Analysis and evaluation of the workplace exposure assessment workbook developed by Keith Tait including some recommended revisions

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ANALYSIS AND EVALUATION OF THE
WORKPLACE EXPOSURE ASSESSMENT WORKBOOK
DEVELOPED BY KEITH TAIT
INCLUDING SOME RECOMMENDED REVISIONS

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INTRODUCTION

Some risk due to the contamination of workplace environments is an inevitable part of human lives. These risks can often be reduced by improving the control of environmental pollution in the workplace. An extremely important challenge for any industry is to develop a mechanism to identify acceptable levels of safety, or "acceptable risk" in the workplace for specific situations, and to assure adequate quality control over measured or calculated exposure concentrations and their possible contributions to adverse health effects.

Workplace exposure assessments are designed to identify, evaluate, and, if necessary, point out the need to control employee exposures to hazardous substances in their environment. Exposure assessments estimate the exposure to determine existing levels in comparison to acceptable levels and establish requirements for measures. (Leidel 1990) Workplace exposure assessments are also used to document historical exposure levels, develop employee participation and communication, and demonstrate compliance with government regulations. (Leidel 1990)

Workplace exposure assessment models and measurement devices assist knowledgeable and qualified people such as safety and health professionals, chemists and engineers to evaluate employee exposures under the review of a
professional hygienist. (Tait 1993) Because of the large number of workplaces and the limited availability of professional hygienists, additional employees in the workplace must assist in the evaluation and documentation of substance hazards, employee exposures, and existing control measures. These employees must understand specific operations, work practices, and workplace conditions in order to be trained to perform workplace exposure assessments under the review of a professional hygienist. (Tait 1993)

The Workplace Exposure Assessment Workbook, developed by Keith Tait, is a qualitative model that defines a decision logic for directing assessment actions. The Workbook incorporates established concepts and principles of exposure assessments. The Workbook includes seven fundamental functions that are performed sequentially with the exposure assessment strategy. The components include:

1. Compile the Initial Characterization
2. Define the Homogeneous Exposure Groups
3. Perform the Workplace Exposure Assessment
4. Perform an Appropriate Monitoring Program
5. Implement the Hierarchy of Controls
6. Verify the Workplace Controls
7. Determine the Frequency of Periodic Review

Although Tait has defined and employed a strategy for workplace exposure assessments, further definitions and proposed revisions of the Workbook are deemed necessary.
to properly analyze and evaluate an assessment, and to develop clear and understandable decisions and actions for the workplace.

The following analysis and evaluation utilize the outline of Tait's Workplace Exposure Assessment Workbook along with information on employee exposures and workplace assessments from the National Institute for Occupational Safety and Health, the Occupational Safety and Health Administration, and the American Conference of Governmental Industrial Hygienists.
COMPILE THE INITIAL CHARACTERIZATION

Before utilizing the Workplace Exposure Assessment Workbook, an Initial Characterization of the facility must be obtained. The Initial Characterization contains three components, Hazardous Substance Inventory, Material Safety Data Sheets, and Industrial Hygiene Information. (Tait 1993) The components must include specific information on substances, workplace, exposures, and preparation of schematic diagrams, workplace descriptions, and job classifications that will assist knowledgeable, qualified people to prepare for implementing the workplace assessment. Tait briefly discusses each component; however, a more complete description is suggested below.

HAZARDOUS SUBSTANCE INVENTORY

The Hazardous Substance Inventory is a complete list of chemical, biological, and physical agents in the workplace. (Tait 1993) This list is determined by tabulating all materials that may be used or produced in the work operations or manufacturing processes under investigation and that may be released into the workplace atmosphere or contaminate the skin. (Leidel 1990) This information can be found from purchasing records or on the Material Safety Data Sheets.
MATERIAL SAFETY DATA SHEETS

Material Safety Data Sheets are a complete file of substances used in the workplace. When these forms are completed, substances should be compared with the Tables of Substances published by the Occupational Safety and Health Administration in the Code of Federal Regulations; 29CFR 1910.1000. (Leidel 1990) This procedure determines if employers are subject to the provisions of federal regulations by the use of, or the possession of substances listed in the published standards. Even if the substances are not federally regulated, the same exposure monitoring procedures that apply to the regulated substances should by instituted.

INDUSTRIAL HYGIENE INFORMATION

Industrial Hygiene Information is a complete description of processes, operations, work practices, monitoring activities, workplace controls, and personal/respiratory equipment. This component should also contain a "Plant Survey". This Survey is done by visiting the workplace to overview work operations. It is here that potential health hazards may be identified and a determination made if employees may be exposed to hazardous airborne concentrations released to the work environment. (Leidel 1990) Several factors that can be observed in the workplace are:
- Air contaminants that can be visually identified in dusty operations.

- Fumes that can be visually identified as in operations that involve welding or electroplating.

- Air contaminants that can be determined by the sense of smell and gases and vapors detected by distinct odor, taste or irritating effects such as burning sensations in the nose, throat and lungs.

- Employee location in relation to a contaminant source. An investigation of the air flow patterns within a workplace must be conducted since many contaminants can be dispersed long distances from their sources. (Paustenbach 1989)

- Procedures employees use to perform tasks should be analyzed since the improper use of control equipment may cause significant exposure to hazardous compounds. Also, careless handling of toxic materials could cause situations in which unacceptable exposures can occur.

