OHTA501

Measurement of Hazardous Substances

STUDENT MANUAL

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Abbreviations

AAS	Atomic Absorption Spectroscopy
ACGIH	American Conference of Governmental Industrial Hygienists
AIDS	Acquired Immune Deficiency Syndrome
AIHA	American Industrial Hygiene Association
AIOH	Australian Institute of Occupational Hygienists
AM	Arithmetic Mean
AREC	Anticipation, Recognition, Evaluation and Control
ART	Advanced Reach Tool
AS	Australian Standard
AS/NZS	Australian Standard/New Zealand Standard
BAT	Biological Tolerance Values
BCIRA	British Cast Iron Research Association
BEI®	Biological Exposure Indices
BIOELV	Binding Occupational Exposure Limit Values
BMGV	Biological Monitoring Guidance Values
BOHS	British Occupational Hygiene Society
C	Ceiling Limit
CIS	Conical Inhalable Sampler
Cl2	Chlorine
cm	Centimetre
CNS	Central Nervous System
COSHH	Control of Substances Hazardous to Health
CS_2	Carbon Disulphide
CV	Coefficient of Variation
DNELs	Derived No-Effect Levels
DRF	Daily Reduction Factor
ECHA	European Chemicals Agency
ERPGTM	Emergency Response Planning Guidelines
ES	Exposure Standard
FID	Flame Ionization Detector
g/cm²	Grams per Square Centimetre
g/L	Grams per Litre
GC	Gas Chromatography
GHS	Globally Harmonized System of Classification and Labelling of Chemicals
GM	Geometric Mean
GSD	Geometric Standard Deviation

H_2	Hydrogen
H_2S	Hydrogen Sulphide
HCN	Hydrogen Cyanide
HEG	Homogeneous Exposure Group
HF	Hydrofluoric Acid
HPLC	High-Performance Liquid Chromatography
HSE	Health & Safety Executive (UK)
IARC	International Agency for Research on Cancer
ICP	Inductively Coupled Plasma Spectrometry
ILO	International Labor Organisation
IOELV	Indicative Occupational Exposure Limit Values
IOM	Institute of Occupational Medicine (UK)
IR	Infra-red
IRSST	Institut de recherche Robert-Sauvé en santé et en sécurité du travail
ISO	International Standards Organisation
L	Litre
L/m	Litre per Minute
LD50	Lethal Dose 50%
LEL	Lower Explosive Limit
LOD	Limit of Detection
LOEAL	Lowest Observed Adverse Effect Level
LOQ	Limit of Quantitation
LTA	Long term average
µg	Microgram
µg/m³	Microgram per Cubic Metre
µm	Micrometre
m³	Cubic Metre
MAK	Maximum Workplace Concentration
MCE	Mixed Cellulose Ester
MDA	Methylene Dianiline
MDHS	Methods for the Determination of Hazardous Substances
MEL	Maximum Exposure Limits
mg/m³	Milligrams per Cubic Metre
MHSWR	Management of Health and Safety at Work Regulations
Mins	Minutes s
ml	millilitre
MMMF	Man Made Mineral Fibre
MOCA	Methylene bis-orthochloroaniline

MS	Mass Spectrometer
MSDS	Material Safety Data Sheet
MSHA	Mine Safety & Health Administration (USA)
MVUE	Minimum Variance Unbiased Estimate
N/A	Not Applicable
NATA	National Association of Testing Authorities (Australia)
NIOSH	National Institute of Occupational Safety & Health (USA)
nm	Nanometre
NMAM	NIOSH Manual of Analytical Methods
NO	Nitric Oxide
NO2	Nitrogen Dioxide
NOAEL	No Observed Adverse Effect Level
NOHSC	National Occupational Health & Safety Commission (Australia)
NTP	Normal temperature and pressure (20 degrees C, 760 mm Hg) (note ACGIH TLV® defines NTP conditions as 25 degrees C, 60 mm Hg)
NVvA	Nederlandse Vereniging van Arbeidsdeskundigen
OD	Outside Diameter
OEL	Occupational Exposure Limits
OES	Occupational Exposure Standards
OSHA	Occupational Health & Safety Administration (USA)
PAT	Proficiency Analytical Testing Programme
PCB	Polychlorinated Biphenyls
PCM	Phase Contrast Microscopy
PDM	Personal Dust Monitor
PEL	Permissible Exposure Limits
PM10	Particulate Matter less than 10 micrometres
PNA	Polynuclear Aromatics
PNS	Peripheral Nervous System
ppb	Parts Per Billion
PPE	Personal Protective Equipment
ppm	Parts Per Million
ppt	Parts Per Trillion
PTFE	Polytetrafluoroethylene (Teflon)
PVC	Poly-Vinyl Chloride
REL	Recommended Exposure Limit
RPE	Respiratory Protective Equipment
S (or SD)	Standard Deviation
SCBA	Self Contained Breathing Apparatus
SCOEL	Scientific Committee on Occupational Exposure Limits

SDS	Safety Data Sheets
SEG	Similar Exposure Groups
SEN	Sensitisation
SIMPEDS	Safety in Mines Personal Environmental Dust Sampler
SiO2	Silicon Dioxide
SK	Skin
SMF	Synthetic Mineral Fibre
SO2	Sulphur Dioxide
STEL	Short Term Exposure Limit
STP	Standard temperature and pressure (0 degrees C, 760 mm Hg).
T ½	Half Life
TD	Thermal Desorption
TDI	Toluene Diisocyanate
TEL	Tetra Ethyl Lead
TEM	Transmission Electron Microscopy
TEOM	Tapered Element Oscillating Microbalance
TLV®	Threshold Limit Value
TLV-C	TLV-Ceiling
TNT	Tri-nitrotoluene
TWA	Time Weighted Average
UK	United Kingdom
UKAEA	United Kingdom Atomic Energy Authority
UKAS	United Kingdom Accreditation Service
USA	United States of America
UV	Ultra Violet
WA	Western Australia
WASP	Workplace Analysis Scheme for Proficiency
WEEL	Workplace Environmental Exposure Levels
WEL	Workplace Exposure Limits
WHO	World Health Organisation
XRD	X-ray Diffraction Spectrometry
XRF	X-ray Fluorescence Spectrometry
Zn	Zinc

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Chapter 1 Course Overview

1.1 Introduction

This Course has been delivered by OHTA approved training providers for over 10 years and reviewed by international experts on two occasions to ensure the information is accurate and current. The latest update was 2023.

The mention of any method, product, manufacturer or vendor as examples in this manual should not in any way be construed as either endorsement or recommendation of such by either OHTA, authors, contributors, or editors of this manual.

1.2 Aim of Course

To provide students with a sound understanding of the techniques for assessing exposure to hazardous substances in the workplace and with an understanding of how exposure information can be used to assess risk.

1.3 Learning Outcomes

On successful completion of this module the student will be able to:

- Describe the general approach to occupational chemical health risk assessment, including the role of atmospheric monitoring;
- Select appropriate equipment to measure specific airborne contaminants and devise a suitable sampling strategy;
- Present the results in a form useful for health risk assessment purposes to enable management to comply with relevant legislation.

1.4 Format of Manual

It should be recognized that the format presented in this manual represents the views of the authors, contributors and or editors, and does not imply any mandatory process or format that must be rigidly observed. Presenters using this manual may well choose to alter the teaching sequence or course material to suit their requirements. In this regard the case studies are provided as illustrative examples and alternate case studies relevant to a particular industry may be used if desired.

In the final outcome, the aim of this manual is to transmit the principles of hazardous substances measurement to attendees and provide guidance as to how those principles should be applied.

Chapter 2 Risk Assessment

This section introduces the concept of risk assessment as it applies to occupational hygiene. Key points of this chapter are as follows

- ✓ **Hazard vs risk vs exposure**
- ✓ **Principles of risk assessment**
- ✓ **Qualitative vs. quantitative approaches**

Risk assessment is a central part of occupational hygiene, the art and science of anticipation, recognition, evaluation and control (AREC) of work place hazards. Risk assessment allows occupational hygienists to evaluate whether controls are needed, or if they already exist whether they need improvement.

The objective of this chapter is to discuss risk assessment as it applies to occupational hygiene practice. Risk assessment encompasses all areas of human activities since all entail some degree of risk. Much has been written about risk assessment, and the language used can be inconsistent in definition and or application. The international standards organisation (ISO) approach (ISO 31000 Risk Management Practices: 2018) provides a useful frame work by which to examine and evaluate occupational hazards as discussed below, and provides insight into what is involved in the risk assessment process.

2.1 Introduction to Risk Assessment

Risk assessment in the context of occupational hygiene practice is generally an evaluation of risk of adverse effect associated with a particular process of activity that uses substances associated with particular hazards. In this publication, the terms “hazard” and “risk” will be treated solely in relation to chemical risk and not in any broader concept. In the context of this course, “hazard” and “risk” are not the same thing. A key role for occupational hygienists is establishing the level of risk in workplace through the evaluation of hazards as discussed in this chapter.

$$\textbf{Risk}\ (\text{uncontrolled}) \propto \text{hazard} \times \text{exposure}$$

One way to express the relation between risk, hazard and exposure is as follows:

Where **risk** is can be seen as an uncertainty of adverse outcome (worker illness for example). Ideally, we might want zero risk, but in reality, this is impractical, so the issue becomes what is acceptable risk, or how safe is safe? The issue of what is an acceptable risk has been much discussed and is a variable quantity depending on

Hazard is an undesirable property of a particular substance, usually toxicity (long or short term or both) or irritation. It is an intrinsic property and usually cannot be changed without altering the substance itself. For example, a concentrated acid can cause serious skin burns on contact, but very dilute acids generally do not, the key hazard being concentrated acid in this example. Essentially, the threat is different.

> **Exposure** is an estimate of how much a person engaged in the process of interest could be exposed to, typically by inhalation but also by skin contact for certain substances. This variable is of central interest in occupational hygiene, and essentially represents an estimate of potential dose. As discussed in this course, exposures are evaluated against benchmarks, most commonly occupational exposure limits (OELs) as discussed in Chapter 3. Exposure is essentially an indicator of risk. These exposures can be measured (as discussed in this class), or they can be estimated in a variety of ways (e.g., previous studies of same or similar processes, exposure modeling).

The AIHA (American Industrial Hygiene Association) offers the following definition for risk assessment

> Risk assessment is the determination of quantitative or qualitative value of risk related to a concrete situation and a recognized threat (also called hazard). Quantitative risk assessment requires calculations of two components of risk (R): the magnitude of the potential loss (L), and the probability (p) that the loss will occur. Acceptable risk is a risk that is understood and tolerated usually because the cost or difficulty of implementing an effective countermeasure for the associated vulnerability exceeds the expectation of loss.

From a risk assessment perspective, it can be deduced from the above equation that making either term in the above equation zero, then the risk would also be zero. So, in occupational hygiene practice, one might eliminate the hazard by using a substance that has a lesser hazard. For example, solvent based paints can be replaced with water-based paints.

However, hazard elimination may not always be feasible so occupational hygiene practice would be to turn to find ways of reducing exposures. For example, use enclosed processes rather than open vessels, or use adequate ventilation, or even require respiratory protection. Exposure measurements can then provide a tool to evaluate how effective controls might be in reducing them or containing them within acceptable limits.

2.2 The Risk Assessment Process

ISO 31000:2018 Risk Management Principles defines risk as the effect of uncertainty. This uncertainty could be positive, and one might be interested in increasing it, for a more desirable outcome. In other words, how to optimize the chances of a good result. In other cases, uncertainty (i.e., risk) could be unwanted, as for example from a catastrophic event or accident. In occupational hygiene terms, one might think of risk in terms of how safe a process or activity might be in terms of substances and or by-products involved. A safety engineer might look at a process in terms of risk of direct injury (rather than long term effects). Many activities may have good and bad risks (for example, financial investments). This course focuses on assessing risks associated with chemical substances that may be encountered in the work place.

ISO 31000 definitions provide a framework by which to consider occupational health risk assessment.

Risk Management is generally defined as coordinated activities to direct and control risks. The general principle is to create and protect value, which in the case of occupational hygiene, is to protect worker health. Workplace health and safety programs are in essence a risk management tool. Risk management is relevant to all areas of human activity including agriculture, business, politics, and even our everyday activities (e.g., driving to work). Often, the entire process is a continuum rather than in the discrete steps described below that are part of the process. Without the need to manage risks, or where risks may be considered negligible, there is no need to conduct risk assessments. ISO's guideline identifies three important components of risk management as follows:

Risk Identification, which is to find, recognize and describe risks that will impact a particular organisation. This is where anticipation and recognition of potential hazards come in.

Risk Analysis the goal of which is to better understand the nature and characteristics of identified risks, and where necessary, estimate the level of risk. This is where hazard evaluation and control start.

Risk Evaluation which supports decisions made in the risk analysis process. How well does the risk analysis compare with established criteria? This is where we refine hazard evaluation, and adjust controls as needed

The concept of risk assessment is central to the occupational health and safety legislative framework in many countries.

2.3 Occupational Hygiene Risk Assessment Overview

There are many guidelines and regulatory requirements for occupational hygiene risk assessment (e.g., United Kingdom (UK) COSHH Regulations, Occupational Health & Safety Administration (OSHA's) general duty clause), all of which generally require identifying, analysing and evaluating work related risks as they pertain to working with chemical substances and or by-products. In some cases, there may be a mandated or recommended approach. Regardless, it is usually better to follow a consistent approach.

This section is intended to provide an overview of risk assessment in terms of occupational hygiene. In occupational hygiene, it is a qualitative approach rather than a quantitative analysis that yields theoretical risks, based on assumptions made for the model used to calculate risk values. This quantitative approach is often related to environmental exposures. It is beyond the scope of this course.

2.3.1 Risk Identification

The process begins with gathering basic information about chemicals in the workplace. Many locations keep chemical inventories, in some cases required by regulation. If there is no inventory, it follows that one will need to be compiled for systematic risk identification. Obviously, it is critical to keep inventories up to date, so therefore also wise to check with end users particularly for anything that raises concerns. It's also important to consider by-products from particular

processes (e.g., welding fume, dust, etc.), as well as waste products, as these may pose additional risks.

An important consideration in identifying chemical hazards are potential routes of exposures. Can the substance of interest be breathed in? Is skin contact an issue? Ingestion is often another possibility, although this is usually managed through good personal hygiene practices.

Physical properties are also important. Is a substance volatile (high vapours pressure)? Is in gas or solid form. If solid, will it generate respirable dust?

Two good sources for identifying risks related to chemical substances at work are Safety Data Sheets (SDS) as well as labels and signs on products and or containers and vessels.

The UN's Globally Harmonized System of Classification and Labelling of Chemicals (GHS) is a worldwide accepted system for classifying and communicating the hazards of industrial and consumer chemicals. The GHS provides for universal pictograms to provide an indication of a hazard that a substance might pose. These pictograms are supported by standard hazard statement language within a particular SDS. In some instances, more than one pictogram may be relevant Figure 2-1 shows examples of GHS pictograms.

Figure 2-1 Examples of GHS Pictograms

 Oxidizer	 Flammables, Self-Reactive, Pyrophoric, Self-Heating, Emits Flammable Gas, Organic Peroxides	 Explosives, Self-Reactive, Organic Peroxides
 Acutely Toxic (severe)	 Burns Skin, Damages Eyes, Corrosive to Metals	 Gases Under Pressure
 Carcinogen, Respiratory Sensitiser, Reproductive Toxicity, Target Organ Toxicity, Mutagenicity Aspiration Toxicity	 Toxic to aquatic environment	 Acutely toxic (harmful), Irritant to skin, eyes or respiratory tract, Skin sensitiser, Hazardous to the Ozone layer.

Note, however, that just because a container may be labeled with one of the above pictograms, it does not necessarily indicate there is a risk to workers. That would depend on whether there is worker exposure, and if so, how much. For example, a small vial of a volatile solvent in a laboratory hood is not the same as an open vat of the same solvent in a factory. This is part of risk analysis, often blended with risk identification into one step, since the next question after "is there exposure?" is "how much exposure is there?"

Other ways to identify potential chemical risks would be through employee interviews, company records (e.g., illness and injury statistics), government and industry standards and associations, as well as the scientific literature. The important thing is to be systematic to reduce the risk of missing something. Table 2-1 Sources of Information about Potential Chemical Risks lists typical sources of information.

Table 2-1 Sources of Information about Potential Chemical Risks

Collection Method	Type of Information	
Interviews of workers, managers and engineers	Tasks Work practices Health issues	Processes Exposure controls Maintenance
Interviews of occupational health and safety personnel	Health problems Patterns of problems	Work practices Exposure history
Records: Process standards Standard operating procedures Production Personnel Medical Engineering Process flow diagrams	Historic conditions Chemical inventories Usage amounts Tasks Work histories	Performance of engineering controls Past occupational hygiene monitoring reports Past biological monitoring results
Governmental and non-governmental standards	Current exposure limits	Proposed exposure limits
Literature	Epidemiological studies Toxicological studies	Emerging issues

2.3.2 Risk Analysis

Having identified potential chemical hazards, the next step is to analyse the extent and magnitude of potential risks associated with them. The following should be considered

- Who might be exposed directly and indirectly. Are there vulnerable workers (e.g., women of reproductive age)?

- How is the work/process done? How are materials handled?
- The level, duration and frequency of exposure.
- What are the relevant occupational exposure limits (OELs)?
- Has this process been studied before? Is there previous data that can be used?
- Are there other ways to estimate exposures (e.g., modeling)?
- Presence and effect of control measures.
- Containment measures e.g., open vs. closed.
- Local exhaust ventilation e.g., fume cupboards; extraction hoods.
- Is there personal protective equipment (PPE) in use? What was the basis for selection?
- Housekeeping and site conditions.
- Are there standard operating procedures? Do they address the hazards of concern?
- Is there any history of reported adverse effects?

In some cases, it may not be possible to obtain complete information in which case one has to rely on good occupational hygiene judgement.

2.3.3 Risk Assessment

Risk identification and risk analysis lead to risk assessment, which can also be seen as an evaluation of how good the initial risk analysis. Initial analysis may show exposures of concern but subsequent monitoring may show otherwise (good news), or we might discover the converse.

We have seen that occupational health related risks will be determined by:

- How much a worker is exposed to a hazardous substance (exposure)
- How the worker is exposed to the substance (inhalation, skin contact, i.e., route of entry to the body)
- How severe are the adverse health effects under the conditions of exposure (health hazards)
- The duration and frequency of exposure (a single short exposure or continuous long-term exposure)

Although occupational hygiene risk assessments rely on estimates of exposures, the usual outcome is qualitative or semi qualitative. In practice, qualitative assessment is usually used first to screen risks and to highlight activities with higher risk. Subsequently, it may be necessary to

conduct a more detailed study of exposures associated with higher risk activities to better assess associated risks.

Generally speaking the outcome of an occupational risk assessment can be summarized as follows:

Table 2-2 Risk Identification

Risk Level	Description
Unacceptable	Significant risk e.g., exposure exceeds OELs. Exposure risk is not adequately controlled. Further risk reduction is required.
Acceptable	Exposures consistently below OEL. May need to consider routine monitoring for change. Adequate controls such that its adverse health effects on worked are not expected.
Inconclusive	Insufficient information available to make a conclusion Monitoring or more information is required to further define exposure.

Risk assessment can also be quantitative rather than descriptive. It may include factors such as exposure monitoring data, modeling data, extrapolation from relevant studies to calculate estimate risk values. Quantitative risk assessment is often used to determine OELs, or sometimes to set exposure limits associated with a particular level of risk. Quantitative risk assessment methods are beyond the scope of this course.

2.4 Risk Assessment Tools

There are various online tools to help with work health risk assessment such as

- UK's Control of Substances Hazardous to Health (COSHH) Essentials e-tools (see https://shrtm.nu/PS9Z)
- International Labor Organisation (ILO) Tool kit (see https://shrtm.nu/nYqk
- US Federal OSHA (see https://shrtm.nu/bcQy

Keep in mind that there may be specific requirements in different geographic areas, so best to find out ahead of time to avoid wasted effort.

2.5 Non-Sampling Approaches

Air sampling is not always necessary to develop control strategies for certain processes. Instead, one may be able use the concept of "control banding" which has achieved significant prominence, especially in Europe. Commonly used approaches include the UK's Control of Substances Hazardous to Health (COSHH) Essentials and the ILO Chemical Control Toolkit.

The control banding approach focuses resources on exposure controls and describes how strictly a risk needs to be managed. This qualitative risk assessment and management tool is intended to

help small businesses by providing an easy-to-understand, practical approach to controlling hazardous exposures at work.

It should also be recognized that all such systems provide general guidance based on the most likely scenario and do not take account of individual process variations. While such systems are a useful tool for small businesses, assessment of a workplace by an experienced occupational hygienist may be (and in many cases is) required.

It is important to realize that non-sampling approaches such as COSHH Essentials and the ILO Chemical Control Toolkit have some limitations, and may not be appropriate for situations, such as some "hot" processes, open spray applications, gases, etc. However, COSHH Essentials scheme is being progressively extended by the addition of industry and task-specific guidance for many situations (see http://www.hse.gov.uk/pubns/guidance/index.htm. Control advice sheets are now available for welding, metalworking fluids, silica exposures and low-level asbestos work. Particular industries such as printing have also developed customized sheets for their own specialized processes.

2.5.1 Control Banding

Control banding is a process in which a single control technology (such as general ventilation or containment) is applied to one range or band of exposures to a chemical (such as 1 – 10 mg/m^3) that falls within a given hazard group (such as skin and eye irritants or severely irritating and corrosive). Four main control bands have been developed for exposure to chemicals by inhalation:

- Band 1 – Use good industrial hygiene practice and general ventilation
- Band 2 – Use local exhaust ventilation
- Band 3 – Enclose the process
- Band 4 – Seek expert advice

For some activities, processes, tasks or jobs, experts can specify that respiratory protective equipment (RPE) (in combination with other control approaches) is always necessary. The most developed model for control banding has been established by the Health & Safety Executive (HSE) of the United Kingdom (UK).

The principle of control banding was first applied to dangerous chemicals, chemical mixtures, and fumes. The control banding process emphasizes the controls needed to prevent hazardous substances from causing harm to people at work. The greater the potential for harm, the greater the degree of control needed to manage the situation and make the risk "acceptable".

The basis of these bands for exposures to chemicals by inhalation is detailed in Table 2-3 Control Bands for Exposures to Chemicals by Inhalation.

Table 2-3 Control Bands for Exposures to Chemicals by Inhalation

Band No.	Target Range of Exposure Concentration	Hazard Group	Control
1	>1 to 10 mg/m³ dust >50 to 500 ppm vapours	Skin and eye irritants	Use good industrial hygiene practice and general ventilation
2	>0.11 to 1 mg/m³ dust >5 to 50 ppm vapours	Harmful on single exposure	Use local exhaust ventilation
3	>0.01 to 0.1 mg/m³ dust >0.5 to 5 ppm vapours	Severely irritating and corrosive	Enclose the process
4	<0.01 mg/m³ dust <0.5 ppm vapours	Very toxic on single exposure, reproductive hazard, sensitiser*	Seek expert help

* Exposure to any concentration of a sensitiser requires expert advice

This approach has been developed into web-based applications specifically to assist small and medium-sized enterprises to do risk assessments for chemicals and mixtures of chemicals.

The most developed of these is COSHH Essentials. COSHH Essentials (http://www.coshh-essentials.org.uk) is a control banding tool that helps small and medium-sized enterprises to do risk assessments for chemicals and mixtures of chemicals. This tool requires four pieces of information:

- The type of task (e.g., mixing liquids, sack filling, manually cleaning and disinfecting surfaces)
- The hazard classification from the material safety data sheet (MSDS) obtained from the chemical manufacturer or supplier
- The volatility or dustiness of the chemical or product
- The amount used in the task (small quantities = grams or millilitres (ml); medium quantities = kilograms or litres (L); large quantities = tons or cubic metres (m³))

The system then:

- Identifies the control band (control approach),
- Produces advice on controlling risk from the chemical used in the specified task, and
- Provides written guidance and documentation as a result of the assessment.

In British law, the duty to control risk remains with the employer. Both the web and paper versions of the COSHH Essentials tools are designed to assist the small or medium-sized employer meet regulatory requirements. COSHH Essentials is a free service and was developed by the HSE in collaboration with British industry and trade unions.

A similar approach to COSHH Essentials has been developed jointly by the ILO, World Health Organisation (WHO) and United Nations Environment Programme and published as the ILO Chemical Control Toolkit

The ILO Toolkit has five (5) stages which need to be followed. These are:

Stage 1: Find the hazard classification and match it to a hazard group. For common solvents this has already been done and the information provided on the ILO website. For other substances there is a need to establish the risk phrases for the substance and then find the hazard group from the ILO website.

Stage 2: Establish the amount of substance to be used and use this to determine the scale of use from the table supplied by the ILO.

Stage 3: Establish how much of the substance will escape to the atmosphere. This is done via looking at the physical state of solids (e.g., pellets – low, crystalline – medium, fine powders – high) or via comparison of the boiling point of liquids to a table provided by the ILO.

Stage 4: Find the control approach by using a selection guide that has been prepared by the ILO.

Stage 5: Find the task-specific control guidance sheet(s) from a table which links the task description and the control approach.

Once the appropriate control approach has been determined it needs to be implemented and maintained.

Control banding approaches have been developed in Belgium (REGETOX project), The Netherlands (Stoffenmanager), and Norway (KjemiRisk). The World Health Organisation is working with its Collaborating Centres to pilot control banding programmes in more than a dozen countries.

It is important to realize that non sampling approaches such as COSHH Essentials and the ILO Chemical Control Toolkit are not appropriate for many situations. Such situations could include some “hot” processes, open spray applications, gases, etc. However, the COSHH Essentials scheme is being progressively extended by the addition of industry and task-specific guidance on many situations; see http://www.hse.gov.uk/pubns/guidance/index.htm. Sheets are now available for welding, metalworking fluids, silica exposures and low-level asbestos work. Particular industries such as printing have developed customized sheets for their own specialized processes.

It should also be recognized that all such systems provide general guidance based on the most likely scenario and do not take account of individual process variations. While such systems are a useful tool for small businesses, assessment of a workplace by an experienced occupational hygienist may be (and in many cases is) required.

2.5.2 Exposure Modelling

Simple modelling approaches can also be helpful to estimate exposures, based on variables such as contaminant emissions rate, room volume, dispersion patterns and worker locations. The AIHA's IHMOD2 is a useful Excel based tool in this regard (see https://tinyurl.com/y92mpsdo)

COSHH Essentials and the ILO's Organisation's Chemical Control Toolkit provide a simple method to identify appropriate controls using basic toxicological information from labels and information on volatility or dustiness and usage rates. The output from these models can be compared with the control measures in use to assist in the evaluation of the suitability of the controls. More sophisticated models, such as Stoffenmanager and the Advanced Reach Tool (ART) can provide an estimate of exposure.

2.6 Documentation

Chemical exposure risk assessments should be documented. The information documented should be proportional to anticipated risks. Besides regulatory requirements, reasons for documenting the risk assessments include:

- To demonstrate to stakeholders that the process has been conducted properly;
- To provide evidence of a systematic approach to risk identification and analysis;
- To enable decisions or processes to be reviewed;
- To provide a record of risks and to develop the organisation's knowledge database;
- To provide decision makers with a risk management plan for approval and subsequent implementation;
- To provide an accountability mechanism and tool;
- To facilitate continuing monitoring and review;
- To provide an audit trail; and
- To share and communicate information.

Many statutory authorities require assessment records are kept for a number of years including risk assessments, monitoring records, health surveillance records, maintenance examination, test or training records (e.g., 5 to 50 years).

2.7 Periodic Review

Chemical exposure risk assessments should be reviewed periodically, depending on the risk level. In some cases, this may be prescribed by regulation. Activities with higher risks may need to be reviewed more frequently. They should also be reviewed if there is any reason to suspect previous risk assessments are no longer valid, e.g., significant changes in the work processes such as use of new substances, improvements in control methods etc.

2.8 An Outline of an Approach to Risk Management

Risk assessments that identify risks that need to be controlled (i.e., managed) should result in the development and implementation of a plan to manage and or control the risks such as codes of safe practices, the use of ventilation, personal protective equipment etc. It is vital to have input from all affected stakeholders (i.e., management, workers, occupational hygienists, etc.). To be able to affect required or recommended operational change within an organisation. This is unlikely to happen without commitment from senior management so that the necessary resources are available. There are many approaches to developing occupational risk management plans, including ISO 45000, which provides a useful frame work.

It is also important is the need to communicate the findings of risk assessments as well as whatever requirements a risk management plan may have. This information needs to be shared with both the management and the employees if there is benefit to be derived from risk assessment.

Also critical is to implement a continuous cycle of improvement (e.g., plan, do, check, adjust), to keep the risk management plan up to date and relevant.

2.9 Hierarchy of Controls

Occupational risk management approaches generally involve the hierarchy of controls as follows:

2.9.1 Elimination and Substitution

Elimination and substitution are the most effective methods to reduce hazards. However, this is not always practical depending on the process. There may not always be a satisfactory alternative process or substance. Some elimination and substitution questions to consider include:

- Can the process be eliminated?
- Can less hazardous substances be used? Can they be used in a less hazardous form (solid rather than dust, or aqueous rather than solvent based)?

2.9.2 Engineering Controls

Engineering controls are designed to remove the hazard at the source so that the exposure be eliminated or reduced such that the risk is acceptable. Some engineering control issues to consider are:

- Can the process be enclosed (so that emissions are contained)?
- Can ventilation be used? General dilution or exhaust ventilation?

While engineering controls may appear to solve problems, they may not always be feasible due to budgets and or other considerations. Some activities may be too infrequent or temporary to justify a ventilation system. Moreover, controls such as ventilation require maintenance to ensure they are operating as designed, and it's important they are properly used. Nevertheless, engineering controls are seen as superior because they are intended to engineer out exposures, and hence

reduce risk, although they can be costly investments that occupational hygienists may need to justify.

2.9.3 Administrative Controls

Administrative controls centre around managing the risk rather than trying to reducing or eliminate it through engineering controls. They include actions such as

- Reducing number of workers exposed (i.e., do it where/when there are fewer workers)
- Reducing the duration of exposure (e.g., use job rotation to reduce the exposure duration for any individual)
- Are there safer ways to do the job (e.g., cover open containers when not in use)?
- Using codes of safe operating practices, and making sure affected people are trained on them

This approach requires following specified procedures, but it can be challenging to modify human behavior. Administrative controls in essence are about managing people to manage the risk.

2.9.4 Personal Protective Equipment

In essence, personal protective equipment is about posing a barrier between an unacceptable (or potentially unacceptable) risk and the worker. Although it can be effective, it is the least reliable way to reduce worker exposure because they allow worker exposure if they are not worn, or not worn correctly. In other words, it's necessary to train users on proper use, limitation and maintenance of these devices. Moreover, the use of respirators generally imposes additional requirements, often regulatory, such as written protocols for their use, medical evaluations. So while they may appear to be initially cost-effective, they may not be so in the long term when costs of administering a personal protective equipment are taken into account.

Note that in practice a combination of these measures may be required to control exposures, including short term and longer-term actions. For example, respiratory protection may be used until a ventilation system can be brought online.

All control measures should be reviewed at regular intervals to ensure that adequate control is maintained. Routine checks, regular maintenance and appropriate supervising procedures are also necessary.

2.9.5 Information, Instruction and Training

Training and information should be provided to workers so that they understand the risks to health from chemical agents and the precautions to be taken. The extent of training will depend on the level of risk, with more extensive training being required for workers who are exposed to greater risks. The information collected during the assessment about the nature of the hazards and the control measures required should be used in preparing information, instruction and training.

