AN INDUSTRIAL HYGIENE SAMPLING STRATEGY TO QUANTIFY EMPLOYEE EXPOSURE

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ABSTRACT

Depending on the invasive nature of performing waste management activities, excessive concentrations of mists, vapors, gases, dusts or fumes may be present thus creating hazards to the employee from either inhalation into the lungs or absorption through the skin. To address these hazards, similar exposure groups and an exposure profile result consisting of: 1) a hazard index (concentration); 2) an exposure rating (monitoring results or exposure probabilities); and 3) a frequency rating (hours of potential exposure per week) are used to assign an exposure risk rating (ERR). The ERR determines if the potential hazards pose significant risks to employees linking potential exposure and breathing zone (BZ) monitoring requirements. Three case studies consisting of: 1) a hazard-task approach; 2) a hazard-job classification-task approach; and 3) a hazard approach demonstrate how to conduct exposure assessments using this methodology. Environment, safety and health professionals can then categorize levels of risk and evaluate the need for BZ monitoring, thereby quantifying employee exposure levels accurately.

INTRODUCTION

WESKEM, LLC is responsible for performing waste management field activities consisting of the collection, database inventory, characterization, sorting, treatment, segregation, packaging, interim storage, and off-site transportation of hazardous, radioactive and mixed wastes including asbestos and polychlorinated biphenyls (PCBs). Depending on the invasive nature of the activity, excessive concentrations of mists, vapors, gases, dusts or fumes may be present thus creating hazards to the employee from either inhalation into the lungs or absorption through the skin. To address these hazards, an exposure assessment is performed to qualitatively or quantitatively estimate the magnitude, frequency, duration and route of exposure. Since quantifying employee exposure is the driving force behind an effective health and safety program, WESKEM, LLC's Environment, Safety and Health (ES&H) Department developed an industrial hygiene (IH) sampling strategy based on the American Industrial Hygiene Association's (AIHA) text, A Strategy for Assessing and Managing Occupational Exposures (1) and the Department of Energy's (DOE) Implementation Guide for Use with DOE Order 440.1, Occupational Exposure Assessment (2). Based on the magnitude of the hazard determined by the exposure assessment, corrective actions can then be initiated such as implementing engineering or administrative controls, determining the number of breathing zone (BZ) samples to collect, medical monitoring, training, upgrading personal protective equipment (PPE), or modifying work practices.

THE EXPOSURE ASSESSMENT PROCESS

Based on the job tasks to be performed, the exposure assessment process consists of gathering as much information as possible to characterize the types, durations and frequencies of hazards encountered during the project. This information is obtained through project planning meetings, process knowledge, analytical data and, if available, previous IH monitoring results. After the initial hazard information is collected, similar exposure groups (SEGs) are established. SEGs are defined as those employees who perform like tasks, handle the same materials and waste streams, and conduct tasks in a similar manner and frequency. SEGs are an important part of the sampling strategy because they are used to link potential exposure, BZ monitoring requirements, and medical monitoring efforts among groups of workers. Based on the outcome of the assessment, engineering, administrative and PPE controls would then be considered to reduce the potential employee exposures that may exist.

EXPOSURE RISK RATING (ERR) AND BREATHING ZONE (BZ) SAMPLES

Each SEG will have a corresponding exposure profile based on the various job tasks and potential hazards expected within those job tasks. The exposure profile is made up of three different variables that are used to calculate an exposure risk rating (ERR). The ERR determines if the potential hazards pose significant risks to employees. A minimum number of BZ samples are then collected, thereby quantifying employee exposure. The BZ is the volume of air surrounding a worker's nose and mouth from where breathing air is drawn in over the course of the work period.

The First Variable - Hazard Index Rating

The *first* variable is based on the hazard's occupational exposure limit (OEL) and the potential health effects of overexposure. This is defined as the hazard index rating (HIR). The HIR is a numerical rating from 1 to 4. Mild irritants or simple asphyxiants with exposure limits greater than 499 ppm (gases or vapors) or 9 mg/m^3 (particulates or fumes) are assigned an HIR of 1. On the other end of the scale, extremely toxic chemicals and carcinogens with OELs of less than 6 ppm (gases or vapors) or 0.6 mg/m^3 (particulates or fumes) are assigned a HIR of 4. Table I lists the HIRs assigned to various OELs and effects from overexposure.

