

**WHITE PAPER**

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**A PRACTICAL GUIDE FOR USE OF REAL TIME DETECTION SYSTEMS FOR WORKER PROTECTION AND COMPLIANCE WITH OCCUPATIONAL EXPOSURE LIMITS**

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## **1.0 Executive Summary**

This white paper presents practical guidance for field industrial hygiene personnel in the use and application of real time detection systems (RTDS) for exposure monitoring. The focus of the paper is on protection of worker health with solid exposure decisions based on occupational exposure limits (OELs), while successfully managing compliance with applicable regulations. This paper discusses occupational exposure assessment, OELs, traditional use of RTDS, use and limitations of RTDS, use of RTDS for compliance, documentation and reporting of RTDS results. It provides practical matrices for real time monitoring decisions, and a data collection and interpretation worksheet. The paper also addresses the use of professional judgement as it relates to RTDS use.

## **2.0 Introduction**

The evaluation of workplace hazards using exposure monitoring techniques is fundamental in understanding the risk to the worker. Workplace exposure monitoring has evolved significantly, both in process and in technology, since the initial promotion of an exposure assessment process by the American Industrial Hygiene Association (AIHA) in 1991<sup>1</sup>. With the proliferation of new sensor technologies, there is an opportunity to refine exposure profile judgments, and more importantly, provide interventions to reduce exposures with RTDS.

RTDS are defined as industrial hygiene instruments with sensors that can detect a hazard. RTDS can assist the industrial hygienist in establishing a hazard's presence or absence (i.e., a qualitative result) or provide a concentration (i.e., a quantitative result). For the purposes of this white paper, an RTDS includes configurable functions such as data logging, intervals, and alarm settings. RTDS are traditionally used as screening tools, or for emergency response. However, RTDS can also be used to examine within-shift variability of peak exposures for fast acting agents such as hydrogen sulfide.

RTDS can also be used to demonstrate compliance with OELs. Combined with data logging instrumentation, RTDS may offer powerful capabilities. Time stamped and logged data, when combined with visual observations, often provide professionals with a clear picture of how and when peak exposures occur. This information may then be used to reduce risks of elevated exposures, health effects, and non-compliance issues.

## **3.0 Discussion**

### **3.1 Occupational Exposure Assessment**

Occupational Exposure Assessment is the process used to understand the degree and variability of workplace exposures to hazards. It is most commonly understood as comparing monitoring results to an OEL. A comprehensive examination of the risks workers face from all hazards, across all activities requires a more formal approach. AIHA volunteer committees in the late 1980's undertook documenting this formal approach in the first edition of "A Strategy for Occupational Exposure Assessment". The foundational concepts established in that text

remain in place today in the current (4<sup>th</sup>) edition<sup>2</sup>.

The traditional perspective of risk is the probability of an event leading to a negative consequence (positive consequences are considered opportunities). Human health risk is often framed as  $R=f$  (hazard magnitude) X (health consequence). More aptly, in the application of exposure assessment judgments, it is that risk as a function of the frequency, when exposures are consistently rated as Exposure Control Category 4 (i.e., greater than the OEL, or a traditional “overexposure”)<sup>2</sup>.

This application of the risk function incorporates the magnitude of being at or above an OEL, with the frequency with which such exposures occur. This application becomes more difficult when “agents with rapidly occurring acute adverse health effects resulting from transient peak exposures” during a single work shift<sup>3</sup> are considered collectively as an exposure profile. These risks are often managed with stationary or portable RTDS, with an alarm set at less than Exposure Control Category 1 (i.e., less than 10% OEL).

### Peak Exposures

For agents with rapidly occurring acute adverse health effects, ACGIH uses default short-term exposure limits for exposures resulting from transient peak exposures during a work shift, where adverse effects may occur at some multiple of the 8-hour Time-Weighted Average (TWA) (the “3/5” rule)<sup>3</sup>. 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”.

**Table 1 Discussion of the ACGIH 3/5 Rule**

<p><b>The “3” Rule:</b> a transient increase in workers’ exposure levels may exceed 3 times the value of the TLV-TWA for no more than 15 minutes at a time, on no more than 4 occasions spaced 1 hour apart during a workday.</p>	<p><b>The “5” Rule:</b> under no circumstances should a transient peak exposure exceed 5 times the value of the TLV-TWA level.</p>	<p><b>8-Hour TWA:</b> the 8-hour TWA is not to be exceeded for an 8-hour work period.</p>
<p>If a RTDS is used, each data point within a 15-minute period is averaged. If worker exposure levels exceed 3 times the value of the TLV-TWA for a 15-minute period, on more than 4 occasions during a workday, work should be paused, and an adjustment using the hierarchy of controls should be immediately implemented.</p>	<p>For any data point that exceeds 5 times the TLV-TWA, including instantaneous RTDS readings, work should be paused, and an adjustment using the hierarchy of controls should be immediately implemented.</p>	<p>If an RTDS is used, each data point within an 8-hour period is averaged. For any 8-hour TWA exceeded in an 8-hour work period, work should be paused, and an adjustment using the hierarchy of controls should be immediately implemented.</p>

### **Historical Guidance on Occupational Exposure Limits and Constraints**

W.P. Yant of Mine Safety Appliance Company addressed his peers during the Thirteenth Annual Meeting of the Industrial Hygiene Foundation in 1948<sup>4</sup>. In speaking to the development of codes and standards, he cautioned that their “usefulness ... and their effect, whether voluntary or legal, [should be towards] good practice”. He also was perceptive in recognizing that the continual advancement of the state of industrial hygiene and technology in particular, would result in subsequent development of codes necessitating administration “with a full understanding of their limitations.” To that end, he promoted the concept that anytime a code was prepared, it would need to be accompanied by underlying guiding principles. Subsequently, with a full appreciation of the practical constraints facing the industrial hygiene profession, he offered the admonition that a single limit value is not a bright line below which no harm occurs, nor above which injury is assured. The spirit of these comments compels this discussion of RTDS and their use in better informed exposure assessments.

S. A. Roach published a theoretical mathematical treatment of sampling intervals and their basis in assignment of dose from a hazardous agent<sup>5</sup>. With mathematical arguments, he ties sampling of air concentrations and demonstration of conforming to allowable limits to the inherent variability of the concentration. He points out the need for understanding the toxicological underpinnings of the eight-hour TWA assigned by ACGIH. Roach stated that once the relationship between physiological effects and body burden is understood, then one can consider the importance of infrequent excursions (peak) exposures.

### **Concentration Variability over Time**

Atherley examined the history related to the underlying determination of exposure and dose across a wide range of sciences<sup>6</sup>. In his discussion, he challenges the community of practice to refine the manner of study in understanding the principles applied to the use of concentration and time to derive exposure and or dose. Such study is complicated by societal demands that any hazard poses risk regardless of exposure (where exposure may mean the magnitude of the hazard presented, the effective biological retention of the hazard, or the duration of exposure) and therefore must be effectively controlled to zero.

Accepting uncertainty around the true effectiveness of OELs to prevent untoward health consequences is a necessary compromise. Henschler (1985) identified seven of them in an address to the British Occupational Health Society in 1983<sup>7</sup>. Specifically, he promoted a classification system to address excursions above an eight-hour average interval. These were a rational compromise to the state of exposure science at that time.