- Design, installation, and maintenance of control equipment must be observed since ineffective control systems may be used in the workplace and can cause unacceptable exposure situations. (Paustenbach 1989)

- Check for location of open doors and windows providing natural ventilation that can disperse or dilute materials released in the workplace. (Paustenbach 1989)

- Check for high-temperature locations that will increase the evaporation rates of toxic solvents. (Paustenbach 1989)
OCCUPATIONAL EXPOSURE LIMITS

An important objective of the Compile the Initial Characterization activity is to assess exposure measurement action levels; which Tait neglected to define in his analysis of the Workbook. Permissible Exposure Limits (PELs), the highest allowable exposure levels, were promulgated by the Occupational Safety and Health Administration. Approximately 400 chemical standards are listed in Tables Z-1, Z-2, and Z-3 of the Code of Federal Regulations (CFR) 1910.1000. An action level is defined as one-half the value of the PEL found in CFR 1910.1000. The action level is the point at which certain provisions of the proposed standards must be initiated. These standards are used when performing the Workplace Exposure Assessment and performing the Appropriate Monitoring Program.

CALCULATION OF POTENTIAL EXPOSURE CONCENTRATIONS

By knowing the ventilation rate in a workplace, and the quantity of material generated, a calculation can be made to estimate if standards might be exceeded. (Leidel 1990) The American Conference of Governmental Industrial Hygienists publishes an Industrial Ventilation Manual of Recommended Practices every two years. This Manual states that safety factor ("K") values of 3-10 are usually chosen for dilution ventilation work. The safety factor, shown in the following
equation, is an approximate ratio of breathing zone concentration at the operation to the general room air concentration.

CALCULATION OF POTENTIAL EXPOSURE CONCENTRATIONS

Steady-state air exposure concentration estimate in parts-per-million (ppm)

\[
\text{Concentration (ppm)} = \frac{(403) \times (a) \times (10^6) \times (b) \times (K)}{(c) \times (d)}
\]

where:

- 403 = Conversion factor so the answer will be in ppm
- \(a\) = Specific gravity of solvents
- \(10^6\) = Conversion factor so the answer will be in ppm
- \(b\) = Pints solvent/hour
- \(c\) = Molecular weight of solvent
- \(d\) = Ventilation rate in cubic feet/hour
- \(K\) = Safety factor, usually 3-10

RANDOM AND SYSTEMATIC ERRORS

An important reason for periodically measuring an employee's exposure is to detect trends, systematic changes (bias), and random variation (random error). If these errors go undetected, much larger variation will be introduced. Primary sources of variation that affect estimates of occupational exposure include: (Leidel 1990)
- Random sampling device errors - random fluctuations in flowrate.

- Random fluctuations in a chemical laboratory procedure.

- Random intraday (within a day) environmental fluctuations in a contaminant's concentration.

- Random interday (between days) environmental fluctuations in a contaminant's concentration.

- Systematic errors in the measurement process - improper calibration, improper use of equipment, erroneous recording of data.

- Systematic changes in a contaminant's airborne concentration due to employees moving to a different exposure concentration or shutting off an exhaust fan.

- Systematic changes due to closing workplace doors and windows as in cold weather.

- Systematic changes due to decreases in efficiency or abrupt failure of engineering control equipment such as ventilation systems.

- Systematic changes in the production process or work habits of the employees.
DEFINE THE HOMOGENEOUS EXPOSURE GROUPS

Homogeneous Exposure Groups are groups of employees who have similar or comparable patterns or profiles of exposure. (Tait 1993) Homogeneous Exposure Groups are critical to the performance of a detailed Workplace Exposure Assessment since they identify similar substance, workplace, and exposure factors: degree of toxicity, nature of hazards, workplace controls, duration of exposure, and frequency of exposure. (Tait 1993)

The Workplace Exposure Assessment Workbook defines Homogeneous Exposure Groups by identifying their fundamental elements. Qualified employees will review and interpret specific information about the substance, workplace, and exposure factors of the facility. This information can be obtained from the Initial Characterization. Tait's fundamental elements are:

**SUBSTANCE NAME**—agents or a mixture of ingredients.
**WORKPLACE LOCATION**—list of departments and all unit areas.
**EXPOSURE SCENARIO**—employees, processes, operations, work practices.

When defining a Homogeneous Exposure Group, Tait does not mention intrinsic and extrinsic factors that must be incorporated into the analysis and interpretation of assessment results. These factors include:

**INTRINSIC FACTORS**—age, race, sex, health, genetic traits, pregnancy.
**EXTRINSIC FACTORS**—diet, smoking, alcohol and medication intake, etc.
Tait also does not show how to determine the Homogeneous Exposure Group. The best procedure for determining the group is to observe and select the employee/employees closest to the source of the material being generated. (Leidel 1990) Based on estimated air concentration for different distances from the contaminant source, employees can be grouped into various zones of potential risk. (Leidel 1990) Other factors used in determining potential risk are: employee mobility, air movement patterns, location of ventilation air exhausts and inlets, location of open doors and windows, size and shape of work area, and differences in work habits of individual workers. (Leidel 1990)

The proposed OSHA Health Regulations requires that if any of the exposure measurements taken on the maximum risk employee/employees show exposures to toxic substance at or above the action level, the employer shall:

1. Identify all employees who may be exposed at or above the action level, and
2. Measure the exposure of the employees so identified.