2.9.6 Workplace Monitoring

A health and safety program may specify routine monitoring as a check on the effectiveness of controls. Additional monitoring may also be required if:

- New control measures have been implemented;
- Interim measures are in place while better controls are procured;
- Control measures have deteriorated or failed such that serious health effect could result: e.g., carcinogens and allergens
- Required by regulation

Personal exposure monitoring should only be conducted by a professional Occupational Hygienist or under the supervision of a professional Occupational Hygienist. Note that occupational hygienists sometimes refer to workplace monitoring “quantitative exposure assessment”, which should not be confused with quantitative risk assessment

2.9.7 Health Surveillance

Some health and safety programmes may require worker medical surveillance when one or more of the following is applicable:

- Identifiable work-related disease or adverse health effect related to exposure;
- Reasonable likelihood that the disease or condition may occur;
- There are validated indicators of early signs of disease or adverse effect; and, or
- Exposures are liable to exceed limits prescribed in substance specific regulations that require health surveillance.

Health surveillance should be conducted by or under the supervision of a health professional. Note also that there may be requirements for preservation of patient confidentiality as well as for retention of health surveillance data. US OSHA regulations for example may require employers to retain medical and exposure records for 30 years following employee termination in some instances, and European regulations require such records to be kept for 40 years from the last entry.

2.9.8 Emergency Procedures

Emergency releases of substances at work can result in exposures and hence present a risk of adverse effect. Most health and safety programs address risks of leaks, spills or other uncontrolled releases of chemicals by having an emergency plan that includes appropriate procedures for prevention, and emergency response (i.e., personal protective equipment, first aid, safety showers and eye wash facilities, evacuation procedures, emergency procedures, etc.). In essence, emergency procedures are the outcome of risk assessments applied to what-if scenarios. Affected parties need to be trained on how to recognize emergencies and how to respond. Emergency procedures regarding chemical substances should be part of a comprehensive health and safety plan.

2.9.9 Management Role

As discussed above, management participation in occupational health and safety programs is essential.

The degree of prescription (i.e., need to follow a specific approach) in occupational health and safety legislation has diminished around the world. Most statutory authorities have moved to a risk-based approach whereby employers must determine risk for all operations within their organisation. This is where recommended practices such as ISO are valuable as they provide systematic approaches. Many statutory authorities produce guidance material, which essentially defines minimum standards, however the onus is on the employer to establish the level of risk associated with any activity.

Large mature organisations have generally adopted risk management practices. However, small to medium enterprises still struggle with the concept because of limitations in resources. Occupational hygienists fill an important role in establishing workplace risks through hazard evaluation.

Case Study Risk Assessment

Lifeguards on a windy beach. Seasonal work (3 months a year), high turnover with few lasting more than 3 seasons. The beach is closed when winds exceed 25 knots due to high waves. You learn that sand has silica and that it causes cancer. Are lifeguards at risk?

Risk ID: crystalline silica hazard.

Risk Analysis: Your research shows that crystalline silica is associated with silicosis and lung cancer in miners with 15 or more years of exposure to dusty conditions.

You also learn that beach sand particles are much larger than silica particles in mines. Also it turns out that beach sand is less biologically active than silica in mines.

In summary: Miners work in dusty conditions, whereas beaches generally not dusty and would be closed when it's too windy. Most lifeguards work 3 months for three years or less, so a total of 0.75 years. The miners in the study work for 15 years or more.

Beach sand is less harmful than crystalline silica in mines

What do you conclude?

Chapter 3 Occupational Exposure Limits

This chapter describes and discusses the concept of Occupational Exposure Limits (OELs):

- ✓ **What are they?**
- ✓ **Why are they relevant?**
- ✓ **Where do they come from?**

3.1 Introduction to OELs

Occupational exposure limits (OELs) generally refer to airborne concentration of substances that should not cause ill health to a healthy adult when exposed. They do not necessarily define a hazard.

OELs are commonly used as a reference value to compare the findings of exposure monitoring to assess potential risks and or to prioritize control actions. The idea of exposure assessment is to obtain a reliable estimate of worker exposure and to compare it to well-defined criteria, as part of the risk assessment process.

OELs normally take three forms:

- Time-Weighted Average (TWA), usually averaged over 8 hours
- Short Term Exposure Limit (STEL), usually averaged over 15 minutes (Mins)
- Ceiling or Peak exposure limits, usually instantaneous values.

There are many sources of OELs worldwide such as

- Threshold Limit Values (TLVs®), a US voluntary standard recommended by American Conference of Governmental Industrial Hygienists (ACGIH)
- Permissible Exposure Limits (PELs), set by OSHA and mandatory in US
- Workplace Exposure Limits (WELs) in the UK
- Maximale Arbeitsplatz-Konzentration (“maximum workplace concentration”) (MAK’s) in Germany

OELs do not necessarily correspond between countries or sources for which reason it is important to consider available OELs when evaluating air sampling data even though technically or legally they may not be applicable to the work place under evaluation. Section 3.11 contains further details on various OELs.

3.2 Definitions and Units

OELs are reported in one of two units:

- Mass per unit volume (e.g., milligrams per cubic meter or mg/m³), typically used for dusts, fumes and mists.
- Proportional by volume (e.g., parts per million or ppm), typically used for gases and vapours. One percent is equivalent to 10,000 ppm, and one ppm is equivalent to 0.0001%.

It is possible to convert concentrations from mg/m³ to ppm, but for gases and vapours only, and not dusts, fumes, or mists because the latter involves solids suspended in air rather than gases/vapours mixed with air. The relevant conversion equation is

$$C\ ppm\ =\ C\ mg/m^3 * 24.45/MW \text{ at NTP} \qquad \text{...Equation 3-1}$$

Where C ppm represents concentration in parts per million

C mg/m³ is concentration in milligrams per cubic meter

24.45 is the molar volume of gas at NTP (25 degrees C and 760 mm Hg)

MW is the molecular weight of substance in question

Example:

The 8-hr OEL for Toluene is 50 ppm. What is the OEL in mg/m³?

$$C\ ppm\ =\ C\ mg/m^3 * \frac{24.45}{MW}, \text{ which re-arranged is same as}$$

$$C\ mg/m^3\ =\ C\ ppm * \frac{MW}{24.45}$$

Substituting in desired values… (MW for toluene is 92.1)

$$C\ mg/m^3\ =\ 50 * \frac{92.1}{24.45}$$

So OEL of 50 ppm toluene is equivalent to 188 mg/m³

This equation can be re-arranged to calculate OELs (as well as exposure data) in ppm from mg/m³ data.

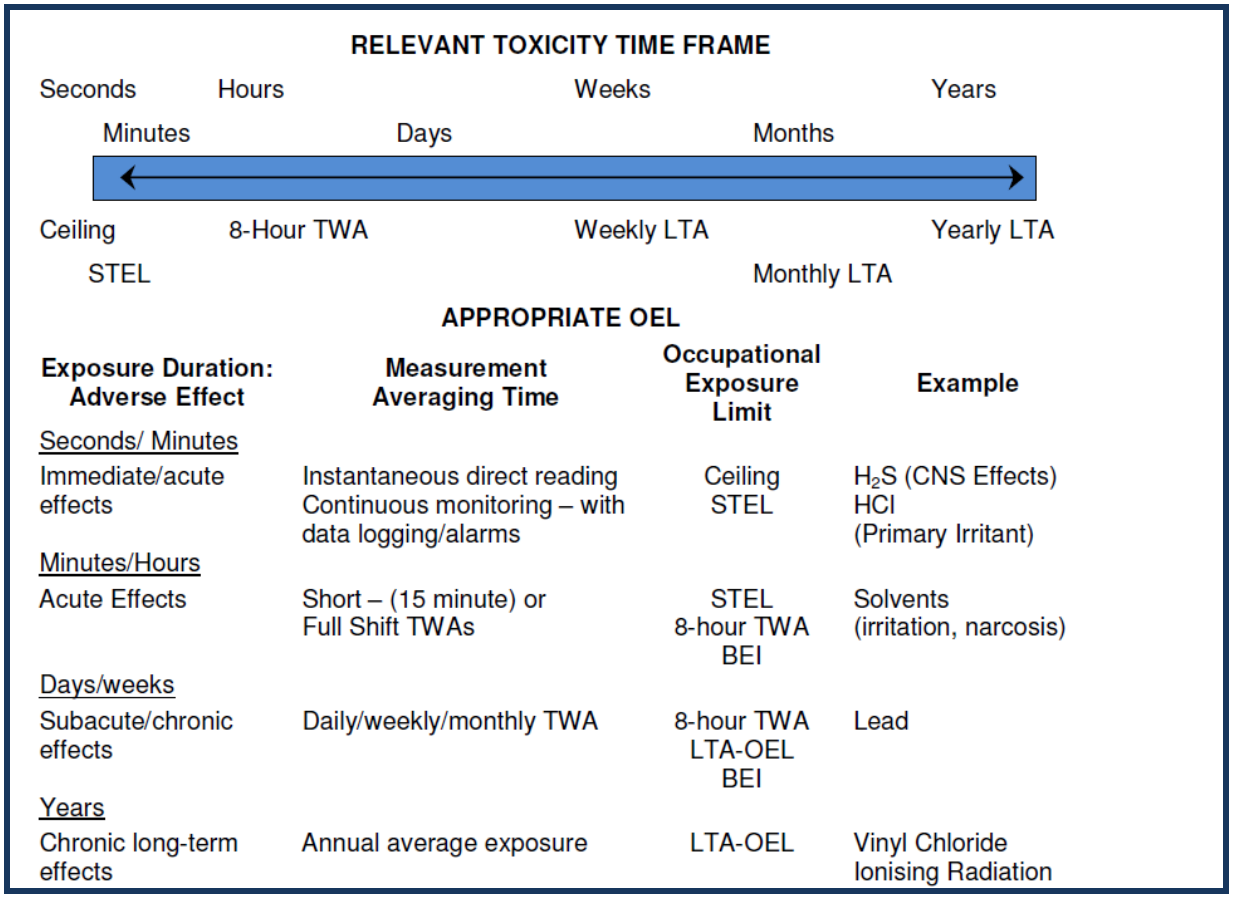
Time is also a key component of OELs, and is used to average exposures over a specified period of time to obtain a time weighted average (TWA). Figure 3-1 Time Weighted Average (TWA) Summary provides a summary of the relationship between time and OEL.

The most commonly used time limits associated with OELs are

- 8 hours, representing a full shift, or 8h-TWA)
- 15-minute short term exposure limit, (also known as STEL).
- Ceiling values (instant measurements)

In general, 8h-TWA OELs apply to substances that are chronically toxic (e.g., asbestos, heavy metals), whereas 15-minute STELs commonly apply to substances that have acute (i.e., short term) adverse effects (e.g., solvents, acid mists). Some substances have acute and chronic adverse effects and so may have 15 mins STEL and 8h-TWA OELs. Irritant substances may also have a ceiling OEL, which is an airborne concentration that should never be exceeded.

Figure 3-1 Time Weighted Average (TWA) Summary



Source: AIHA 1997

3.3 Time Weighted Average OELs

Time weighted average (TWA) OEL's apply to long-term exposure to a substance over an 8-hour workday, for a five-day working week, over the working life and should be applied to full shift personal exposure estimates for substances with chronic effect(s).

When using TWA based OELs, it is important to adjust your results accordingly. In other words, it is necessary to calculate 8h-TWAs to compare the results against an 8h-TWA OEL.

The equation to calculate 8-hour time weighted average exposures is:

$$8h\ TWA = \frac{C_1 * T_1 + C_2 * T_2 + \ldots\ldots C_n * T_n}{8} \quad \text{...Equation 3-2}$$

Where C_1 is the concentration for Time period T_1 (in hours)

C_2 is the Concentration for Time period T_2 (in hours)

C_n is the Concentration for Time period T_n (in hours)

*Care is advised in making sure that time values are in the same units. If time T is measured in minutes rather than hours, the denominator becomes 8*60 i.e., 480 minutes.*

Example

You sampled an all-day painting project for xylene. The project involved three samples: paint preparation for 30 minutes (result of 150 ppm), paint application for 3 hours (i.e.) 180 minutes (result of 40 ppm), and then cleanup for 90 minutes (result of 70 ppm). What is the 8h-TWA result? Assume zero exposure outside the periods sampled.

$$8h\ TWA = \frac{(150 * 30) + (40 * 180) + (70 * 90)}{480}$$

$$8h\ TWA = 37.5\ ppm$$

3.4 OELs for Extended Shifts

Most OELs assume a traditional 8-hour work day and a 40-hour work week. These need to be adjusted where work schedules are extended or unusual to provide an equivalent level of protection. This section discusses various approaches to adjusting OELs. Please note that regulations in certain jurisdictions may prescribe a specific approach for estimating OELs for longer shifts. The Australian Institute of Occupational Hygienists (AIOH) has published a position paper that includes a comparison of calculated adjustments using the different approaches discussed below for 13 substances (see https://shrtm.nu/DzHf, see Page 14). The AIOH position paper includes pharmacokinetic approaches that are beyond the scope of this course.

3.4.1 OSHA (Direct Proportion) Model

The US Occupational Safety and Health Administration (OSHA)'s approach adjusts OELs directly proportionally to the hours worked. This approach is appropriate for substances where the OEL is based on estimated life-time excess risk (parts per million – years) rather than a specific toxic threshold.

The OSHA approach adjusts 8h-TWA OELs as follows:

$$Adjusted\ OEL\ =\ 8/h * OEL$$ …Equation 3-3

Where h indicates the number of hours worked

Example

A worker is exposed to toluene for a 12-hour shift. The 8-hr OEL for toluene is 50 ppm. Calculate the daily adjusted OEL using the OSHA Model

$$Adjusted\ OEL\ = \left(\frac{8}{12}\right) * \ 50\ ppm$$
$$Adjusted\ OEL\ = 0.667 * \ 50\ ppm$$
$$Adjusted\ OEL\ = 33\ ppm$$

Note that OSHA has prescribed a specific method to derive long shift OELs for lead (see 29CFR1910.1025, and 29CFR1926.62), whereby the adjusted OEL for shifts longer than 8 hours is derived as follows:

$$Adjusted\ TWA\ OEL\ (Pb)\ =\ 400/h\ \text{mg/m}^3$$ …Equation 3-4

Where h indicates the number of hours worked.

3.4.2 Brief and Scala Model

This Brief and Scala Model OEL adjustment model, originally derived in the petroleum industry, reduces the 8-hour OEL proportionally for both increased exposure and reduced recovery time.

The OEL can be adjusted by a Daily Reduction Factor (DRF), so that

$$Adjusted\ OEL = OEL * DRF$$ …Equation 3-5

Where DRF indicates daily reduction factor, as follows:

$$Daily\ Reduction\ Factor = (8/h) * ((24 - h)/16)$$

Where h = hours worked per day

The OEL can also be adjusted for week long exposures as follows:

$$Weekly\ Reduction\ Factor\ (WRF) = (40/h) * ((168 - h)/128)$$
$$Adjusted\ OEL = \ OEL\ *\ WRF$$ …Equation 3-6

Example:

A worker is exposed to toluene for a 12-hour shift. The 8-hr OEL for Toluene is 50 ppm. Calculate the daily adjusted OEL using the Brief and Scala Model

$$Adjusted\ OEL\ = \left(\frac{8}{12}\right) * \left(\frac{24-12}{16}\right) *\ 50\ ppm$$

$$Adjusted\ OEL\ = 0.5 *\ 50\ ppm$$

$$Adjusted\ OEL\ = 25\ ppm$$

NOTE: The adjusted exposure limit should be calculated daily and weekly reduction factors. The most conservative value (i.e., lowest should be used).

As shown in the two worked examples, use of the Brief and Scala Model yields a more conservative OEL value (25 ppm) whereas use of the OSHA model resulted in a higher value for the adjusted OEL (33 ppm).

3.4.3 UK Approach

The UK's HSE's approach is to convert air sampling results collected over long shifts into 8h-TWAs (for direct comparison to 8h-TWA WELs) using a proportional approach as follows:

Example (From EH 40 Publication):

An operator works a 12-hour shift each day for 5 days, and then has seven days' rest. WELs are based on an 8-hour reference period each 24 hours in which an exposure occurs; the seven days' rest makes no difference. While at work, the operator is exposed to 4 mg/m^3. The WEL for the substance of concern is 5 mg/m^3 (8h-TWA). Was the WEL exceeded?

$$Adjusted\ 8h-TWA\ Exposure\ = \left(\frac{shift\ duration\ in\ hours}{8\ hours}\right) *\ 4\ mg/m^3$$

$$Adjusted\ 8h-TWA\ Exposure\ = 1.5 *\ 4\ mg/m^3$$

$$Adjusted\ 8h-TWA\ Exposure\ = 6\ mg/m^3$$

So, it can be concluded that the operator's exposure would have exceeded the WEL.

3.4.4 Quebec Model

This approach, developed by Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST) in Quebec, Canada, is based on OSHA's Direct Proportion model but also considers length of daily shift as well as hours worked in a week in addition to toxicological properties of substances of concern. For example, no adjustment is considered necessary for substances regulated by a ceiling value, or for substances that are simple asphyxiants, malodorous or irritating. On the other hand, a daily adjustment is recommended for substances that have acute effects, and weekly adjustments for substances that have chronic effects.

The Quebec model, presently in its 4th edition, offers adjustments based on shift duration as well as length of work week. It may be downloaded at https://shrtm.nu/K6wR.

3.5 Short Term Exposure Limits

Short term exposure limits (STELs) are important supplements to TWA OELs. They are relevant when evaluating exposures to substances that can cause short term health effects such as intolerable irritation or central nervous system effects such as nausea or dizziness. Conformance with relevant STELs will help to prevent acute and chronic adverse health effects.

STEL OELs are generally averaged over 15-minute intervals. Worker exposures should not exceed the 15 min STEL for longer than 15 minutes, or for more than 4 such periods per work day. Moreover, a minimum of 60 minutes should be allowed between successive exposures at the STEL.

STELs should not be time adjusted

3.6 Ceiling Limit (C)

The ceiling limit (C) represents an instantaneous exposure concentration that should not be exceeded at any time. Ceiling exposure limits are set to prevent short term effects such as physical irritation, as sufficient evidence demonstrates such physical irritation may initiate, promote, or accelerate adverse health effects through interaction with other chemical or biological agents or through other mechanisms.

If real time data (i.e., direct measurement) is not feasible, it's important to review the sampling method to ensure that the sample volume allows the lab to report a limit of detection that is less than the ceiling limit.

Ceiling limits should not be time adjusted.

3.7 Long Term Average (LTA) Exposure Limit

Long term average exposure limits have longer time periods, for example, months to a year and are appropriate for substances which take longer to leave the body or affect the body for longer periods of time. Limitations in scientific evidence supporting the establishment of many OELs is recognized and therefore LTA OELs can be determined as ¼ of the 8 hour-TWA OEL.

LTA OELs should not be time adjusted.

3.8 Excursion Limits

Although many substances may not have a STEL, it is considered good practice to control short term exposures (excursions) that exceed an 8h-TWA OEL value even if though a calculated 8-hour exposure may not exceed the 8h-TWA OEL. Other approaches are that of the American Conference of Governmental Industrial Hygienists (ACGIH) and the UK HSE based on excursion limits.

The ACGIH Threshold Limit Value (TLV®) guidance recommends limiting excursions in worker exposure levels to 3 times the OEL for no more than a total of 30 minutes during the workday, and under no circumstances should they exceed 5 times the OEL, provided the TWA OEL is not exceeded. A process is not considered to be under reasonable control if these levels occur.

In the UK, an excursion limit of 3 times the workplace exposure limit (WEL) OEL is considered good practice.

Relevant STELs or Ceiling limits take precedence over the peak exposure limits (formerly known as excursion limits).

3.9 Notations

A notation is a designation in the OEL listing documentation that provides additional information regarding a particular substance. These notations may indicate biological monitoring limits, carcinogenicity, sensitisation and whether absorption through the skin should be considered. Each of these types of notations are discussed below:

3.9.1 Biological Monitoring Limits

Biological monitoring notations indicate that there are biological indices of exposure for a particular substance. These indices include blood measurements (e.g., blood lead levels) or urinary measurements. These are further discussed in Chapter 10 of this manual.

Correct application of biological monitoring limits requires consideration of all routes of exposure, including non-occupational sources (e.g., diet). Employee resistance may be encountered with biological monitoring because of the use of invasive collection techniques e.g., urine and blood sampling.

Biological monitoring can be valuable in evaluating accidental exposures associated with incidents, such as chemical spills.

3.9.2 Carcinogenicity

A carcinogen is an agent capable of causing cancer. Evidence of carcinogenicity comes from epidemiology, toxicology, and mechanistic studies. Note that not all carcinogens may have designated OELs.

The International Agency for Research on Cancer (IARC) has the following carcinogen classification scheme based on the strength of published evidence for carcinogenicity.

- Group 1 Carcinogenic to humans
- Group 2A Probably carcinogenic to humans
- Group 2B Possibly carcinogenic to humans
- Group 3 Not classifiable as to carcinogenicity to humans

- Group 4 Probably not carcinogenic to humans

The results of IARC's evaluation on the carcinogenicity of more than 900 substances have been published in a series of monographs published since 1972. (See https://shrtm.nu/Hrs2.

Different jurisdictions use different schemes, so care needs to be taken regarding local notations. ACGIH, OSHA and National Institute of Occupational Safety & Health (NIOSH) in the US have their own classifications. In the UK, carcinogenicity is indicated by 'Carc' meaning the chemical can cause cancer and or heritable genetic damage.

3.9.3 Sensitisation

The notation SEN or Sen refers to the potential for the chemical to produce sensitisation in exposed workers. Sensitisation may relate to respiratory, dermal or conjunctival exposures. A sensitised, subsequent exposure(s), even at very low levels, usually results in adverse allergic reactions.

> Example: Toluene diisocyanate (TDI) often found in two-pack paint is a respiratory sensitiser and subsequent exposure can result in severe asthmatic reactions to those sensitised.

In the UK, 'Sen' is used as the notation for sensitisers whereas the ACGIH TLV© uses 'SEN'. The AIHA uses DSEN for dermal sensitisers and RSEN for respiratory sensitisers.

When considering substances with a SEN/Sen notation it is important to understand:

- Occupational exposure limits are not meant to be protective of those who are sensitised.
- When there is a SEN/Sen notation, reference must be made to the documentation to understand the nature of the sensitisation and the potency of the sensitiser.

3.9.4 Skin

The 'Skin' or 'Sk' notation indicates that the cutaneous route of exposure can contribute significantly to the overall exposure. Cutaneous exposures include mucous membranes and the eyes, either by contact with vapours or, of probable greater significance, by direct skin contact with the substance. Typically, skin exposure results from handling substances without the use of gloves or protective clothing, splashes or handling contaminated clothing and equipment.

> Examples: Organophosphate pesticides (e.g., Malathion), and glycol ethers

Skin notations are not assigned on the basis of any harmful effects on the skin such as irritation or allergic contact dermatitis but that it absorbs through the intact skin.

The use of a 'Skin'/'Sk' notation indicates that biological monitoring may be required to supplement air sampling to quantify worker exposure. Skin notations also inform the selection and use of control measures, for example the use of personal protective equipment to prevent skin absorption.

The OELs refer to exposures via the inhalation route only, and so take no account of any absorption that may occur as a consequence of exposure via the cutaneous route.

3.10 Basis of OELs

OEL's are based on the notion of a threshold of intoxication whereby there exists a dose concentration which the human body is capable of tolerating and detoxifying without injury to itself. These "threshold doses" below which no significant adverse effect is expected to occur in most people are often derived from epidemiological and toxicological studies coupled with occupational hygiene measurements.

Two commonly used toxicological concepts, used in the derivation of OELs are:

- NOEL: no observed adverse effect level
- LOEAL: lowest observed adverse effect level

Appendix A provides a review of these concepts, which are also discussed in W 507 Health Effects of Hazardous Substances Course.

OELs for chemicals are established based on a number of factors including toxicity, physiological response (biologic action). Examples of such factors include:

Table 3-1 OEL Factors

Type of Hazard	Basis of OEL
Irritants	Ability to cause inflammation of mucous membrane with which they come in contact e.g., hydrochloric acid fumes, ammonia, ozone, acrolein.
Asphyxiants	Ability to deprive the tissue of oxygen. Simple asphyxiants e.g., nitrogen, carbon dioxide, helium. Chemical asphyxiants e.g., carbon monoxide, cyanides.
Narcotic	Depressant action upon the central nervous system, particularly the brain e.g., ether, chloroform.
Carcinogens	Cancer causing substances e.g., asbestos, arsenic, vinyl chloride monomer
Toxic Effects	Chronic adverse effects (e.g., lead, silica, solvents)

Overall, there is very limited human exposure data that can be used to derive OELs. In many cases, OELs are derived from either animal studies, studies of similar but not identical industries or on the notion that similar compounds (e.g., chlorinated hydrocarbons, or heavy metals) have similar toxicological properties. In other cases, there are limited data, or the available data addresses other routes of exposures. To address these issues, uncertainty factors (also known as safety factors) are applied. These may range from 1 (as in the case of certain irritants for which there is human data) to several thousand for carcinogens.

Agencies that develop or recommend OELs usually have documentation that explains the basis for the OEL in question. The following table summarizes this information:

Table 3-2 OEL Documentation

OEL Name	Agency	OEL Documentation
TLV Threshold Limit Value	US ACGIH	"Documentation of Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices" - see acgih.org
PEL Permissible Exposure Limit	US OSHA	Preambles to OSHA regulations. See osha.gov
REL Recommended Exposure Limit	US NIOSH	Criteria for a Recommended Exposure Standard (ES) series of documents. See https://www.cdc.gov/niosh/index.htm
SCOEL Recommended Exposure Limits	EU	Scientific Committee on Occupational Exposure Limits (SCOEL) - see https://tinyurl.com/y8amyun3

3.11 Application of OELs

OELs provide a useful reference point by which to compare air monitoring results. It is important that air sampling data be representative of the employee exposures, and that the samples be collected from employee breathing zones.

Before comparing results with relevant OELs, it is important to consider the following general rules:

- Make sure that the units of measurements (i.e., results) are in the same units as the relevant OEL
- Calculate relevant time weighted averages (TWA) of exposure, where relevant, to allow direct comparison to TWA OELs. For extended shifts, see Section 3.4.
- If short term data was collected, it should be compared to STELs or Ceiling Values. If there are no relevant listed value, then the data can be compared with the TWA value (without calculating any time weighted average value).

3.12 Types Occupational Exposure Limits

There are numerous OELs in use worldwide. Some are enforceable by regulators (e.g., OSHA PELs), others are advisory (e.g., ACGIH TLVs) and represent best practice.

This section provides an overview of various OELs commonly used by occupational hygienists in various jurisdictions but is not intended to be an all-inclusive list. It's wise to see what OELs are relevant to any particular location an occupational hygienist may be working in. These are usually available online. There are also specific publications and applications that are a compendium of

OELS for different countries such as the German Institute for Worker Health and Safety's (IFA) downloadable GESTIS data base (see https://shrtm.nu/7CH3.

3.13 Threshold Limit Values (TLVs)

TLVs® were developed by the American Conference of Governmental Industrial Hygienists (ACGIH), which was founded in 1938. TLVs, first established in 1941, are regularly reviewed and updated, and generally represent best occupational hygiene practice. TLVs are listed in a booklet that is updated annually. The basis for each TLVs is discussed in the Documentation of TLVs, first published in 1961, and presently in its 7th edition. See www.acgih.org for further details.

There are three types of TLVs®

1. TLV-Time Weighted Average (TLV-TWA)
2. TLV-Short Term Exposure Limit (TLV-STEL)
3. TLV-Ceiling (TLV-C)

3.13.1 TLV-TWA

The time weighted average (TWA) Threshold Limit Value (TLV) is defined as:

> "The TWA concentration for a conventional 8-hour workday and a 40-hour work week, to which it is believed that nearly all workers may be repeatedly exposed, day after day, for a working lifetime without adverse effect."

However, during this eight-hour averaging period, excursions above the TLV- TWA are permitted providing these excursions are compensated for by equivalent excursions below the standard during the working day. Because some substances can give rise to acute health effects even after brief exposures to high concentrations, it is prudent that excursions above the TWA concentration should be restricted, moreover, the magnitude of excursions is an indication of the true degree of effective control over the release of contaminants from a process.

3.13.2 TLV-STEL

The ACGIH has recommended short-term exposure limits (STELs) for many substances that exhibit acute (i.e., short-term) adverse health effects. STELs are defined as:

> "A 15-minute TWA exposure that should not be exceeded at any time during a workday, even if the TWA is within TLV-TWA. The TLV-STEL is the concentration to which it is believed that workers can be exposed continuously for a short period without suffering from:

- Irritation
- Chronic or irreversible tissue damage
- Dose-rate dependent toxic effects, or

- Narcosis of sufficient degree to increase the likelihood of accidental injury, impaired self-rescue, or materially reduced work efficiency."

The TLV-STEL is not a separate, independent exposure guideline, but it supplements the TLV-TWA where the recognized acute effects from a substance whose toxic effects are primarily of a chronic nature.

Exposures above the TLV-TWA up to the TWA-STEL should be less than 15 minutes, should occur fewer than four times a day, with at least 60 minutes between successive exposures.

3.13.3 TLV-C

The ACGIH has also recommended ceiling limits for certain substances. These ceiling limits are defined as:

> "The concentration that should not be exceeded during any part of the working exposure. If instantaneous measurements are not available, sampling should be conducted for the minimum period of time sufficient to detect exposures at or above the ceiling value."

The ACGIH believes that TLVs® based on physical irritation should be considered no less binding than those based on physical impairment. There is increasing evidence that physical irritation may initiate, promote, or accelerate adverse health effects through interaction with other chemical or biological agents or through other mechanisms.

Ceiling values are instantaneous guidelines that should not be exceeded at during any part of working exposures. They are best evaluated using direct reading instruments. If none exist, then sampling duration should be the minimum necessary to detect exposures (often 5-10 minutes)

3.13.4 Peak Exposures (Formally Excursion Limit)

The ACGIH revised its terminology in 2016 to replace the term "Excursion Limit" with "Peak Exposures" In practice, the actual concentration of airborne substances can and does vary significantly. For many substances with a TLV-TWA there is no TLV- STEL. However, excursions above the TLV-TWA should be controlled even if the recommended 8-hour TLV-TWA is not exceeded. Excursion limits are applied to TLV-TWAs that DO NOT have TLV-STELs.

Peak worker exposure levels may exceed 3 times the value of TLV-TWA for no more than 15 minutes during the workday, on no more than 4 occasions spaced one hour apart during a work day. Under no circumstances should peak exposures exceed 5 times the TLV-TWA. Additionally, the relevant 8h-TWA should not be exceeded for an 8-hour work period.

A process is not considered to be under reasonable control if these levels occur (3 times the workplace exposure limit (WEL) in the UK), where the toxicological data exists to establish a TLV-STEL or TLV-C these values take precedence over the excursion limits.

3.13.5 Mixtures

When two or more hazardous substances have a similar toxicological effect on the same target organ or system, their combined effect rather than that of either individually, should be given primary consideration. In the absence of information to the contrary, different substances should be considered as additive where the health effect and target organ or systems is the same.

The ACGIH approach does not calculate a combined OEL for a mixture of substances. Instead, measured exposures would be considered as exceeding TLVs when:

$$C\_1/〚OEL〛\_1 + C\_2/〚OEL〛\_2 + \cdots C\_n/〚OEL〛\_n \geq 1$$ ...Equation 3-7

Where C1 is the airborne concentration and TLV1 is the corresponding threshold limit value.