In the 35 years that have elapsed since Henschler’s address, a myriad of RTDS with data logging and alarming capability, as well as increased accuracy and precision, have been introduced. These new instruments could provide the data needed to understand exposure profiles leading to health risks, as well as allow interventions to reduce or stop the exposures.

### **Excursions from an Exposure Assessment Standpoint**

A 95% confidence means we have a certainty of 95% that the true exposure value is below the OEL. Conversely, we believe there is only 5% chance that the sample we collected measured below the OEL due to random chance or error. Data have shown that daily variability for a given person is actually more important than variability from person to person. Workers may vary their behavior from day to day, or may not follow process instructions in a consistent manner from day to day. With the addition of variations in process equipment and materials properties, exposure profile variations begin to appear. When excursions are noted, it is important to address the risk associated with the excursions and determine appropriate actions in the future to avoid or minimize them.

### **Use of RTDS Instruments in Exposure Assessments**

When designing an exposure assessment strategy we often define Similar Exposure Groups (SEGs). A SEG is a group of workers having the same general exposure profile for the agent(s) being assessed because of the similarity and frequency of the activities and tasks they perform, the process with which they work, and the similarity of the way they perform the tasks. RTDS can provide sufficient basic characterization screening information for the field industrial hygienist as part of an initial qualitative assessment, to determine initial SEGs<sup>2</sup>.

RTDS present some clear advantages over laboratory methods. Most obvious is the immediate availability of the data. In some cases, RTDS may offer better accuracy and precision than sampling pumps and laboratory analysis. Method performance specified in widely used laboratory methods is +/- 25%. Many RTDS claim best-case accuracy of better than 1%. It is certain that the quality of lab data has improved greatly over the past several decades as wet chemistry has given way to analysis using electronic instruments. So too, has the quality of RTDS<sup>8</sup>.

One of the most powerful aspects of RTDS is the ability to data log and provide an exposure profile over the sample period. This can also be done with pumps and media but at a greater cost with shorter term samples used to define exposure risk for specific tasks. In no instance can a short duration exposure evaluation using sampling pumps and media approach the ability to provide an instantaneous assessment, due to the need to collect adequate analyte mass on a sampling medium for the analytical process to be used.

RTDS with data logging also bring industrial hygiene into a new era of “big data” where we have thousands of data points per year rather than a few. This changes our data analysis and likely provides a better picture of risk that will allow better risk management decisions to be made.

### **Confidence in Data and Its Meaning**

Industrial hygienists generally use a 95% confidence interval with a student T-Test or Bayesian Statistics to evaluate data. Industrial hygienists have traditionally worked with small data sets, often using one or two data points to model exposure risk for a given population of

workers. Toxicology is used to demonstrate the differences of dose response within individuals, and within worker populations. Industrial hygienists are challenged to apply exposure limits, which, simply stated, are meant to protect most of the workers most of the time.

With this perspective, it is important to realize that the target is fairly broad when evaluating risks associated with exposures. Using the T-Test, 95% confidence means that 95 times out of 100 the result will be below an exposure limit. Using Bayesian statistics, there is a 95% confidence that the “true” value being sampled is in the confidence interval that we are reporting (i.e., below the OEL).

This also means that when the data is above the OEL 4 times out of 100, health risks are no different from when the data is above the OEL 6 times out of 100. *When results are close to the OEL, the conclusion is one of action.* The action is to intervene with controls to reduce the exposure profile, or increase exposure assessment activities until a greater level of confidence is reached.

## 3.2 Regulatory Compliance

Some regulators generally have the administrative burden to demonstrate non-compliance conditions that could affect the health and safety of workers. The historical posture of the U.S. Occupational Safety and Health Administration (OSHA) is anchored in the regulatory authorizations of 1970. Significant technological advances in detection and data recording capabilities have shortened collection time spans and lowered reportable levels of data. However, regulatory interpretations grounded in updated legal precedent are lacking. As a result, some practitioners believe that any data point recorded above the OEL is a de facto demonstration of non-compliance, regardless of the time interval of the recorded data point, or the linkage of that datum to the evidence of a health consequence. These beliefs lead to real implications for industrial hygienists such as:

- abandoning technical toxicological foundations for the interpretation of information;
- application of the hierarchy of controls and the resources to implement them when they may not be needed; or
- overprotection of the employee through assignment of personal protection equipment, resulting in significant costs in work productivity, efficiency, and finances.

### **Occupational Safety and Health Administration Compliance**

As a regulatory agency, OSHA enforces exposure standards through inspections, writes citations when violations are alleged, and subsequently deals in legal proceedings with regard

to the citations. RTDS are specifically discussed in OSHA standards, such as the use of a multi-gas meter for evaluation testing (“using equipment of sufficient sensitivity and specificity”) or verification testing for acceptable entry conditions in the General Industry Confined Space Standard<sup>9</sup>. OSHA regulations in general neither require nor prohibit measurement of air contaminants using RTDS for an employer to determine compliance with exposure standards.

Employers covered by OSHA regulations are responsible to comply with specifics found within the various regulations. They also have a general duty to provide workplaces “free from recognizable hazards that are causing or likely to cause death or serious harm to employees<sup>10</sup>.” Hazards associated with many industrial processes are widely known, but in many cases recognizable hazards exist that are identifiable by an individual with expertise in hazard recognition and evaluation. The regulations promulgated by OSHA thus imply a practical need for employers to obtain competent assistance when needed. This approach is advisable from a moral perspective if not a legal perspective, and experts with such hazard recognition and evaluation responsibilities have an ethical obligation to maintain knowledge of best practices and tools available for hazard recognition and exposure assessment. To the degree that RTDS may be used for exposure assessment, they should be embraced and used to the extent of their capabilities, with full understanding of their limitations of RTDS (see Section 3.5).

### **Department of Energy Compliance**

The Department of Energy (DOE) exercises its authority to regulate the safety and health of its contractors by implementing the DOE Worker Safety and Health Program (10 CFR Part 851) at its facilities which are operated under the authority of sections 161(i)(3) and 234C of the Atomic Energy Act of 1954. 10 CFR Part 851 requires compliance with the 2016 ACGIH® TLVs when the TLVs® are lower (more protective) than the OSHA PELs<sup>11</sup>. DOE enforces exposure standards through investigations, and may issue a Notice of Violation to a contractor or subcontractor for violating a Part 851 requirement. Part 851 permits DOE to impose either a civil penalty or contract fee reduction (not both) on an indemnified contractor, as well as a civil penalty for their subcontractors at any tier, with certain limitations. The Price-Anderson Amendments Act (PAAA)<sup>12</sup> indemnifies DOE contractors and subcontractors. Under PAAA, prompt identification, reporting, and timely correction of noncompliances may provide DOE with a basis to exercise discretion to mitigate civil or other penalties, and to suspend the issuance of Notices of Violation for certain violations.

DOE sites are required to report exposures over an OEL in accordance with *DOE Order 232.2a, Occurrence Reporting and Processing of Operations Information*<sup>13</sup>. An exposure over the OEL is categorized under Group 2-Personnel Safety and Health 2A(6):



- (High) Personnel exposure to chemical, biological, or physical hazards that exceed 10 times the limits established in 10 CFR Part 851, Worker Safety and Health Program (see 10 CFR Section 851.23 Safety and Health Standards) or exceed levels deemed Immediately Dangerous to Life and Health (IDLH).
- (Low) Personnel exposure to chemical, biological or physical hazards above limits established in 10 CFR Part 851, Worker Safety and Health Program (see 10 CFR Section 851.23, Safety and Health Standards), but below levels deemed IDLH.

