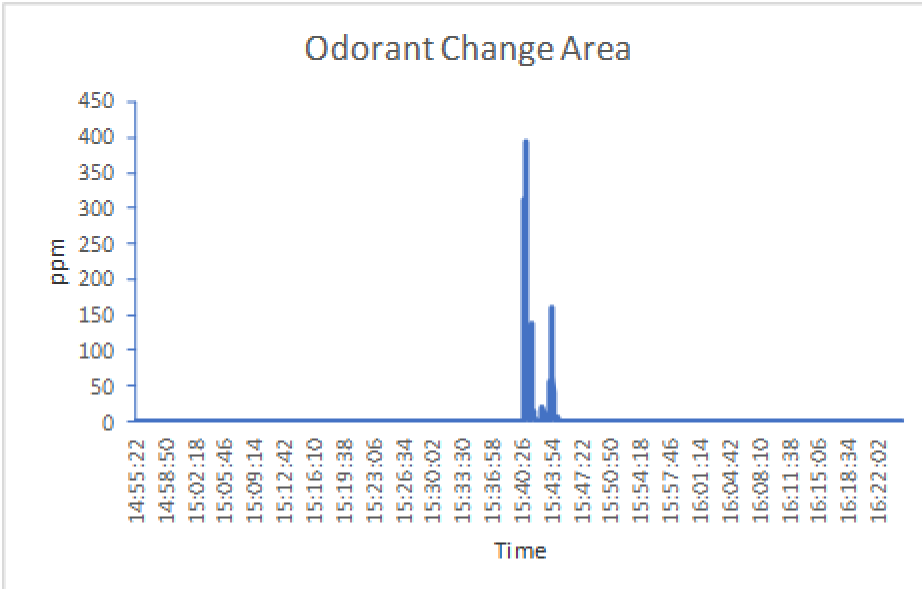


Figure 5C) Time vs. Concentration Plot of PID Readings from the PBZ of Worker 1

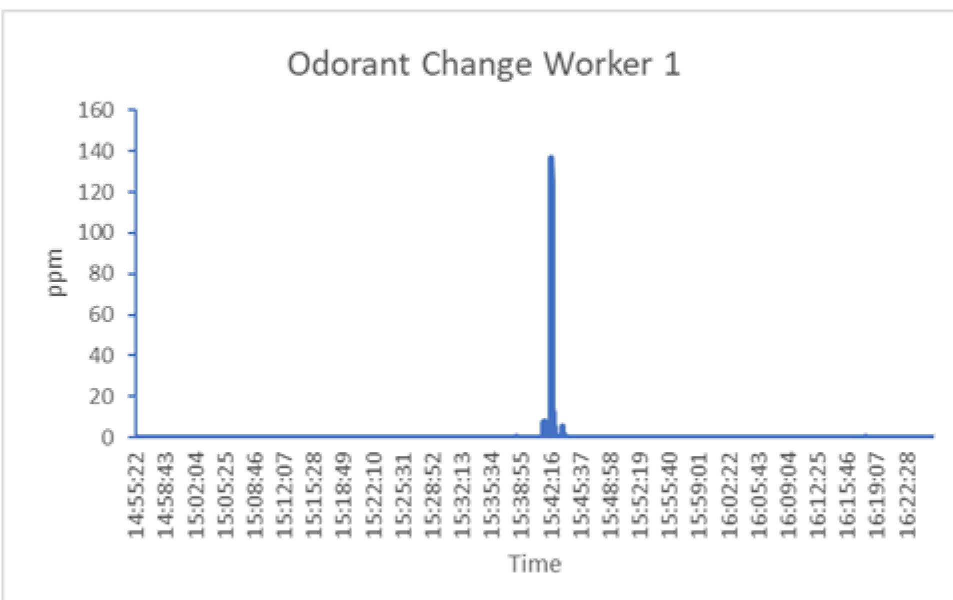
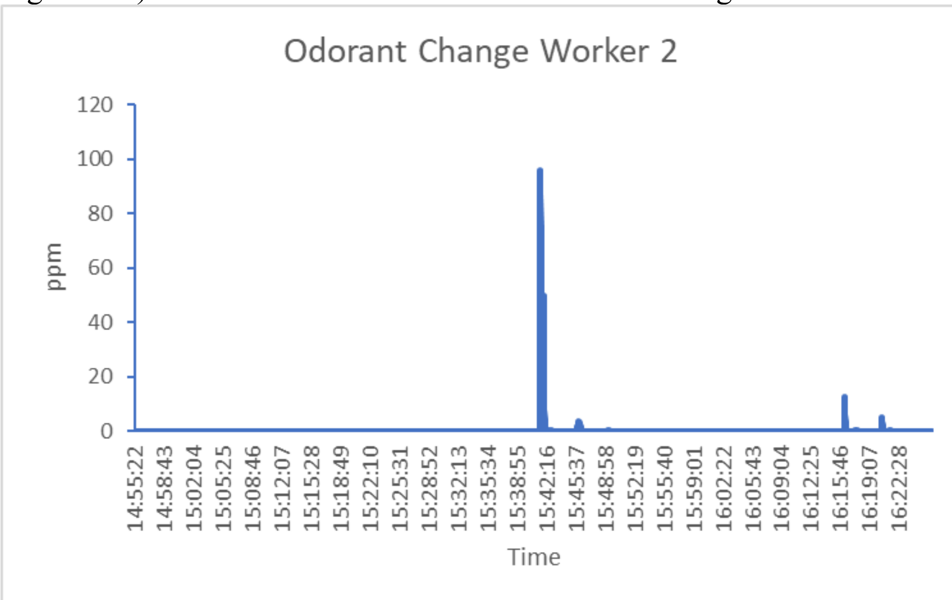