Table I. HIRs Assigned to Various OELs and Effects from Overexposure

HIR	OEL (ppm)	OEL (mg/m^3)	Effects from Overexposure
1	> 499	> 9	Minor, temporary or reversible effects following excess exposure to mild-to-moderate irritants, simple asphyxiants or odorous materials.
2	50 – 499	5 – 9	Serious, but not life threatening, following exposure to chemical asphyxiants and central nervous system (CNS) depressants. Exposure characterized by marked irritation.
3	6 – 49	0.6 – 4	Serious, but not immediately life threatening, or non-reversible consequences following exposure to suspect human or animal carcinogens, mutagens, teratogens, or corrosives. Exposure characterized by potential chronic systemic (e.g., respiratory tract, CNS, kidney, liver, heart) effects.
4	< 6	< 0.6	Highly serious, extremely toxic, life threatening, non-reversible effects characterized by acute lethal toxicity, non-reversible chronic cumulative systemic effects, known human carcinogens or reproductive hazards.

The Second Variable - Quantitative Exposure Rating

The *second* variable is based on a quantitative or qualitative approach from either exposure monitoring data or professional judgment related to the probability of exposure. For example, if previous IH monitoring data showed that a concentration of a chemical was reported to be less than its detection limit, the assigned exposure rating (ER) would be 1. If the measured concentration were greater than 50% of the OEL, the assigned ER would be 5. Table II lists the ERs assigned to various monitoring results.

Table II. Exposure Ratings Assigned to Various Monitoring Results

Exposure Ratings	Monitoring Results
1	< Detection Limit
2	< 10% of the OEL
3	> 10% but < 25% of the OEL
4	> 25% but < 50% of the OEL
5	> 50% of the OEL

The Second Variable - Qualitative Exposure Rating

A qualitative approach is used if no previous monitoring data exists. The ES&H Department would evaluate the probability of exposure based on the type of job being done and the controls in place to minimize exposure. A fully-enclosed system, such as working with non-leaking closed drums, would have little to no potential exposure yielding an ER of 1. However, an uncontrolled or poorly-controlled system with large volumes of volatile materials, such as opening drums that contain hazardous sludges or liquids, would be assigned an ER of 4. Table III lists the ERs for different types of exposure probabilities and controls.

Table III. Exposure Ratings for Different Types of Exposure Probabilities and Controls

Exposure Ratings	Exposure Probabilities	Controls
1	None	Totally enclosed system with no potential for exposure.
2	Low	Controlled or open-ventilated systems. Low volume of volatile materials. Clean environment, relatively dust free. Probability of exposure under normal conditions is remote.
3	Medium	Controlled or open-ventilated systems. Large volumes of volatile materials. Increased risk of generating dust by sweeping or working in a ventilated, but dusty environment. Manually opening containers of PPE/soil. Probability of exposure under normal working conditions.
4	High	Uncontrolled or enclosed systems. Manually opening containers of sludges, lab waste or unknown materials. Large volumes of volatile materials. High risk of generating dust/particulates by welding, cutting, grinding or working in poorly ventilated, dusty environments. Probability of excessive exposure under normal working conditions.

The Third (and Final) Variable - Frequency Rating

The *third* and final variable in determining an exposure profile is based on the frequency and duration of the job task. The frequency rating (FR) is a numerical value between 1 and 4. If the frequency of potential exposure were less than 4 hours per week, the assigned FR would be 1. A frequency of greater than 20 hours per week would be assigned an FR of 4. Table IV lists the FRs assigned to potential exposure periods during a 40-hour work week.

Table IV. Frequency Ratings Assigned to Potential Exposure Periods

Frequency Ratings	Frequency of Potential Exposure
1	< 4 hours/week
2	5 – 12 hours/week
3	13 – 20 hours/week
4	> 20 hours/week

The Exposure Risk Rating (ERR)

The ERR is assigned according to the exposure profile results (EPR), which is the product of the three variables as shown in Eq. 1.

$EPR = HIR \times ER_{\textit{quantitative or qualitative}} \times FR$ (Eq. 1)

This rating is based on a statistical analysis incorporating actual exposure assessment data collected over many years in industrial settings (1). Table V lists the EPR and monitoring requirements for each ERR.