In addition to the PAAA structure of compliance, the DOE Enforcement Office may examine any data surrounding worker exposure assessment by the contractor. In a recent DOE Safety and Health Regulatory and Policy Response Line response<sup>14</sup>, the DOE clarification statement issued states that default, lower, calculated Short Term Exposure Limits (STELs) and Ceiling Limits apply when no STEL or Ceiling is declared by ACGIH in chemical-specific documentation of the TLVs.

### 3.3 Occupational Exposure Limits

Professional judgment is required in the selection and application of OELs. In order for any exposure judgment to be made, the industrial hygienist should be able to defend the logic of assigning OEL values. In some cases the exposure judgement follows a very prescriptive criterion found in OSHA standards (e.g., formaldehyde), while in other cases, there is discretion for applied professional judgment. It is in these cases that a transparent technical basis for the assignment of proper OEL selection and interpretation are necessary.

Occupational Exposure Limits (OELs) are stated in several different ways.

**Ceiling** – A ceiling limit is generally accepted as a value which should not be exceeded at any time. Values related to ceiling limits are generally based upon a minimum sample volume. Minimum sample volumes are specified in OSHA Ceiling limits.

**Excursion** – OSHA defines an excursion limit as a 15-minute or a 30-minute TWA exposure that must not be exceeded at any time. In the asbestos expanded standards for construction and general industry, the excursion limit is a concentration that must not be exceeded over a 30-minute period. In the ethylene oxide general industry standard, the excursion limit is a concentration that must not be exceeded over a 15-minute period. See Section 3.1 for excursions as they relate to exposure assessment.

**Immediately Dangerous to Life or Health (IDLH)** - an atmospheric concentration of any toxic, corrosive or asphyxiant substance that poses an immediate threat to life or would cause irreversible or delayed adverse health effects or would interfere with an individual's ability to escape from a dangerous atmosphere. Refer to the [NIOSH Pocket Guide](#) for further explanation of IDLH values<sup>15</sup>.

### **Peak Exposure**

A peak exposure is typically considered the highest recorded data point within a defined set of data. OSHA (29 CFR 1910.1000, Table Z-2) also uses the term “acceptable maximum peak above the acceptable ceiling concentration for an 8-hr shift” in a unique regulatory sense for a select group of chemicals with regulatory OEL values derived from 1960s era American National Standards Institute (ANSI) standards.

**STEL** - A STEL is used to address acute health effects such as irritation when chronic health effects may also be expected. For example, many organic vapors, which may be irritating at high levels, may also cause disease within a target organ with lower exposure levels over prolonged periods (e.g., months or years).

**TWA** – Time-Weighted Average (TWA) exposures are used to assess risk of chronic ill health effect over prolonged periods of time, generally 8 hours. An averaged concentration obtained over any time period is actually a TWA value. For example, a 15-minute STEL sample collected using a sampling pump and sampling medium provides a 15-minute TWA exposure value.

## **3.4 Traditional Use of RTDS**

RTDS were initially created based on market needs to manage occupational health consequence risks, not to support exposure assessment programs nor compliance demonstrations. Early examples were instruments for flammable gases and carbon monoxide. This differentiation is important, as many of the RTDS in the marketplace are built to warn of dangerous atmosphere conditions. Others are created to collect data that allows for targeted actions to identify controls. Many newer RTDS have merged the two functions into a single instrument.

Original uses of RTDS in the context of exposure assessment were represented in the first edition of “A Strategy for Occupational Exposure Assessment” by Hawkins et al (1991)<sup>1</sup>. Within this approach, grab samples or screening samples would be collected to verify that a hazard had moved from a potential exposure to a real exposure risk. Priority for collection of that type of sample was codified from instinctive professional judgment to a formal monitoring step.

From 1970 to 1990, reliance on RTDS was limited to a few methods. One could “grab” a volumetric air sample for lab analysis as verification. Noise and carbon monoxide RTDS were prevalent at this time. Detector tubes have been available since the 1920s, and were in widespread use as early as the 1970s. NIOSH set up a detector tube certification program at that time.

Nearly thirty years later, the AIHA Strategy Book is in its fourth edition, and sensor technologies coupled with instrument computer memory now allow integrated instrument responses over time. AIHA’s companion text “Important Instrumentation and Methods for the Detection of Chemicals in the Field” (2013)<sup>16</sup> provides an excellent summary of the issues

surrounding historical exposure assessment philosophies. It also presents the value of improved real time detection towards comprehensive exposure assessments.

### **Screening**

A screening measurement is often defined as an inexpensive test that will provide insight into whether further work is needed. This may be performed using a detector tube, with a cost as low as \$8 per sample. It can also be the use of an electronic/electrochemical RTDS instrument, which may have a high initial cost of ownership, but a low cost per test.

Screening with the instrument or tube will involve a short sample for specific tasks of concern. The intent of screening is to provide information needed to make a decision about whether or not further sampling is appropriate. One can place results into categories: <1% of OEL, <10% of OEL, <50% of OEL, and over the OEL. General current practice involves further work over the short term when data shows exposures are over 50% of the OEL.

### **Emergency Response**

RTDS are commonly deployed to emergency response organizations for the initial assessment of field conditions. Emergency situations by nature involve conditions unknown or not within control; most responding departments look for chemical, radiological and biological hazards. Common devices from the suite of RTDS include four gas monitors (oxygen, carbon monoxide, hydrogen sulfide and hydrogen cyanide detectors), photoionization instruments and more specific devices. Instrument configurations are set for the purposes of quick response and threat identification where possible, with longer-term analysis for later phases of the emergency recovery actions.

## **3.5 Use and Limitations of RTDS**

The population of RTDS is growing dramatically as technologies advance, computing power increases, and the “Internet of Things” and “Big Data” discussions evolve. As framed in the AIHA text “Important Instrumentation and Methods – Detection of Chemicals in the Field”<sup>16</sup>, those classes of instruments that may be considered for assessment of peak exposures would include colorimetric tubes, photoionization detectors, and specialized sensors configured within detector arrays (e.g., multiple gas detectors).

### **Specifications for RTDS**

Before one uses RTDS, the specifications must be reviewed in order to determine the applicability of RTDS to an exposure scenario. These specifications include:

- information specifications such as hazard type, instrument type, sensor type, manufacturer, battery type, and safety standards;
- performance specifications such as measuring range, minimum detection limit, resolution, uncertainty/accuracy, linearity, recovery time, continuous operating time, battery operating time, sampling rate, and response time;
- operation specifications such as temperature, humidity, and pressure and any

- corrections that must be made to results based on these or other factors;
- readings specifications such as instantaneous reading frequency, TWA, STEL, Peak, alarm set point, and alarm indicator;
  - interference specifications such as cross-sensitivities and interferences;
  - maintenance specifications such as recommended factory service interval, detector/sensor life expectancy, instrument life expectancy, function check interval, and full calibration interval;
  - data management specifications such as data logging memory, computer interface, and required software; and
  - safety specifications such as hazards area ratings and classification, and ingress (e.g., resistance to dust and water) protection.

For more information, refer to Reporting Specification for Electronic Real Time Gas and Vapor Detection Equipment, Fact Sheet sponsored by the AIHA Real Time Detection Systems Committee, October 17, 2016<sup>17</sup>.