The additive formula applies to simultaneous exposures for hazardous agents with TWA, STEL and Ceiling values.

3.13.6 TLV Notations *

* **Special Note** – Section 3.9 of this Manual is a general discussion about the use of Notations in lists of OELs. This section discusses Notations in the annual list of TLVs specifically.

A notation is a designation that appears as a component of the adopted TLV® value to provide additional information with respect to the particular chemical:

3.13.6.1 Biological Exposure Indices (BEIs®)

The notation BEI® is listed when a BEI® (or BEIs®) is (are) recommended for the substance. Biological monitoring is recommended for such substances to determine the exposure from all sources, including dermal (skin) ingestion or non-occupational.

Most BEIs® are based on a direct correlation with the TLV® (i.e., the concentration of the determinant that can be expected when the airborne concentration is at the TLV) with an assumption that there is no exposure by skin absorption or ingestion. Further information can be found in the TLV book (published annually), or in the documentation for the TLVs® and BEI® for these substances.

Correct application of BEIs® requires significant knowledge of the accompanying documentation and may be valuable in evaluating what exposure has actually occurred in an incident. Employee resistance may be encountered with this type of monitoring as many BEIs® require the use of invasive collection techniques.

3.13.6.2 Carcinogenicity

“A carcinogen is an agent capable of inducing benign or malignant neoplasms. Evidence of carcinogenicity comes from epidemiology, toxicology, and mechanistic studies”.

The ACGIH system uses the following notation related to carcinogenic potential. These notations differ from IARC's approach (see Section 3.9.2):

- **A1 Confirmed Human Carcinogen:** The agent is carcinogenic to humans based on the weight of evidence from epidemiologic studies.

- **A2 Suspected Human Carcinogen:** Human data are accepted as adequate in quality but are conflicting or insufficient to classify the agent as a confirmed human carcinogen; OR, the agent is carcinogenic in experimental animals at dose(s), by route(s) of exposure, at site(s), of histologic type(s) or by mechanism(s) considered relevant to worker exposure. A2 is used primarily when there is limited evidence of carcinogenicity in humans and sufficient evidence of carcinogenicity in experimental animals with relevance to humans.

- **A3 Confirmed Animal Carcinogen with Unknown Relevance to Humans:** The agent is carcinogenic in experimental animals at relatively high dose, by route(s) of administration, at site(s), of histologic type(s) or by mechanism(s) that may not be relevant to worker exposure. Available epidemiologic studies do not confirm an increased risk of cancer in exposed humans. Available evidence does not suggest that the agent is likely to cause cancer in humans except under uncommon or unlikely routes or levels of exposure.

- **A4 Not Classifiable as a Human Carcinogen:** Agents which cause concern that they could be carcinogenic for humans but which cannot be assessed conclusively because of a lack of data. In vitro or animal studies do not produce indications of carcinogenicity which are sufficient to classify the agent into one of the other categories.

- **A5 Not Suspected as a Human Carcinogen:** The agent is not suspected to be a human carcinogen on the basis of properly conducted epidemiologic studies in humans. These studies have sufficiently long follow-up, reliable exposure histories, sufficiently high dose, and adequate statistical power to conclude that exposure to the agent does not convey a significant risk of cancer to humans, OR, the evidence suggesting a lack of carcinogenicity in experimental animals is supported by mechanistic data.

3.13.6.3 Sensitisation

The notation SEN refers to the potential for the chemical to produce sensitisation which may relate to respiratory, dermal or conjunctival exposures. Once a person has become sensitised, subsequent exposure to the agent, even at very low levels, usually results in an adverse allergic reaction.

Example: Toluene diisocyanate (TDI) often found in 2-pack paints is a respiratory sensitiser and subsequent exposure can result in severe asthmatic reactions to those sensitised.

When considering substances with a SEN notation it is important to understand:

- Occupational exposure limits are not meant to be protective of those who are sensitised.

- When there is a SEN notation, reference must be made to the documentation to understand the nature of the sensitisation and the potency of the sensitiser.
- Some bodies (e.g., AIHA) use different notation to indicate specific sensitisation, e.g., DSEN for dermal sensitisers, RSEN for respiratory sensitisers.

3.13.6.4 Skin

The Skin notation refers to the potential significant contributions to the overall exposure by cutaneous route, including mucous membranes and the eyes, either by contact with vapours or, of probable greater significance, by direct skin contact with the substance. Typically, skin exposure occurs from splashes, wearing of contaminated clothing, or handling materials without adequate protective clothing and or gloves (e.g., organophosphate pesticides, glycol ethers).

It is important to note that skin notations are not assigned on the basis of any harmful effects on the skin such as irritation or allergic contact dermatitis. Substances with a skin notation are not necessarily harmful to the skin.

The use of a skin notation is to alert the user that air sampling alone is not sufficient to quantify worker exposure, biological monitoring may also be required in addition to changes to work practices including the use of personal protective equipment to prevent cutaneous absorption.

3.14 Australian Exposure Standards

The first edition of an Australian list of exposure standards (ES) was published in 1990 by WorkSafe Australia as “Exposure Standards for Atmospheric Contaminants in the Occupational Environment - Guidance Note and National Exposure Standard.”. These standards were based on ACGIH TLV® list but also cross-referenced exposure standards from Germany, Sweden and the UK. Specific differences included reference to Workplace Exposure Standards and the use of Peaks rather than Ceilings.

The second edition was published in October 1991, and a third edition in May 1995 by the National Occupational Health and Safety Commission. Australian Exposure Standards for more than 700 substances are now published on the Safe Work Australia website: https://tinyurl.com/y878tse3. These standards also have notations in regards to carcinogenicity, sensitisation.

Australia’s Work Health Safety Act requires that employers maintain exposures not only below exposure standards but as low as reasonably practical.

3.15 United Kingdom Workplace Exposure Limits (WELs)

The UK Health & Safety Commission has established Workplace Exposure Limits (WELs) for a number of substances hazardous to health as part of The Control of Substances Hazardous to Health Regulations.

HSE’s publication EH40 Workplace Exposure Limits (see https://tinyurl.com/yajjckvs, includes the list of substances assigned WELs and provides more detailed guidance on their use. WELs are

maximum acceptable levels of exposure that should not be exceeded. Moreover, exposure should be reduced below the limit as far as is reasonably practicable by applying the principles of good occupational hygiene practice. The listing includes: 8-hour TWA, STEL, the Comments Column containing Safety & Risk Phrases plus the Carcinogen, Skin, Respiratory Sensitiser and Biological Monitoring Guidance Value notations.

Note that WELs also address substances for which no short-term limit is specified. HSE recommends that a figure of three times the long-term limit be used as a guideline for controlling short-term peaks in exposure. Some workplace activities give rise to frequent short (less than 15 minutes) periods of high exposure which, if averaged over time, do not exceed either an 8-hour TWA or a 15-minute TWA.

3.16 European Exposure Limits

3.16.1 European Agency for Safety and Health at Work

There are two kinds of Occupational Exposure Limit Values set by the European Agency for Safety and Health at Work.

- Indicative (Directive 98/24/EC on chemicals)

  Indicative Occupational Exposure Limit Values (IOELVs) have been established when an assessment of the available scientific data indicates that a threshold can clearly be identified below which exposure to the substance should not have an adverse impact on human health.

  IOELVs do not consider feasibility factors (including socio-economic and technical). Published values are available from https://tinyurl.com/y76v2se9 in a series of lists (2000, 2006, 2009, and 2017)

- Binding (Directive 2004/37/EC which applies to carcinogens and mutagens)

  Binding Occupational Exposure Limit Values (BIOELVs) reflect socio- economic and technical feasibility factors, as well as the same factors used to derive IOELVs

European Agency for Safety and Health at Work OEL values can be 8-hour TWA, short term, and/or biological limit values and can be supplemented by further information such as notations and routes of absorption.

3.16.2 Scientific Committee on Occupational Exposure Limits

The European Commission's Scientific Committee on Occupational Exposure Limits (SCOEL) also recommends exposure limits for a number of substances. SCOEL's summary table (Available from https://tinyurl.com/y76tuzlz) provides links to detailed reports outlining the basis of their recommendations.

3.16.3 REACH Derived No Effect Limits

REACH Regulation allows manufacturers and importers of chemical substances to place their substances on the European market only if they possess sufficient knowledge of the substances' toxicological data. Manufacturers and importers must compile relevant information on the substances' properties and register it in a central database maintained by the European Chemicals Agency (ECHA) which provides guidance documents for compliance. The substance-specific information required by REACH also includes occupational exposure limits in the form of DNELs (derived no-effect levels).

A DNEL is required for each population anticipated to handle a particular substance (e.g., workers, end users, humans via the environment, etc.). Certain vulnerable sub-populations (e.g., children and pregnant women) may also need to be considered. Recall that OELs are generally focused on healthy adult workers. Thus, any given substance may have several different types of DNELs as follows:

- Acute – inhalation, systemic effects
- Acute – inhalation, local effects
- Acute – dermal, local effects
- Long-term – inhalation, systemic effects
- Long-term – inhalation, local effects
- Long-term – dermal, systemic effects
- Long-term – dermal, local effects
- Long-term – oral, systemic effects (not relevant to workers)

ECHA has developed guidance documents for the development of DNELs (see https://shrtm.nu/KH1c). The German Social Accident Insurance Scheme maintains a current list of DNELs through the GESTIS program. They are available from

https://shrtm.nu/yMW9

3.17 OSHA Permissible Exposure Limits

In the US, the Occupational Safety and Health Administration established Permissible Exposure Limits (PEL) in 1970. Most are based upon the 1968 Threshold Limit Values OSHA. Since 1970 has also promulgated PELs and substance specific regulations for approximately 30 substances (e.g., asbestos, benzene, lead, and vinyl chloride). Due to the US regulatory process, many OSHA OELs are outdated, even though they continue to be enforceable.

OSHA PELs are contained in Title 29 of the US Code of Federal Regulations, which has three tables of interest as follows:

Table Z-1: See https://shrtm.nu/p6sP for about 400 substances.

Table Z-2: See https://shrtm.nu/PwjQ for about 20 substances.

Table Z-3: See https://shrtm.nu/p8AZ for mineral dusts.

Note also that more than half of US states have their own state OSHA programs that are required to be "at least as effective as" Federal regulations. However, it is possible that state-set OELs regulations may be more restrictive (i.e., lower) than Federal PELs.

3.18 NIOSH

National Institute of Occupational Safety and Health (NIOSH) in the US has established Recommended Exposure Limits (RELs). They are available on CD-ROM or http://www.cdc.gov/niosh.

It should be noted that NIOSH is directed to recommend limits that will ensure protection of "all" workers rather than "nearly all" workers, as with ACGIH TLVs. Consequently, many RELs are lower than existing OELs (e.g., PELs or TLVs).

3.19 AIHA

From 1980, the American Industrial Hygiene Association (AIHA) produced Workplace Environmental Exposure Levels (WEELs) which, were updated annually until 2013, when the development of WEELs was transferred to the Occupational Alliance for Risk Sciences (OARS), managed by Toxicology for Risk Assessment. Updated WEEL values may be found on https://www.tera.org/OARS/WEEL.html.

WEELs are intended to provide guidance on exposure levels for substances for which there is (was) neither legal nor authoritative limits (e.g., benzyl alcohol, butylene oxide). WEELs include recommendations for 8-hour TWA, Ceiling limit and a Short-Term TWA limit plus Skin, Dermal sensitiser and Respiratory sensitiser notations.

The AIHA also publishes Emergency Response Planning Guidelines (ERPGTM). These should be used for risk assessments when considering exposures of either the workforce or for the public for accidental releases. There are three levels of ERPGs guidelines:

- ERPG–1: The maximum airborne concentration below which nearly all individuals could be exposed for up to 1 hour without experiencing more than mild, transient adverse health effects or without perceiving a clearly defined objectionable odor.

- ERPG–2: The maximum airborne concentration below which nearly all individuals could be exposed for up to 1 hour without experiencing or developing irreversible or other serious health effects or symptoms that could impair an individual's ability to take protective action.

- ERPG–3: The maximum airborne concentration below which nearly all individuals could be exposed for up to 1 hour without experiencing or developing life-threatening health effects.

ERPGs may be purchased either for individual substances or in a handbook that also includes WEELs from AIHA (www.aiha.org).

3.20 Germany – MAK Commission

In Germany, the Commission for the Investigation of Health Hazards of Chemical Compounds in the Work Area (MAK Commission) is responsible for determining the current state of research relating to the health risks posed by substances and materials used at the workplace and for advising public authorities accordingly. The MAK Commission draws up proposals for MAK values (maximum concentration at the workplace) for volatile chemicals and dusts, BAT values (biological tolerance values), and also develops procedures to analyse chemical substances in the air and in biological materials. Substances that are carcinogenic, germ cell mutagenic, sensitising or percutaneously absorbed, as well as those that pose a risk to the embryo or fetus, are classified accordingly.

MAK and BAT values may be found in https://tinyurl.com/yd5hsk95 or, https://tinyurl.com/y7ceo7s5. Every year the proposals for the MAK and BAT values and the classifications are published and presented to the German Federal Minister of Labour and Social Affairs. The Ministry's Committee of Hazardous Substances subsequently reviews the proposals and makes a recommendation for their inclusion in the Hazardous Substances Ordinance.

3.21 Limitations of OELs

OELs are useful tools for occupational hygienist. However, like all tools they have certain limitation as listed below:

- Safe vs Unsafe: OELs do not divide between safe and unsafe exposures but are guides to assist in making conclusions about exposure risk. It is considered good practice to reduce exposure to at least less than 50% of the OEL, or as far below it as is reasonably practicable.

- Enforceability: Certain OELs in certain countries are legally enforceable, and may carry civil and criminal penalties. Exceeding these values places a regulatory responsibility on employers to control these exposures. However, there may be lower recommended OELs that may represent more up to date information regarding the risks associated with a particular substance although they may not necessarily be enforceable.

- Healthy Workforce: OELs are generally developed for working populations assumed to be healthy. They do not consider the general population that may include those who are very young, old, infirm or disabled. OELs are generally not relevant to community exposures.

- Adjusting OELs for unusual and extended work schedules, needs to consider effects such as synergism (where the combination of exposures can result in an effect greater than the sum of effects of each individual substance) and potentiation (where one agent can increase the potency of another).

- Not all substances have OELs: It is impossible to develop appropriate OELs for each of the hundreds of thousands of chemicals on the market. However, there are techniques by which to derive values based on analogy with certain compounds (e.g., hydrocarbons). In addition, in recent years certain bodies, in particular NIOSH, have published methodologies for the setting of Occupational Exposure Bands (OEBs) for substances for which there is no official OEL. The setting of an OEB is outside the scope of this course, but for the benefit of anyone who is interested, details of the NIOSH methodology can be found at https://wwwn.cdc.gov/Niosh-oeb/

- Often regulatory standards include consideration of non-health-based factors when setting OELs including engineering feasibility, economic impact on business/country, analytical limits etc. Recommended OELs such as the ACGIH TLVs® and AIHA's WEELs are usually health based and do not take any such factors into consideration.

- For some chemicals, there are likely to be several OELs in existence which have been set by different countries and scientific authorities. When deciding on which OEL to use, consider the OEL most likely to provide the best worker protection i.e., a health/science based OEL such as the ACGIH TLVs as well as the applicable country OEL that must be complied with which may be different.

- OELs apply to personal exposure data rather than to either area or static monitoring data which may not correspond with worker exposure.

Expert help can be provided by toxicologists, exposure scientists and occupational hygienists with experience in the setting of OELs as well as the application of OELs in the workplace, if needed.

Chapter 4 Air Sampling Theory and Practice

4.1 Introduction

Occupational hygienists often use air sampling to evaluate worker exposures for various reasons, including risk assessment and/or evaluating engineering controls. A sampling strategy is essentially a plan that defines the goals of the air sampling and how those goals will be achieved.

4.2 Workplace Sampling Strategies

A workplace sampling strategy is essentially a plan to collect data about worker exposure. A sampling strategy, like any other experimental design, cannot be formulated until the objectives of the exercise are clearly understood and documented. The concept of just collecting a few samples to see how "good" or "bad" a workplace may be, is potentially biased and may not give an accurate picture of workplace exposures.

The plan will depend on what its objectives are. In other words, what is (are) the question(s) that need to be answered.

A possible objective of a monitoring strategy is to provide analytical information about the workplace, which workers and management can use to ensure that, as far as is reasonably practicable, no-one in that workplace suffers injury or illness as a result of exposure to hazardous contaminants. Other objectives could include: determining exposures in response to complaints, determining compliance with respect to various recommended occupational health exposure limits, or to evaluate the effectiveness of engineering controls installed to minimize workers exposure.

Thus, when developing any monitoring strategy, it is important to ask the fundamental question: *"How will the data generated from this exercise be used?"* Without a reasonable answer to this question the survey merely becomes the collection of data "for the sake of it", which can turn out to be a wasteful and meaningless exercise in retrospect.

The British Occupational Hygiene Society (BOHS 1993) also suggests other factors should be considered before developing any monitoring programme. These include:

- The requirement for a qualitative risk assessment and appraisal of the workplace prior to doing any measurements.
- The need to obtain measurements other than those of airborne contaminant concentrations, e.g., wipe tests to determine surface cleanliness as a way of assessing the potential for skin contact or measurements of ventilation plant performance.
- Any requirements for biological monitoring and the integration of these into the overall survey strategy.
- Any requirements for monitoring overall performance or auditing the process.

- Any other health hazards which may exist within the workplace, e.g., noise or biological hazards, etc. which may also need to be considered.
- Any environmental or personal characteristics of the workers which may affect the measurement.

Once these factors have been assessed it is appropriate to develop a workplace exposure sampling strategy. In doing so it is appropriate to consider the following:

- What type of sample(s)? (area vs personal)
- Where should the sampling device be located?
- How many samples should be taken?
- How long should the sampling interval be?
- What periods during the work day should the employee's exposure be determined?
- How should the samples be taken?
- What contaminants are likely to be present?
- What is (are) the expected concentration(s)?
- What (if any) compounds are present which may interfere with the sampling (or analytical) procedure?
- What analytical methods are to be used and what (if any) constraints will these places on sampling techniques?

When developing a sampling strategy, it is important to understand that the variability of the workplace environment is such that no universal approach is possible to cover all possible situations.

The inconsistency of the workplace, in terms of density and intensity of activity, variability of activity, variability of exposure cloud and the influence of uncontrolled factors such as wind direction, employee practices, etc. results in the fact that data can only be related to the situation being studied at the time it was studied.

Any exposure assessment based on a single worker for a single day will have errors of space (location) and time and we will have little to link this outcome to the real situation.

Individual measurements will not necessarily represent the group, but by accounting for as many influencing factors as is practicable, we can ensure that some assessments are substantially better than others.

Other factors affecting the measurement results include:

- The choice of monitoring equipment

- The choice of the sampling method
- The choice of the analytical method
- The skill level of persons conducting the sampling and analysis

All the above factors need to be considered when considering a sampling strategy. It is important to appreciate that monitoring the workplace does not in itself protect anyone, it merely provides information; however, in some circumstances the mere act of monitoring does raise awareness of the workforce and management which often results in initiatives to reduce exposure, regardless of the actual results of the measurements.

The sampling system should be appropriate to the situation being studied and part of an overall occupational hygiene monitoring strategy.

Guidance on the assessment of exposure can also be obtained from other sources such as BSEN 689 (1996) "Workplace Atmospheres – Guidance for the Assessment of Exposure by Inhalation to Chemical Agents for Comparison to Limit Values and Measurement Strategy".

4.3 Types of Surveys

Regulatory authorities throughout the world have different approaches to the design of monitoring surveys. Some bodies are very prescriptive whereby individual workers in a workplace are listed in regulation to be monitored at set frequencies using prescribed methods. In recent years this approach has changed, with a move by some authorities to a risk-based approach.

In such situations it is not unusual for a common approach to be adopted with the following components:

- Initial appraisal
- Basic survey
- Detailed survey
- Routine survey

While the names given to these components may be different in various countries and some components may be combined (e.g., initial appraisal and basic survey), the concept remains the same.

4.3.1 Initial Appraisal

In many situations this is commonly referred to as a "walkthrough survey" and has the objective of being able to provide sufficient information to answer these questions:

- What are the potential exposures?
- Where and when do they occur?

- Can the exposures be prioritized in terms of risk?
- Is further evaluation necessary?
- If further evaluation is necessary what is the preferred approach?

As previously indicated, collection of sufficient information to answer these questions is paramount. While the walkthrough survey provides valuable information on the process, (e.g., materials being used and current controls), it may be necessary to seek further details. Such information regarding the substances being used could include:

- Physical properties. For example, boiling point, vapours pressure, relative evapoursation rate, dustiness, particle size distribution, ability to sublime, etc.
- What form is the substance? Is it a gas, vapours, mist, fume, or if it is an aerosol, is it fibrous?
- Hazardous nature of the substance. This could include any known toxic effects in man (both acute and chronic); other indications of toxicity (e.g., animal studies, in vitro tests, structural factors, etc.); any special toxic potential (carcinogenicity, respiratory sensitisation, reprotoxicity, etc.); and any indication of increased hazard from exposure to mixtures of substances.
- Potential routes of entry to the body.
- Any effects on skin (e.g., corrosion, dermatitis) or mucous membranes (e.g., drying, irritation).
- Any available exposure limits and the documentation for these.

During this initial information collection stage, the use of direct reading instruments or detector tubes may be helpful in identifying emission sources or employees with potentially significant exposures. Talking to the employees about the work that they do can also provide useful information during a walk-through survey.

This information will be very limited and should only be used to support observations. At the conclusion of the information collection exercise, it may be possible to make a reasonable assessment of potential risk. It should at least provide sufficient information to decide if a more detailed study is required or if a non-sampling approach would be effective.

4.3.2 Basic Survey

A basic survey is generally required when one or more of the following situations arise:

- The initial appraisal suggests that unacceptable exposures may be present in the workplace.
- A new process is being started up.

- Substantial changes have been made to the process, operations or control measures.
- Unusual, infrequent or intermittent processes or operations are to be conducted, e.g., maintenance.
- An occupational exposure limit has been set where one did not previously exist.

A basic survey will have limited objectives but these should include obtaining sufficient information to answer the following questions:

- Does an exposure problem exist as suggested by the initial appraisal?
- Is available engineering, or other, controls adequate and likely to remain so?
- Is a more detailed survey necessary and what strategy should it follow?

In some cases, an initial appraisal may be followed by a detailed survey without the intermediate step of a basic survey. This depends on what was found during the initial assessment and the skill and experience of the hygienist performing the evaluation.

4.3.3 Detailed Survey

A detailed survey has a clear objective, usually to obtain reliable measurements of personal exposures for comparison to exposure standards, reach conclusions regarding exposure levels and decide (if necessary) what measures need to be taken to control unacceptable exposures. Thus, for a detailed survey, results need to be representative of personal exposures so personal sampling techniques are normally used. Moreover, the appropriate measurement period must be used if the results are to be compared to an exposure standard which has a specific reference period.

In addition, all aspects of the survey need to be reviewed to ensure errors which may affect results are minimized. In many cases statistical based sampling techniques are adopted and detailed statistical analysis of the data undertaken.

No matter what the circumstances, the essential questions of: “Who?, When?, Where and How?” remain central to the development of an effective monitoring strategy.

4.3.4 Routine Monitoring

When developing a routine monitoring strategy, four issues need to be considered. These are:

- The frequency at which the monitoring survey is conducted
- The sampling methodology
- The number of samples required to meet the goals of the exercise
- The type of analysis of data that will be undertaken

There are no set rules for the frequency of monitoring except where it is defined in local legislation. Some mathematical models have been developed. However, such models are very reliant on the quantity and quality of available data.

Irrespective of the above, there are a few simple guidelines which can be used to help in the decision process regarding the frequency of routine surveys.

- How close are exposures to the relevant exposure standard – as exposures approach the exposure standard more frequent monitoring will be required (as distinct from being either well below or excessively above the exposure standard).
- The effectiveness of controls – in a well-controlled environment where the likelihood of control failure is low, monitoring frequency can be reduced.
- The process cycle – monitoring frequency will need to match the process cycle. This is especially important in situations where periodic events occur (e.g., maintenance shutdowns) or irregular process cycles.
- The temporal variability of exposures - consideration needs to be given so as to take account of seasonal and shift variations (e.g., increased production on night shift).
- The variability of exposure - in a process where a high level of variability of exposure is present, increased monitoring would be required to establish the reason for such variability.

Other factors that need to be considered are:

- Changes in sampling methods
- Changes in analytical methods
- Changes in behavior patterns of workers

Such changes can affect the survey results from year to year and some understanding of these issues is necessary if data from varying years is to be compared.

4.3.5 Statistically Driven Approaches

The problem of how to correctly (or more accurately) measure workplace exposures has been the subject of debate within the occupational hygiene profession for many years.

In the last 25 years there has been a gradual move to statistically based monitoring programmes where the workforce is divided into groups of similar exposures called “Homogeneous or Similar Exposure Groups” (HEGs or SEGs) and a statistically based subset of each group is monitored on a random basis for an extended period of time. In essence, employees are placed into groups (SEGs) based on past monitoring data or via using the knowledge of persons working in a plant as to possible exposures.

A number of persons in each group are then monitored and it is assumed that the exposures measured represent that of the whole group (SEG).

Once sufficient data has been collected a statistical analysis of the exposures can be undertaken to establish the level of compliance to the relevant exposure standard and to provide an indication in the variability of the data.

While statistically based sampling and evaluation of workplace exposures is very useful in giving a more accurate picture of employee exposures, it should not be considered as being the absolute test. There are many assumptions (and thus potential errors) in such programmes but by controlling as many influencing factors as is practicable a better estimate of exposure will be guaranteed.

Where considered appropriate, evaluation of workplace exposures should be conducted using non-biased (random) sampling programmes using the concept of SEGs Survey Design.

4.4 Who Should Be Sampled?

The question of whose exposure should be monitored can be answered only by reference to the objectives of the proposed survey and the details of the observed work practices. If the process only involves several workers doing exactly the same thing, then the task is relatively easy, however if the process involves large numbers of persons doing different tasks, then the choice of who to monitor becomes more difficult.

In many basic surveys the practice is to target “worse case” situations, however there is merit in including some workers who are expected to have lower exposures. This provides a level of quality control in respect to the initial appraisal and the choice of “worse case” individuals sampled.

4.5 When

The choice of when to monitor is directly related to what process or tasks give rise to significant exposures. The other major factor that must be considered is the toxicology of the substance under consideration.

For example, it is important to undertake short term sampling for acutely toxic substances because they are fast acting, whereas longer sampling would be more appropriate for substances that are chronically toxic.

The other point to consider when considering when to monitor is the type of exposure standard appropriate to the substance of concern (e.g., TWA, STEL, Ceiling or Peak). These are generally related to the toxicological properties of the substance.

As a general rule it is reasonable to state that if the objective of the survey is to evaluate the exposure of a worker during a specific task, then the monitoring duration should equal the whole, or a representative part, of the task.

4.6 Where?

Potential sources of contaminants of interest should be identified when developing a sampling strategy to identify where samples should be collected. Direct reading instruments (See Section 6.12) are useful in this regard, although results obtained would not generally represent personal exposures. Air samples should be collected on representative individuals working with or around contaminants of interest, during operations of interest (e.g., routine work, maintenance activity). Actual samples would be placed in employee breathing zones (see Section 4.12).

Note that while fixed location (i.e., static) sampling is of use to identify either where workers may be exposed, or whether controls are effective, or where there may be leaks, or other purposes, its limitation is that its results represent a specific location rather than actual worker locations (See Section 4.13). In many cases, sampling for compliance with OELs requires personal air monitoring.

4.7 How?

The selection of sampling equipment and analytical methods will in general result from the properties of the contaminant under investigation. Other factors that will come into the equation include:

- Legislative requirements
- The accuracy and precision required
- Intrinsic safety requirements
- The need for subsequent laboratory analysis
- Transport of samples to the laboratory
- Portability of equipment

In all cases it is prudent to use sampling methods from recognized authorities (e.g., National Standards, NIOSH, OSHA, HSE).

Both the sampling method and the analytical method are subject to error and thus what may be the most desirable choice from one standpoint may not be from the other.

Ultimately the choice will be a compromise, often dependent on the experience of the occupational hygienist and the working relationship between the hygienist and the laboratory that will perform the analysis.

The BOHS (1993) suggests the following considerations when selecting the sampling method.

- Is the sampling device (and collection medium) suitable for collecting the contaminant of interest and is the medium compatible with the subsequent analytical method?
- Is sufficient known about the dynamics of the collection process so that any variables can be accounted for in the design of the sampling programme?

- A number of factors can influence the selection of the sampling device and collection medium, but in practice they are generally limited to:

- For aerosols, what is the most appropriate device to collect the size range of particles of interest? Are wall losses (material which sticks to the sampling head and does not lodge on the filter), either within the sampling head or train, of an order such that account needs to be taken of them?

- For mists, especially, does possible vapours loss need to be taken into account?

- For gases and vapours sampled from a mixed atmosphere does preferential sorption of one or more contaminants take place in the collection medium? Does the presence of high water-vapours levels affect sorption characteristics of the sampling medium or the presence of particulate material adversely affect the collection characteristics?

- With all contaminants, is the total capacity of the collecting medium sufficient to cope with the likely loading of the contaminant given the intended sampling rate over the proposed sampling period?

Other issues (such as the number of samples) need to be addressed but these will be discussed in Section 4.8.

4.8 Sample Numbers

An occupational hygiene challenge in air sampling is to determine the appropriate numbers of samples to achieve the stated goals of an air sampling strategy. The answer depends on what information is required from the exercise. Some examples would be:

- Compliance – The number of samples is sometimes prescribed in legislation so the decision process may be straight forward. In other cases, it is necessary to collect enough samples to be able to demonstrate compliance. For very low exposures this may be just a few samples but as exposures approach the exposure standard this will require many more samples.

- Epidemiology – Such exercises invariably involve collecting as much data as possible and is usually limited by time, budgets and resources.

- Corporate Requirements – Again, such programmes usually have specific requirements but in many organisations are based on one or more of the statistical monitoring approaches.

- Degree of Confidence – In such cases an increased level of confidence (99% as against 95%) will result in a significant increase in sample numbers.

Some general “rules of thumb” have been proposed (e.g., 1 in 10 workers should be sampled or a minimum of 3 samples with a spread of less than 25%), however such approaches should be used with care as they could significantly affect the quality of the data.

While it is possible to obtain a reasonable approximation of an exposure distribution with 6-10 samples, as the exposures approach the exposure standard 30 or more measurements may be necessary to ensure the distribution of exposures is well defined.

4.8.1 Coefficient of Variation

Grantham (2001) describes the use of estimates of the mean and the standard deviation (S or SD) of previous data to derive sample numbers as follows:

$$Number\ of\ samples = \ (t\_(value\ *)\ \ CV/E)\text{^}2 \qquad \text{...Equation 4-1}$$

Where

$t\_(value\ *)$ is the t-statistic for the number of degrees of freedom (n-1, with n being the number of originals samples).

CV is the coefficient of variation

E is acceptable error rate

4.8.2 Rappaport & Selvin

[Reference – Am Ind Hyg Ass J, 1987 Apr;48(4):374-9]

This is another method that requires prior data. It essentially determines the number of samples needed to test the mean exposure of a lognormal distribution of exposures against an OEL. Table 4-1 summarizes the process.

To use Table 4-1, one must first estimate an F value as follows:

$$F = (sample\ mean)/OEL \qquad \text{...Equation 4-1}$$

Secondly, one needs to have an estimate of the Geometric Standard Deviation. You should be able to estimate this using the preliminary data. An easy way to do this would be to use the AIHAs IHSTAT, an Excel based approach (See https://shrtm.nu/S9VM. Or, it can be done in Excel.