One important note that Tait states is that difficulties may arise when certain substance have "dynamic physical or toxicological properties, or employees are exposed to multiple substances during intermittent time intervals or or unpredictable events". Due to this difficulty, the scope of the Workbook's guideline is narrowed to the analysis of an exposure to one substance. Statistical techniques such as analysis of variance can be applied to test the
homogeneity of exposure within Homogeneous Exposure Groups when large numbers of monitoring results are available. (Tait 1993)

MISCLASSIFICATION OF HOMOGENEOUS EXPOSURE GROUPS

The effect of misclassification can be described by two incorrect decisions: a false negative or a false positive. A false negative is defined as a group that is classified as unexposed when it is actually exposed, or the estimated exposure is below the action level when it is truly above the action level. (Flatman 1991) If a decision is false negative, investigations will be stopped and employees will continue to be exposed to unacceptable risks.

A false positive is defined as a group that is classified as exposed when it is actually unexposed, or the estimated exposure is above the action level when it is truly below the action level. (Flatman 1991) If a decision is false positive, unnecessary action will be taken.

Unbiased and careful estimation of exposure is the most careful way to avoid misclassification of Homogeneous Exposure Groups. The best way to avoid incorrect decisions is to study employees with heavy exposure and those definitely without exposure. If this is not possible, analyze those uncertain exposure groups as separate classes, and do not mix them with exposed or unexposed groups. (Rappaport, 1991)
PERFORM THE WORKPLACE EXPOSURE ASSESSMENT

The Workplace Exposure Assessment provides a systematic means for qualitatively evaluating risks and prioritizing workplace monitoring and control activities. (Tait 1993) According to Tait, the Workplace Exposure Assessment Workbook strategy performs the assessment by asking three screening questions. These questions provide critical information to determine appropriate actions. The assessment screening questions inquire about substance hazards, hierarchy of controls, and magnitude and duration of employee exposure. The answers to the questions are ranked to categorize the outcome of the Workplace Exposure Assessment. Tait's ranking system to the screening questions are vague and can be interpreted differently, resulting in inconsistent answers from the assessors. The following shows Tait's screening questions and decisions based on their rankings, and the proposed rankings for clarification in order to properly categorize the outcome of the assessment.
WORKPLACE EXPOSURE ASSESSMENT SCREENING QUESTIONS

QUESTION 1

WHAT HEALTH HAZARDS ARE POSED BY THE SUBSTANCE?
(The answer is ranked by degree of toxicity and nature of hazard)

TAIT'S RANKINGS

5-Life-threatening or enabling injury or illness
4-Irreversible health effects of serious concern
3-Severe reversible health effects of major concern
2-Reversible effects of moderate concern
1-Reversible effects of limited concern
0-No known or suspected health effects

PROPOSED REVISED RANKINGS

The ranking system used for the first question is based on the physiological classifications of toxic effects which are first defined below: (Leidel 1990)

IRRITANTS—are corrosive in action. They inflame the moist mucous surfaces of the body. The airborne concentration is more important than the length of time of exposure. Examples of irritant materials that exert effects on the respiratory tract and lung tissues are aldehydes, alkaline dusts and mists, ammonia, chlorine, and bromine.

ASPHYXIANTS—exert effects on the body by interfering with the oxygenation of the tissues. There are two classes of asphyxiants; simple asphyxiants which include methane, ethane, hydrogen, and helium, and chemical asphyxiants that include carbon monoxide, hydrogen cyanide, and nitrobenzene.

ANESTHETICS AND NARCOTICS—exert action on the body as a simple anesthesia through depressant action on the central nervous system. Examples are acetylene, ethylene, and ethyl ether.

SYSTEMIC POISONS—are materials that cause injury to particular organs or body systems. Examples include halogentaed hydrocarbons which cause injury to the liver and kidneys, benzene and phenol which cause damage to the blood-forming system, carbon disulfide and methyl alcohol which are nerve poisons, and metallic systemic poisons that include lead, mercury, cadmium, and manganese.

CHEMICAL CARCINOGENS—are chemicals that have been demonstrated or are strongly suspected to cause tumors in humans. Carcinogens may induce a tumor type not observed, or induce an increased incidence of a tumor type normally seen. In some cases, the tumor appearance is separated from the exposure by a latent period of 20-30 years.
PROPOSED REVISED RANKINGS TO QUESTION 1 CONTINUED

LUNG SCARRING AGENTS—are particulate matter other than systemic poisons that slowly produce damage to the lung. The damage occurs by lung scarring rather than by immediate irritant action.

CHEMICAL TERATOGENS—are chemicals that produce malformation of developing cells, tissues, or organs of a fetus. These effects may result in growth retardation or congenital malformations.

Question 1 answers are based on the physiological classification of toxic effects.