### **Data Logging Use and Constraints**

RTDS have transformed in recent decades to include the capability of data logging. Data logging is a great resource to document peak exposures, demonstrate compliance with ceiling limits, or characterize tasks that have variable exposures. Data logging is especially useful in situations where the industrial hygienist is not able to be near the task (e.g., limited space, additional exposure risk) or when variable exposures are difficult to manually document in real time.

By nature, large sets of data are collected when using the data logging functionality, which could ultimately lead to problems in regards to data storage. Variables to consider include where the data is stored (i.e. internally to the equipment or to the cloud environment), how often the data is recorded (i.e. every second or every 10 seconds), and what format the data is in (i.e. raw data points or calculated time weighted averages). Data collected during sampling would likely be considered an employee exposure record per 29 Code of Federal Regulations (CFR) 1910.1020 (Access to Employee Exposure and Medical Records) and would need to be preserved and maintained for the appropriate length of time.

### **Sensor Use and Constraints**

The wide range of sensors available and their integration into RTDS have made detection and quantitation of specific airborne target analytes or unsafe conditions extremely reliable. However, in other cases interferences or specific environmental conditions may limit the applicability of a sensor or detection instrument to a given target analyte or unsafe condition. The user of such instrumentation must understand the capabilities and limitations of such instrumentation, and not give an instrument or the data it produces unwarranted credibility.

There are several important points to consider in assessing the suitability of a sensor for a given application:

- (1) Sensor selectivity
- (2) Sensor accuracy, precision and repeatability
- (3) Effect of environmental conditions on sensor performance
- (4) Known inherent characteristics of the sensor

A highly selective sensor is one that responds only to a known target analyte by relying on unique physical or chemical attributes of that specific analyte. An example of a highly selective sensor is seen with the use of infrared (IR) absorbance at a specific wavelength to detect and quantify a single target analyte, even when other airborne chemicals are also present. A non-selective sensor is one that responds to many analytes based on a common attribute shared by all chemical species, which cause a response to that sensor. An example of a non-selective sensor is the photoionization detector (PID), which uses ultraviolet light to ionize any chemical species with ionization potential suitable to remove a single electron from the intact molecule. Sensitivities and interferences must be considered when selecting a sensor.

A non-dispersive IR (NDIR) sensor for carbon dioxide (CO<sub>2</sub>) provides an example of a highly selective sensor with reasonable accuracy, known and correctable environmental condition effects, and inherent sensor characteristics that do not interfere with reasonable use in a detection instrument. A CO<sub>2</sub> NDIR sensor uses the Beer-Lambert law and absorbance at a wavelength near 4.3 μm (asymmetrical stretch band) to quantitatively determine the concentration of CO<sub>2</sub> in air. Other components of air and commonly encountered airborne contaminants do not absorb in this region; thus, this sensor is highly selective for CO<sub>2</sub>. Hill and Smith described the use of NDIR sensors for CO<sub>2</sub> measurement, and showed good accuracy and precision for this sensor, with water vapor having no noticeable effect on the ability to measure CO<sub>2</sub><sup>18</sup>. The absorbance of IR energy by a gaseous sample is affected by gas density. This means that atmospheric pressure and temperature can affect an NDIR sensor output; however, these are easily measured and the output may be corrected.

The Photoionization Detector (PID) sensor is widely used in exposure assessment fieldwork, but for quantitation, the instrument response must be assumed to result from exposure to a single gas or vapor. As all ionized species will cause ion current in the sensor, the relative contributions of gas mixture components cannot be determined. The presence of unknown non-ionizable species can effect PID sensor output, and humidity effects can be

considerable<sup>16</sup>. A PID sensor is simple, however, the ultraviolet energy used to create ions is produced by a sealed lamp, and heavy use can lead to deposits on the lamp window, affecting PID response.

The wide range of sensors available and their widely different attributes in terms of selectivity makes it critical that a user understand the capabilities and limitations of each that is to be used. A properly used sensor, where potential interferences have been ruled out (i.e., compounds that would also absorb at the same wavelength used) can conceivably provide quantitative exposure data in near real time. In many cases, that data is qualitatively similar to data produced from integrated sampling and laboratory analysis.

### **Alarm Set Points**

The determination of an appropriate alarm set point for RTDS involves a process that encompasses multiple variables of consideration. These variables should be evaluated for each use to make an informed decision concerning the alarm set point. Each use could potentially contain a high degree of variability. In deciding on an applicable alarm set point, take into consideration all of the possible factors for each scenario. For example, consider the duration of the exposure, the type of monitor and its capabilities (integrating or instantaneous direct reading), the location and type of sampling (e.g., breathing zone (BZ) or area), goal of the sampling (e.g., personal evaluation, confirmation of adequacy of controls), and the OEL.

When selecting RTDS to use, the type of instrument, its capabilities, and the environment where it will be utilized can all play a part in the selection of an alarm set point. All types may present unique challenges and issues to address. For example, some RDTs utilize sensors that may display a false positive because of cross sensitivities while others may require a minimum oxygen content to allow a combustion reaction for the explosive limit to be read. Others (e.g., PIDs) utilize lamps of a designed level of electron volts (eV) to ionize the sample drawn into the pump and then display a reading. It is important to know the respective ionization potentials of the chemical of concern. A PID with a particular lamp will only detect the chemical(s) that have an ionization potential less than the lamp. Consequently, any chemical above that ionization potential will not be detected and may pose an exposure risk. If the environment being monitored is a complex mixture of chemicals and not a single chemical, then consider setting an alarm set point for the most toxic chemical known that can be detected, to be more conservative.

The goal of the planned monitoring is another factor to consider. Is the purpose of the monitoring to evaluate potential exposures in the BZ of the worker, general area sampling, source sampling, or assessing controls that have been established for a hazard? When OELs are based on personal exposure in the BZ, the alarm limits for personal monitoring should be based on those OELs.

The environment and circumstances of the atmosphere and task being monitored can have an impact on the decision of an alarm set point. For a hazardous material release, the potential exposure level, evacuation requirements, and first responder needs may alter the normal set points used for the instrumentation. A response to rapidly changing conditions could necessitate the setting of an even more conservative alarm set point. Evaluation of an environment with a mixture of chemicals would require the need to determine a mixture TLV to use as basis for determining the alarm. Typically, if there is a potential for a varying degree of exposures throughout the monitoring period, using the most toxic chemical as the controlling chemical for the basis of the alarm set point is a prudent practice. Additive and synergistic effects must also be considered where multiple chemical exposures occur simultaneously or sequentially.

A review of the specific chemical or chemicals of concern from the monitored environment must include the applicable OEL of each chemical. The OEL may be a PEL, TLV, ceiling, STEL, excursion, peak, IDLH or a company derived OEL. Alarm set points are typically based off an OEL. When choosing an OEL as an alarm set point, careful thought must be given to the type of monitoring conducted, instantaneous or integrated, along with the duration of the task and the goal of the monitoring. PELs, TLVs, STELs, and peaks have an integrated time-weighted aspect to them. These values can be exceeded if the value over the applicable time frame is not exceeded. The chosen alarm level should be set at a low enough level to ensure the protection of the workers yet high enough to avoid spurious alarms that can be caused by temporary fluctuations in air concentrations, or fluctuations due to environmental changes (humidity, temperature, or pressure). Multiple strategies may be employed when setting an alarm set point. For example, the low alarm may be set at a percentage of the 8-hour TWA while the high alarm is set at a percentage of the STEL.