Before using Table 4-1 Rappaport and Selvin Sample Number Model (α= 0.05, β= 0.10), you need to understand what α and β mean:

α= 5% chance that it is claimed that the workplace complies with the exposure standard when in fact it does not.

β= 10% chance that it is not claimed that the workplace complies with the Exposure Standard when in fact it did.

IHSExample

Say you had some previous data from 5 samples, with a mean of 60 ppm and a standard deviation of 15 ppm. Assuming an acceptable error rate of 10%, how any samples would be needed?

Step 1 would be to look up the t-value for 4 degrees of freedom in a reference table. That value corresponds to 2.776.

Step 2 would be to estimate the co-efficient of variation as follows

$$CV = \frac{Standard\ Deviation}{Mean}$$

$$CV = \frac{15}{60} \text{ or } 0.25$$

Step 3 would be to insert values into the equation. So

$$Number\ of\ samples = \left(2.776 * \frac{0.25}{0.15}\right)^2\ or\ 21.4\ (22\ rounding\ up)$$

So, using the preliminary data from the boxed example above (60 ppm average), assuming an OEL of 120 ppm, if the preliminary data had a Geometric Standard Deviation (GSD) of 2.0, one would need to collect 21 samples. Note, however, that if the preliminary data represents a greater percentage of the OEL than the 50 percent value in this example, the number or recommended samples increases. In other words, as the mean of the exposures approaches the exposure standard, more samples are necessary to make an accurate judgement as to whether the exposure standard is exceeded. The same is the case where the data is more scattered (higher GSD), one would need substantially more samples. However, if the data exceeds the OEL (calculated F > 1), assuming no changes in the processed monitoring, additional sampling is less useful.

Table 4-1 Rappaport and Selvin Sample Number Model (α= 0.05, β= 0.10)

Fraction of the OEL F	Geometric Standard Deviation (GSD)				
	1.5	2.0	2.5	3.0	3.5
0.10	2	6	13	21	30
0.25	3	10	19	30	43
0.50	7	21	41	67	96
0.75	25	82	164	266	384
1.25	25	82	164	266	384
1.50	7	21	41	67	96
2.00	2	6	11	17	24
3.00	1	2	3	5	6

4.8.3 NIOSH

NIOSH's 1977 approach is on SEGs (Similarly Exposed Groups). The number of samples SEG can be determined from Table 4-2 and the exact sampling days should be determined using random number tables.

Table 4-2 NIOSH Sample Size Guide

Sample size n for top 10% (τ = 0.1) and 95% confidence (α= 0.05)

Size of Group (N)	12	13-14	15-16	17-18	19-21	22-24	25-27	28-31	32-35	36-41	42-50	∞
Required No. of Measured Employees (n)	11	12	13	14	15	16	17	18	19	20	21	29

Source: NIOSH 1977

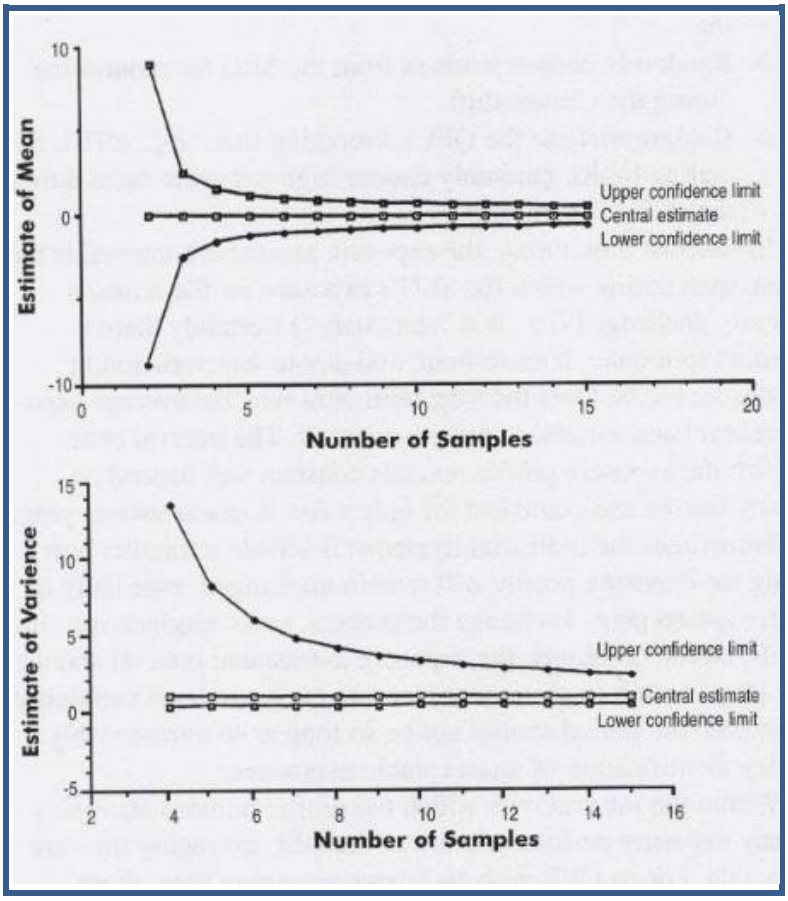
$$\text{If N} <= 11 \text{ then n} = \text{N}$$

Such an approach should ensure that at least one result should be within the top 10% of exposures with 95% confidence. However, following NIOSH's recommendations may result in collecting more samples than needed to obtain a reasonable estimate of exposures.

4.8.4 AIHA

The AIHA (1998 and 2006) indicates that there is a point of diminishing returns in respect to the number of samples required to adequately define an exposure profile. Fewer than six (6) measurements leave a great deal of uncertainty about the exposure profile, while more than ten (10) provides additional refinement in exposure estimates but the marginal improvement is rarely cost effective, as indicated in Figure 4-1.

Figure 4-1 AIHA Sample Guide



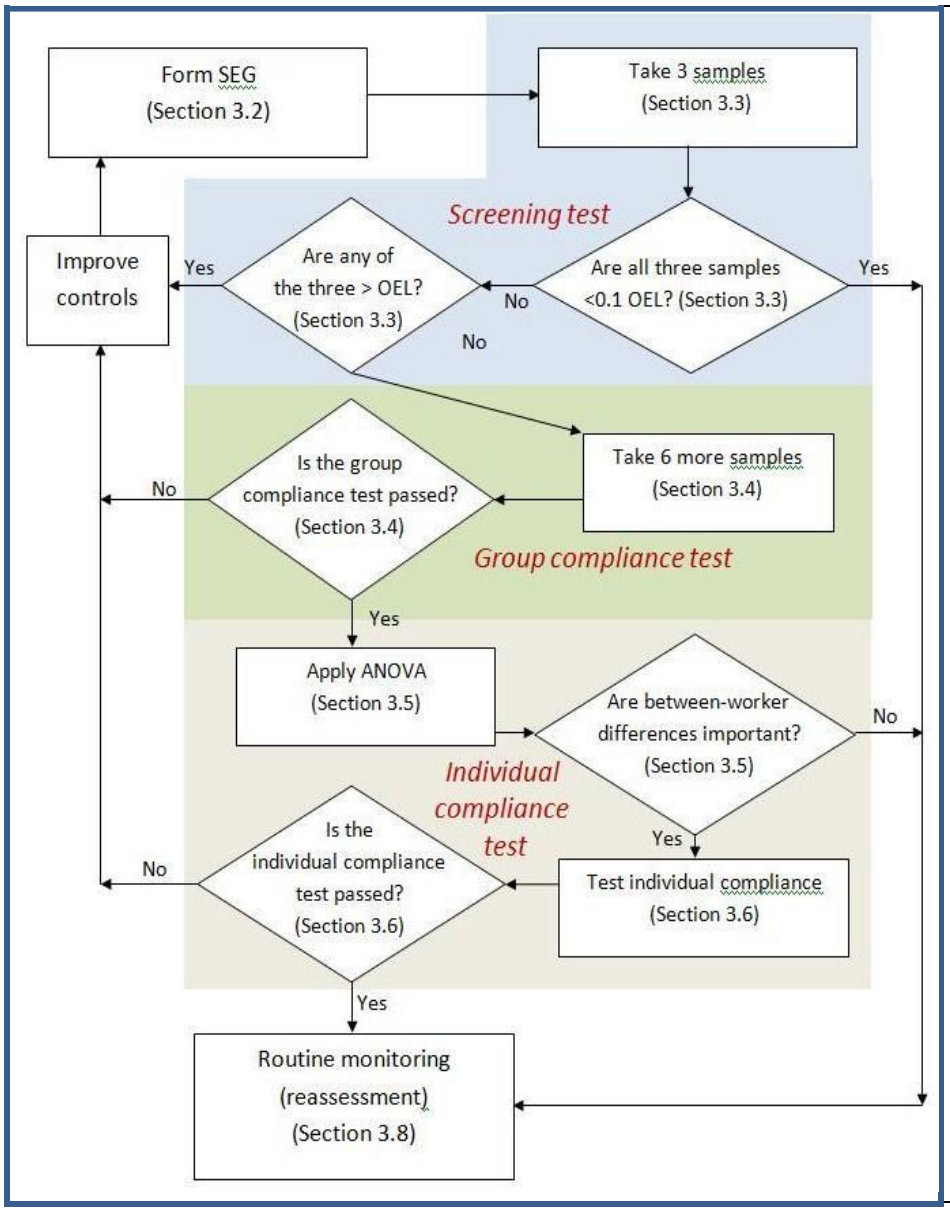
Source: AIHA 1998 – Used with permission of the American Industrial Hygiene Association (2007)

4.8.1 The BOHS/NVvA Guidance

The British Occupational Hygiene Society (BOHS) in conjunction with its sister organisation in the Netherlands, Nederlandse Vereniging van Arbeidsdeskundigen (NVvA), have also developed some guidance on measurement strategies specifically for determining compliance with OELs. The approach is designed to take account of both between worker and within worker variability. It does not, however, give general guidance on conducting a survey of exposure in the workplace.

Sample numbers are based on statistical considerations. During the first phase, 3 samples from workers selected randomly, are taken from a SEG and if all of these are below 10% of the OEL then it can be concluded that the limit is unlikely to be exceeded. If one or more of the results is above the limit, then this indicates that it can be exceeded. In either case no further sampling is required. Otherwise at least 2 more samples are required from each of the same 3 workers. Including the original 3 samples this will give a total of at least 9 results which can then be analysed using the recommended statistical tests. Figure 4-2 provides a summary of the BOHS/NVvA sampling scheme.

Figure 4-2 BOHS/NVvA Sampling Scheme



Source: BOHS/NVvA

During a basic survey, it may only be possible to take a few samples due to practical considerations or because only a few workers carry out the work. It may still be possible to arrive at valid conclusions about exposure in such circumstances by taking account of observations and other types of evidence providing care is taken when interpreting the results, bearing in mind the typical exposure profiles discussed above.

4.9 How Long to Sample

In many cases, occupational hygienists may be collecting samples to evaluate 8h-TWAs, in which case the sampling period will last a full shift. In other cases, sampling times will be shorter because the process of interest is shorter or because one is interested in 15-minute exposures.

However, it is also important to review the analytical method of detection for the proposed method of analysis. Although this information may be listed in the documentation for the proposed method, it is important to discuss this with the laboratory BEFORE undertaking sampling. Knowledge of the limit of detection (LOD) dictates the minimum sampling volume and therefore the length of sampling time required. In some cases, it may not be possible to measure 15-minute exposures because the sample volume is not large enough to contain detectable quantities of the contaminant of interest.

Example

You have been asked to collect air samples for a metal that has an OEL of 0.1 mg/m^3 (i.e., 100 µg/ m^3). Exposure controls appear adequate so you estimate that exposures might be about 10% of the OEL. The lab where you plan to have the samples analysed tells you the analytical limit (LOD) of detection is 10 µg per sample. Using a flow rate (FR) of 2 liters per minute (i.e., 0.002 m^3/min), how long should you collect the sample for to get a detectable amount of metal on the sample?

The minimum sampling time (t in minutes) can be calculated as follows:

$$t = \frac{LOD}{\%OEL * FR} \; minutes$$

i.e.:

$$t = \frac{10}{10 * 0.002} \; minutes$$

4.10 Sampling Patterns

When designing a sampling strategy there are a number of different sampling approaches that can be adopted. These are usually based on the contaminant, type of survey, work patterns and process variability. These include:

- Grab samples
- Partial period consecutive samples
- Full period consecutive samples
- Full period single samples

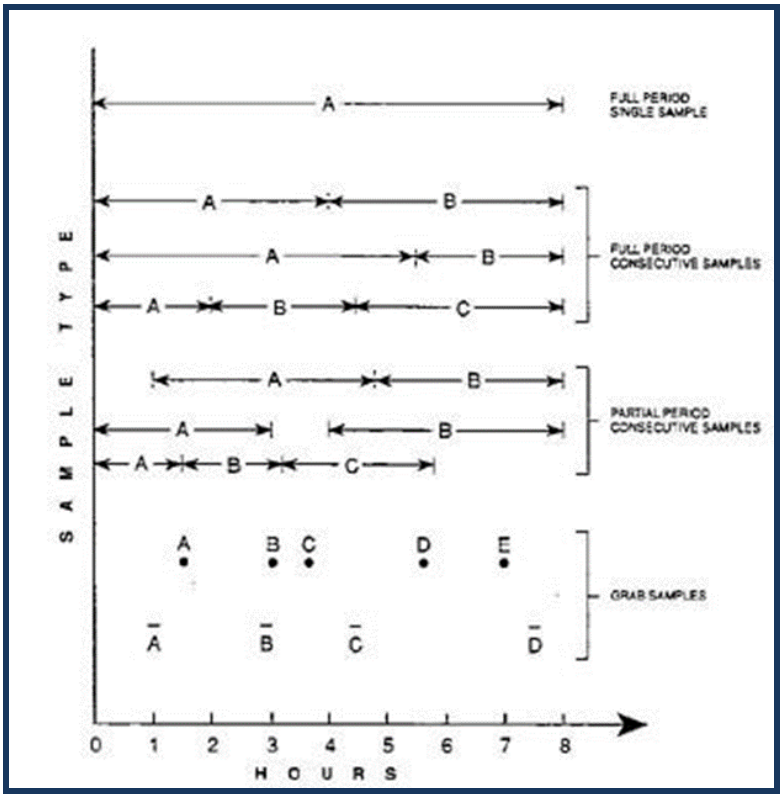
In some countries this is referred to as:

- Grab sampling

- Task duration sampling
- Short period sampling (less than the task duration and sometimes taken consecutively)
- Full shift sampling

Irrespective of the nomenclature used the fundamental concept is similar. These different approaches are shown graphically in Figure 4-3.

Figure 4-3 Sampling Patterns



Source: NIOSH 1977

What is important to appreciate is that the sampling approach adopted must take into account the exposure pattern of the person being sampled if representative data is to be obtained. In the following discussion "period of interest" can refer to either the period upon which the exposure standard is based (8 hours in many cases) but also in modern working patterns to the period of exposure while conducting a task. It is for the hygienist to make a judgement as to what is their "period of interest" for the exercise being conducted.

- Grab Samples – are samples lasting only a few minutes or seconds. They are usually taken using direct reading instrumentation during an initial survey (walkthrough survey) to highlight potential exposures or sources of exposure. Other types of grab samples are canisters or bags (into which air is drawn for later laboratory evaluation), and color indicator detector tubes.

- Partial Period Consecutive Samples – consists of one or more samples of equal or unequal duration covering only a part of the period of interest. The major problem with this approach is how to estimate the exposure that occurred during the period not sampled. NIOSH (1977) recommend that at least 70-80% of the full period is sampled.

Some international standards indicate that in situations where exposures are likely to be constant as little as 50% of the full period need be sampled. In all cases professional judgement plays a significant role in choosing the best approach.

- Full Period Consecutive Periods – these cover the full period of the relevant standard (e.g., 8 hours for an 8-hour TWA exposure standard or 15 minutes for a STEL). This approach is very useful in those situations where the process is intermittent, thus giving

data not only on the TWA exposure but also the variation in exposures in relation to the process. This approach can also be useful in situations where sampling media may get overloaded if sampling is carried out for single extended periods of time such as 8-hours.

- Full Period Single Samples – are normally carried out to establish the average exposure of workers during their normal work day. Such samples enable the results to be compared directly to an OEL based on an 8-hours TWA.

4.10.1 Sampling to Assess Acute or Chronic Effects

The toxicology air contaminants of concern can have a significant influence on the design of sampling strategies. For example, chronic acting substances such as crystalline silica (quartz) are sampled over an extended period (e.g., full shift duration) while acute acting substances should be sampled over a time period in accordance with the appropriate STEL or if the onset of an effect is rapid the appropriate use of alarmed direct reading instrumentation may be appropriate.

In some instances, it may be appropriate to sample for both the full shift and over short periods as a substance may have both TWA and STEL exposure standards (e.g., trichloroethylene).

4.11 Practicalities of Sampling Programmes

While the previous sections (see also Section 4.8) describe the various approaches to sampling and the number of samples to be collected, there are a number of practical issues that also need to be addressed.

The first of these is cost effectiveness. Large statistically-based monitoring programmes are very difficult to undertake in terms of the equipment required, the resources necessary to undertake the exercise and the ongoing disruption to the process. Consequently, it is rare for such programmes to be implemented outside of multi-national corporations and thus the question arises “what can reasonably be done?”

For example, a single person operating without any assistance will find it difficult to calibrate, distribute, monitor and recalibrate more than five sample collection devices at one time. Given this, it is important that the quality of the monitoring be excellent, the persons and situations determined for monitoring be appropriate and the collection of data be such that any abnormalities in results can be explained.

Obviously, professional judgement and experience are major factors in this situation but provided the basics are clearly understood and correctly applied, a good assessment of worker exposure can be made.

The relationship between observations (work practices, control measures, dustiness of process, etc.) and measurements cannot be over-stated; it is better to have fewer samples that can be clearly interpreted than a large number of samples with limited data which can’t. The balance between what is reasonably possible to achieve and what is necessary to obtain a picture of exposure needs to be assessed for each and every exercise. If one person cannot achieve what is necessary to obtain an exposure profile, then extra resources will be required.

Unfortunately, there is a shortage of good quality well trained people to perform sampling exercises in the workplace, which may well limit what can be done.

The final limitation on sampling programmes, in many cases, is the process itself. In some situations, the processes (e.g., batch process which occurs infrequently), do not lend themselves well to statistically-based random sampling monitoring exercises. An evaluation of each process is required before considering what can be reasonably achieved.

4.12 Personal Sampling

4.12.1 Breathing Zone

As the main route of entry into the body for many substances is via inhalation, it is logical that any estimate of exposure of such substances should be conducted in a location consistent with normal inhalation patterns of workers. By convention, this has been deemed the "breathing zone" and is defined by some statutory authorities (e.g., Australian Standard AS2985) as:

"A hemisphere of 300 mm radius extending in front of the face and measured from the midpoint of a line joining the ears."

Samples collected in the breathing zone of a worker are termed "personal samples" and are directly linked to workplace exposure standards.

Research in wind tunnels has demonstrated that the location of the sampling head can result in significant concentration differences over short distances. To avoid such variations, it is common practice to attach sampling heads in the area of the worker's lapel but still within the breathing zone.

The other variable in the sampling head location equation is worker practices, which may have a significant influence on exposure. One such case occurs when a worker inserts his or her head into a reaction vessel to monitor the process.

Such actions may give rise to incredibly high exposures of short duration. The sampling device needs to be positioned in such a manner within the breathing zone to collect the contaminant of concern.

One approach to overcome (or at least minimize) some of the difficulties if factors are significantly influencing the exposure cloud, is the use of dual lapel sampling – that is, collecting duplicate samples on the worker with one sample collected on the left lapel and the other sample collected on the right lapel. This at least gives some estimate over the variation in the exposure profile over relatively short distances.

4.12.2 Operator Variability

The concentration of contaminants in the workplace is subject to both temporal and spatial variation and thus likely to be in a constant state of flux. This is not only due to changes in the process, but also ventilation rates, climatic conditions, etc.

For workers, the range of tasks undertaken during a work day can dramatically influence an exposure pattern and concentrations. In many cases individual approaches to performing the same task (e.g., left or right-handed shoveling) may (and often does) result in significant exposure differences between workers performing the same task.

Such factors must be considered when designing a sampling strategy so as to ensure their influence on the exposure levels is taken into account.

4.13 Area Sampling

4.13.1 General or Background Measurements

Samples which are not taken on the individual in the breathing zone are generally referred to as static (or area) samples. Such samples do not normally correlate well with actual personal exposures but they still do have a useful role. Static samples are useful for the following purposes:

- To check the performance of control devices.
- As a surrogate for personal exposures, when a clear correlation between the results from static samples and personal samples has been established.
- In identifying and quantifying contaminant sources in the workplace and in delineating areas of unacceptable contamination.
- As part of the process for assessing trends in baseline concentrations.
- Are sometimes the only realistic means of measurement when certain types of continuous monitoring are required.
- As the only realistic method of sampling high volumes of air (e.g., asbestos clearance monitoring, or where there is a very low exposure limit and the sampling method LOD is not low enough).

It should be understood that workplace exposure standards are linked to personal sampling and the use of static or area samples for health assessment is not generally accepted.

Chapter 5 Dusts, Fumes and Mists: Health Effects and Sampling Methods

This section describes and discusses airborne dusts, fumes and fibres and methods available to evaluate airborne concentrations. This section addresses:

- ✓ **What are dusts, fumes and fibres?**
- ✓ **Particulate deposition in the lung and why it's important**
- ✓ **Basics of Particulate Air Sampling**
- ✓ **Air Sampling Pump use and Calibration**
- ✓ **Commonly Particulate Air Sampling Methods**
- ✓ **Particulate Air Sampling Calculations**
- ✓ **Direct Methods for Particulate Air Sampling**

This section provides and overview of some generally accepted practices and procedures used to evaluate airborne exposures to dusts, fumes and fibers, for which there are many accepted methods, including those developed by HSE (UK), and NIOSH (US).

5.1 Introduction to Dusts, Fumes and Fibres

Airborne dust is one of the most common issues in work places notably mines, quarries, cement mills and construction sites. It originates from applying forces such as crushing on a parent material, which may be either natural (e.g., mining ores), or man-made (e.g., asbestos products, building components, etc.). Dust typically consists of particles larger than 0.5 µm.

Fume can be defined as the condensation product of materials vapoursized during hot processes (e.g., smelting, or welding). Fume particles are typically smaller than 0.05 µm and tend to agglomerate.

Fibres are generally defined as particles with an aspect ratio (length to width) of ≥ 3:1.

Particulates is a collective noun generally used to refer to aerosols such as dust, fumes, mists, and, smoke.

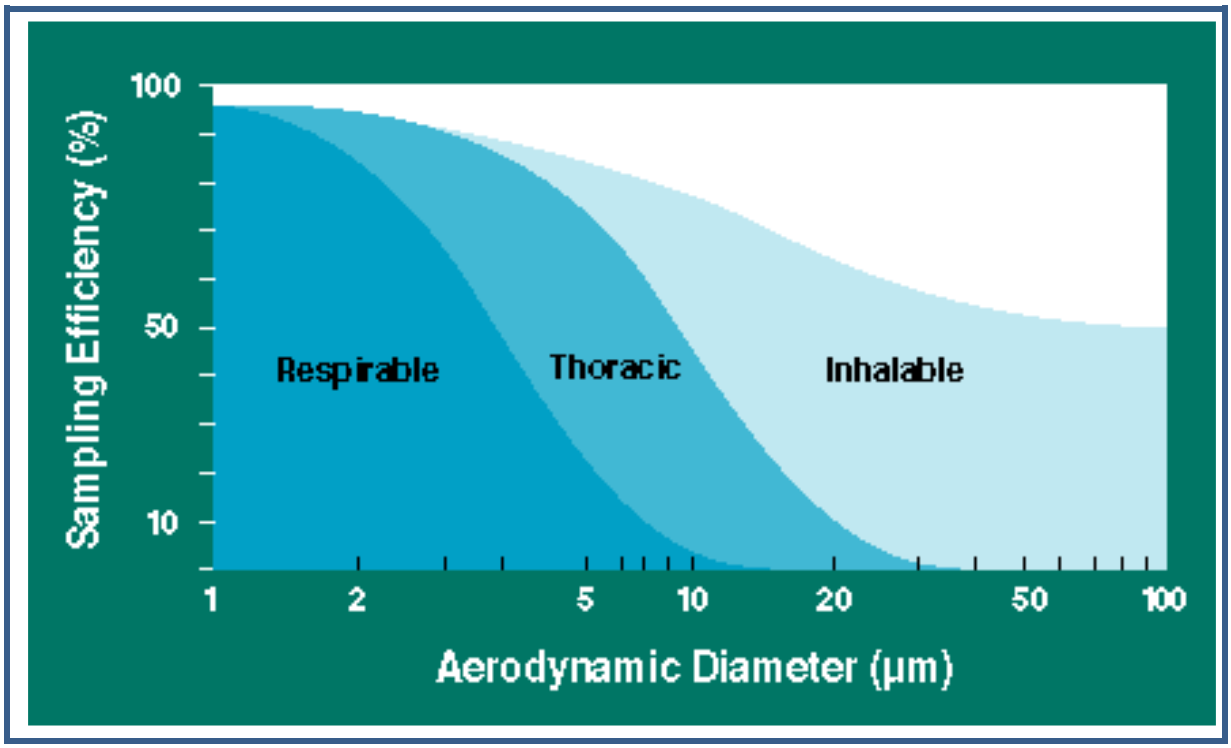
The adverse effects of dusts, fumes and fibres depend on particle size and chemical composition. Particle size is important because it influences where in the body the particles may be deposited. Chemical composition is important to understand the intrinsic toxic (i.e., hazard) properties of the material in question.

5.2 Particulate Deposition

The fraction of particles that are inhaled depends on factors such as speed and direction of air movement around the body, rate of breathing, whether breathing is through the mouth or nose.

Inhaled particles may then be deposited along the respiratory tract or may even be exhaled with exhaled breath.

Figure 5-1 The Differences Between the Different ISO Fractions



Source: TSI Inc, Reproduced with Permission

Over the years, various terms (e.g., total dust, total inhalable dust, inspirable dust) have been used regarding airborne particles, sometimes inconsistently. However, the general consensus is that the International Standards Organisation (ISO 1995) conventions are most appropriate. ISO 1995 has defined three sampling conventions (inhalable, thoracic and respirable) for use in assessing potential health effects of airborne particles in the workplace.

Inhalable fraction: The mass fraction of total airborne particles inhaled through nose and mouth. In general terms the inhalable fraction includes all particles <100 µm, though it may include larger particles, although there is no data to support this.

Thoracic fraction: The mass fraction of inhaled particles that penetrate the respiratory system beyond the larynx.

In general terms the thoracic fraction includes all particles <50 µm and having a 50% cut (of total airborne particles) of about 10 µm.

Respirable fraction: The mass fraction of inhaled particles that reach unciliated airways (alveoli) where gas exchange takes place. In general terms the respirable fraction includes all particles <16 µm (majority <10 µm) and having a 50% cut at about 4 µm.

The importance of the above deposition curves cannot be overstated as this links the potential health effect with the sampling device necessary to assess the potential health risk.

For example, consider the following dust examples, common in the international mining environment, coal and lead dust. If we first consider the health effect of each:

- Coal dust: Gives rise to the respiratory disease “pneumoconiosis” whereby normal lung tissue is replaced by fibrous scar issue due to the long-term inhalation of coal dust. Here, the issue is respirable dust.
- Silica Dust: Prolonged exposure to respirable silica is associated with scarring of the upper lobes of the lung (silicosis), as well as with lung cancer. These effects do not occur if silica dust is too large to be respirable.
- Lead dust: Lead is a systemic poison which has been associated with kidney dysfunction, increased blood pressure and sperm abnormalities. Historically the major toxic effect of lead has been on the blood system, resulting in anemia. Thus, inhalable fraction is of greatest interest.

Figure 5-2 Respirable Dust Sampling Train

Source: University of Wollongong

5.3 Particulate Air Sampling

5.3.1 General

Exposures to airborne particulates can be evaluated through traditional air sampling methods that involve drawing air at a known flow rate through a pre-weighed membrane filter for a specified time, and later submitting the filter to a laboratory for gravimetric analysis (i.e., post sample weight to determine mass of particulate collected over a specified time). These filters may be mounted in different housings (or sampling heads) as detailed in Sections 5.4 to 5.9.

In earlier times, it was common practice for industrial hygienists to weigh sample filters before and after. Nowadays, sample filters are weighed before and after in a laboratory.

Airborne particulates are typically sampled using a sampling train that consists of a calibrated air sampling pump connected to the sample filter via a short length of tubing as shown in Figure 5-2 which shows a sampling train for respirable dust.

Sampling trains can also be assembled for other types of particulates, as described in Sections 5.4 to 5.9.

Once assembled, and calibrated (see Section 6.3), the sampling train is installed on a worker of interest. The pump is usually attached to the worker's belt. It's a good idea to have spare web belts or a suitable harness to mount the air sampling pump if the worker is not wearing a belt. Some practitioners have also used vests to hold the equipment and reduce worker inconvenience.

It is important to place the sampling head near the worker's breathing zone as shown in Figure 5-3.

The standard convention for placing the sampling head is in a worker's breathing zone. In the case of welding fume evaluations, if possible, the sample head needs to be placed inside the welding helmet, rather than outside as this will overestimate actual exposure.

The following sections provide details on commonly used particulate sampling methods and is not intended to be all inclusive. Other methods may be specific to certain industries, jurisdictions and regulations (local or national). Practicing occupational hygienists are advised to be familiar with local requirements in addition to industry standards.

Figure 5-3 Sampling Train Placed on Worker

Source: University of Wollongong

Exposures to airborne particulates can also be achieved through direct reading real-time instruments as discussed in Section 5.3.1

5.3.2 Sample Filters

There are a variety of airborne particulates of occupational hygiene interest that are captured onto different filter media for subsequent analysis for the contaminant of interest from the air being sampled.

The choice of collection media will normally be dictated by the choice of sampling method, and by analytical considerations. In general, there are three types of mechanisms which capture particles during filtration. These are:

- Interception (impingement) – This occurs when the particle is smaller than the pore of the filter.
- Inertial Impaction – This occurs with a change in direction of airflow and requires high velocities and dense fibre packing of filters.
- Diffusion – This occurs with very fine particles and occurs at low flow rates and is assisted by electrostatic forces.

There are a number of properties that are desirable (but not always present) in filter media. These include:

- High collection efficiency that is known
- Manageable resistance (particularly as the load on the filter increases)
- Low moisture picks up or loss
- Low electrostatic properties
- Compatibility with the selected analytical technique
- Low cost

Not all these properties are achievable in one filter so the selection of a particular filter media for a particular measurement becomes one of compromise.

The filter selection guide below shows which filters can be used for particular contaminants, but local or statutory requirements may necessitate using an alternative.

Notwithstanding the information provided above, many Occupational Hygienists choose not to use mixed cellulose ester filters for metal fume – metal dust analysis due to the poor electrostatic properties which make them difficult to weigh. Alternatives commonly used include glass fibre or polyvinyl chloride.

One aspect of filter selection that is sometimes confusing concerns pore size. When sampling for respirable dust (50% cut at 4 µm), it is not uncommon to use a filter (PVC) of nominal pore size 5 µm. This seems illogical but since most membrane filters allow air to follow a tortuous path, aerosols smaller than 1 µm are commonly captured. However, this does not apply to polycarbonate filters which allow air to pass straight through because of how they are built.