Figure 5 C) Time vs. Concentration Plot of PID Readings from the PBZ of Worker 2



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. In anticipation of these conditions, workers wore supplied air respirators during the 15 to 20 minutes that ethyl mercaptan was flowing from tank to tank.

3. **Comment on whether the method is general enough to be used directly, or if it can be extrapolated, for application to other chemicals and/or problem formulations. Please explain why or why not.**

   The method is general enough that it may be translated directly for most gas and vapors with OELs, and mode of action and toxic outcome is known. There are some peak concentrations encountered for some chemicals for which there is limited literature from an occupational standpoint. In the case of very high concentrations of low molecular weight hydrocarbon gases, toxicological data from inhalant abuse fatalities combined with instrument response rate was used to estimate adverse outcomes from concentrations up to 50 times an OEL.

4. **Discuss the overall strengths and weaknesses of the method.**

   The method works well when NIOSH SMEs work directly with stake holders and research partners in an iterative, process driven activity. NIOSH collaborations with AIHA, OSHA , TNO and the HSE, are refining many components and tools. Next steps include developing drop-down menus for worksheets and stand-alone tools. At present, the process is very much one-on-one efforts between NIOSH and industry partners, especially the first time the *Right Sensors Used Right* approach is tried. Fortunately, other than monitor selection, for other tasks, second and third time users do most of the approach on their own.

5. **Outline the minimum data requirements and describe the types of data sets that are needed.**

   The minimum data requirements for average users include gas and vapors with established OELs. When Peak or Ceiling values are not available, the ACGIH 3/5 rule may be used. The 3/5 rule states: "a transient increase in workers' exposure levels may exceed 3 times the value of the Threshold Limit Value – Time-Weighted Average (TLV-TWA) for no more than 15 minutes at a time, on no more than 4 occasions spaced 1 hour apart during a workday, and under no circumstances should they exceed 5 times the value of the TLV-TWA level. In addition, the 8-hour TWA is not to be exceeded for an 8-hour work period"[18]. ATSDR ToxFacts, The NIOSH Pocket Guide to Chemical Hazards, NIOSH Criteria Documents, CHEMM (National Library of Medicine, Chemical Hazards Emergency Management web site and the WISER (Wireless Information System for Emergency Responders) web site and mobile app may provide information make informed decisions. The user needs to have knowledge about what instruments and methods are available for the hazards of concern. The user needs to understand the operation of a given instrument it's strength and limitations.

Does your case study:

A. **Describe the dose-response relationship in the dose range relevant to human exposure?**

This case study uses published and derived OELs to use real-time instruments to predict but, especially avoid adverse events from peak concentrations of potentially harmful chemicals. Concentration and time along with hazard type and mode of action are incorporated into developing strategies to a) better detect and characterize peak exposures and b) make better informed decisions to interpret them.

B. Address human variability and sensitive populations?

The approach is very conservative, it relies of published OELs to address the general worker population. It also allows the end-user to apply their own knowledge and judgement to decision making.

C. Address background exposures or responses?

These are not addressed

D. Address incorporation of existing biological understanding of the likely mode of action?

Biological understanding of the mode of action is incorporated in the worksheet. Concentrations and exposure times are considered in interpretation of Peak data.

E. Address other extrapolations, if relevant – insufficient data, including duration extrapolations, interspecies extrapolation?

None.

F. Address uncertainty?

The user needs to address uncertainty on a case-by-case basis. In many cases, peak exposures may exceed OEL values by many times. Concentration/Time relationships along with mode of action to address uncertainty. Adding at least an uncertainty factor of 10 and using different approaches to calculate an amended OEL should be defined prior to conducting the assessment.

G. Allow the calculation of risk (probability of response for the endpoint of interest) in the exposed human population?

Risk from peak exposures can be interpreted into the STEL, Ceiling, TWA measurements. Data management tools are helpful in incorporating these values into the exposure assessment

H. Work practically? If the method still requires development, how close is it to practical implementation?

The method does work practically, with guidance from NIOSH SMEs. It is hoped, with feedback from the panel, the CDRST will refine the approach and develop applications and tools to use the approach. Currently, efforts are focused gas and vapor exposures related to oil and gas production and respirable particulates in a collaboration with TNO and HSE.

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