Multiple strategies exist for setting alarm set points. In all cases, when deciding on an alarm set point position, one must be sure to evaluate all applicable aspects of the individual monitor being used, the environment being monitored, the task parameters, the direction given to workers and the expected response to alarms, and the applicable OEL of concern. Industrial hygienists should always consult instrument manufacturers' technical support to verify the manner of data treatment resulting in alarms.

### **Temporal Variability**

A dimension of exposure assessment that may only be fully addressed by RTDS is temporal exposure variability, and a properly selected RTDS may assess this with minimal or no averaging. Such measurements allow exposure excursions above a target value to be readily identified, whereas integrated sampling onto a medium (generally analyzed in a laboratory) provides information only about the average exposure across the full sample collection period.

Smith et al<sup>19</sup> explored the difficulty of conventional integrated sampling detecting peak

exposures. In doing so, “even when actual exposure concentrations exceed an exposure peak standard one or more times during a brief integrated sampling event, the exceedance may not be discernible by laboratory analysis.” Additionally, short sampling intervals collecting adequate analyte to submit for analysis often leads to missed intervals for sample swaps, potentially skewing (reducing) a TWA measure. As a result, the authors propose that RTDS devices “equipped with a suitable sensor may be used to monitor rapidly changing exposure concentrations” in order to address dynamic concentration variability. The ability to “trigger the instantaneous collection of a small volume whole-air sample” potentially “could provide high certainty determination that an exposure in excess of an exposure peak has occurred.”

Figure 1, Data Resolution Comparison, is found in the AIHA “Important Instrumentation and Methods” and “Exposure Assessment Strategy” texts<sup>1, 16</sup>. Starting with the color red in the key, assessing the variability of the exposure profile using a single collective sample for about half an eight-hour shift is the least useful detail. The green line of one-hour intervals marginally improves through the impression of some dynamic shifts. The blue line improves yet again with sequential 15 minute intervals, but does not present sufficient detail of the exposure profile to judge conformance to the constraints of peak exposures demanded from application of the “3/5” rule of thumb. Only the real time instantaneous plot provides actual worker exposure changes in concentration, such that actions can be matched through observation or video monitoring revealing where interventions should occur.



Figure 1 Data Resolution Comparison

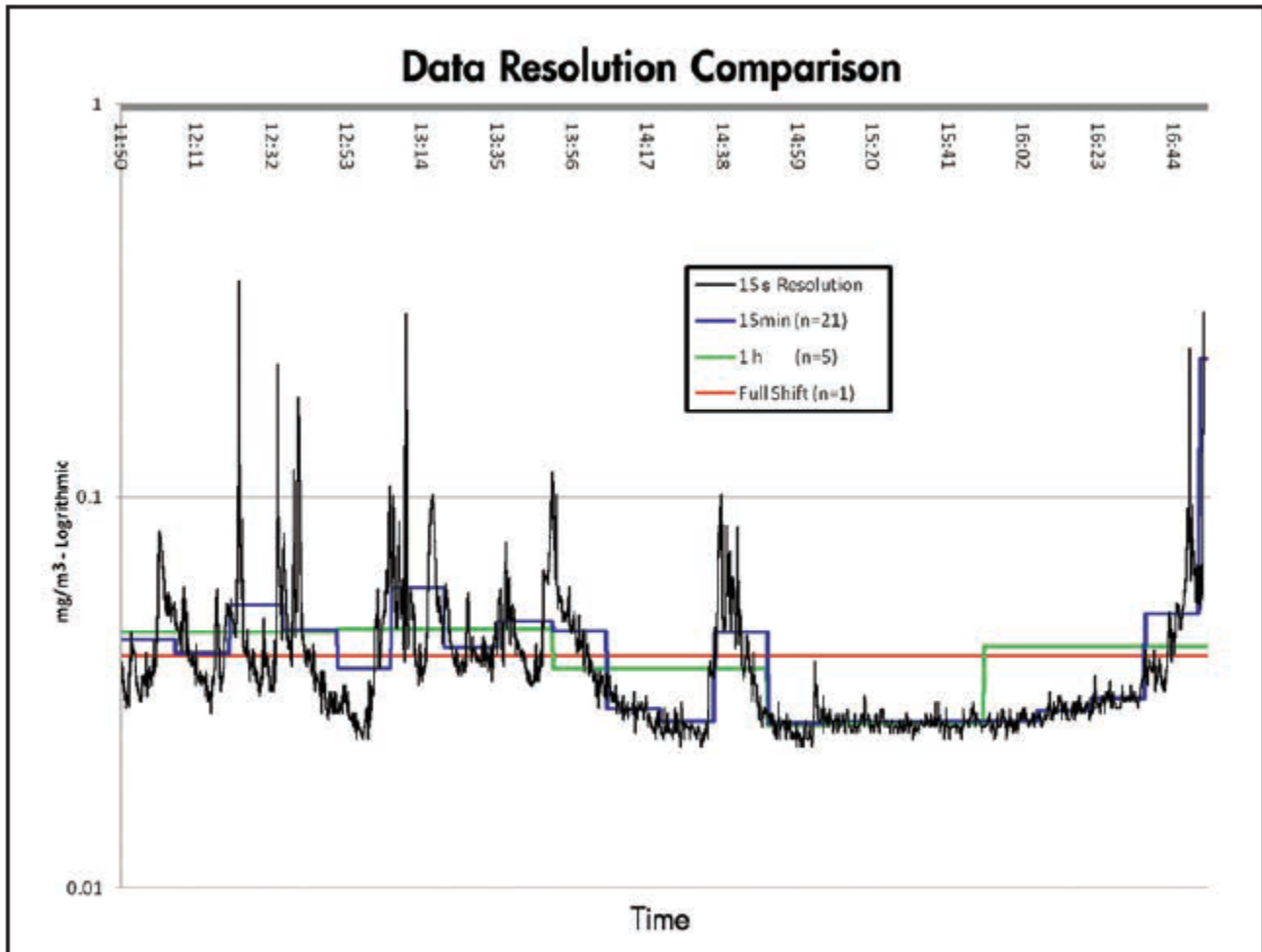
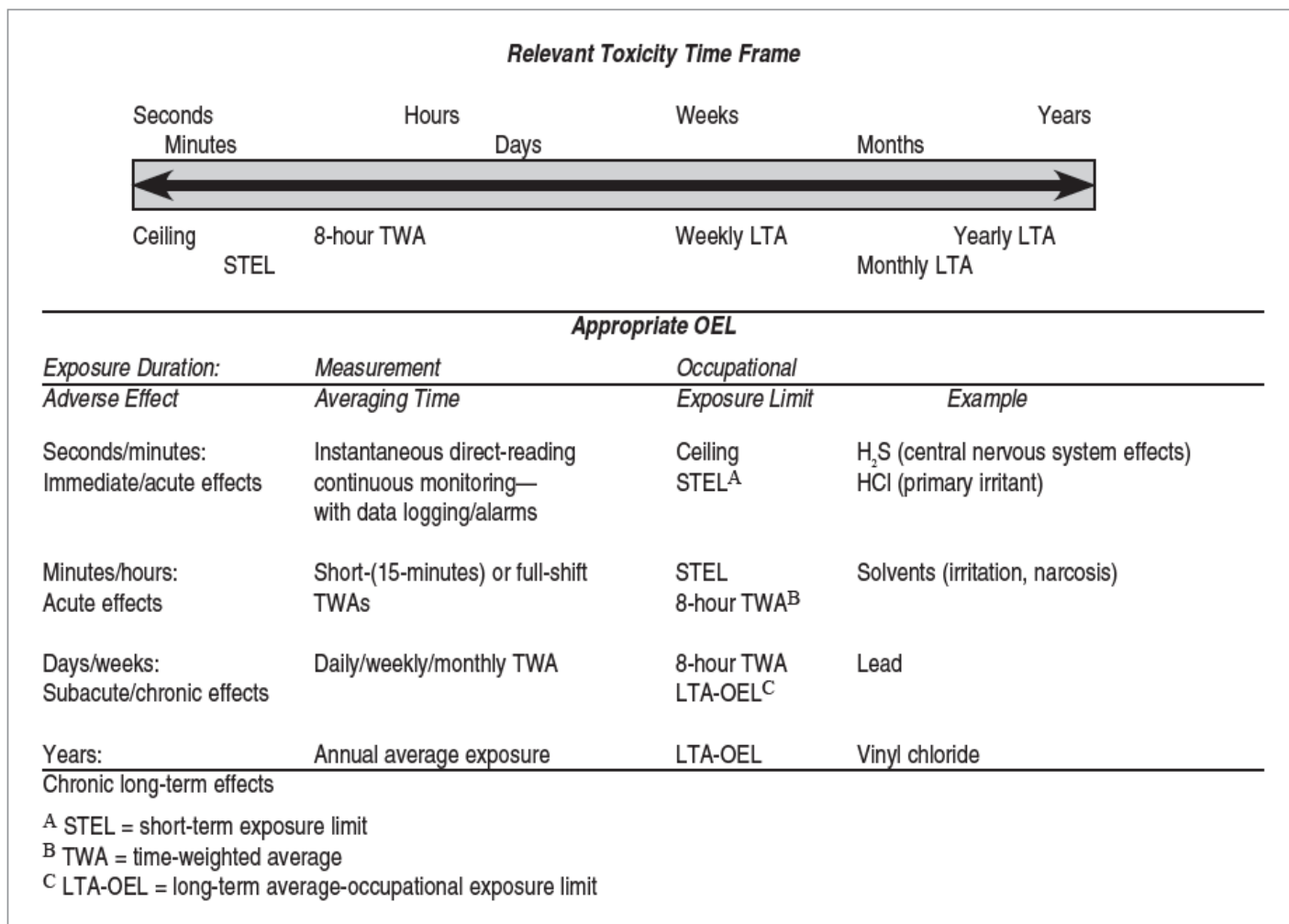