3-Life-threatening or disabling injury or illness-systemic poisons, chemical carcinogens, lung scarring agents, chemical teratogens
2-Irreversible health effects of serious concern-asphyxiants, anesthetics, narcotics
1-Reversible effects of concern-irritants, physical irritations, sensory irritations, odor effects
0-No known or suspected health effects (NOEL-no observed effect level)

QUESTION 2

WHAT IS THE PRIMARY TYPE OF WORKPLACE CONTROLS TO REDUCE OR PREVENT EMPLOYEE EXPOSURE TO THE SUBSTANCE?
(The answer is ranked by the basis of the workplace controls)
(The proposed ranking system is the same as Tait's, but the definitions are expanded)

5-Employees wear personal/respiratory equipment
4-Employees practice administrative controls-knowledge of job duties, processes, materials, work practices, and safety procedures
3-Engineering controls are installed in the workplace-isolation/containment, exhaust ventilation equipment, maintenance of control equipment, inspections for leaks, corrosion, faulty latches and seals
2-A combination of control measures are used
1-Controls are verified to ensure their effectiveness
0-No controls are needed to prevent employee exposure
QUESTION 3

WHAT IS THE NATURE OF EMPLOYEE EXPOSURE TO THE SUBSTANCE IN THE WORKPLACE?
(The answer is ranked based on duration of exposure and frequency of exposure)

TAIT'S RANKINGS

5- Very high exposure, continuous at very high levels
4- High exposure, frequent contact at high levels
3- Moderate exposure, frequent contact at low levels; or infrequent contact at high levels
2- Low exposure, rare contact at low levels
1- Incidental exposure, contact may occur due to a nonroutine situation
0- No exposure, contact is not possible

PROPOSED REVISED RANKINGS

4- Exposure is above the exposure limit and continuous contact of the material occurs at the workplace
3- Exposure is above the exposure limit, but not continuous contact at the workplace; employee leaves workplace at random times
2- Exposure is below the exposure limit and no continuous contact of the material occurs at the workplace; employee leaves workplace at random times
1- Incidental exposure, contact due to employee at the workplace in passing to another area or due to a nonroutine situation
0- No exposure, contact is not possible

TAIT'S DECISION RULES

1. If the substance has no known or suspected health hazard or employee's exposure is not possible, the assessment is complete.

2. If the substance may be life-threatening or may cause irreversible or severe reversible health effects or employees use protective equipment or employee exposure is very high with continuous or frequent contact, the assessment outcome is above the exposure limit and the Hierarchy of Controls must be implemented. Perform an Appropriate Monitoring Program after implementing and verifying the workplace controls.
PROPOSED DECISION RULES

1. If the substance has no known or suspected health effects or employee exposure is not possible, the assessment is complete.

2. If the substance has reversible effects and there is incidental exposure or exposure is below the exposure limit, and employees practice administrative or engineering controls, examination of references such as the Hazardous Substance Inventory, Material Safety Data Sheets, Industrial Hygiene Information, and other documents are used to perform an Appropriate Monitoring Program.

3. If the substance may be life-threatening or may cause irreversible health effects, and employees wear personal respiratory equipment, and exposures are above the exposure limit with continuous or frequent contact, then the Hierarchy of Controls must be implemented. Perform the Appropriate Monitoring Program after implementing and verifying workplace controls.
PERFORM AN APPROPRIATE MONITORING PROGRAM

Appropriate Monitoring Programs evaluate chemical, physical, or biological agents within a variety of media locations and exposure pathways; air, water, workplace, skin surface, biological fluids. (Tait 1993) Specified sampling and analytical methods are used to obtain objective data to compare with established exposure limits or action levels. Appropriate Monitoring Programs can assist hygienists in determining the acceptability of employee exposure and the adequacy of workplace controls. (Tait 1993) The selection of an Appropriate Monitoring Program depends on the substance, its hazards, and the routes of exposure.

The Workbook monitoring strategy evaluates Appropriate Monitoring Programs by asking three screening questions that inquire about the sampling and analytical methods, sampling strategy, and the results of these methods. The answers to the questions are ranked to categorize the outcome of the Appropriate Monitoring Program.

Tait's ranking system to the screening questions is not clearly defined. Tait also does not define each sampling strategy. The following shows Tait's screening rankings and decision rules with proposed revisions to provide a more accurate monitoring program.
QUESTION 1

ARE THE SAMPLING AND ANALYTICAL METHODS ADEQUATE FOR THE SUBSTANCE?

TAIT'S RANKINGS
(The answer is ranked based on sampling and analytical methods)

4-Excellent sampling and analytical methods
3-Good sampling and analytical methods
2-Poor sampling and analytical methods
1-Numerical model available
0-No sampling and analytical methods or numerical model available

PROPOSED REVISED RANKINGS
(The answer is ranked based in precision and accuracy)*
(To be consistent with the rankings of Question 1, the rankings are arranged as (4) as lowest and (0) as highest)

4-No sampling and analytical methods or numerical model is available
3-25% required precision and accuracy for exposure above the exposure limit
2-35% required precision and accuracy for exposure at or below the exposure limit
1-50% required precision and accuracy for at or below the action level
0-95% of measurement are as precise and accurate as the standard requires

*The proposed OSHA Health Standards define the term "accuracy" as the "difference between a measured concentration and the true concentration of the sample". OSHA proposes that "95% of the measurements taken must be as accurate as the standard requires". (Leidel 1990)

QUESTION 2

WHAT SAMPLING STRATEGY WAS UTILIZED BY THE APPROPRIATE MONITORING PROGRAM?
(The answer is ranked based on sampling strategy used)

TAIT'S RANKINGS

5-Worse case exposure evaluation
4-Short-term or peak exposure evaluation
3-Representative employee exposure monitoring
2-Background employee exposure monitoring
1-Randomized employee exposure monitoring
0-Continuous workplace monitoring
**PROPOSED REVISED RANKINGS***

3-**Grab Samples Measurement**—samples are taken over some number of short periods of time, usually less than 1 hour each; generally only minutes or seconds. Grab samples are taken at random intervals over the standard time period.