Table V. Exposure Risk Ratings Assigned to Exposure Profile Results and Monitoring Requirements

Exposure Risk Rating (ERR)	Exposure Profile Results (EPR)	BZ and Real-Time Monitoring Requirements
1	< 18	Negligible risk activity. No BZ monitoring required.
2	19 – 36	Low risk activity. Collect 10 BZ samples. Collect 2 BZ samples monthly after baseline is established.
3	37 – 53	Medium risk activity. Collect 20 BZ samples. Collect 2 BZ samples monthly after baseline is established. Conduct weekly real-time monitoring in area, if applicable.
4	> 54	High risk activity. Evaluate if engineering/administrative controls are possible. If possible, conduct additional exposure assessments. If not possible, perform BZ sampling until 10 valid sample results are received. Collect 2 BZ samples monthly after baseline is established. Conduct weekly real-time monitoring in area, if applicable.

EXPOSURE ASSESSMENT CASE STUDIES

The following three case studies demonstrate how the ERR process can identify hazards and help determine a sampling strategy to quantify employee exposure levels accurately.

Exposure Assessment Case Study #1 - Hazard-Task Approach

WESKEM, LLC was contracted to characterize, repackage, transport and dispose of waste container contents ranging from paper and PPE to liquid and sludge. The main chemical hazard associated with these containers was trichloroethylene (TCE), which has an occupational exposure limit (OEL) of 100 ppm (3).

The first step was for the ES&H Department to meet with the project managers, planners, supervisors and waste samplers. During the pre-job planning sessions, project scope, job tasks and their associated hazards that posed the greatest risk to worker health and safety could be identified and finalized. The next step consisted of reviewing all available documentation for the project. For example, documentation such as field work requests (FWRs), activity hazard reviews (AHRs), activity hazard analyses (AHAs), and sampling and analysis plans (SAPs) painted a clear picture about the overall scope of the project and potential hazards. The SAP listed all containers, waste codes and container contents, if known. All of this information helped establish a "game plan" for IH monitoring.

The exposure assessment process was used to determine if BZ samples were needed to accurately characterize employee exposures to TCE during this project. Because there was only one field work group for this project (i.e., waste samplers), only one SEG was established. However, there were different types of waste sources and these sources were divided into different tasks because of the variability of exposure. Table VI lists the numerical ratings for each variable and ERR resulting from a potential exposure to TCE.

Table VI. ERRs Resulting from a Potential Exposure to TCE

Hazard	Job Task	HIR	ER	FR	EPR	ERR
TCE	Sampling PPE & paper	2	2	4	16	1
TCE	Sampling liquid & sludge	2	4	4	32	2

Since the job task requiring the sampling of PPE and paper had an ERR of 1, no BZ monitoring was required. However, sampling liquid and sludge had an ERR of 2. Therefore, 10 BZ samples were required including 2 BZ samples to be collected monthly for reverification purposes after a baseline was established.

Exposure Assessment Case Study #2 - Hazard-Job Classification-Task Approach

A PCB leak was reported inside of a designated work area. The initial exposure assessment for PCBs in this area was 1, but because of the leak, a new assessment was conducted by the ES&H Department. The most conservative Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) for PCBs was used; 0.5 mg/m^3, which is for chlorodiphenyl (54% chlorine) (3). The OSHA PEL is defined as an 8-hour time-weighted-average concentration that should not be exceeded for any 8-hour work shift of a 40-hour work week.

There were many different work tasks performed within the area. Because of the variability of work, different SEGs were developed for this particular area. The first job task performed after the leak was cleaning and decontaminating the area. This type of work was performed by "A" operators. After clean-up and decontamination was complete, normal operations resumed in the area. Inspectors were responsible for evaluating items found in the area to determine if they could be exempted from nuclear criticality safety regulations. The next step was for "B" operators to enter the area to begin characterizing the items. A subject matter expert (SME) assisted with the characterization process by determining if any items were regulated by the Resource Conservation and Recovery Act (RCRA) or the Toxic Substances Control Act (TSCA). After all RCRA and TSCA waste was containerized and removed from the area, the remaining items were tagged and repackaged, if necessary, for disposal.