Figure 2.3 - A batching operation with local exhaust provided for exposure control. If the 15 s resolution graph represents actual worker exposure, it can be clearly seen that the local exhaust ventilation is not effectively capturing the containment. Furthermore, the generally observed rapid concentration rise and asymptotic declines depicted indicate that the contaminant is being removed from the work area by general exhaust (dilution) ventilation. Neither a full-shift or full-task interval task basis sampling approach would provide this information. TWA=0.039 mg/m<sup>3</sup>, max 1-hour=0.046 mg/m<sup>3</sup>, max 15-minute=0.059 mg/m<sup>3</sup>, max 15-second=0.357 mg/m<sup>3</sup>

An important consideration in “instrumentation” is framed in a Figure 2, Relevant Toxicity Time Frames<sup>2</sup>. Not all STELs or IDLHs values are created equal. Therefore, the disciplined interpretation of data collected and compared to these OELs must have some flexibility to account for the underlying toxicological basis, as noted in sources of toxicological data such as EPA's Registry of Toxic Effects of Chemistry (RTECS) or the Agency for Toxic Substances Disease Registry (ATSDR) databases, or the ACGIH TLV Documentation.

**Figure 2 Relevant Toxicity Time Frame**



**Table 2.1** – Increased importance in the availability of real-time exposure assessment methods with increased toxicity (Bullock and Ignacio, 2006).<sup>(4)</sup>

### 3.6 Use of RTDS for Compliance

In monitoring a task with RTDS, multiple potential OELs must be considered when setting the alarm set points or evaluating the data.

To ensure compliance with OSHA limits, the values must be compared to the OSHA 8-hour TWA, to the ceiling values listed for specific substances, or to the maximum peak values listed for certain chemicals.

The ACGIH has established TLVs for 8-hour TWAs, STELs, ceiling limits, and peak exposure limits.

To apply the applicable OEL it must be understood that the values are based on sample results in the worker's BZ and the monitoring capability of the instrumentation. For example, TWAs and STELs are integrated samples over a certain time period. Ceiling limits are used when irritation (an acute health effect) is the only hazard associated with the material. It is often measured over a period of time up to 15 minutes, due to minimum volume requirements for traditional sampling methods such as personal sampling pumps.

### 3.7 Documentation/Reporting

Monitoring results should be documented and retained as part of the assessment of workplace hazards. The DOE, in the promulgation of the *Worker Safety and Health Program*, 10 CFR 851, mandates that contractors must:

- 1) 10 CFR 851.21(a)(2) Document assessment for chemical, physical, biological and safety workplace hazards using recognized exposure assessment and testing methodologies,
- 2) 10 CFR 851.21(a)(3) Record observations, testing and monitoring results, and
- 3) 10 CFR 851.26(a)(1) Establish and maintain complete and accurate records of all hazard inventory information, hazard assessments, exposure measurements, and exposure controls.

The DOE also requires that all RTDS readings used for evaluating personal exposures must be retained in accordance with the DOE Epidemiological Moratorium<sup>20</sup>.

Not only are results of employee exposure monitoring evolutions required to be reported to the employee, DOE, under the DOE Order for *Occurrence Reporting and Processing System (ORPS)* has specific requirements to report exposures above established exposure limits to the ORPS database<sup>13</sup>. The order includes the criteria for reporting the results within the established bounding conditions contained in the order.

OSHA also has requirements for monitoring reports. OSHA has stated the employee exposure records include, among other types in 29 CFR 1910.1020(c)(5)(i): "environmental (workplace) monitoring or measuring of a toxic substance or harmful physical agent, including personal, area, grab, wipe, or other form of sampling, as well as related collection and analytical methodologies, calculations, and other background data relevant to interpretation of the results obtained."

OSHA further states that employee exposure includes "...past exposure and potential (e.g., accidental or possible) exposure." OSHA, in a letter of interpretation has said: "If the employer does record the result of a grab sample taken to determine whether the concentration of a fumigant is within "safe" levels, such a record would be an employee exposure record as defined in 29 CFR 1910.1020(c)(5)(i). The record would have to be maintained and access to it would have to be provided."<sup>21</sup>

Both OSHA and DOE require that the records be maintained and retrievable. DOE contractors must comply with the federal records requirements for maintaining the records, and work with records management personnel to determine specific requirements for RTDS electronic or hard copy records.

### **3.8 Peak Exposures Data Interpretations**

The technical basis for the selection, use and interpretation of data should be carefully constructed and documented for all stakeholders prior to the deployment of a RTDS for data collection. The basis should include all those criteria and decisions reflected in the applicable attached matrices.

The selection or creation of OELs for regulatory interpretation should employ all available information but especially reflect the underlying toxicological mechanisms that cause harm to workers. Recognizing the wide variety of authoritative sources for OELs and the toxicological frameworks themselves, vetting of determinations must be made across all stakeholders.