2-**Partial Period Consecutive Samples Measurement**—one or several samples (equal or unequal time duration) are obtained for only a portion of the period appropriate to the standard. For an 8-hour period standard, the samples cover about 4 to less than 8-hours.

1-**Full Period Consecutive Sample Measurement**—several samples (equal or unequal time duration) are obtained during the entire time period appropriate to the standard. The total time covered by the samples must be 8 hours for an 8-hour standard.

0-**Full Period Single Sample Measurement**—sample is taken for the full period of the standard. This period is 8 hours for an 8-hour standard.

*OSHA recommends these four sampling methods for exposure measurement strategies. There is no "best" strategy for all situations, however, some strategies are better than others based on the following considerations: (Leidel 1990)

- Availability and the cost of sampling equipment, sample analytical facilities, and the cost of personnel to take the samples.
- Location of employees and work operations.
- Occupational exposure variation (intraday/interday).
- Precision and accuracy of sampling and analytical methods.
- Number of samples needed to attain the required accuracy of the exposure measurement.

**QUESTION 3**

**WHAT WERE THE RESULTS OF THE APPROPRIATE MONITORING PROGRAM?**
(The answer is ranked based on sampling results and variability of results)

**RANKINGS**

4-Employee exposures are above the exposure limit
3-Employee exposures are below the exposure limit
2-Employee exposures are above the action level
1-Employee exposures are below the action level
0-Employees are unexposed
DECISION RULES
(The decision rules are the same for Tait and the proposed revised rankings.)

1. If employees are unexposed, then the Appropriate Monitoring Program is complete. Define another Homogeneous Exposure Group.
2. If employee exposures are below the action level, then verify the workplace controls.
3. If employee exposures are above the action level or below the exposure limit, then implement the Hierarchy of Controls and repeat the Appropriate Monitoring Program.
4. If employee exposures are above the exposure limit, then implement the Hierarchy of Controls and verify the workplace controls.
5. If the sampling and analytical methods for the substance do not exist, then determine if a numerical model is available, and implement the Hierarchy of Controls and verify the workplace controls.

Under OSHA Health Regulations, developed under the Standards Completion Program require the following interval between days monitored: (Leidel 1990)

1. The employee's exposure measurements are at or above the action level, but not above the exposure limit, must be measured every two months.
2. The employee's exposure measurements exceeding the exposure limit must be measured at least every month until the exposure is reduced to Below the standard by appropriate control measures.
3. Exposure monitoring may be terminated if two consecutive exposure measurements taken at least one week apart reveal that the exposure measurements are less than the action level.

PERSONAL EXPOSURE MONITORS

The best approach to assess the Appropriate Monitoring Program is to use personal exposure monitors for evaluation. Personal exposure monitors, through the use of micro-electronic components and small pollutant sensors, monitor individuals at the workplace to determine if exposures are above the exposure limit. (EPA 1979) Personal exposure monitors can also be used in a great variety of application fields including: (Schyga 1992)
- Triggering alarms in case of sudden substance outbreaks.
- Detecting leaks in project systems.
- Protecting visitors on company premises.
- Clearance of workplaces once freedom of substance has been verified.

The Environmental Protection Agency has determined six major benefits in using personal exposure monitors: (EPA 1979)

1. More detailed knowledge of individual, day-to-day exposure.
2. Identification of high-risk subpopulations and the quantification of their exposure.
3. Measurement of exposure during episodes lasting 3-4 days.
4. Validation of diffusion models and activity pattern models which can be used to validate models of personal behavior, such as when an employee is commuting or when he is at home.
5. Calibration of fixed-station readings.

Examples of different types of personal exposure monitors include: (AOEH 1993)

MINIRAM Personal Continuous Reading Aerosol Monitor
PAC FAMILY Personal Gas Monitors
ADSORBENT PRODUCTS INC. Personal Air Purifier
ENMET Portable Gas Detector
QUEST ELECTRONICS Personal Vibration Sound Monitoring System

The Environmental Protection Agency recommends the following steps to be taken for personal exposure monitors: (EPA 1979)

1. At the end of each shift, the monitor should be tested, calibrated and results recorded on data sheets or computer compatible data files.
2. The monitor equipment should not interfere with work performance.
3. Direct employees not to tamper with the monitors.
4. Always record activities that were performed when measurements are above the exposure limit.
5. The monitors must be maintained carefully and on a regular basis.
IMPLEMENT THE HIERARCHY OF CONTROLS

Employee exposures can be eliminated or reduced by modifying processes or operations, isolating substances and employees, and containing workplace hazards. (Tait 1993) The Hierarchy of Controls employs technologically based workplace control measures and is more important when the substance hazards are unknown or workplace concentrations approach or exceed the exposure limit. (Tait 1993) The Workplace Exposure Assessment Workbook implements the Hierarchy of Controls based upon the effectiveness and reliability of various control measures. According to Tait, the following rules assign the appropriate control measures based upon the outcome of the Workplace Exposure Assessment and the Appropriate Monitoring Program:

1. If the employees exposures are below the action level, then the Hierarchy of Controls is not required. Administrative controls and personal/respiratory protective equipment are acceptable.
2. If employee exposures are above the action level and below the exposure limit, then implement partial Hierarchy of Controls; engineering controls, and administrative controls. Repeat Appropriate Monitoring Program to make sure that employee exposures are acceptable.
3. If employee exposures are above the exposure limit, then implement the full Hierarchy of Controls; engineering controls (substitution, process modification, isolation/containment), and administrative controls. After the controls are implemented, repeat the Appropriate Monitoring Program to make sure that employee exposures are acceptable.
VERIFY THE WORKPLACE CONTROLS