Two other features of filters are critical and can cause significant errors in gravimetric analysis if not considered. These are moisture and electrostatic charge.

In the case of some filters (especially membrane filters), moisture pick-up or loss can be significant. This can be corrected for by the process of “equilibration”. This process requires that sample filters and a suitable number of blanks be placed in clean containers with the lids slightly ajar, in the balance room where they are to be weighed. They are then left for a suitable time to come to equilibrium with the balance room atmosphere (overnight, but this may depend on the filter type) before weighing. At the end of the sampling exercise the process is repeated and a correction made for any gain or loss of mass in the blank filters (this should be minimal if the balance room atmosphere is well controlled).

The other critical issue is electrostatic charge. This can be overcome by the use of a static eliminator (usually an Americium 241 or Polonium 210 source). A high voltage static eliminator may be used but it should be checked to ensure that it does not punch holes through the filter.

Table 5-1 Filter Selection Guide

Material	Main Properties	Air Sampling Applications
Mixed Cellulose Ester (MCE)	Hydrophilic Readily soluble for atomic absorption analysis Readily rendered transparent for transmitted light microscopy Dissolves and clear easily	Metal dust analysis Asbestos and man- made fibres
Polyvinyl Chloride (PVC) (Pure homopolymer)	Hydrophobic Non-oxidizing surface Silica-free Low ash Low tare weight for gravimetric analysis	Gravimetric analysis of dusts Hexavalent chromium Quartz analysis by IR spectrophotometry
Polytetrafluoroethylene (Teflon)	Hydrophobic Inert to solvents, acids and bases Autoclavable	Alkaline dusts Polynuclear aromatics (PNA) Pesticides
Polycarbonate	Hydrophobic Microscopically smooth surface Straight-through pores Extremely thin (10 –20 µm) and transparent Autoclavable	Scanning electron microscopy Asbestos fibres
Silver	Wide solvent compatibility Higher temperature tolerance Autoclavable Uniform porosity and thickness	Bromine Asbestos by TEM Silica by x-ray diffraction
Glass Fibre (MMMF)	Partially hydrophobic Higher temperature tolerance Autoclavable High particulate retention	Pesticides Coarse gravimetric analysis Isocyanates Ethylene glycol
Quartz	Low level metals content High temperature 300°C Autoclavable	Particulate Matter less than 10 micrometres (PM10) Diesel particulates
Cellulose	Autoclavable Uniform strength Ashless (Type 40)	AA HPCL

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One final aspect needs to be considered and that is the transportation of dust-laden filters after collection. Experience has shown that the layer of dust on the filter is fragile and any shocks or vibration may cause loss of material unless precautions are taken. The safest way is to deliver samples to the lab is by hand. If not possible, then filters should be carefully packed to avoid dislodging collected dust from the filter.

5.3.3 Basic Sample Collection Procedure

As indicated above, air sampling for particulates requires assembling a sample train consisting of a calibrated air sampling pump connected to the appropriate air sample collection device (also known as sampling head). Sections 5.4 to 5.9 provide details on commonly used particulate air sampling heads.

The following are the basic steps for air sampling:

- Calibrate pump flow rate with sampling head attached (see Section 5.4.1)
- Place pump on worker of interest. Record relevant information (e.g., Name, location, job classification, work activities, date, temperature, engineering controls, personal protective equipment used, anticipated breaks, etc.) The use of a standard form to collect information consistently is recommended (e.g., AIHA's).
- Secure air sampling head in worker's breathing zone.
- Turn pump on, and record time. Allow worker monitored to go about their business.
- Periodically verify that pump is still in operation by inspection of pump mounted flow meter. Inspect and review processes of interest to verify activities monitored are as expected. Keep detailed notes. You will find them useful later when reviewing the results.
- At the end of the sampling period, note time, and record flow rate at end of sampling period. Post sampling flow rates should be within ± 5% of pre-sample flow rates. If the difference is greater, the sample should be considered invalid.
- Use the difference in the start and end times to calculate the period sampled in minutes.
- Carefully remove the air sample filter cassette, weigh if analysing on-site, or package and send to the lab. You will need to calculate the sample volume (i.e., product of sample time and average before and after flow rate). Be sure to indicate units of measure for volumes (i.e., how many cubic metres or litres).
- See Section 5.11.2.2 for example calculation.

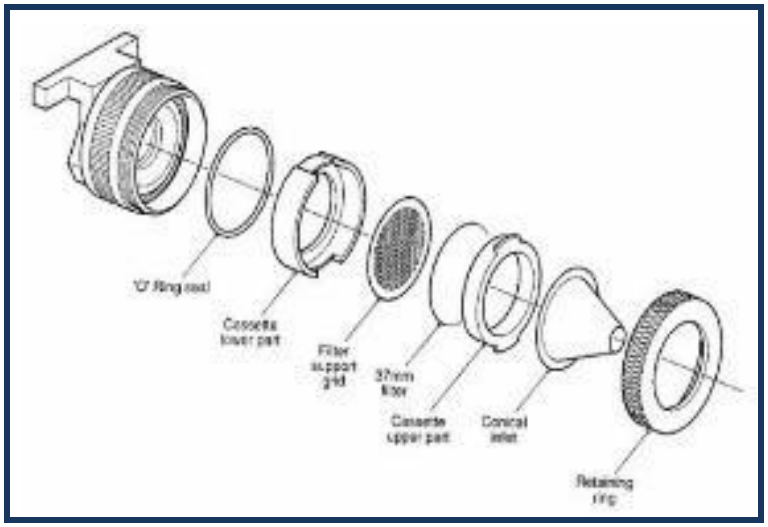
Sections 5.4 to 5.9 provide details on commonly used particulate sampling methods and is not intended to be all inclusive. Other methods may be specific to certain industries, jurisdictions and regulations (local or national). Practicing occupational hygienist are advised to be familiar with local requirements in addition to industry standards.

Figure 5-4 IOM Sampling Head

Courtesy: University of Wollongong

Exposures to airborne particulates can also be achieved through direct reading real-time instruments as discussed in Section 5.15.

Figure 5-5 CIS Sampler



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5.4 Inhalable Dust

There are a number of sample collection devices for measuring airborne inhalable dust as detailed below. A number of comparative studies conducted over the years indicate that the Institute of Occupational Medicine (IOM) Sampling Head has been shown to give the best agreement to the ISO criteria for inhalable dust under the widest range of workplace conditions and is therefore the preferred method of sampling inhalable dust in many (but not all) countries.

5.4.1 IOM Sampling Head:

This device (Figure 5-4 IOM Sampling Head) was developed by the UK Institute of Occupational Medicine (IOM). It consists of a single orifice entry and a filter contained within a cassette. The sampler requires a sampling pump operating at 2 L/mins and an appropriate filter.

5.4.2 Conical Inhalable Sampler (CIS)

This device (Figure 5-5) was developed in Germany. It is known as either the Conical Inhalable Sampler (CIS) or GSP sampler. It requires a sampling pump operating at 3.5 L/min. This device can also be used with porous foam plugs and specific cassettes so as to sample the respirable or thoracic fractions.

Figure 5-6 SKC Button Sampler

Source: SKC - Reproduced with Permission

5.4.3 SKC Button Aerosol Sampler

This device (Figure 5-6 SKC Button Sampler) was originally developed for the collection of inhalable bioaerosols but has been found to closely follow the ISO sampling criteria for inhalable dust when operated at a flow rate of 4 L/min.

5.4.4 Pre-Loaded Cassettes

The commonly used approach in the United States of America (USA) is to use 37-mm pre-weighed PVC membrane filter loaded into a plastic cassette (Figure 5-7) to measure "total particulate dust not otherwise regulated", sampled at a flow rate of 1 to 2 L/min per NIOSH

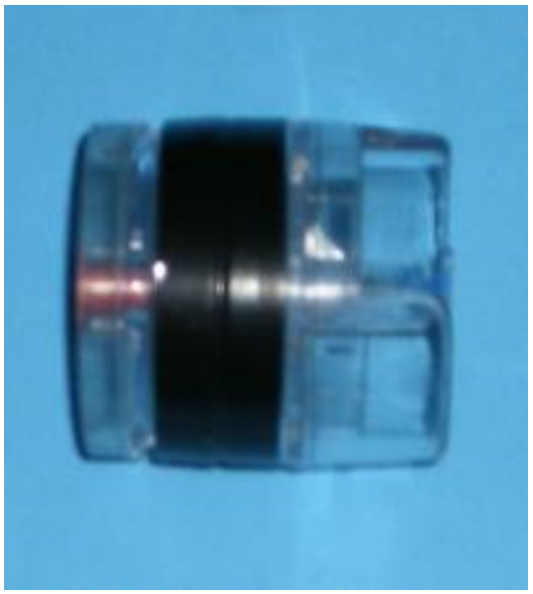
Method 0500. Note that this approach does not correspond to ISO criteria so it should not be used to sample for that purpose.

5.5 Respirable Dust

The respirable fraction of airborne dust can be collected using any of several miniature cyclones developed over the past 30+ years. These cyclones separate airborne particulates into respirable from non-respirable fractions and allow the collection of the respirable fraction onto a pre-weighed membrane filter, usually mounted in a sampling cassette.

Available cyclones include British Cast Iron Research Association (BCIRA), Safety In Mines Personal Environmental Dust Sampler (SIMPEDS), Dorr-Oliver, and Aluminum. All operate under the same principle (see Figure 5-8), albeit at different flow rates. All require a steady flow rate to select aerosol into the correct fraction (i.e., 50% cut at 4 µm) as listed in

Figure 5-7 Pre-Loaded 37 mm Plastic Cassette



Source: University of Wollongong

Figure 5-8 Mini Cyclone

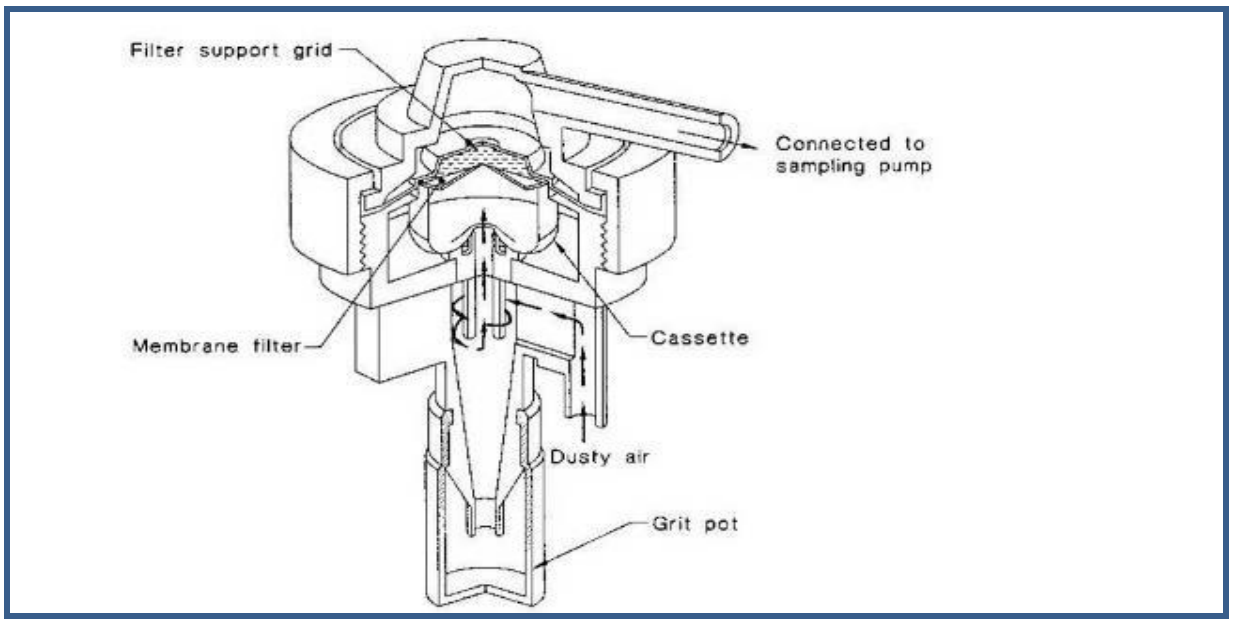


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Table 5-2 Required Flow Rates for Different Cyclone Types

Cyclone Type	Required Flow Rate (L/m)
BCIRA Cyclone	2.2
SIMPEDS Cyclone	2.2
Aluminum Cyclone	2.5
10 mm Nylon Cyclone (Dorr-Oliver)	1.7
SKC Cyclone Model 225-69	3.0

5.6 Thoracic Dust

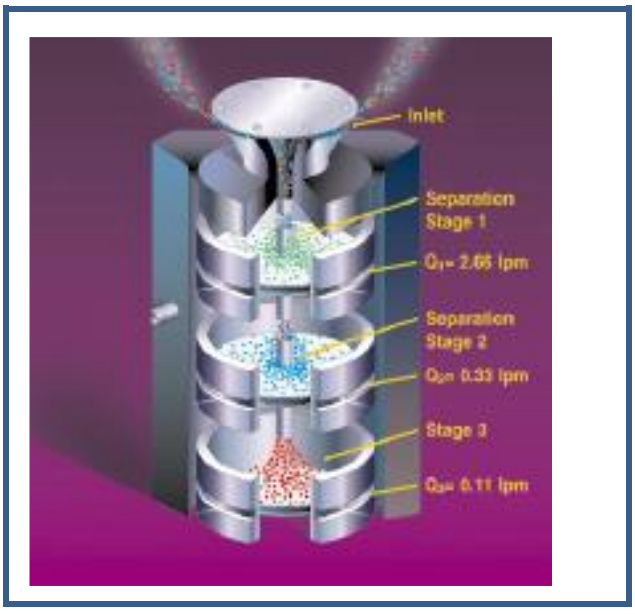
It should be noted that in practice it is unusual for there to be a need to measure airborne dust in the thoracic size range. One exposure limit that does specify the thoracic fraction is for sulfuric acid mist, although being a mist strictly speaking this is not a dust.

There are several different approaches to measure the thoracic fraction of airborne dust. One device, the “Respicon” (Figure 5-9 Respicon Sampler) is a multistage impactor that traps the various size fractions on to individual collection filters of 37 mm diameter (Figure 5-10 Schematic of Respicon Stage Impaction). A sampling pump operating at 3.1 L/mins is required as is a 4 µm stage 1 cut module.

Figure 5-9 Respicon Sampler

Sour Source: TSI, Inc. - Reproduced with Permission

Figure 5-10 Schematic of Respicon Stage Impaction



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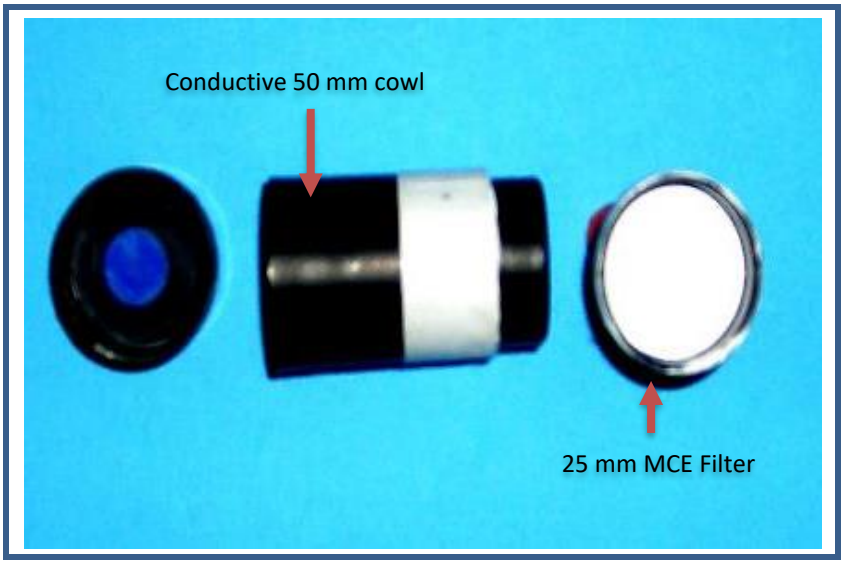
A second approach to measuring the thoracic fraction is the use of polyurethane foam filters specifically designed to separate the individual fractions. These foam filters can be inserted into

either the IOM or CIS sampling head (see Figure 5-10 and Figure 5-5) to act as size selection devices, with the individual dust fractions being collected on membrane filters.

Figure 5-11 3-Piece Conductive Cassette for Fibre Sampling



Source: University of Wollongong

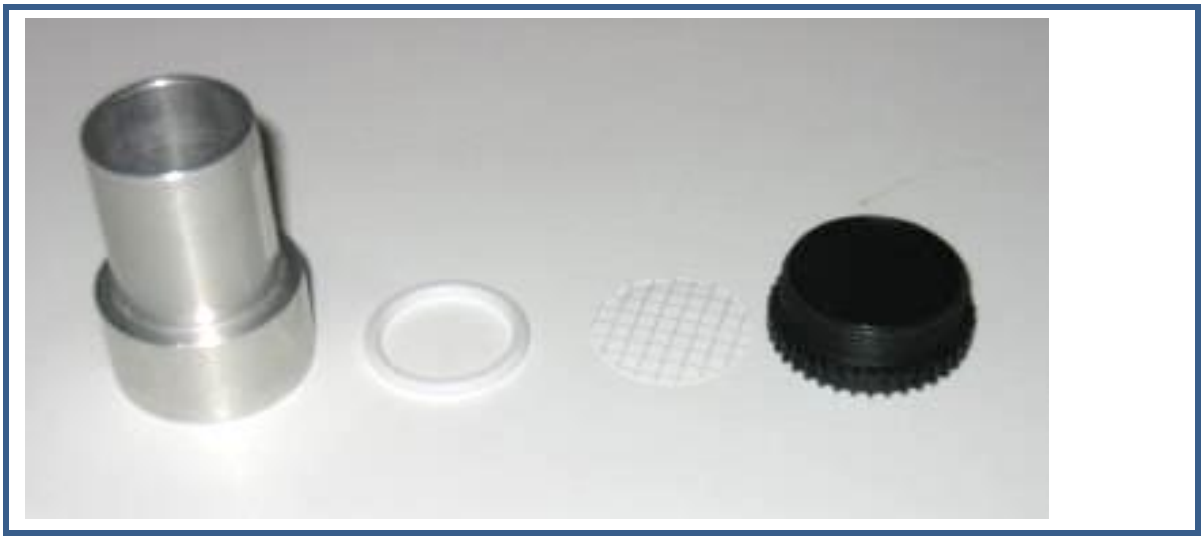
A third device called the CIP 10 has been developed in France by the French National Institute for Research and Safety. It is based on the novel method of separation using annular impaction within a rotating housing containing a miniature filter made of polyurethane foam. The device comes in three versions depending on the inter-connectable selector that is installed. Both the respirable and inhalable versions operate at a flowrate of 10 L/min, but the thoracic version operates at 7 L/min. - for details of how the CIP 10 is used see https://airsamplingdevices.com/video-ppts/.

5.7 Fibres

Samples for airborne asbestos or synthetic mineral fibres (SMF) are usually collected on to an open-faced membrane filter in a three-stage cassette fitted with an electrically conductive cowl. This method uses optical microscopy to count fibres in a section of the membrane filter that is dissolved with acetone in the lab instead of gravimetric analysis used for particulates.

Airborne fibres are collected on to mixed cellulose ester (MCE) membrane filters instead of commonly used pre-weighed PVC filters. Membrane pore size is typically 0.8µm although 1.2µm is used in some countries.

Figure 5-12 Metal Cowl and Sampling Head for Fiber Sampling



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MCE membrane filters are preferred for airborne fibre sampling because they can be dissolved in acetone to allow mounting of a section of the filter onto slides that allow fibre counting by optical microscopy.

Figure 5-11 3-Piece Conductive Cassette for Fibre Sampling shows a widely used filter assembly used for airborne fibre monitoring:

Personal fiber air samples are usually collected at 1-4 L/m whereas samples collected following asbestos removal are collected at rates of 8-15 L/m. The latter requires mains electricity so is not suitable for personal sampling.

Figure 5-13 Diesel Emission Particulate Filter

Source: SKC, Inc. Reproduced with Permission

Figure 5-12 Metal Cowl and Sampling Head for Fiber Sampling shows original metal design for fibre filter collection.

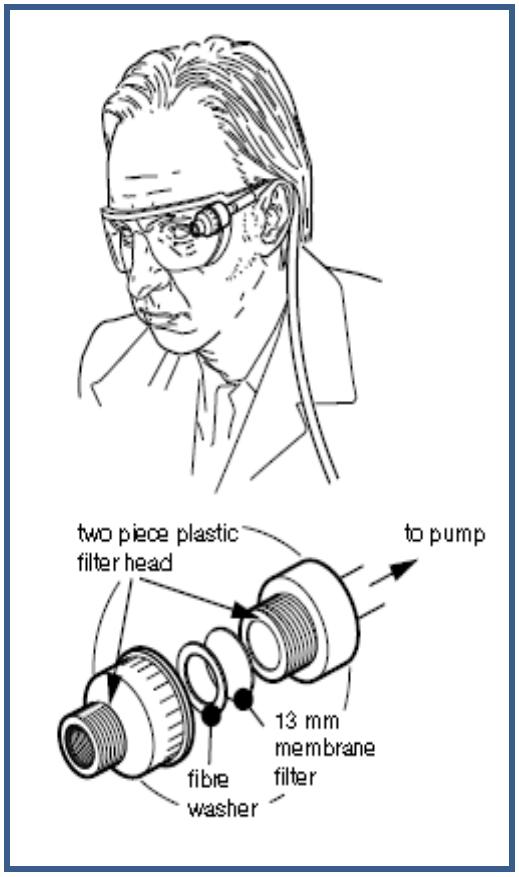
5.8 Diesel Particulate Emissions

Nowadays, diesel particulate emissions (DEP) exposures can be evaluated using a specialty cassette as shown in Figure 5-13.

This device (Figure 5-13 Diesel Emission Particulate Filter) contains an integral precision-jeweled impactor that screens out particles >1 µm. This is important for workplaces where there may be other airborne particulates such as coal mines. The DEP sample is collected into a heat-treated quartz filter to facilitate laboratory analysis.

The DEP cassette can be used in conjunction with a cyclone where airborne dust levels are high enough to potentially overload the built-in impactor.

Figure 5-14 Sampling for Rosin Based Solder Flux Fume



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5.9 Rosin Fume

The UK Health & Safety Executive has developed a unique method for sampling of rosin acids in rosin (also known as colophony) solder flux fume (see method MDHS 83/2).

Sampling in this case is performed by using a 13 mm Millipore Swinnex type sampling head containing a 5 µm pore size mixed cellulose ester filter. Sample rates of between 1 and 2 L/mins are recommended,

depending on the fume load in the atmosphere. The sampling head is attached to the worker's safety glasses as indicated in Figure 5-14.

5.10 Air Sampling Pumps

Typically, calibrated air sampling pumps are used to draw air through the appropriate sample filter. Pumps are connected to the sample filter via short lengths of flexible tubing, often Tygon or similar material. Most pumps are battery operated to allow an operator to wear the sampling train so as to collect personal breathing zone samples. However, in some circumstances, electrically powered pumps can be used to collect area air samples.

There are three types of air sampling pumps: diaphragm, rotary vane and piston. Table 5-3 Comparison of Different Type of Air Sampling Pumps compares these types of pumps.

Figure 5-15 Dual Sampling Head Set

Source: SKC

Table 5-3 Comparison of Different Type of Air Sampling Pumps

	Diaphragm	Piston	Rotary Vane
Power Consumption	Low	Medium	High
Battery Size	Small	Medium	Large
Weight	Low	Medium	High
Repair	Simple	Difficult	Moderate
Cost	Cheap	High	Medium
Flow Smoothness	Strongly pulsating	Mildly pulsating	Smooth
Pressure Drop Limits	About 5 kPa	None	None
Valve Problems	Can leak	Can leak	No valves

The most commonly used type of pump in industrial hygiene work is the diaphragm pump. Its principle of operation is illustrated in Figure 5-15.

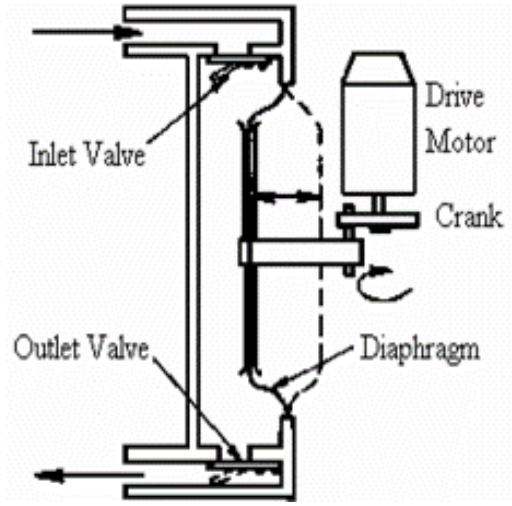
Most particulate air sampling pumps have an operating range of 0.5 to 5 L/M, although most particulate air sampling methods call for 1 to 2.5 L/M.

There are a variety of available air sampling pumps from different manufacturers. The following are useful features for particulate air sampling pumps:

- Automatic flow control: Automatic flow control ensures that flow rates remain constant over the sampling period as the sample builds up on the filter creates additional loading (back pressure) on the pump. Excessive back pressure can reduce sample air flow rates, and can also result in early pump shut off.

- Pulsation dampening: This is critical when sampling using a cyclone as variations in air flow alter the cutoff point of the sampling device. Pulsation dampening is needed on reciprocating pumps but is not necessary on rotary vane pumps (see Table 5-3).

Figure 5-16 Diaphragm Air Sampling Pump Schematic



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- Capacity to operate at a reasonable back pressure: As material builds up on the capture filter the back pressure on the sampling pump will also increase. Capacity is related to, but slightly different from, automatic flow control. The latter concerns the pump automatically speeding up as back pressure increases in order to keep the flow rate constant throughout the sampled period. Capacity is about the maximum back pressure that the pump can overcome.

- Ability to set flowrates over a reasonable flow range: Necessary as capture devices vary in flow rate requirements.

- Good battery capacity: This allows continuous operation for the full duration of a work shift.

- Intrinsically safe: This is a mandatory requirement for those pumps that are used in workplaces where the risk of an explosion may be high (e.g., coal mines, oil refineries).

Figure 5-17 Soap Film Meter

Source: SKC - Reproduced with Permission

- Battery charge: Some types of pump battery (e.g., Nickel-Cadmium) have an unusual characteristic in that they can develop a "memory effect" if operated for short periods and then recharged. Subsequently, these types of batteries may only operate for short periods. This can be overcome by “cycling” the battery. This entails running the pump (can be after the sampling period) until the battery is nearly exhausted and then recharging it. This cycle should be repeated several times. If after this process the battery still has a “memory effect” a new battery should be installed. This effect is less common with newer Nickel Metal Hydride batteries. Modern chargers are designed to adjust

the flow of current to the battery so that they are maintained on “trickle” charge (instead of overcharging) so that they are ready for use. Some chargers also have a discharge/recharge feature that makes battery cycling very simple.

- Internal flowmeters: Flow meters built into sampling pumps are generally not considered accurate, and so should not be relied upon for calibration purposes (see Section 5.11). However, they provide a quick visual indicator that the pump is running (or not).

5.11 Pump Calibration

5.11.1 Basics

The accurate analysis of atmospheric dust concentrations is dependent on the determination of the mass of dust, fume or fibre on the collection media (either gravimetrically, chemical analysis or microscopy) and the total volume of air sampled (i.e., total number of m^3 of air sampled).

The purpose of pump flow calibration is to set the sample flow rate at the specified rate, and to verify sample flow rate at the end of the sampling period. The sample volume can be calculated based on average flow rate (provided it remains within a range of accepted variability, usually ± 5%) and sample time (see Section 5.12).

Figure 5-18 Rotameter

Source: SKC- Reproduced with Permission

Figure 5-19 Electronic Flow Meter

Source: University of Wollongong

Good occupational hygiene practice requires that a path of traceability is established and maintained. This is via use of either a primary or secondary standard. Primary standards are directly traceable to a national standard and are not significantly affected by variables such as temperature and pressure. However, primary standards are often impractical for field use, so it is common practice to use secondary standards. Examples of primary standards are:

- Soap film meters (also known as bubble burette) - See Figure 5-17 Soap Film Meter
- Wet test gas meter

- Bell spirometer

A secondary standard references a primary standard. As such, secondary standards need to be calibrated at regular intervals against a primary standard. In the case of rotameter use, it will be necessary to correct for differences in atmospheric temperature and pressure between site of rotameter calibration and site of rotameter use.

In certain countries, some electronic calibration units (e.g., BIOS Frictionless Piston) are considered primary standards. However, third party accreditation bodies do not agree.

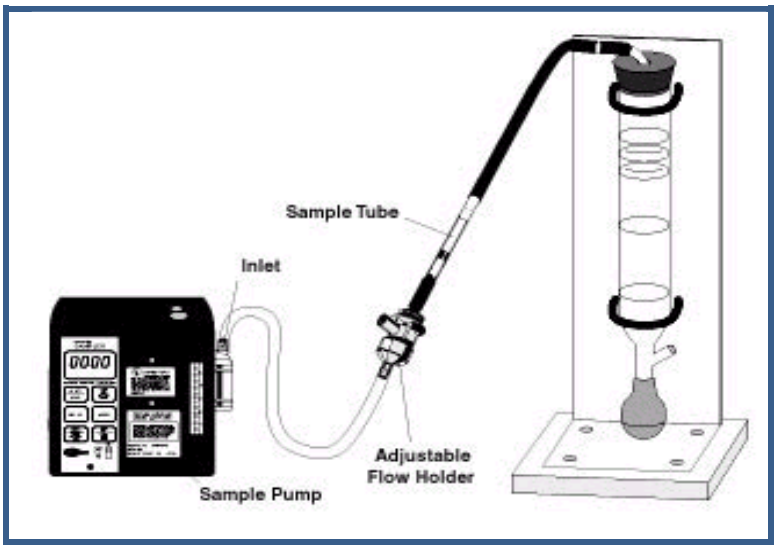
Examples of secondary standards commonly used in occupational hygiene monitoring are:

- Electronic meters
- Rotameters

Rotameters can have two different types of floats. With the ball type of float the air flow reading is taken at the centre-line of the ball. With the cone type of float the air flow reading is taken at the top of the float.

Figure 5-18 and Figure 5-19 show some typical secondary standards.

Figure 5-20 Calibration with Bubble Flow Meter



Source: University of Wollongong

5.11.2 Calibration Procedure

5.11.2.1 General Practices

When measuring or setting sampling pump airflow, the following points should be considered:

- Always calibrate a sampling pump with a sample head identical to what will be used in the field. Figure 5-20 Calibration with Bubble Flow Meter shows a calibration set up for vapours sampling.
- Allow the sample pump to stabilize for at least 5 minutes after it has been switched on. Adjust the flow to the required flow rate.
- Measure the pump flow rate until three consecutive results are within ±2% of the mean. This accuracy is easily achievable using an electronic calibrator, which is the preferred technique. It is also achievable with a soap film meter, but it may not be
- possible using a rotameter. Use the mean value of the three consecutive results for airflow calculation (Section 5.12).

- Changes in environmental conditions can adversely affect the accuracy of a calibration device.
- Flow rate measurements at altitudes differing by more than 500 m from calibration of secondary standard.
- Temperature differing by more than 15°C from that at the previous calibration.

Figure 5-21 Calibration with Electronic Flow Meter

Source: University of Wollongong

The following suggested calibration schedule for sampling equipment is provided as guidance only and reference should be made to national standards or local statutory authorities.