The purpose of this assessment was to determine the number and frequency of air samples that the ES&H Department was required to collect for operations within the area, as well as, assess the types of controls that were needed to prevent exposure. The other main route of exposure was skin absorption. Table VII lists the different SEGs, their job tasks and their exposure profiles for this project.

Table VII. ERRs Resulting from a Potential Exposure to PCBs

Hazard	Job Classification	Job Task	HIR	ER	FR	EPR	ERR
PCB	Operator A	Decon & Clean-up	4	4	1	16	1
PCB	Inspector	NCS Characterization	4	3	3	36	2
PCB	Operator B	Characterization & Material Handling	4	3	4	48	3
PCB	SME	Characterization	4	3	1	12	1

Based on the evaluation performed by the ES&H Department, the “B” operators had the highest potential for exposure based on relatively high exposure and frequency ratings. Although the “A” operators had a higher exposure rating due to the clean-up of the leak, their exposure time was much less than the other employees working in the area. After clean-up of the leak was complete, routine operations continued. The exposure ratings were then expected to decrease because of the clean-up of the material. However, in the judgment of the ES&H Department, there was still a good possibility of exposure due to residue and contaminated objects left in the area. Based on this assessment, 20 BZ samples were still collected, obviously providing supplemental data and documenting with greater confidence that the “B” operators were not being exposed while performing characterization and material handling activities.

Exposure Assessment Case Study #3 - Hazard Approach

WESKEM, LLC was contracted to neutralize three containers of nitric acid that has an OEL of 2 ppm (3). Based on previous data, the original pH of the acid was zero and was to be neutralized to a pH between 6 and 8. The work was to be performed in a temporary enclosure located inside a RCRA-permitted storage building. Since nitric acid is very corrosive, skin protection was required for all personnel working inside the enclosure. The employees assigned to work inside of the enclosure were the front line manager (FLM), an ES&H technician, a chemist, and an “A” operator. All of these employees were placed in the same SEG due to their relative proximity to and the nature of the hazard. The job tasks consisted of: 1) removing the container lid; 2) performing IH monitoring to determine the lower explosive limit (LEL) and reporting any other unusual readings; 3) adding a basic, neutralizing solution to the acid; and then 4) transferring the neutralized solution to a separate container. Table VIII lists the results of the initial exposure assessment.

Table VIII. ERR Resulting from a Potential Exposure to Nitric Acid

Hazard	HIR	ER	FR	EPR	ERR
Nitric Acid	4	4	4	64	4

The initial EPR resulted in an ERR of 4 without taking credit for the enclosure being ventilated by a negative air machine (NAM) with special carbon filters to scrub the air before being emitted to the outside of the building. The ES&H Department then performed a second exposure assessment to determine if adding engineering controls and PPE would minimize exposure to the employees. Engineering controls such as a NAM hose and glove box would be expected to reduce the exposure risk. In addition, PPE consisting of a double-encapsulated suit with supplied air was used as secondary measure to prevent exposure. Table IX lists the new ERR after implementing the engineering controls and PPE.

Table IX. ERR Resulting from a Potential Exposure to Nitric Acid After Implementing Engineering Controls and PPE

Hazard	HIR	ER	FR	EPR	ERR
Nitric Acid	4	3	4	48	3

By adding the engineering controls and PPE, the ERR was reduced from 4 to 3, thus reducing the overall project risk from high to medium, respectively.

CONCLUSION

The preceding three case studies demonstrate how to conduct exposure assessments based on different types of activities and hazards. The first case study was a hazard-task approach; i.e., even though there was only one SEG involved, the various tasks changed the exposure risk. The second case study was a hazard-job classification-task approach. Because of the different job classifications performing the work, the tasks were different causing the ERRs to be different. Finally, the third case study, a hazard approach, was used when the exposure risk variability was based on time and distance instead of job task. All three approaches should be considered when performing an exposure assessment to ensure that all variables are weighed equally. ES&H professionals can then determine levels of risk and employee exposure. Specifically, WESKEM, LLC has designed this strategy to categorize project risks and evaluate the need for BZ monitoring, thereby quantifying employee exposure levels accurately.

REFERENCES

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