Verifying the workplace controls is critical to determine adequacy of workplace controls and the acceptability of employee exposures. Workplace controls should be evaluated soon after they are installed or modified to determine if they are functioning properly. Since the effectiveness and reliability of most control measures decrease over time, routine assessment of workplace controls is necessary. (Tait 1993)

Workplace controls are identified for three potential routes of exposure: inhalation, eye/skin contact, and ingestion. Although the specific types of controls that are implemented to prevent employee exposure by each route are acceptable and applicable, a more extensive background or exposures routes, and the physical and chemical states of contaminants and particle size of contaminants is necessary for proper evaluation of the work environment.

ROUTE OF EXPOSURE

The route of exposure is defined as the way the chemical moves from the exposure medium in the body. (Rodricks 1992) The primary routes of exposure are inhalation through the respiratory tract, eye/skin absorption, and ingestion by oral route through the digestive tract. There are other
ways chemicals may enter the body, such as injection under the skin or directly into the bloodstream, or by direct application to the eye.

In most cases, a medium results in only one route of exposure, but there are some cases where this is not true. Suppose that a chemical is contained in or on a small particle of dust (0.1-25 micrometers in diameter) that is present in the air. The air is inhaled by an employee and the dust particles containing the chemical enter the respiratory tract. Some of these particles can be trapped before entering the lungs, and others are raised from the lungs, by coughing up the particle or by ciliary action. These particles can be collected in the mouth and then swallowed. These types of possibilities need to be considered when exposures are being evaluated. (Rodricks 1992).

**INHALATION**

The respiratory tract includes the air passage through the nose and mouth that connect the bronchi that lead to the lungs. Gases can readily enter the respiratory tract and the lungs. (Paustenbach 1989) Other solvents that can enter the lungs include vapors of volatile liquids, such as gasoline, and aerosol particles. (Paustenbach 1989) These chemical can cause local toxicity; from minor, reversible irritation of the airways, to serious, irreveresible injury such as lung cancer. (Leidel 1990) Dusts can also enter
the airways, where fine particles can reach deep into the
alveolar region of the lungs. (Paustenbach 1989) Larger
particles either do not enter the respiratory tract or are
trapped in the nose and then excreted by blowing or sneezing.
(Paustenbach 1989)

To estimate the amount of a chemical absorbed by the
respiratory tract, several factors must be measured or estimated:
(Paustenbach 1989)

1. Contaminant concentration in air-gas, vapors, or particulates.
2. Particle size distribution for chemicals that are retained
on the surface of particles.
3. Contaminant concentration in dust may vary with particle size.
4. Respiration rate.
5. Degree of pulmonary absorption-bioavailability depending on the
physicochemical properties of a contaminant, physicochemical
properties of particles, and site of particulate deposition
in the pulmonary system.
6. Duration of exposure.

SKIN ABSORPTION

Skin absorption is defined as the diffusion of a chemical
through the epidermis, which includes the outer layer of
dead cells called the stratum corneum. (Paustenbach 1989)
This is a tough barrier for chemicals to enter and most
do not make it. If the chemical enters this barrier, it
has to pass the second layer, the dermis, then it reaches
the bloodstream. (Paustenbach 1989)

The effectiveness of the stratum corneum in blocking
the passage of chemicals varies from one part of the body
to another. For example, the palms of the hands and the
soles of the feet are difficult for chemicals to cross. (Paustenbach
1989)
The physical properties of a chemical influence the likelihood it will absorb through the skin. Chemicals must be capable of dissolving readily in both water and fat-like materials, whereas substances that do not dissolve well in water or any other solvents cannot penetrate in measurable amounts. (Leidel 1990) Finally, smaller molecules can move easily through the skin, and large molecules cannot. (Paustenbach 1989)

To estimate dermal exposure to contaminated particles, the following parameters need to be known: (Paustenbach 1989)

1. Contaminant concentration in medium in contact with skin.
2. Area of exposed skin.
3. Dermal absorption coefficient—bioavailability of chemicals depending on physicochemical properties of the contaminant and particle on which it is sorbed, length of time contaminant has been in contact with the skin, and length of time contaminant has been in contact with particles on which it has sorbed.

INGESTION

The digestive tract includes the mouth, throat, esophagus, stomach, small intestine and large intestine, colon, and the rectum. Chemicals found in food, water, medicines, solids, or dusts can be ingested and absorbed by movement through the membranes into the bloodstream by the entire digestive tract. There are a few chemicals such as lead that do not absorb to the same extent as others through the walls of the digestive tract. (Paustenbach 1989) Absorption can be influenced by factors such as age, sex, health status,
race, genetic traits, pregnancy, diet habits, smoking, and alcohol or medication intake. (Rappaport 1991)

The following parameters are used to estimate the risks associated with the ingestion of chemical contaminants:
(Paustenbach 1989)

1. Amount of contaminated medium ingested per day—liquids, food, medicines, soils, dusts.
2. Contaminant concentration in each medium.
3. Gastrointestinal absorption coefficient—the medium in which the chemical contaminant is found influences the bioavailability.