The interpretation of data against instrument configured alarms and data logging parameters should reflect all relevant limits addressing Immediately Dangerous to Life and Health (IDLH), Ceiling (TLV-C, Calculated TLV-C [from the “3/5” Rule] or PEL-C), or STEL (TLV-STEEL, Calculated TLV-STEEL [from the “3/5” Rule] or PEL-STEEL). Data interpretations should exist for single datum, grouped data, or SEG-linked data. These data interpretations are necessary to comply with 10 CFR 851.21 requirements for exposure assessment.

The sum of all the determinations made by the industrial hygienist around instrument selection, data logging parameters, and data interpretation should be transparent to all stakeholders. A sample template of necessary determinations is provided as Attachment 1.

### **3.9 Conclusions**

Protection of worker health is best achieved with solid exposure decisions based on occupational exposure limits (OELs), while successfully managing compliance with applicable regulations. Traditional use of RTDS as well as use of RTDS for compliance are good approaches to exposure assessment, as long as the use and limitations of RTDS for compliance, documentation and reporting of RTDS results are known.

### **4.0 Matrices**

The authors have included two matrices to show how field industrial hygienist should approach use of RTDS for compliance.

Figure 3 Real Time Monitoring for Compliance

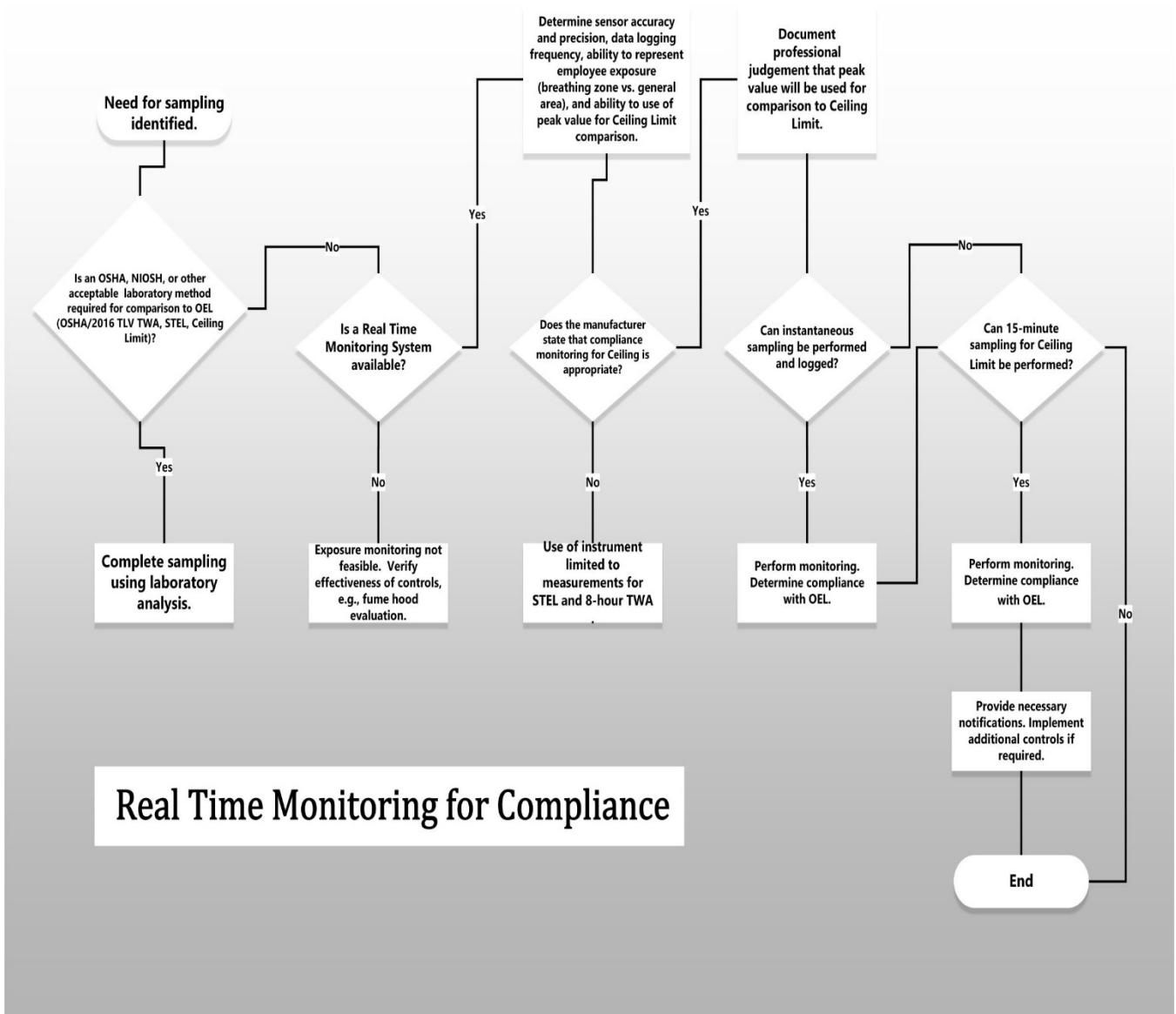
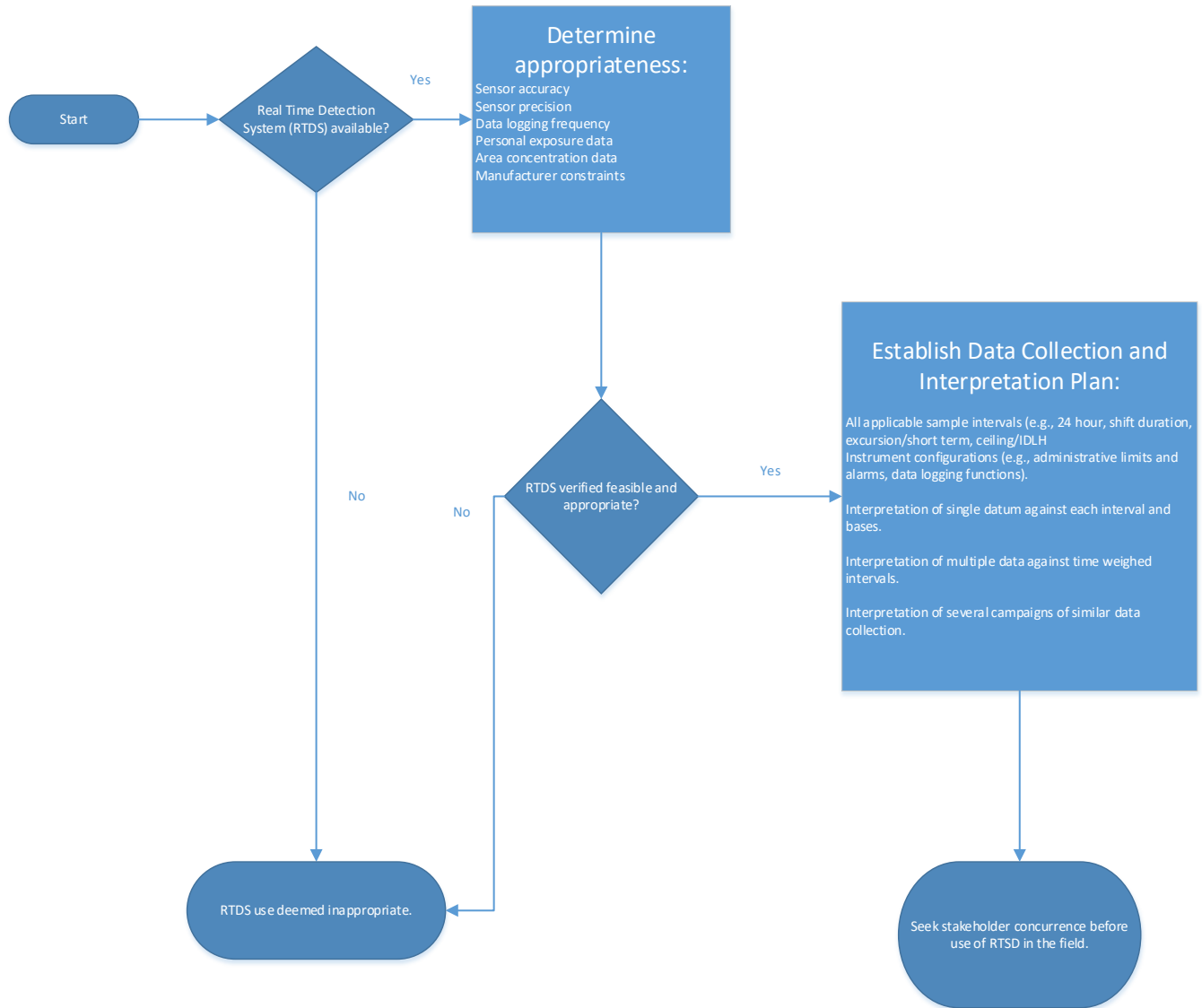