5.11.2.2 Suggested Calibration Intervals

Table 5-4 Calibration Intervals

[As Suggested by A Group Of Experienced Occupational Hygienists]

Item	Maximum Interval Between Successive Calibrations	Comments
Pumps	On use	Flow check
Pumps: Direct and Indirect Automatic Flow Control	Initially 12 months but after 3 consecutive tests (i.e., two years) with results within ±5%, the interval can be lengthened to three years	
Rotameters	Monthly for 3months. If results are within ±3%, interval can be extended (one-year small bore and two years large bore)	Calibrated against a primary flowmeter over range of use
Soap Film Meter	On commissioning	Check volume marks
Electronic Meters	Monthly for three months then if measurements are within ±3% of expected results, the interval can be extended to six months	Calibrated against a primary flowmeter over range of use
Stop Watch	Every 6 months	Against a national time system (speaking clock) over at least one hour (see UKAS requirements for asbestos sampling accreditation)
Balances (Electronic)	1 month 6 month 12 months 36 months	One point check Repeatability check Service Full range calibration by external accredited calibration authority

5.12 Calculation of Particulate Air Sampling Results

5.12.1 Calculation of Sample Volume

Example Sample Volume Calculation:

Let the pre-sample flow rate be 2.0 L/m

Let the post-sample flow rate be 1.9 L/m

Note this is acceptable since the difference before and after is 5%.

Then the average flow rate (FR).

$$\mathrm{FR} = \frac{2.0 + 1.9}{2}$$
$$\mathrm{FR} = 1.95\ \mathrm{L/m}$$

Now, let's say you sampled for 7.75 hours at that average rate. That is equivalent to 7.75* 60 minutes.

Then, the volume, V litres, would be given by the following:

$$\mathrm{V} = \mathrm{FR\ (L/min)} * \mathrm{Time\ (min)}$$
$$\mathrm{V} = 1.95 * 7.75 * 60$$
$$\mathrm{i.e.\ V} = 906.75\ \mathrm{litres\ or}\ 0.907\ \mathrm{m}^3$$

It's important to indicate air sample volume units (litres or m^3) when submitting samples to the lab.

5.12.2 Calculation of Particulate Mass

Most dust samples are analysed gravimetrically to establish the total amount of dust on the filter (usually in mg). This is done by subtracting the pre-weight of the filter from the post weight of the filter and correcting for moisture pick-up or loss via a blank correction. Thus, the weight of the dust on the filter is:

$$Mass = Post\ Sample\ Filter\ Weight - Pre\ Sample\ Filter\ Weight\ - Blank\ Correction$$ ...Equation 5-1

Example Dust Mass Calculation:

Let the pre-sample weight of filter be 5.76 mg.

Let the post-sample weight of filter be 7.84 mg.

Let the blank correction be - 0.01 mg.

Then the corrected mass on the filter, m (in mg) is given by

$$m = 7.84 - 5.76 - (-0.01)$$

$$m = 2.09\ mg$$

5.13 Calculation of Air Sample Result

To calculate the air concentration of dust (usually in mg/m³), it is necessary to know the mass collected over the sampling period (see Section 5.12.2 above), as well as the volume of air that flowed through the filter during sample collection (see Section 5.12.1 above).

So, say that your dust sample contained 2.09 milligrams of dust, and that you sampled 0.907 m³ of air. That is equivalent to a dust air concentration of:

$$Dust\ Conc.(\ 〚mg/m〛\ ^3) = (2.09\ mg)/(0.907\ m^3\ )$$

$$Dust\ Conc. = 2.30\quad 〚mg/m〛^3 \qquad \text{...Equation 5-2}$$

5.14 Calculation of 8h-Time Weighted Average

The equation to calculate 8-hour time weighted average exposures is:

$$8h\ TWA = (C\_1 * T\_1 + C\_2 * T\_2 + \ldots\ldots C\_n * T\_n)/8 \qquad \text{...Equation 5-3}$$

Where C_1 is the concentration for Time period T_1 (in hours)
C_2 is the Concentration for Time period T_2 (in hours)
C_n is the Concentration for Time period T_n (in hours)

Care is advised in making sure that time values are in the same units. If time T is measured in minutes rather than hours, the denominator becomes 8*60 i.e., 480 minutes.

Consider the following data:

Table 5-5 Data for TWA Example Calculation

Working Period	Sampling Duration (h)	Dust Exposure Result (mg/m³)
08:00 to 10:30	2.50	0.32
10:45 to 12:45	2.00	0.07
13:30 to 15:30	2.00	0.20
15:45 to 17:00	1.25	0.10

What is the worker's 8h-TWA dust exposure based on the above results?

Note that there is no exposure data between 10:30 to 10:45, 12:45 to 13:30 and 15:30 to 15:45, which would correspond to breaks and lunch. Assume zero exposure for these periods.

Using the equation above, the 8h-TWA exposure would be given by the following:

$$8h\ TWA = ((0.32 * 2.5) + (0 * 0.25) + \ (0.07 * 2) + (0 * 0.75) + (0.2 * 2) + (0.25 * 0) + (0.1 * 1.25))/8$$

$$i.e\ 8h\ TWA = \ 0.18\ mg/m^3 \qquad \text{...Equation 5-4}$$

5.15 Particulate Air Sampling: Direct Reading Methods

There are a number of instruments that measure airborne particulate matter in real time. Many have data logging capabilities, which allow minute by minute data that can be very useful in evaluating sources and or activities associated with dust exposures.

Figure 5-23 Personal Dust Monitor

Source: Thermo Fisher Scientific- Reproduced with Permission

Direct reading particulate air monitors include the TSI Dust Trak, and Thermo Scientific's Personal Dust Monitor (PDM). There are also other devices available such as the RAM and MiniRAM, not discussed in this manual. Users of any direct reading instrument are urged to be familiar with each instrument's use, calibration and limitations before use.

The TSI Dust Trak (Figure 5-22) uses laser photometry to detect light scattered by airborne dust particles. It can be very useful for evaluating dust control procedures and for pinpointing emission sources.

The instrument response depends on the size, shape and reflectivity of the airborne particles rather than on particle mass. Some instruments can give a mass readout, but this is only accurate if calibrated for the specific dust in question. Please refer to the manufacturer's instructions for further details.

Note that environments with elevated airborne moisture (e.g., sprays, water mist, etc.), will cause this instrument to over-respond (i.e., read higher than true). This issue, common to most optical detection-based instruments, needs to be taken into consideration.

Figure 5-22 Dust Trak

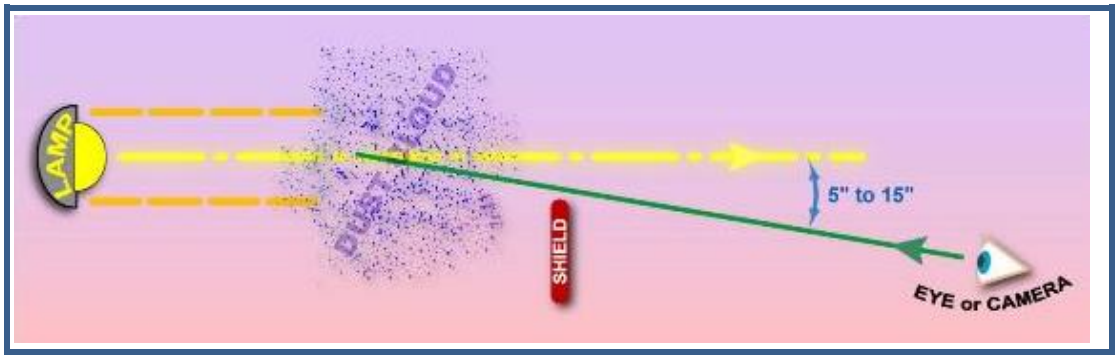
Source: TSI Inc. Reproduced with Permission

Thermo Fisher Scientific developed Personal Dust Monitor (PDM) for the US coal mining industry that uses a tapered element oscillating microbalance (TEOM to measure dust mass. It uses an internal heater to overcome moisture issues.

The dust lamp is an instrument that visually highlights airborne dust particles. Its application is explained in MDHS 82. It is based on the “Tyndall effect”, essentially light scattered by particles suspended in air, discovered by John Tyndall in the mid 1800’s.

Essentially, a bright beam of light is shone through the area where it is thought a particle cloud may be present. The particles present diffract the incident light and an observer looking up the beam to the source of the illumination (at an angle of about 5 – 15°) can see the dust particles. The process is described schematically in Figure 5-24 and can be a powerful tool if linked to photography or digital video equipment.

Figure 5-24 Principle of Dust Lamp



Source: HSE - Reproduced with Permission

This device has been included to demonstrate how a simple beam of light can be used to investigate possible sources of dust exposure but as with most things some level of knowledge and skill is required to achieve good results (see MDHS 82).

5.16 Particulate Air Sampling Selection Guide

Table 5-6 provides basic guidance on the selection of the appropriate sampling head, capture mechanism and flow rate for a range of contaminants. It is based on the experience of the authors and may not reflect local statutory requirements.

Table 5-6 Summary of Air Sampling Guide

Contaminant	Sampling Head	Collection Medium	Flowrate (L/min)	Comments
Asbestos and synthetic mineral fibres	Open face with conductive cowl	MCE membrane filter	1 – 4 (8 – 16 in UK)	0.8 µm pore size Requires conductive cowl (3-piece cassette). See Section 0
Respirable dust (including silica)	Miniature cyclone	PVC	1.7 – 3.0	5.0 µm pore size Depends on type of cyclone used See Section 0
Inhalable dust	IOM (or equivalent)	PVC or glass fibre filter	2	5.0 µm pore size Filter can be subsequently analysed for metals, etc.) See Section 5.4
Welding + other metal fumes	IOM (or equivalent)	PVC	2	0.8 µm pore size
Rosin solder flux fume	Millipore, Swinnex	MCE membrane filter	1 - 2	5.0 µm pore size Flow rate depends on fume load in atmosphere. See Section 5.9

PVC= Polyvinyl Chloride MCE= Mixed Cellulose Ester

Chapter 6 Gases and Vapours

This section describes and discusses general methods and procedures to evaluate airborne concentrations of gases and vapours. This section addresses:

- ✓ **What are gases and vapours?**
- ✓ **Basics of Air Sampling for Gases and Vapours**
- ✓ **Active Sampling Methods**
- ✓ **Sorbent Tubes**
- ✓ **Liquid Sample Media**
- ✓ **Passive Diffusion Monitors**
- ✓ **Example Calculations**
- ✓ **Direct Reading Instruments**

Review of relevant air sampling documents should be part of sample planning to get key information such as sample flow rates, sample collection media, limits of detection. Documents to consider would be NIOSH's Manual of Analytical Methods (NMAM) and the HSE's Methods for the Determination of Hazardous Substances (MDHS). In some jurisdictions, relevant regulations provide specific sampling details (e.g., OSHA certain substance-specific rules such as for asbestos, benzene, cadmium, lead.). Agencies such as UK's Health and Safety Lab and commercial labs are also useful resources as are some occupational hygiene equipment suppliers such as Casella, MSA, SKC etc.

6.1 What Are Gases and Vapours?

Gases are formless fluids that expand to occupy the space of any enclosure they happen to be in. They are neither solid nor liquids. Examples of gases of occupational hygiene interest are ammonia, carbon monoxide, chlorine and nitrogen oxides.

Vapours are the gaseous phase of a liquid at room temperature. They result from evapoursation of molecules from the surface of a liquid into the gaseous phase. Examples of occupational hygiene interest are solvents such as acetone, benzene, gasoline, as well as mercury in its elemental form.

You may hear the term fume in connection to solvents, paints etc. Technically, fume applies to finely divided particulates associated with hot processes (e.g., welding), so it is incorrect to talk about solvent fumes when you mean solvent vapours.

Some vapours are associated with certain solids. Here, molecules are going from solid to vapours phase in a process known as sublimation. One common example is dry ice (solid carbon dioxide). Other examples are arsenic, iodine, naphthalene (moth balls).

6.2 Fundamentals of Air Sampling for Gases and Vapours

There are four general methods for sampling gases and vapours in air

- Active Sampling
- Passive Sampling
- Grab Sampling
- Direct Reading Instruments

The first two approaches involve lab analysis. In the case of grab sampling, a volume of air is collected into a container (e.g., an evacuated flask, or a Tedlar bag) which is then sent to a laboratory for analysis for specified substances (see Figure 6-1 Sampling Train for Sorbent Tube. In the case of active sampling, air is drawn through a sorbent tube that absorbs the gas or vapours of interest (see Sections 6.3 and 6.4). The sorbent tube is submitted to the lab for analysis after the sampling period. Active air sampling is the most commonly used approach in occupational hygiene for solvent vapours.

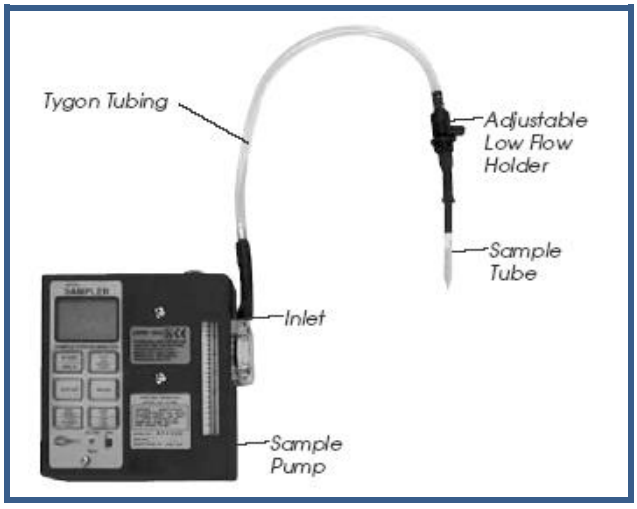
The third method, passive sampling, is a method whereby vapours of interest are allowed to diffuse into a sorbent material usually in a badge-type assembly, usually worn on the lapel. After a specified period of exposure, the badge is sealed, packaged and shipped to a lab for analysis. Further details on this method may be found in Section 6.9.

The fourth method, which involves the use direct reading instruments, is further discussed in Section 6.12.

6.3 Active Air Sampling: Basics

Active air sampling uses a sampling train, similar to particulate air sampling (see Section 5.3), except that air is drawn at a much lower rate (typically 0.050 to 0.200 L/m instead of 1 - 4 L/m) through an adsorbent tube (e.g., charcoal) instead of a filter. After lab analysis to determine the mass of contaminant collected in the sorbent tube, one can calculate air concentration based on the volume of air that passed through the sorbent.

Figure 6-1 Sampling Train for Sorbent Tube



Source: SKC - Reproduced with Permission

Figure 6-1 and Figure 6-2 shows a typical active air sampling train used with a sorbent tube.

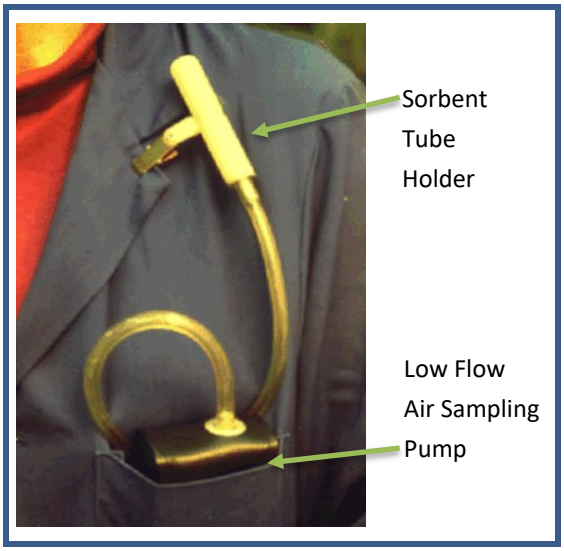
Air sampling pumps used for sorbent tube sampling are usually referred to as low flow pumps. Some air sampling pumps used for particulate air sampling may be converted for low flow use through the use of manufacturer supplied accessories (e.g., adjustable low flow holder shown in Figure 6-2 Air Sampling Train for Sorbent Tube). As

with particulate air sampling, these pumps would be attached to a worker's belt, with the sorbent tube located in the breathing zone. There are also available specialty low flow air sampling pumps that are much smaller and lighter, and are thus less burdensome for a worker to wear. The smaller pumps can be worn in a pocket rather than on a belt (see Figure 6-2).

In organic vapours sampling, total volume of air collected is most important rather than low pulsation flow; hence, some low flow pumps do not have as sophisticated flow control systems as dust sampling pumps.

As with particulate air sampling, the sampling flow rate needs to be set to the rate specified in the sampling method. In other words, the air sampling pump needs to be calibrated (with the sorbent tube in place), just as with dust air sampling before use, and verified after use. If the final (i.e., post sampling) flowrate differs from the initial flowrate by greater than ±5% (UK and US), the sample should be discarded and sampling repeated if possible. Australian Standards (AS) allow a greater variability (±10%) in flow rate before and after sampling. However, this is considered too high by many occupational hygienists. A variability of ±5% represents best practice.

Figure 6-2 Air Sampling Train for Sorbent Tube



Source: 3M Australia - Reproduced with Permission

Keep in mind that adsorbent tubes need to be sealed after use, and that there are limits to how long the sample can be kept before is analysed. This is usually specified in the sampling method. If you are collecting samples over several days, it is a good idea to keep samples in a refrigerator. In addition, it should be noted that some samples may need to be refrigerated immediately after sample collection and shipped cold, such as by using dry ice or freezer packs.

6.4 Sorbent Tubes

The use of sorbent tubes is based on the concept of adsorption whereby the gas or vapours of interest is collected by passing it over the surface of solid sorbent media such as activated charcoal, silica gel, porous polymers and molecular sieves, on to which the contaminant of interest is adsorbed. Section 6.4.1 describes different types of sorbent media. Collection efficiencies are affected by factors such as temperature, humidity, sampling rate, other contaminants and breakthrough (see Section 6.4.2).

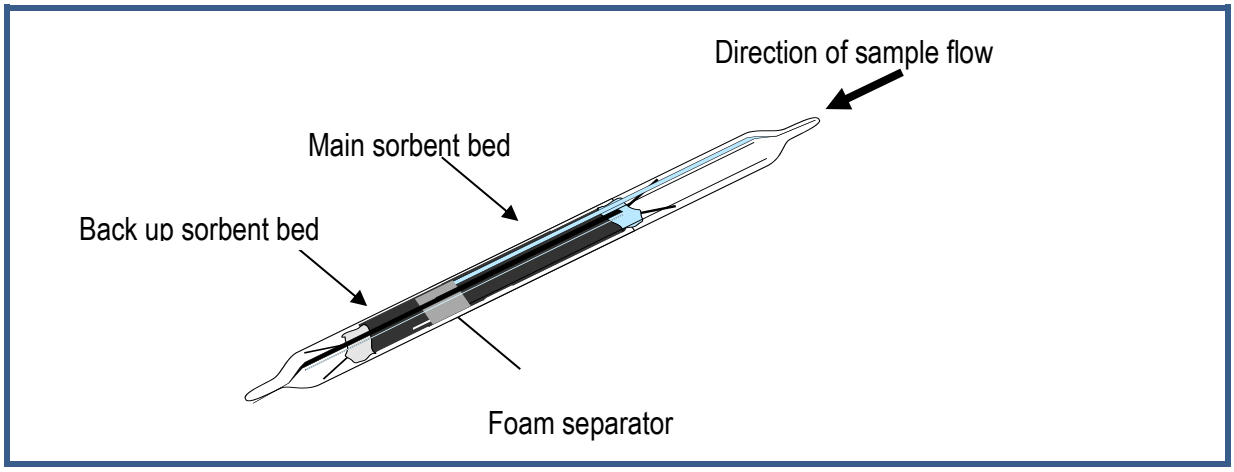
6.4.1 General

The adsorbent material is usually packed in a sealed glass tube as shown in Figure 6-3 Sorbent Tube. Before sampling, both ends of the glass tube need to be carefully broken off and the tube connected into the sampling train, usually via a sample tube holder. The printed arrow on the sampling tube shows the direction of the airflow. Insert the tube so arrow points towards the pump. If there is no arrow on the tube, insert the tube with the smallest sorbent section (referred to as the back-up section) into the tube holder so air flows through the main (largest) bed first.

At the end of the sampling period, after verifying flow rates (see Figure 6-3 Sorbent Tube), seal the ends of the tubes using the plastic caps that are provided with the sample tube. Be careful of sharp edges, and of using too much pressure to avoid shattering the tube and injuring yourself. After labeling the tube(s), it (they) needs to be sent to the lab for the required analysis. If you are batching samples over several days, it is good practice to store them under refrigeration. Please check the sample methods for maximum hold times (i.e., how long one can keep samples before analysis after which they become void).

Sample analysis involves separate desorption of each section of sorbent tube (i.e., front and back sections). This is commonly done using either solvents (e.g., carbon disulphide) or thermal methods in the lab.

Figure 6-3 Sorbent Tube

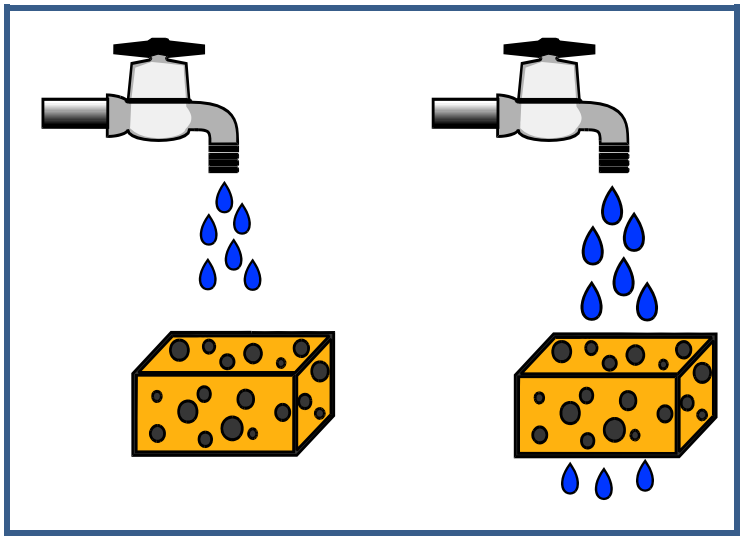


Source: SKC Inc – Reproduced with permission

6.4.2 Sorbent Tubes: Breakthrough

Breakthrough occurs when the sorbent is saturated and can adsorb no further contaminant from the air sampled, and can thus underestimate actual exposures. Figure 6-4 Illustration of Breakthrough Concept illustrates the concept using a sponge model. When a dry sponge is put in a water stream, it initially absorbs water without letting it through. Once it becomes saturated, water passes through.

Figure 6-4 Illustration of Breakthrough Concept



Source: SKC, Inc.: Reproduced with permission

Breakthrough can occur for any of the following reasons:

- Sample rate is too high, reducing contact time with sorbent material
- Large sample volumes
- Sample media has reduced affinity for sorbent medium

- Allowing too long between sample collection and sample analysis

To address breakthrough, and avoid underestimating, sorbent tubes contain two layers, front and back. Each layer is analysed separately. NIOSH air sampling methods define breakthrough as having occurred when the back layer contains 20% or more of the quantity of the contaminant(s) collected in the front layer. UK Guidelines (MDHS para 69) define breakthrough as occurring when the back layer contains 10% of the front layer. Where breakthrough is noted, the process or activity should be re-evaluated after reducing sample volumes (e.g., reduced sample flow rates, or multiple samples over shorter periods).

6.4.3 Sorbent Tubes: Common Varieties

There are a variety of sorbent tubes used in occupational hygiene air sample collection. The most commonly used are charcoal and silica gel tubes.

Table 6-1 Sorbent Tubes Types

Type	Use	Issues	Comments
Charcoal	Best for non-polar organic vapours (e.g., hydrocarbons, ketones, esters, ethers). Also chlorinated solvents.	Can't use for polar substances. Poor recovery for reactive compounds such as aldehydes, amines, phenols, low molecular weight alcohols.	Coconut shell, crushed and conditioned at high temperature and low O2. Carbon disulphide (CS2) commonly used to desorb. Thermal desorption with specialty tubes.
Silica Gel	Acid gases, polar substances (e.g., glutaraldehyde, amines)		Water and methanol commonly used to desorb.

There are also specialty sorbent tubes such as:

- Chromosorb and XAD-2: Used for certain pesticides
- Florisil: PCBs (Polychlorinated biphenyls)
- Polyurethane foams (PUF): Pesticides and polynucleated hydrocarbons
- Thermal Desorption (TD) (see Figure 6-6 Thermal Desorption Tubes) Typically used in conjunction with an automated GC analysis instrument that can be set up to run a large batch of samples overnight

Figure 6-5 Multi-Tube Sample Tube Holder

Source: SKC Inc., Reproduced with Permission

Sorbent tube selection should be made in accordance with the corresponding air sampling method such as those from NIOSH, OSHA, HSE or local standards organisations and industry guides such as the SKC website – see https://www.skcinc.com/catalog/index.php for the contaminant of interest.

Sometimes an occupational hygienist may want to measure exposure to a variety of airborne vapours that require the use of different sorbent tubes. This can be done using a multi-tube holder, such as the triple tube holder seen in the photo here. This enables the personal sampling to be carried out using a single sampling pump on each employee, rather than requiring the use of multiple sampling pumps. It is important that the flow rate through each of the tubes is calibrated before and after use with all of the sampling tubes in position.

6.4.4 Sorbent Tubes: Collection Efficiency

While adsorption of a contaminant from the atmosphere on to a tube of some specific type is a very effective way of collecting the contaminant, difficulties arise during the laboratory analysis in the recovery of that analyte from the tube.

Basically, the problem is that it is not possible to extract 100% of a given contaminant from a sorbent tube. If not accounted for, it will lead to errors in the calculation of an exposure. To overcome this, the lab establishes a “desorption efficiency” for each batch of samples. The general approach is to load (i.e., spike) sample tubes from a batch with varying amounts of the contaminant of interest and to then analyse them as normal. In other words, the idea is to compare mass detected via analysis against the mass added. The percentage recovered (e.g., 80% or 0.8) is deemed the desorption efficiency for that particular batch of tubes, and for that particular contaminant.

It is important that the laboratory understand the reasons for this process and be familiar with the appropriate methods to establish such values. Some tube manufacturers publish a list of typical desorption efficiencies for common contaminants as a guide for the laboratory.

6.4.5 Sorbent Tube: Desorption Efficiency

Factors that can affect the collection efficiency of adsorption tubes include:

- Temperature – adsorption, an exothermic process decreases with temperatures.
- Humidity – charcoal's great affinity for water vapours reduces its collection of other contaminants.
- Sampling flow rate - if sampling pump flow rates are too high, contaminant residence times may be too short to be adsorbed resulting in collection losses.
- Channeling – Improper packing of sorbent can create channels or gaps in the bed through which the gases can flow more easily and thus not be adsorbed on to the sorbent.
- Overloading of sorbent tubes can occur if concentrations/sampling times are too long or by the presence of other contaminants including water vapours.

The manufacturers' information and standard sampling methods e.g., NIOSH, OSHA, HSE, ISO Standards Australia etc. should be referred to for specific details pertaining to the sampling for the particular contaminant.

6.4.6 Sorbent Tubes: Thermal Desorption

The use of solvents such as carbon disulphide [CS_2] to extract volatile organic compounds (VOCs) from charcoal tubes was developed in the 1970s. This approach has the following limitations:

- Potential low desorption efficiencies, meaning not all the contaminant is extracted. Typical desorption efficiencies are in 80% range, less under high humidity conditions or when sampling for substances with marked polar characteristics.
- Lower reproducibility when desorption efficiencies are low.
- Solvent impurities may mask contaminant of interest.
- Difficult to reliably measure substances with similar physical properties as extraction solvent.
- About 0.1% of the solvent extract is actually analysed, thus resulting in a dilution factor of 1,000, raising limit of detection.
- Detection limits in the range of 0.1 ppm.
- Work with CS2 in the lab requires appropriate measures to minimize its hazards.

Thermal desorption (i.e., the use of heat to drive off contaminants adsorbed onto the solid sample media) addresses these limitations and offers the following advantages:

- Much higher desorption efficiencies (in 95% range).
- Analysis of entire sample instead of an aliquot.
- Analysis based on mass spectrometry.
- No solvent related effects.
- Detection limits that are 10^3 to 10^4 times better than solvent extraction, making it possible to detect contaminants in parts per billion (ppb) or parts per trillion (ppt) range.

For these reasons, some vapours and gas sample methods that require solvent extraction have been superseded by thermal desorption methods in Europe.

However, thermal desorption sample collection requires specialty sampling tubes. The "industry standard" is ¼ inch (6.4 mm) OD x 3½ inch (88.9 mm) long stainless-steel sorbent tube pre-packed with the sorbent of choice, most commonly Tenax. In addition, a ¼ inch brass SwageLok type storage cap (fitted with a PTFE ferrule) for the non-sampling end of the tube, and a diffusion cap at the end of the tube is normal practice as shown in Figure 6-8.

A suitable sorbent must be selected for the compound or mixture to be sampled. If more than one sorbent is required (due to the different volatilities of the compounds in question), two or more samplers packed with different sorbents should be exposed simultaneously.

In contrast with the glass sorbent tubes described in Section 6.4.3, the stainless-steel thermal desorption tubes can be reused many times. It is therefore essential that the stainless-steel thermal desorption tubes are always pre-conditioned before they are used for sample collection to ensure that there is no contaminant on them, by the laboratory putting the tubes through a pre-set heating sequence. Once sampling or analysis is completed, tubes should be recapped with the brass storage caps as soon as possible and returned to a clean environment for storage.

An additional point to note is that each thermal desorption tube can only be analysed once. In contrast, it may be feasible to re-analyse a glass sorbent tube sample if some of the liquid desorption solution has been retained by the lab.

Specific details including the general handling of thermal desorption tubes, sorbent selection, tube conditioning, post sampling short- and long-term storage should be obtained from the manufacturer before use.

6.5 Filters

Some mists and vapours require samples to be collected on to specialty filters. For example, certain pesticide and isocyanate air sampling methods require the use of glass fiber filters.

For some contaminants it may be necessary to use a filter impregnated with a stabilizing agent or a backing pad treated with a collection media where the contaminant may be present in the gaseous form or in both the particulate and gaseous form.

Figure 6-6 Thermal Desorption Tubes

Source: Markes International Ltd – Reproduced with permission

An example of this is:

- Fluoride - PTFE (Teflon) membrane filter with sodium carbonate treated cellulose backing pad

6.6 Mixed Phase Exposures

In certain circumstances, an air contaminant of interest may be present in more than one phase. For example, mists may also be associated with related component vapours, or certain solids may have appreciable vapours pressures. In such cases, it is important to sample both phases of the contaminant of interest to avoid under estimation of exposures.

The following examples illustrate approaches issues for mixed phase sampling:

Example 1: Coke Ovens

The “traditional method” for sampling and measurement for coke oven emissions was to collect samples onto membrane filters that were extracted with benzene to report results as the “Benzene Soluble Fraction of the Total Particulate Matter”. However, polyaromatic hydrocarbons emitted from coke ovens are present in both particulate and vapours phases and hence sampling for just the particulate phase underestimates coke oven emission measurements. Modern sampling trains for coke oven emissions include a sorbent layer behind the particulate membrane filter to collect the vapours phase that passes through the membrane filter.

Example 2: Impingers

Practical difficulties associated with the use of impingers (see Section 9.5) have led to the development of impregnated filters for contaminants such as isocyanates, formaldehyde and glutaraldehyde.