PHYSICAL STATES OF CONTAMINANTS

Airborne contaminants can be present in the air as particulate matter in the form of liquids or solids; as gaseous material in the form of a true gas or a vapor; or in a combination of both gaseous and particulate matter.

Definitions of these physical states of contaminants are as follows: (Rodricks 1992)

GASES are formless fluids that occupy a space and that can be changed to a liquid or solid state only by the combined effect or increased pressure and decreased temperature. Examples are carbon monoxide and chlorine.

VAPORS are the gaseous form of substances that are normally in the solid or liquid state at normal temperatures and pressures. Examples are mercury vapors and carbon tetrachloride vapors.

DUSTS are airborne solid particles that range in size from 0.1–25 micrometers in diameter. Examples are lead dusts and asbestos.

FUMES are solid particles that are generated by condensation of materials from the gaseous state, generally after volatilization from the molten state. The formation of fumes is often accompanied by a chemical reaction such as oxidation. Examples are lead oxide fume and iron oxide fume.
MISTS are suspended liquid droplets generated by condensation from the gaseous to the liquid state or by dispersing a liquid. Examples are oil mists, acid mists, and pesticide mists.

PARTICLE SIZE OF A CONTAMINANT

The effect of particulate material on the body depends on the particle size. Typical airborne contaminant particle sizes range from less than 0.01 micrometer to over 25 micrometers. (Rodricks 1992) The diameter of particles of health concern is below 10 micrometers, since the larger airborne particles have a greater probability of being captured in the upper passages of the respiratory system. (Rodricks 1992) Particles such as fumes and smoke, whose sizes are approximately 0.5 micrometer, penetrate deeper but are usually collected on the mucous lining of the airway ducts. (Rodricks 1992) Particles less than 0.5 micrometer can reach the lung air exchange wall deep in the lungs; the location where the lung is most vulnerable to damage. (Rodricks 1992)

CONTROL MEASURES

The following workplace control measures are applicable to prevent employee exposure by each route:

INHALATION

Personal respiratory equipment
Process modification-elimination/substitution
Engineering controls-isolation/containment, dilution or local exhaust ventilation
EYE/SKIN

Personal protective equipment—"bunny suits", eye goggles
Process controls—elimination/substitution
Administrative controls—safe work practices, administrative procedures
Engineering controls—isolation/containment

INGESTION

Sanitary measures—washing hands before contact with mouth
Avoid accidental ingestion
Process controls—elimination/substitution
Engineering controls—isolation/containment
Administrative controls—safe work practices, administrative procedures

The frequency of Verification of Workplace Controls is based on the outcome of the Workplace Exposure Assessment or the Appropriate Monitoring Program. The following lists Tait's recommendations, followed by the proposed revised recommendations:

TAIT'S RECOMMENDATIONS OF THE FREQUENCY OF VERIFICATION OF WORKPLACE CONTROLS

1. If the Appropriate Monitoring Program indicates that employee exposures are above the exposure limit, then verify the workplace controls at least every year.
2. If the Appropriate Monitoring Program indicates that the employee exposures are above the action level and below the exposure limit, then verify the workplace controls at least every 2 years.
3. If the Appropriate Monitoring Program indicates that employee exposures are below the action level, then verify the workplace controls every 3 years.

PROPOSED REvised RECOMMENDATIONS OF THE FREQUENCY OF VERIFICATION OF WORKPLACE CONTROLS

1. If the Appropriate Monitoring Program indicates that employee exposures are below the action level, then verify the workplace controls every 2 years.

2. If the Appropriate Monitoring Program indicates that employee exposures are above the action level and below the exposure limit, then verify the workplace controls every year.
3. If the Appropriate Monitoring Program indicates that employee exposures are above the exposure limit, measurement of Homogeneous Group's exposure will be conducted at least every month until the exposure is reduced to below the standard by appropriate control measures. The Hierarchy of Controls and verification of workplace controls must be implemented. Exposure monitoring may be terminated if two consecutive exposure measurements taken at least one week apart reveal that the exposure measurements are less than the action level.
DETERMINE THE FREQUENCY OF PERIODIC REVIEW

The Periodic Review of a Homogeneous Exposure Group is an essential function of exposure assessments since changes in substance hazards, workplace controls, and employee exposures must be routinely identified and evaluated. (Tait 1993) Periodic Reviews are necessary when new substances are introduced, previously unknown hazards are discovered, and workplace controls are modified or employee exposures are increased (Tait 1993)

The Workplace Exposure Assessment Workbook determines the frequency of Periodic Review by asking three screening questions to determine changes in substance, workplace, and exposure factors. Tait's answers to the questions are ambiguous in determining the outcome. Listed below are Tait's ranking to the screening questions and his recommendations, followed by the proposed revised rankings and recommendations, along with a Quality Assurance and Quality Control plan.
QUESTION 1

HOW MUCH DO YOU KNOW ABOUT THE HEALTH RISKS POSED BY THE SUBSTANCE? 
(The answer is ranked based on information on substance properties and hazards)

TAIT'S RANKINGS

4-Substance hazards are currently being reviewed
3-Little knowledge of substance hazards
2-Some knowledge of substance hazards
1-Much knowledge of substance hazards
0-Complete knowledge of substance hazards

PROPOSED REVISED RANKINGS

2-No knowledge of substance hazards
1-Substance hazards are currently being reviewed based on information obtained from the Hazardous Substance Inventory, Material Safety Data Sheets, the Workplace Exposure Assessment, and the Verification of Workplace Controls
0-Complete knowledge of substance hazards