Figure 4 Decision Tree for Use of RTDS



## 5.0 References

<sup>1</sup>N. C. Hawkins, S.K. Norwood, J.C. Rock, A Strategy for Occupational Exposure Assessment, 1<sup>st</sup> Edition, AIHA (1991).

<sup>2</sup>S. Jahn, W. Bullock, J. Ignacio, A Strategy for Assessing and Managing Occupational Exposures, 4th edition, AIHA, (2015) .

<sup>3</sup>“Peak Exposures”, 2016 TLVs<sup>®</sup> and BEIs<sup>®</sup>, Documentation of the Threshold Limit Values, ACGIH<sup>®</sup> (formerly known as the American Conference of Governmental Industrial Hygienists) Cincinnati, Ohio.

<sup>4</sup>Yant, W.P.: Industrial Hygiene Codes and Regulations. In Industrial Hygiene Foundation: Transactions of Thirteenth Annual Meeting, Pittsburgh, Pennsylvania, November 13, 1948. pp. 48-61.

<sup>5</sup>Roach, S.A.: A More Rational Basis for Air Sampling Programs. American Industrial Hygiene Association Journal 27: 1-12 (1966).

<sup>6</sup>Gordon Atherley (1985) A Critical Review of Time Weighted Average as an Index of Exposure and Dose, and of Its Key Elements, American Industrial Hygiene Association journal, 46:9, 481-487.

<sup>7</sup>Henschler Conference Address to British Occupational Health Society, “Exposure Limits: History, Philosophy, Future Developments by Dietrich Henschler, Institute of Pharmacology and Toxicology, University of Wurzburg, Federal Republic of Germany. *Annals of Occupational Hygiene, Volume 28, No. 1, pp. 79-92, 1984.*

<sup>8</sup>“Validation Guidelines for Air Sampling Methods Utilizing Chromatographic Analysis.” Available at <https://www.osha.gov/dts/sltc/methods/chromguide/chromguide.pdf> (accessed March 1, 2019).

<sup>9</sup>29 CFR 1910.146 Confined Space Standard Appendix B.

<sup>10</sup>Occupational Safety and Health Act of 1970, Section 5(a)1.

<sup>11</sup>10 CFR 851 Department of Energy Worker Safety and Health Program, 851.23 (a) (9) Safety and Health Standards (2016 ACGIH TLVs).

<sup>12</sup>Price-Anderson Amendments Act (PAAA).

<sup>13</sup>DOE Order 232.2a, Occurrence Reporting and Processing of Operations Information.

<sup>14</sup>D18-08-002 Department of Energy Safety and Health Regulatory and Policy Response Line Approval, regarding the assignment of Peak Exposure Values from 2016 ACGIH TLVs. Downloaded 2-10-2019 from <https://responseline.doe.gov/question/Search.aspx>

<sup>15</sup>NIOSH Pocket Guide to Chemical Hazards, Department of Health and Human Services Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, September 2007, DHHS (NIOSH) Publication No. 2005-149.

<sup>16</sup>Important Instrumentation and Methods for the Detection of Chemicals in the Field. AIHA Publications. First Edition, Smith and Cook Editors.

<sup>17</sup>Reporting Specification for Electronic Real Time Gas and Vapor Detection Equipment, Fact Sheet sponsored by the AIHA Real Time Detection Systems Committee, October 17, 2016.

<sup>18</sup>R. Jedd Hill & Philip A. Smith (2015) Exposure Assessment for Carbon Dioxide Gas: Full Shift Average and Short-Term Measurement Approaches, Journal of Occupational and Environmental Hygiene, 12:12, 819-828.

<sup>19</sup>Philip A. Smith, Michael K. Simmons & Phillip Toone (2018) Sensor-triggered sampling to determine instantaneous airborne vapor exposure concentrations, Journal of Occupational and Environmental Hygiene, 15:6, 510-517.

<sup>20</sup>Complete Listing, Disposition Authorities Frozen Under the Epidemiological Moratorium, March 2008.

<sup>21</sup><https://www.osha.gov/laws-regs/standardinterpretations/1983-03-01> March 1, 1983 DOL to Bargmann of Longshoreman's Union.

## **6.0 Attachments**

**Attachment 1: Real Time Monitoring Data Planning Collection and Interpretation Worksheet**



## Attachment 1

### Real Time Monitoring Data Collection and Interpretation Worksheet

<b>Targeted Hazardous Agent</b>	
<b>Proposed Technology/Instrument</b>	
<b>Sensor Accuracy at 50% and 100% OEL Concentration</b>	
<b>Sensor Precision at 50% and 100% OEL Concentration</b>	
<b>Data Logging Frequency</b>	
<b>Personal Sample or Area Sample Collection</b>	
<b>Manufacturer Constraints or Prohibitions</b>	
<b>OEL Selection Basis and Source</b> <ul style="list-style-type: none"> <li>• 8-hour TWA:</li> <li>• STEL:</li> <li>• C:</li> <li>• IDLH:</li> <li>• Other:</li> <li>• ACGIH 3/5 Rule (i.e., peak exposures for hazards with rapidly occurring acute adverse health effects):</li> </ul>	
<b>Instrument Configuration</b> Data logging interval duration Alarm Settings (i.e., names and values as displayed on instrument display and data logged report)	
<b>Environmental/Other Factors (e.g., temperature, humidity, age of sensor)</b>	
<b>Logged Data Reporting and Analysis</b>	
<b>Data Interpretation</b>	
<b>Interpretation of any single exceedance of all applicable criteria (Shift TWA, STEL, Ceiling, IDLH)</b>	
<b>Interpretation of multiple exceedance of all appropriate criteria (e.g., number of STEL occurrences in Shift TWA, number of alarm points occurring during work)</b>	
<b>Interpretation of several campaigns of data collection (multiple random days of the month, or sequence of days in a week, or something else defined as an exposure campaign).</b>	
<b>Stakeholder Concurrence:</b> Surveyed Workgroup Manager _____ ESH Management _____	