In the case of the spraying of “two pack” isocyanate-based paints, isocyanates may be present both as mist and as a vapour. In order to ensure that both phases of the isocyanate exposure are collected a sampling train comprising of an impinger followed by an impregnated filter can be used – for details see MDHS 25/4 published by the UK Health and Safety Executive http://www.hse.gov.uk/pubns/mdhs/pdfs/mdhs25-4.pdf.

Example 3: Fluorides

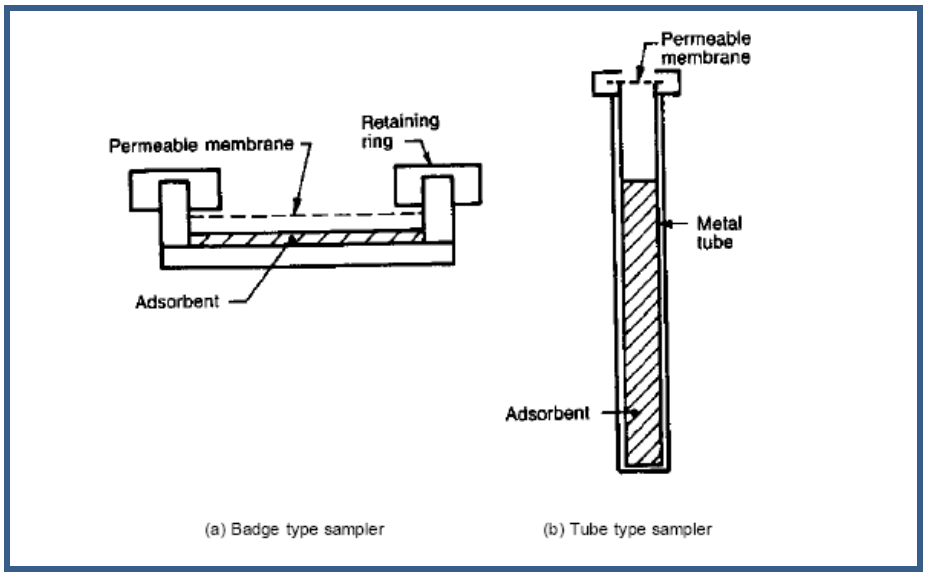
Fluorides are commonly found contaminant in aluminum smelters. They may exist as particulates, as a hydrofluoric acid (HF) mist or as hydrofluoric acid gas. They need to be sampled as described in HSE MDHS 35/2. This method entails a Teflon filter mounted on a sodium carbonate impregnated paper pad mounted in an inhalable sampler. The Teflon filter removes the particulate fluorides, whilst the sodium carbonate impregnated pad collects the hydrogen fluoride. Hydrofluoric acid mist is not retained on the Teflon filter and is collected on the sodium carbonate impregnated pad.

6.7 Liquid Sample Media

Absorption (or solvation) is the technique whereby the gas or vapours is collected by dissolution into a liquid contained in either an impinger, midget impinger (see Figure 6-7 Midget Impingers), fritted bubbler or gas wash bottle. Some liquid sample collection methods are based on a chemical reaction between contaminant and sample collection liquid (e.g., derivatization, oxidation, neutralization). Many of these methods were early occupational hygiene developments and have been superseded by methods that involve specially treated or impregnated filters.

Collection efficiencies for liquid sample collection rely on surface area produced during sampling (i.e., the size and number of bubbles), liquid volume, sampling flow rate and reaction rate. Sometimes bubblers may be connected in series to increase efficiencies and to collect any liquid carryover.

Figure 6-8 Typical Passive Samplers



Source: 3M Australia – Reproduced with permission

The use liquid sample collection media requires careful handling to avoid spills, or introducing liquid into the pump, and loss of sample volume through evapoursation. The need to keep sample collection devices upright to avoid spills and the fragility of equipment limits practical use of this methodology for personal sampling. There are alternative methods that do not involve liquid sample collection media for many substances (e.g., isocyanates). These alternate methods typically involve specially treated or impregnated filters, so the sampling is essentially a variation of particulate air sampling.

6.8 Air Sampling: Diffusion Methods

Passive or diffusion sampling is the passive collection of airborne gases and vapours on to sorbent beds, usually mounted badges or tubes (see Figure 6-8). They are light, simple and easy to use and do not require the use of sampling pumps, tubing, and batteries or air flow calibration. They can be simply clipped on to the collar of the worker (see Figure 6-9) for personal sampling (TWA or STEL) or can be used for area monitoring as long as there is sufficient airflow at the location sampled. The sampling process generally consists of exposing the badge for a known period of time, and then re-sealing the badge for subsequent lab analysis.

Figure 6-7 Midget Impingers

Source: University of Wollongong

Air sample collection rates are based on principles of gaseous diffusion across a permeable membrane (Australian Standard AS 2986), based on Fick's Law. Fick's first law of diffusion can be applied to the mass uptake rate:

$$m/t = (A * D)/L * \ (C - C\_0) \qquad \text{...Equation 6-1}$$

Where

m mass of adsorbate collected in grams

t sampling time in seconds (s)

A cross sectional area of the diffusion path in cm².

D diffusion coefficient for the adsorbate in air in cm²/s– available from manufacturer of the sampler for a given chemical

L length of the diffusion path in cm (from porous membrane to sampler)

C concentration of contaminant in ambient air in g/cm³.

C_0 concentration of contaminant just above the adsorbent surface in g/cm³.

From Equation 6-1 above, if C_o is zero (i.e., the collection medium is effective), then mass transfer or collection rate is proportional to the ambient concentration C.

Sample rates using passive samplers depend on the diffusion coefficient of the contaminant and the geometry of the monitor. Some monitors such as 3M, SKC monitors and Dräger ORSA monitors have a diffusion path axial to the sorbent whereas others such as the Radiello badge have a diffusion path to that is radial to the sorbent surface.

Sample rates remain constant as long as the sorbent media does not reach its capacity (i.e., does not become saturated) and as long as adequate airflow is maintained across the face of the monitor. These rates are available from monitor manufacturers.

Organic vapours diffusion monitors typically contain activated charcoal so that volatile contaminants that can be sampled with a charcoal tube-based sampling train can instead be sampled with a diffusion monitor.

Activated charcoal and other sorbents can be impregnated with certain substances to allow sampling for materials that might otherwise have poor capture, retention and recovery from the sorbent. For example, a solid sorbent can be treated with 2-(hydroxymethyl) piperidine to collect formaldehyde, or activated charcoal can be treated with a bromine compound to collect ethylene oxide.

Figure 6-9 3M Diffusion Monitor

Source: 3M Australia – Reproduced with permission

There are also diffusion monitors for inorganic mercury and for amines.

Diffusion monitors meet or exceed an accuracy of ± 25% at 95% confidence for many workplace contaminants. Diffusion monitors can also be used for area monitoring provided there is sufficient airflow, defined as at least 25 ft/min or 0.13 m/sec in any orientation. Care needs to be taken not to place diffusion area monitors away from corners and or other dead air spaces.

Although passive badges offer a number of advantages (e.g., ease of use and relatively inexpensive), some of their disadvantages are as follows:

- Cannot sample low vapours pressure organics such as glutaraldehyde, or reactive compounds such as phenols and aldehydes.
- Charcoal based diffusion monitors have the same moisture and recovery issues associated with the use of active sampling tubes.
- With some diffusive samplers inaccuracies can occur at wind speeds >2.5 m/s, depending on their design.
- “Sampling rates” are supplied by the manufacturer and differ for each compound.
- It can be difficult to know if breakthrough (see Section 6.4.2) has occurred, especially for the more volatile compounds such as methylene chloride, as some diffusion monitors do not have a back-up section.

6.9 Grab Sampling Basics

This method collects air into either a rigid evacuated container or canister, or into a flexible bag. The latter requires an air sampling pump to draw into the bag. This approach is also sometimes referred to as "whole air sampling" or "grab sampling". In both cases, the container/bag has to be analysed in a lab within a specified time after use (referred to sometimes as hold times).

Contaminant recovery during analysis depends on relative humidity, reactivity of contaminants of interest and inertness of the container, which need to be considered before sample collection to minimize sample losses due to interaction of the contaminant with the container. As a general rule, grab sampling should be used for chemically stable target compounds that have vapours pressures greater than 0.1 torr (or 0.1 mm Hg) at NTP (i.e., 760 mm Hg atmospheric pressure and 25°C).

Grab sampling is often used for sampling unknowns, for evaluating contaminant sources, where the air contaminant concentration is known to be constant, or where peak concentrations are of interest.

Sampling periods are short and generally last from a few seconds to a few minutes. However, in the case of an evacuated container, it is possible to install specific flow controllers to regulate air flow into the container over known periods of time.

Note that grab sampling is generally not a suitable method for personal air sampling.

6.9.1 Canisters

Grab sampling canisters are typically made from stainless steel and are usually spherical or cylindrical. Their use does not require a sampling pump. Canisters range in size from 1 to 10 L.

SUMMA canisters have internal surfaces specially treated using a process (also known as summa process) that combines electro polishing with chemical deactivation to produce nearly chemically inert interior surfaces to maximize recoveries of air contaminants from the container in the lab.

Canisters are generally furnished from the lab that will analyse the sample(s) where they are cleaned before use. It's important to review desired limits of detection with the lab to ensure that canisters that have been suitably cleaned are provided.

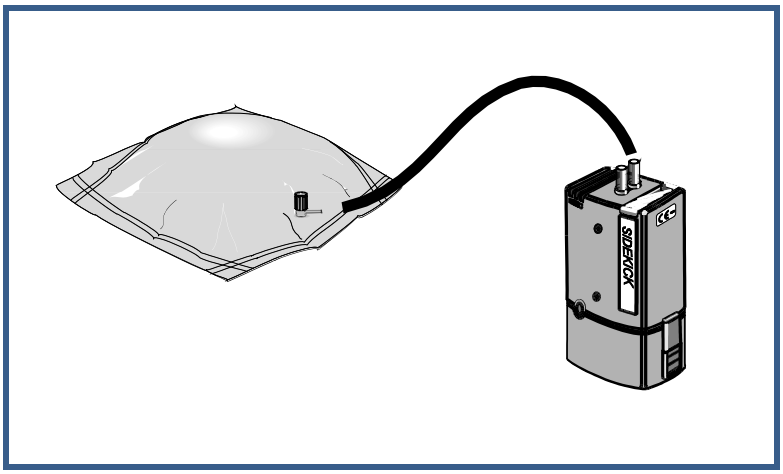
Canisters are provided under vacuum, so sample collection involves simply opening the valve to fill the container. This takes from a few seconds to a few minutes (depending on container size), unless flow controllers (usually supplied by the lab) are used to sample over a longer specified time (e.g., 1- 8 hours).

Grab sampling using canisters can yield limits of detections that are in the ppb (or µg/m³) range. When used to sample for unknowns, the contents are analysed by gas chromatography/mass spectrometry (GC/MS). While it can yield useful information, SUMMA canister sampling can be expensive.

6.9.2 Grab Sampling Bags

Gas sampling bags are made of different materials such as polyester, polyvinylene chloride, Teflon (polytetrafluoroethylene or PTFE), and Tedlar (polyvinyl fluoride). They are often laminated with aluminum to reduce contaminant permeation through the walls. Sample loss and adsorption on to the bag material can be significant concerns so samples should be analysed as soon as possible after collection.

Figure 6-10 Use of Air Sampling Pump to Fill Grab Bag



Source: SKC-Reproduced with Permission

Grab sampling bags are relatively inexpensive, can be carried to site in a brief case, filled in seconds and shipped easily to the laboratory for analysis. See Figure 6-10, although they come in different sizes (up to 250 L), bags used for occupational hygiene sampling purposes bags are typically between 5 and 15 litres. Pump flow rates of 1 L/min are typically used to fill these bags. Keep in mind that overfilling gas bags in low temperatures can create leakage and or damage when moving bags to warmer temperatures, and that insufficient filling at warmer temperatures can reduce sample volumes if analysed in lower temperatures.

6.9.3 Colorimetric Tubes

Colorimetric tubes can also be used to collect grab (short-term) samples although technically they provide a direct result rather than a sample for lab analysis. See Section 6.13 for more details.

6.10 Sample Analysis

Samples for gases, vapours and mists are analysed in a variety of ways discussed in Chapter 7. Organic vapours samples are most commonly based on chromatography (see Section 7.2.2).

6.11 Example Calculations of Results

Calculation of results requires calculating volume of air sampled (i.e., how much air flowed through the sampling media) and later calculating the concentration of air contaminant of interest.

6.11.1 Air Volume Calculation

This requires calculating the average air flow rate based on pre- and post-sampling flow rates, which is then multiplied by the sample duration. Consider the following sampling data shown in Table 6-2 Sampling Flow Rates:

Table 6-2 Sampling Flow Rates

	Start	End		
Flow Rate (L/m)	1.00	0.96	0.98	Average flow (L/m)
Sample Time	0730	1500	420	Sample period (min)

Thus, the volume of air sampled (V, in litres) would be as follows:

$$V = 0.98\,L/min * 420min$$ …Equation 6-2

$V = 411.6$ Litres or 0.412 m³ (since 1 m³ = 1000 litres)

Note that post sampling flow rate was within 5% of initial flow rate, and so is acceptable.

Now, say that the lab reports a total 6.3 mg of toluene in the sample represented by the above air sampling data. The lab report also shows that there were 5.6 mg in the front section and 0.7 mg in the back section, and that desorption efficiency was 90%.

Since only 90% of toluene was recovered from the charcoal tube, the corrected amount collected in the tube would be $6.3/(90\%)$ or 7 mg.

Therefore, the air sample concentration would be $(7\ \mathrm{mg})/(0.412\ \mathrm{m}^3)$ or 17.0 mg/m³.

This is equivalent to $17.0/24.45 * 92.14$ or 1.45 parts per million (ppm) by volume where 24.45 represents the molar volume of gas at NTP, and 92.14 is toluene's molecular weight.

The ratio of back results to front results is $0.7/5.6$, or 12.5%. This is less than 20%, so sample breakthrough did not occur.

Note that labs will usually report air concentrations in either in mg/m³ or ppm, provided sample volumes were submitted with samples.

6.11.1.1 Diffusion Sampling Calculations

Sampling period duration, the contaminant weight determined by the laboratory, the recovery coefficient and the calculation constant either A or B are required to calculate air concentrations when using diffusion samplers. A constant "A" is used to calculate results in milligrams per cubic metre (mg/ m³) whereas a constant "B" is used to calculate results in parts per million (ppm). These constants, which are specific to each brand of monitor and specific for each contaminant, are supplied by the diffusion monitor manufacturer.

Air temperatures influence diffusion monitor sampling rates, as exemplified in Table 6-3 3M Diffusion Monitor Temperature Correction Factors. Atmospheric pressure variations do not require correction factors.

Table 6-3 3M Diffusion Monitor Temperature Correction Factors

Celsius (°C)	-8	-3	2	7	13	19	25	31	37	44
Fahrenheit (°F)	18	27	36	45	55	66	77	88	99	111
Correction Factor	1.06	1.05	1.04	1.03	1.02	1.01	1	0.99	0.98	0.97

Source: 3M – Reproduced with permission

Note that for temperatures between 13°C and 37 °C (i.e., 55°F and 99 °F), correction factors are quite small (2%).

6.11.1.2 Diffusion Monitor Calculation Example

The time weighted average (TWA) concentration of contaminant in mg/m³ can be

$$C = (\mathrm{W}\ (\mu g) * \mathrm{A})/(r * t\ (minutes)) \quad \text{...Equation 6-3}$$

Where W = weight of contaminant in sample, based on lab analysis.

A = a manufacturer supplied constant for a specific contaminant for calculating results in mg/m³.

r = the recovery coefficient as reported by the lab.

t = time that the diffusion monitor was exposed.

The TWA concentration of contaminant in ppm can be calculated from the following expression:

$$C = (\mathrm{W}\ (\mu g) * \mathrm{B})/(r * t\ (minutes)) \quad \text{...Equation 6-4}$$

Where W = weight of contaminant in sample, based on lab analysis.

B = a manufacturer supplied constant for a specific contaminant calculating results in ppm.

r = the recovery coefficient as reported by the lab.

t = time that the diffusion monitor was exposed.

Consider the following data for benzene sampled with a diffusion monitor:

Table 6-4 Diffusion Monitor Data

Sampling time	420 minutes
Temperature	75 °F
Calculation Constant A	28.2
Calculation Constant B	8.82
Contaminant weight in monitor (W)	27.2 µg
Recovery coefficient (r)	0.97

The corresponding air concentration C (in mg/m^3) would be derived using the first equation above, using A:

So, $C = (27.2 * 28.2)/(0.97 * 420)$ or 1.88 mg/m^3 …Equation 6-5

Similarly, the concentration of benzene in ppm can be derived from application of Equation 3-1 (Chapter 3).

So, $C = (27.2 * 8.82)/(0.97 * 420)$ or 0.59 ppm …Equation 6-6

Note that no temperature correction was required for the sample since it was collected at 75 °F.

Note also that labs will usually provide results in terms of either in mg/m³ or ppm, so it's not common to have to calculate air sample concentrations from lab data.

6.12 Direct Reading Instruments: General

Early direct reading instruments were bulky and impractical for personal monitoring. They were generally used for area (i.e., static) monitoring. However, these instruments have evolved over the years so that there are now available a variety of sophisticated battery powered direct reading instruments, many with real-time data logging capabilities, suitable for personal air sampling. Continued technology evolution has allowed the deployment of remote sensing devices linked via telemetry to a central location. While these features can indeed be very useful, it also means it is

more critical than ever before to be familiar with manufacturer's instructions to obtain best results, and minimize time lost through operator error.

The biggest advantage of direct reading instruments is obtaining real time data that can be compared to relevant exposure criteria. The advent of data logging technology now allows analysis of instantaneous (seconds), short term 15-minute STEL concentrations and 8-hour TWA concentrations for certain contaminants.

Although many direct reading devices are intended to measure specific contaminants (e.g., carbon monoxide or hydrogen sulphide), some can monitor simultaneously multiple gases and vapours (e.g., confined space entry monitors). Others (e.g., flame ionization detectors [FIDs] and photo ionization detectors [PIDs]) are not able to differentiate between the different gases and vapours that may be present and instead report a "composite" single result that may require careful interpretation.

Direct reading instruments are useful for the following activities:

- To obtain real time data (employee concerns, leaks, emergency response, confined space entry).
- To develop and or prioritize air sampling programmes.
- To evaluate effectiveness of controls in real time.
- To evaluate intraday variability in exposures.
- To obtain information about peaks in exposure levels that traditional air sampling is unable to measure.
- For stationary installations to record area exposure levels and as well as to sound an alarm should concentrations of concern be detected.
- For respirator fit testing.

Table 6-5 lists some commonly used direct reading instruments. Some will be discussed during the practical session.

6.12.1 Direct Reading Instrument Limitations

Although direct reading instruments offer many advantages as stated above, they have some limitations that need to be considered:

- Often costly to purchase though they may be available for rent in some countries.
- Need for regular calibration and associated records.
- Sensors are generally substance specific, have a finite life and may have limited range. May not always be user replaceable.
- Cross sensitivity (see Section 6.12.2).
- Need for intrinsically safe instruments in situations where it is possible for a potentially flammable atmosphere to be present.

6.12.2 Direct Reading Instrument Cross Sensitivity

Cross sensitivity means that an instrument sensor can give an erroneous reading from the presence of an air contaminant it was not designed to measure.

Consider a carbon monoxide electrochemical sensor, often found as a feature of confined space entry monitors. These sensors are responsive to gases other than carbon monoxide, and can give either false positive results or false negative results that manufacturers address by using a sensor filter. The following data from one particular supplier illustrates results obtained when applying 100 ppm of the listed gas to the CO sensor:

Table 6-5 Direct Reading Instrument Cross Sensitivity

	CO read out (no filter)	CO read out (with filter)
Hydrogen Sulphide (H2S)	≈ 315 ppm	< 10 ppm
Sulphur Dioxide (SO2)	≈ 50 ppm	< 5 ppm
Nitric Oxide (NO)	≈ 30 ppm	< 10 ppm
Nitrogen Dioxide (NO2)	≈ - 55 ppm	- 15 ppm
Chlorine (Cl2)	≈ - 30 ppm	< -5 ppm
Hydrogen (H2)	< 40 ppm	< 40 ppm
Hydrogen Cyanide (HCN)	≈ 40 ppm	< 15 ppm
Ethane	≈ 90 ppm	< 50 ppm

So, for example, the presence of small amounts of ethane (100 ppm or 0.01% in air) without a sensor filter might lead one to incorrectly conclude that 90 ppm of CO was present.

Figure 6-11 Dräger Tubes and Bellows Sampling Pump

Source: Dräger Safety – Reproduced with permission

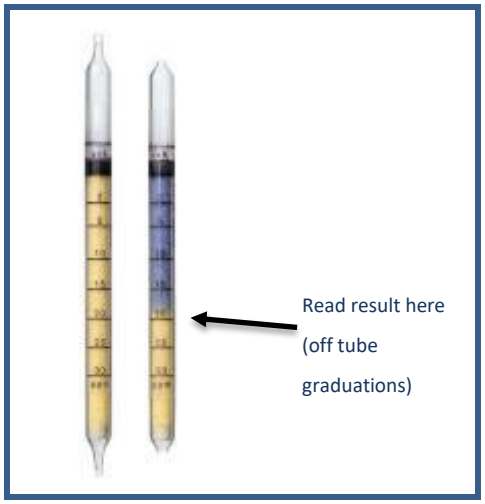
The operating manual of the direct reading instrument should provide information about known cross sensitivities. Where relevant information is not provided in the manual, and if there are contaminants present other than the one that the instrument is designed to measure, the supplier should be consulted about the possibility of cross sensitivity.

6.13 Detector Tubes (Colorimetric Tubes)

Colorimetric tubes are a convenient and inexpensive way to provide an initial evaluation of potential gas and vapours exposures. However, they are less accurate than other approaches and results are based on short sample periods (usually a few minutes or less).

Colorimetric tubes are based on a specified colour change of a specific reactant when it comes into contact with the contaminant of interest. Most tubes contain a solid reactant through which a known volume of air is drawn through the tube using a manual pump. It's important to operate the pump correctly and to track the number of strokes to collect the required number as specified in the tube instructions. The tubes usually have an arrow that should point towards the pump to ensure the tube is in the correct orientation. Air concentration of the particular contaminant, if present, are read off directly from gradations on the colorimetric tube (i.e., length of stain, see). In some cases, the result is based on counting the number of strokes required to match colour change in the tube with reference colour provided with the instructions. So, again, reading manufacturer instructions before use is critical.

Figure 6-12 New (Left) and Used (Right) Colorimetric Tubes



Source: Dräger Safety – Reproduced with permission

The accuracy of colorimetric tubes is dependent on factors including sample pump volume, efficiency of the chemical reaction, humidity, temperature, manufacturer's calibration of the graduations and interpretation of the length or colour of the stain. Typically, accuracy is quoted as 10 – 30%, and varies according to tube, presence of interferents and tube concentration range.

There are various manufacturers of colorimetric tubes such as Dräger, Kitagawa, Gastech and MSA for grab or short term (seconds to minutes) available

to measure approximately 300 gases in different concentration ranges. Please note that colorimetric tubes from one manufacturer CANNOT be used with the pump from another manufacturer.

There are also direct reading long term colorimetric tubes that use low flow battery operated pumps or diffusion type badges for long term measurements of 1 to 4 hours.

Some of the advantages of direct reading colorimetric tubes include:

- Relatively inexpensive and cheap to use
- Wide range of gases and vapours
- Immediate results
- No expensive laboratory costs
- Can be used for spot checks
- No need for calibration (tubes are pre calibrated)
- No need for charging or electric power during operation

However, such devices have definite limitations such as:

- Interferences from other contaminants (cross sensitivities)
- Need to select correct tube and correct range of tube
- Results should not be compared to TWA
- Storage requirements limit shelf life. Check before use.
- They cannot be used to measure personal exposures, but they may be useful to provide an on-the-spot indication of the order of magnitude of exposures, as a preliminary to a decision on which exposures would warrant the collection of personal exposures.

It is very important to read the particular manufactures' instructions for any colorimetric tube before use to select the correct tube and to use it correctly, noting the effect of any potential interferent, some of which can give false positive or false negative results.

6.13.1 Maintenance and Calibration

Readings from direct reading instruments are only as good as the maintenance and calibration of the equipment. An approach used in the mining industry that has also found use in general industry is to set out the requirements and responsibilities for the examination and calibration of different classes of equipment based on their use. These classes are as follows:

Table 6-6 Calibration Classes

Group I	Hand held or portable equipment Ia – provides scaled indication of actual gas concentration. Ib – provides alarm indication of actual gas concentration
Group II	Equipment that used in severe conditions e.g., mounted on operating equipment, where it could be exposed to vibration, high levels of dust and humidity.
Group III	Equipment installed at a fixed location for appreciable periods of time with a local read out of concentration.
Group IV	Equipment permanently installed with remote readout of concentration.

The mining industry approach also sets out the requirements for a Certificate of Compliance, recordkeeping, accuracy requirements and the minimum competencies for persons and accredited authorities engaged in the examination, maintenance and testing of equipment covered.

The mining industry approach also provides advice for techniques and equipment to carry out span and zero tests on gas detecting equipment. Span test is the test of response to certified test gas(es). Zero test is test of response to zero gas conditions.

Test equipment for single point span checks consists of a cylinder containing the certified test gas fitted with either a calibrated flow meter with a precision regulator or a flow restrictor and pressure gauge.

For equipment in which the external atmosphere reaches the sensor or detector by diffusion, the test procedure usually involves dispensing the certified test gas to the sensor via tubing and suitable calibration cup. Calibration cups should conform to equipment manufacturer requirements.

For sample-draw equipment containing an integral pump or hand-held aspirator, the sample inlet is connected via tubing to grab sample bag that has been pre-flushed and filled with the certified test gas.

Table 6-7 Suggested Maintenance Schedule Based on Instrument Use

Group	Group Type	Suggested Maintenance Schedule*
Ia	Handheld/portable	Shift / or before use Weekly Calibration 6 Monthly Service
Ib	Handheld/ portable with alarms	Shift / or before use Weekly Calibration 6 Monthly Service
II	Machine mounted	Shift / or before use Zero – Weekly Calibration – Weekly Alarm - Weekly Switching – Weekly 6 Monthly Service Overhaul - 4 Yearly
III	Underground fixed	Status – Daily System – Daily After relocation Switching – Monthly Yearly Service
IVa	Surface fixed	Status - Daily System – Monthly Yearly Service
IVb, IVc	Surface fixed	Status – Daily System – Monthly Line Integrity – Monthly Yearly Service

* Daily – typically by user

Weekly – typically by maintenance person / department

Monthly – typically by maintenance person / department

Yearly – typically by external authority

6.13.2 A Primer on Explosion Safe Equipment

The International Electrotechnical Commission Scheme for standards for equipment that may be used in explosive atmospheres is known as IECEx. This scheme has gained worldwide acceptance in countries that include Europe, United Kingdom, South Africa, USA, Canada, Asia and Australia and New Zealand. The 60079 Series for Gases and Vapours and the 61241 Series for dusts has been widely accepted. Intrinsically safe instruments refer to instruments that are incapable of acting as ignition sources for flammable gases or vapours. To be so designated, instruments must comply with IECEx guidelines for design and operation.

The modern automation of equipment has led to its increased use in Explosive or Ex areas. Such equipment is termed “Ex equipment” and is found in areas such as:

- Automotive refueling stations or petrol stations
- Oil refineries, rigs and processing plants
- Chemical processing plants
- Printing industries, paper and textiles
- Hospital operating theatres
- Aircraft refueling and hangars
- Surface coating industries
- Underground coalmines
- Sewerage treatment plants
- Gas pipelines and distribution centres
- Grain handling and storage
- Woodworking areas
- Sugar refineries
- Metal surface grinding, especially aluminum dusts and particles

Explosions require the presence of three conditions:

- A flammable gas or vapours in concentrations within a specified flammable range, or the presence of suspended dust in combustible concentrations
- Oxygen
- An ignition source

6.13.2.1 Explosive Zone Classification Scheme

Potentially explosive atmospheres may be defined into zones as follows:

Table 6-8 Explosive Zone Classifications

Gases, Vapours, Mists	Dusts	Explosive Atmosphere is Present
Zone 0	Zone 20	Most of the time
Zone 1	Zone 21	Some time
Zone 2	Zone 22	Seldom or short term

Source: TestSafe – Reproduced with permission

6.13.2.2 Explosive Proof Classification Scheme

Equipment that is explosion proof is classified as follows:

Table 6-9 Explosion Proof Classification

Group I	Equipment that is used in underground mines where it could be subjected to methane and coal dust
Group II	Equipment used in industries other than mining with the following subgroups IIA - Where least readily ignited gases such as propane and benzene may be present IIB - Where more readily ignited gases such as ethylene and diethyl ether may be present IIC - Where most readily ignited gases such as hydrogen and acetylene may be present

6.13.2.3 Explosive Proof Surface Temperature Classification Scheme

Equipment that is to be used within potentially flammable atmospheres may be rated based on surface temperature. The concept is to ensure that operating temperatures do not exceed ignition temperatures of gases and or vapours that may be present.

Group I temperature designation requires that the temperature of the components and surfaces exposed to dust and methane to be less than 150°C. Where components and surfaces are protected from the ingress of dust, the maximum temperature of such must be less than 450°C.

For Group II designation, the maximum surface temperature must not exceed values shown Table 6-10 Maximum Surface Temperature / Ignition Temperature which corresponds to the temperature class of the equipment. For convenience, a temperature class may be assigned to a gas or vapours based on its ignition temperature.

Table 6-10 Maximum Surface Temperature / Ignition Temperature

Temp Class	Maximum Permissible Surface Temp(°C)
T1	450
T2	300
T3	200
T4	135
T5	100
T6	85

Source: TestSafe – Reproduced with permission

6.13.2.4 Intrinsically Safe Equipment and Zones

Intrinsic Safety has 3 levels of protection:

- "ia" – means that the type of protection 'intrinsic safety" (no release of spark energy or thermal energy that can cause ignition) is maintained with up to two faults.
- "ib" – means intrinsic safety is maintained with up to one fault.
- "ic" – means intrinsic safety is maintained, but no requirement to apply faults.

Table 6-11 Level of Explosion Protection and Explosion Zones

Level of Protection	Suitable For…
"ia"	Zones 0, 20
"ib"	Zones 1, 21
"ic"	Zones 2, 22

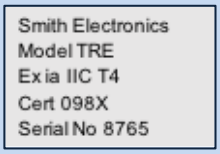
Source: TestSafe – Reproduced with permission

What's In A Label?

Only appropriate certified and marked electrical equipment may be used in hazardous areas. Users of electrical equipment must ensure that the equipment complies with the relevant regulations and local standards.

Equipment for use in hazardous atmospheres has to be labelled with the name of the manufacturer, model number, Ex code and certificate number. This information, which will be in short hand, has to be attached to the equipment.

Consider the following equipment label example:



What does it mean?

Ex indicates the equipment may be used in potentially explosive atmosphere.

"ia" indicates equipment is suitable for zone 0 application.

IIC the equipment is suitable for Groups IIA, IIB, IIC.

T4 the equipment is suitable for gases with auto ignition temperature greater than 135°C

Table 6-11 Level of Explosion Protection and Explosion Zones links intrinsic safety classifications with explosion zone.

Safety factors are applied and the equipment evaluated for spark and thermal ignition energy after the application of faults.

Only explosive protected equipment can be used in areas where explosive atmospheres may occur.

Explosive protective equipment can be manufactured to IEC protection type levels which are subject to the requirements of their own specific standards. Intrinsic safety, Flameproof, Increased Safety, Encapsulation etc. are

some of the common types of protection used for explosion protected electrical equipment.