QUESTION 2

HOW EFFECTIVE ARE THE WORKPLACE CONTROL MEASURES? 
(The answer is ranked based on effectiveness of the workplace controls)

TAIT'S RANKINGS

3-Unknown effectiveness of workplace controls
2-Workplace controls are marginally effective
1-Workplace controls are moderately effective
0-Workplace controls cannot fail

PROPOSED REVISED RANKINGS

2-Unknown effectiveness of workplace controls
1-Workplace controls are effective
0-No controls are needed to prevent employee exposure

QUESTION 3

HAVE EMPLOYEE EXPOSURES INCREASED SINCE THE LAST EVALUATION WAS CONDUCTED? 
(The answer is ranked based on variability of exposure)

TAIT'S RANKINGS

4-Large increase in employee exposures
3-Moderate increase in employee exposures
2-Slight increase in employee exposures
1-No change in employee exposures
0-Decrease in employee exposures
PROPOSED REVISED RANKINGS

2-Increase in employee exposures
1-No change in employee exposures
0-Decrease in employee exposures

TAIT'S DECISION RULES

1. If the substance and hazards are currently being reviewed, or if there is little or no information about the substance hazards, or if the workplace controls have unknown or marginal employee exposures, then the Homogeneous Exposure Group should be reviewed at least every year.

2. If there is much or complete knowledge of substance hazards, and the workplace controls are very effective or cannot fail, and exposure shows a decrease or no change, the verify the workplace controls every 3 years.

PROPOSED REVISED DECISION RULES

1. If there is complete knowledge of the substance hazards, or workplace controls are effective or not needed, or if there is no change or a decrease in the employee exposures, then review the Homogeneous Exposure Groups every year since unpredictable changes in substance, workplace, and exposure factors may occur.

2. If there is no knowledge of substance hazards or if the substance hazards are currently being reviewed, then information of a similar substance and any other information of the hazard must be gathered to make a prediction of the hazard and its exposure. The measurement of the predicted exposure will be conducted at least every month until the exposure is reduced.
QUALITY ASSURANCE AND QUALITY CONTROL

Periodic Reviews can be analyzed carefully by Quality Assurance and Quality Control Programs. The Environmental Protection Agency defines Quality Assurance as a program of planned, systematic actions that are necessary to ensure that specified data quality criteria are achieved. (EPA 1981) Quality Control is defined as a system of activities designed to achieve and maintain a previously specified level of quality in data collection, processing, and reporting. (EPA 1981) The Environmental Protection Agency devised a Quality Assurance/Quality Control Program Plan as a written document that presents in general terms the overall policies, organization, functional responsibilities designed to achieve specified data quality goals in an organization. The Quality Assurance/Quality Control Program Plan components are:

1. Title page with provision for approval signatures.
2. Table of contents.
3. Project description (experimental design).
4. Project organization and responsibility-list of individuals who are responsible for ensuring the collection of valid measurement data and the routine assessment of measurement systems.
5. QA/QC objectives for measurement data in terms of precision, accuracy, completeness, representativeness, and comparability.
6. Description of sampling procedures.
7. Sample custody-chain-of-custody procedures where samples are needed for legal purposes.
8. Calibration procedures and frequency.
10. Data analysis, validation, and reporting.
11. Internal quality control checks and frequency.
12. Performance and systems audits—required to monitor capability and performance of the measurement system.
13. Preventive maintenance that includes a schedule of preventive maintenance tasks and inspection activities.
14. Specific routine procedures used to assess data precision, accuracy, and completeness.
15. Corrective action that includes limits for data acceptability for which corrective action is required as well as the procedures for corrective action.
16. Quality Assurance reports to management that includes any significant Quality Assurance problems and recommended solutions.

Quality Assurance and Quality Control Program Plans can be used in formating an Employee Exposure Monitoring Program.

The following information, proposed by the Occupational Safety and Health Administration, incorporates QA/QC controls for an Employee Exposure Monitoring Program: (Leidel 1990)

1. Identify variations in measurement of employee's daily exposures due to:
   - Differences in work techniques of individual employees (even in the same job category).
   - Differences in the exposure concentrations between days.
   - Differences in the average daily exposure concentrations.
   - Differences due to random variations in sampling and analysis.

2. Detect if any employee exposures exceed a exposure limit.

3. Institute a Monitoring Program that needs a minimum amount of sampling for a maximum amount of protection against exposure measurement errors.

4. Institute exposure measurement plans that indicate when occupational exposures are hazardous or approaching hazardous levels before overexposures occur.

5. Periodically measure an employee's daily exposure.

6. When not all exposure days are measured, determine an employee's probability of overexposure caused by failure to detect high exposure days.

7. Detect and try to eliminate sources of high employee exposures.
SUMMARIZE AND VALIDATE WORKPLACE EXPOSURE ASSESSMENTS

The final step in the Workbook Exposure Assessment is to document all information so that it may be reviewed by a professional hygienist and communicated to employees. The assessor can develop a worksheet to assist employees in conducting and documenting Workbook Exposure Assessments. The decisions and actions based on the results should be summarized. One final note that Keith Tait strongly recommends is that "decisions and actions should not supersede human judgement until a validation study is conducted, peer reviewed, and published."
WORKS CITED