Further and much more detailed information for the use of gas detection equipment in potentially explosive atmospheres including the Classification of Zones, Explosion Groups, Temperature Classes, the Types of Protection provided by equipment, the requirements for Certification and Marking is available from the different National Standards and Certification bodies.

6.13.2.5 Explosion Control Basics

Eliminating or controlling one will usually control potential explosive hazards. The currently accepted hierarchy for control of these hazards is as follows:

- Reduce or avoid the use of flammable substances
- Do not allow any releases of flammable substances to form potentially explosive atmospheres
- Remove sources of ignition from the potentially explosive atmosphere
- Use adequately designed equipment that reduces the probability of causing an explosion (i.e., Ex equipment)
- Provide measure to reduce the effects of explosions

Chapter 7 Sample Analysis

This section provides an overview of occupational hygiene sample analysis. Occupational hygienists are expected to have a general understanding of the principles and applications of these methods

7.1 Introduction

Analysis of occupational hygiene samples may be done on the job using some form of direct reading device or instrument. Alternatively, a sample is often collected at the workplace and sent to a laboratory for analysis. This analysis could vary from a relatively simple weighing of the contaminant on a filter to the determination of a metal using an inductively coupled plasma (ICP) spectrometer or the use of a gas chromatograph linked to a mass spectrometer (MS) for the determination of an organic solvent.

In most cases the hygienist does not perform the laboratory analysis, but an understanding of some of the basics is required to:

- Select an appropriate monitoring and analytical method
- Communicate with the analytical laboratory
- Understand the principles of the direct reading instrument
- Make an assessment of the reliability of the results

7.2 Analytical Methods

Most modern methods of occupational hygiene sample use instruments rather than the classical “wet chemical methods” common before the 1960s.

The types of analysis can typically be divided into the following main types

- Spectroscopy
- Atomic
- Molecular
- Chromatography

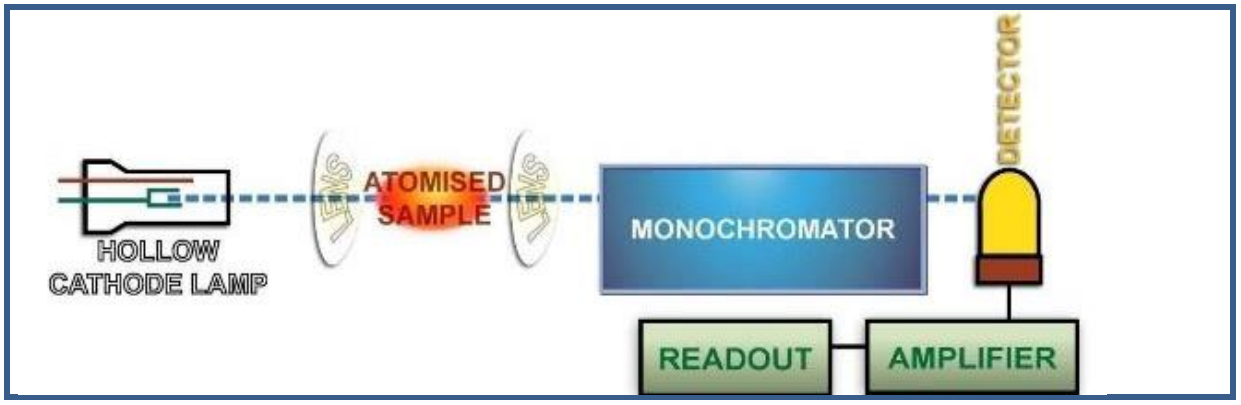
7.2.1 Spectroscopy

The basic underlying principle of spectroscopy is that all elements or chemical compounds absorb or emit electromagnetic radiation at specific frequencies. If a sample is radiated at a specific frequency for a particular element, if that element is present the amount of radiation absorbed or emitted is proportional to the concentration of that element in the sample.

7.2.1.1 Atomic Spectrometry

Typically used for the analysis of the metallic elements. Samples usually collected using conventional sampling methods on to filters, impingement into liquids or adsorption on to a solid. Samples then prepared by appropriate method for subsequent analysis.

Figure 7-1 Schematic of an Atomic-Absorption Spectrometer



Source: BP International

7.2.1.1.1 Flame Atomic Absorption Spectrometry (AAS)

The sample in solution is atomized by flame and the absorption of a specific wavelength of light from the hollow cathode lamp in the flame is measured to quantify the element. This technique typically used for the analysis of approximately 60 metals.

7.2.1.1.2 Hydride Generation

Arsenic and selenium have poor sensitivity using conventional Flame AAS because their spectral lines are in the far UV. Hydride generation overcomes this issue. As and Se are converted to their respective hydrides AsH3 and H2Se. When these hydrides are swept through the flame or a through a heated quartz cell a larger proportion of the element reaches the light path resulting in increased sensitivity.

Figure 7-2 Atomic Absorption Spectrometer

Source: University of Wollongong

7.2.1.2 Flameless Atomic Absorption

AAS is not sensitive enough for analysis of low concentration of metals in biological samples such as blood. During AAS there is a high flow rate of sample through the flame and a more sensitive method where less material is used is required.

7.2.1.2.1 Graphite Furnace

Atomization of elements without the use of a flame can be achieved with the use of electricity (electrothermal atomization). The sample is placed inside a hollow graphite tube and rapid heating of the tube using a high electric current causes the sample to atomize.

7.2.1.2.2 Cold Vapours Generation

This technique is used for the analysis of mercury because of the volatility of mercury at room temperature. Mercury compounds are reduced to metallic mercury and the mercury vapours is transported to the absorption cell by a stream of gas for determination.

7.2.1.3 Atomic Emission Spectrometry

This technique is also based on the flame excitation of an element, but is looking at the emission of energy when the excited element is returned to its ground state.

7.2.1.3.1 Flame Emission

Atomic absorption spectrometers can be operated in the emission mode or a separate instrument, a flame photometer can be used. Typically, the elements where this technique is used are the alkali and some alkaline earth metals e.g., Sodium and Potassium.

7.2.1.3.2 Inductively Coupled Plasma Spectrometry

An extension of atomic emission spectrometry is inductively coupled plasma spectrometry (ICP). By using gas plasma temperatures up to 10,000°C can be obtained resulting in a large increase in excited atoms and hence sensitivity. Plasma is a cloud of highly ionized gas comprising ions, electrons and neutral particles. In ICP the gas used is usually argon because it is easily ionized with radio frequency electromagnetic fields.

Since all elements in a sample emit their characteristic wavelengths simultaneously it is possible to measure a large number of elements, up to 60, simultaneously or sequentially.

The scanning ICP has a distinct advantage over AAS in that a separate lamp for each specific element is used in AAS but up to 60 elements can be analysed by ICP on the same sample.

Figure 7-3 Graphite Furnace

Source: University of Wollongong

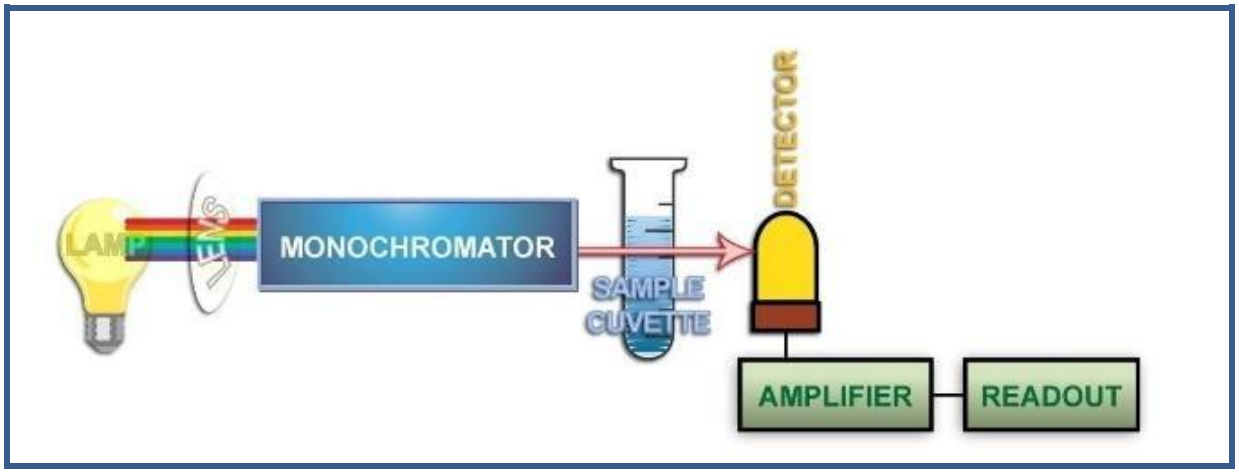
7.2.1.4 Molecular Spectrophotometry

7.2.1.4.1 UV-Visible Spectrophotometry

This technique is used for metals or organic compounds. Samples are collected by conventional sampling methods on to filters or by impingement into solutions.

The principle of the method is based on the absorption of ultraviolet and visible radiation by the excitation of bonding electrons in molecules.

Figure 7-4 Schematic of a Single Beam UV-Vis Spectrophotometer



Source: BP International

Most chemicals species absorb UV or Visible radiation and thus can be quantified, e.g., oil. For non-absorbing compounds a reaction with a colour producing reagent (a chromophore) may allow its quantification.

E.g., the reaction of hexavalent chromium with s-diphenyl carbazide to produce a red complex with an absorption peak at 540 nm.

7.2.1.5 IR Spectrometry

Infra-red (IR) spectrometry provides a way of identifying pure species as each molecular species has its own unique absorption spectrum, i.e., fingerprint.

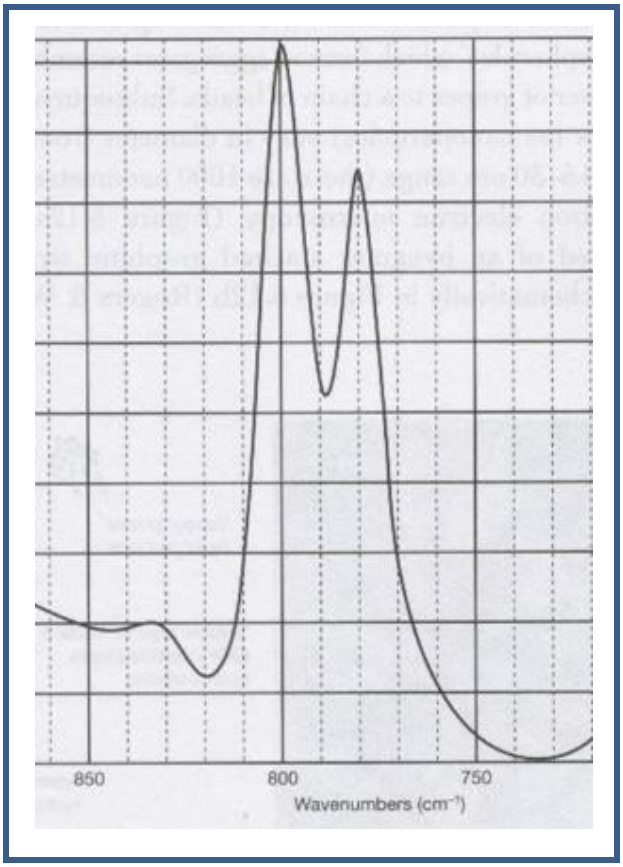
Absorption or emission of infra-red radiation results in the change in vibration or rotation of a molecule. The number of ways a molecule can absorb energy is related to the number of

atoms and the number of bonds it contains. IR is particularly applicable to organics and covalently bonded metal complexes.

The IR spectrum for quartz is provided in

. Note the distinctive quartz “doublet” at 798 and 779 cm-1 wavenumbers.

Figure 7-5 IR Spectrum for Quartz



Source: University of Wollongong

The main application of infra-red spectrophotometry is identification of compounds and in occupational hygiene is also used for direct gas and vapours monitoring using portable instruments and for the measurement of quartz in dust.

7.2.1.6 Molecular Fluorescence

Fluorescence is one of the ways a molecule returns to its ground state after excitation. It involves the emission of radiation at characteristic wavelengths of the molecule and different from the exciting wavelengths. Fluorescence can be used to measure compound which fluoresce such as aromatic hydrocarbons.

7.2.2 Chromatography

Chromatography is a separating method that relies on differences in partitioning behavior between a flowing mobile phase and a stationary phase to separate the components in a mixture.

A column or other support holds the stationary phase and the mobile phase carries the sample through it. Sample components that partition strongly into the stationary phase spend a greater amount of time in the column and are separated from components that stay predominantly in the mobile phase and pass through the column faster.

There are a number of different chromatography techniques and include:

Figure 7-6 Gas Chromatograph

Source: University of Wollongong

- Gas chromatography (GC): Applied to volatile organic compounds. The mobile phase is a gas and the stationary phase is usually a liquid on a solid support or sometimes a solid adsorbent.
- High-performance liquid chromatography (HPLC): A variation of liquid chromatography that utilizes high-pressure pumps to increase the efficiency of the separation.

Figure 7-7 Gas Chromatograph Mass Spectrometer

Source: University of Wollongong

As the components elute from the column they can be quantified by a detector and or collected for further analysis. An analytical instrument can be coupled with a separation method for on line analysis and includes gas and liquid chromatography with mass spectrometry.

7.2.3 Other Analytical Techniques

7.2.3.1 X-Ray Diffraction

X-Ray diffraction (XRD) can help identify and quantify crystalline substances. However, it cannot give information on the elements present in the sample. An example where XRD is used is in the analysis of materials containing silicon and oxygen:

- Quartz (SiO2) has a TLV of 0.1 mg/m³ (respirable)
- Kaolin is a hydrated aluminum silicate Al2Si2O5(OH4) has a TLV of 10 mg/m³ (inhalable)
- Amorphous Silica has a TLV of 10 mg/m³

Conventional analysis only showing the amounts of silica and oxygen is not helpful in this situation; we need to know the form that the silica and oxygen is in. XRD is able to both identify and quantify the different crystalline phases that have quite different potential health effects.

7.2.3.2 X-Ray Fluorescence

X-ray fluorescence (XRF) is widely used for the identification of elements. The absorption of x-rays produces an excited atom that returns to its ground state via a series of electronic transitions. These transitions are accompanied by an emission (fluorescence) of X radiation which is characteristic of the element.

Multi-channel instruments permit up to 24 elements to be analysed simultaneously for samples such as ashes, ores, minerals, ceramics, alloys and metals.

7.2.3.3 Mass Spectroscopy

This technique is based on the conversion of a sample into gaseous ions and their separation on the basis of charge to mass ratios. This provides both qualitative and quantitative information. The spectra obtained are relatively easy to interpret since they provide information based on the mass of structural components and the total molecular weight of the compound.

7.2.4 Detection Limits, Sensitivity, Chemical Interferences

7.2.4.1 Detection Limits

As discussed in Section 4.9, the analytical detection limit can have an impact on whether it is possible to collect a sample of sufficient volume to yield a measurable result.

7.2.4.2 Method Sensitivity

Does the analytical method cover the concentration range of interest? Some analytical methods may not have sufficiently low limits of detection to measure short term exposures. Is there another method that could be used to get better sensitivity e.g., the use of ICP rather than AAS for the analysis of metals.

7.2.4.3 Chemical Interferences

What other substances are likely to be present in the sample and are they likely to interfere with the proposed analytical method?

For example, if a welder is being sampled for “welding fumes” the gravimetric determination, i.e., the filter weighing, will be adversely affected if “grinding dusts” have also been sampled during the fume collection period.

An example of chemical interference is calcium in the presence of phosphate as it forms the stable compound calcium phosphate, which can reduce the absorbance of calcium.

Chemical interferences can be especially a problem if chemical speciation of individual contaminants is required.

7.2.5 Sources of Analytical Methods

There are a number of recognized sources of standard and recognized methods that are used for occupational hygiene analysis. These include:

- NIOSH Manual of Analytical Methods (NMAM) – a collection of over 1,700 methods for sampling and analysis of contaminants in workplace air, and in the blood. Available on line at: www.cdc.gov/niosh.nmam.
- UK HSE Methods for the determination of hazardous substances (MDHS Series) more than 100 methods available on line at: www.hse.gov/uk/pubns/mdhsindex.htm.

- OSHA – Standard methods for sampling www.osha.gov/dts/osta/otm/otm_toc.html.
- ISO – Standard methods for sampling and analysis www.iso.org/iso/en/ISOOnline.frontpage.
- National Standard – A number of standards including the sampling for respirable and inspirable dust, welding fumes and organic vapours are available through the National Standards organisations of a number of countries.
- SKC Inc Comprehensive Catalog and Sampling Guide – annual publication and also on their website www.skcinc.com provides references to the method, sampling parameter, analysis and equipment for over 2,500 specific compounds.
- Although mainly aimed at measuring contaminant concentrations that are emitted from a workplace rather contaminant concentrations within a workplace, methods published by the Environmental Protection Agency (EPA) in the USA may also be worth considering.

7.3 Laboratory Balances

While weighing is often considered the simplest of the analytical tools, there are a number of sources of error that must be considered.

The analyst is often weighing sub milligram quantities of material and greater care has to be taken during both filter/sample head preparation and filter reweighing after sampling.

Insufficient sampling time may mean not enough material is collected and cannot be detected unless an appropriate laboratory balance is used.

Calibration of the microbalance is a key aspect and the following extract from AS3640 can be used as a guide to what is required.

“The accuracy of the microbalance used in the gravimetric measurements shall be checked in the following manner:

1. Repeatability: Every 6 monthly, an appropriate repeatability test shall be conducted on the microbalance.
2. Before every weighing session: Before weighing the filters:
    i) Check the balance with a reference weight at or near to full electrical capacity; and
    ii) Check the linearity of the balance inside or near to the working range.
3. During every weighing session: When weighing filters:
    i) Conduct a zero check after each sample/blank filter weight determination; and

ii) Verify that electrostatic effects are insignificant by repeat sample weighing.

4. After every weighing session: Check the calibration of the balance with a reference weight at or near to full electrical capacity.

5. Long weighing sessions

If a series of filters is being weighed the microbalance accuracy shall be checked at appropriate intervals during the procedure."

7.4 Microscopy

Polarized light microscopy (PLM) together with dispersion staining is the technique that is used for the identification of types of asbestos fibre, and phase contrast microscopy (PCM) is used for the counting of fibres.

Fibres are particles that have a needle-like or thread-like appearance with a specific length to width ratio. Some examples of fibres include asbestos, fiberglass, rockwool and ceramic fibres.

Monitoring for asbestos fibres is carried out following the appropriate Standards methods such as:

- Determination of Airborne Fibre Number Concentrations: A recommended method by phase contrast optical microscopy (membrane filter method) published by the WHO (1997)
- NIOSH Method 7400 Asbestos and other fibres by PCM
- HSG 248 Asbestos: The analysts' guide for sampling, analysis and clearance procedures – Appendix 1: Fibres in air: Sampling and evaluation by Phase Contrast Microscopy (UK)
- NOHSC Code Asbestos: Code of Practice and Guidance Note or the Membrane Filter Method for Estimating Airborne Asbestos Dust (Australia)

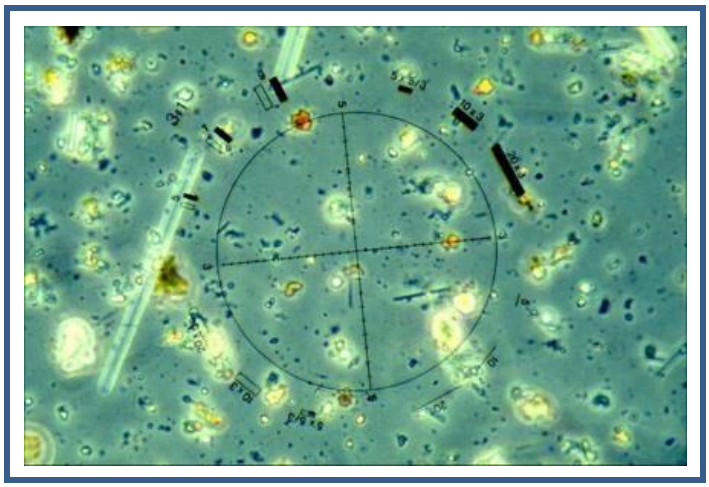
Figure 7-8 Sampling Head for Asbestos Fibres

Source: University of Wollongong

Microscopy should only be performed by a trained and certified person. Typically, such persons routinely participate in an inter laboratory system to maintain their skills and validate their consistency with international standards.

The principle of the method is air samples are collected on a gridded mixed cellulose ester or cellulose nitrate filter mounted in a cowled asbestos sampling head.

Figure 7-9 Phase Contrast Microscopy – Amosite Fibres & Synthetic Mineral Fibres



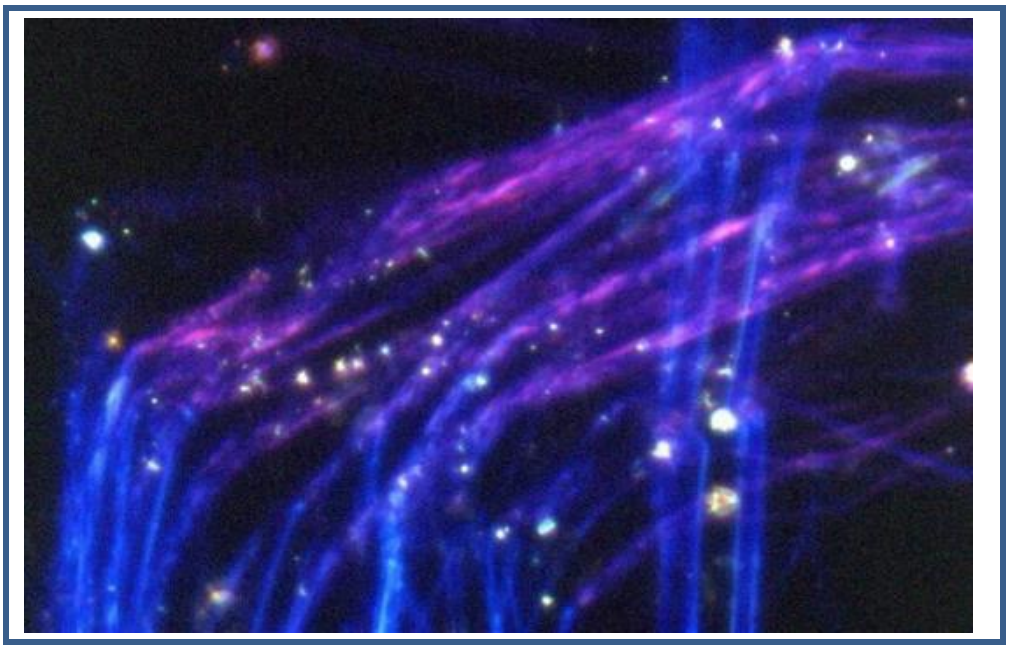
Source: A Rogers – Reproduced with permission

After sampling the filters are mounted on a microscope slide by collapsing the membrane using acetone vapours making it transparent. Glyceryl triacetate is added to the slide to provide a suitable medium for seeing the fibres.

The fibres are then counted using phase contrast microscopy following standard fibre counting rules. Results are expressed as numbers of fibres/ml of air.

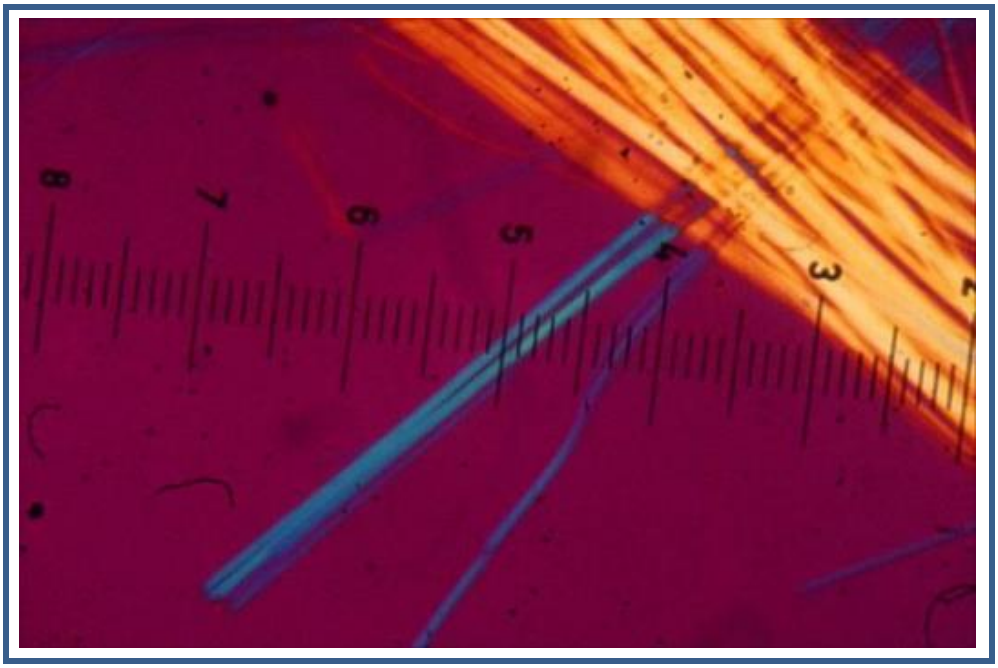
The other area of analysis in regard to asbestos fibres is that of identification in bulk materials. This involves the suspension of fibres in liquids of known refractive indices and observation of the colours displayed under polarized light at different orientations of the fibres. A variety of microscope configurations can be used, including dispersion staining and crossed polars with first order red compensator plate. This technique is both rapid and sensitive in the hands of a trained operator.

Figure 7-10 Chrysotile



Source: A Rogers – Reproduced with permission

Figure 7-11 Amosite (1st Order Red Retardation)



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7.5 Quality Assurance of Analysis

7.5.1 Internal Quality Control

The internal quality control process is the set of procedures adopted by a laboratory to assess whether the results from each set of tests are consistent. Occupational hygiene samples can often pose quality control concerns including the very low levels being measured, matrix effects from the sampling medium, interfering substances, incomplete recoveries, degradation in storage or transport etc. The procedures typically used include method validation, the use of standards, blanks and controls, recoveries and quality control charts.

7.5.1.1 Method Validation

Before use an analytical method must be validated to ensure it is sufficiently accurate and precise.

Its accuracy may be tested by analysing known concentrations of the analyte. For example, by adding known amounts of solvent to charcoal tubes, desorbing it and analysing it by gas chromatography; or by spiking blood or urine samples with lead for example and analysing by atomic absorption. The recovery of the analyte is the percentage of added analyte recovered, i.e., measured in the analysis.

Precision is determined by analysing enough replicate samples to enable the calculation of the standard deviation or coefficient of variation. Several different concentrations over the range should be selected.

The measurement range is a guide as to the usual operating range of the method. At the lower end this involves an estimate of the limit of detection (LOD) and the limit of quantitation (LOQ).

Other factors to be evaluated include:

- Interfering substances
- Capacity of the collection media (e.g., breakthrough volume for sorbent tubes)
- Stability of samples
- Critical steps in the analysis where special care must be taken

There are well established and validated methods for many common chemicals.

7.5.1.2 Standards

Standard reagents: are chemicals of known purity and composition. These materials are often available from external agencies e.g., Standard Reference Materials from the US National Bureau of Standards.

Calibration standards: these are reference standards against which all test and control samples are compared.

Where standard calibration curves are prepared at least 5 points should be used and appropriate regression analysis should be undertaken to ensure the viability of the calibration curve.

7.5.1.3 Blanks

Field sampling blanks should be submitted with field samples to determine if there has been contamination during sample handling and storage. The blank is treated in the same manner as the field sample but with no air being drawn through it.

Reagent blanks are used in the laboratory to correct for any contribution made by the laboratory reagents used in the analysis.

7.5.1.4 Control Materials

These have been previously analysed and are analysed with the test samples so that a comparison between actual and expected result can be made.

7.5.1.5 Recoveries

Recoveries should be assessed both as part of the method validation process, but also on an ongoing basis as part of the quality control process.

7.5.1.6 Duplicates

Duplicate samples, i.e., from the field are more useful in assessing the reproducibility of the sampling or analysis than are duplicate analysis, i.e., two chromatograph injection from the one air sample.

7.5.1.7 Quality Control Charts

These can provide a means of showing the reliability of each method and to identify trends or cyclical changes in laboratory performance.

7.5.2 External Quality Assurance

7.5.2.1 Proficiency Testing Schemes

Many countries run inter-laboratory testing schemes and some of these are International:

- NIOSH - Proficiency Analytical Testing (PAT) – solvents on charcoal, asbestos, silica and metals on filters
- UK HSE – Workplace Analysis Scheme for Proficiency (WASP) – solvents on charcoal, metals on filters

They involve the distribution of control samples to laboratories by an outside agency. The material is analysed and the results returned to the coordinating body for statistical analysis.

7.5.2.2 Laboratory Accreditation

The purpose of accreditation is to ensure a laboratory's results are reliable. A laboratory applying for accreditation is visited by assessors, who examine all aspects of the laboratory's operations including the qualifications and experience of staff, quality, calibration and maintenance of instruments, accommodation, laboratory practice including sample handling, quality control, recording and reporting, and the test methods used. If satisfied, the appropriate approval to undertake the type of analysis being sought is granted.

Chapter 8 Other Sampling Tools

This chapter describes and discusses other types of sampling occupational hygienists may be called upon to do. These include

- ✓ **Bulk Samples**
- ✓ **Surface Contamination**
- ✓ **Dermal Exposure**
- ✓ **Confined Space Sampling**
- ✓ **Compressed Air Quality**

8.1 Bulk Sampling

In many instances it will be necessary to collect some bulk samples to identify which contaminants are likely to be present in the workplace. This is commonly the case in regard to asbestos identification where bulk samples are collected and the presence and type of asbestos identified by dispersion staining or other confirmatory techniques.

The same principles can be applied to other unknown substances found in workplaces. Before developing a monitoring programme, bulk samples of an unknown material can be sent to a laboratory for analysis to check on the specific contaminants present and to check for any contaminants which may interfere with some sampling methods.

The results will guide what type of monitoring strategy is required and thus it is very useful in the overall process.

8.2 Surface Contamination Measurements

If a comprehensive risk assessment for exposure to contaminants in the workplace is to be developed, it is essential that any contribution from surfaces be evaluated. This will always be dependent on the toxicological properties of the substance and is common practice in the nuclear industry.

There are various methods used for evaluating surface contamination, such as micro vacuuming, disposable paper towels and manual wipe methods. The manual wipe method (also called smear and wipe) is the most commonly used and involves a filter paper being drawn over a known area of contaminated surface and then being analysed to produce an assessment of the level and nature of the deposit.

Another method which has shown good results in laboratory trials (Wheeler & Stancliffe 1998) is the use of adhesive tape, more specifically forensic tape. Such tapes are constructed of a clear plastic top coat, a sticky middle layer and a base layer. By removing the clear plastic top coat, the sticky layer can be pressed into a surface thus collecting what contaminants are present. In general samples (both wipe and adhesive tape) are treated with acid to dissolve any contaminants

present, followed by atomic absorption spectrophotometry, or the samples can be analysed without any acid digestion by X-ray fluorescence spectrometry (XRF).

Other approaches to assessing contaminated surfaces involve the use of pH sticks or colorimetric pads (acids and alkalis) or instrumentation such as mercury sniffers (the high vapours pressure of mercury makes this a particularly effective technique).

The question as to why you would undertake surface contamination invariably arises. Such sampling (especially during evaluation of contaminated waste sites) improves the characterization of what hazards may be present and allows for better decision-making.

Surface contamination samples can indicate sources of leakage and help to track the spread of contamination. They can give an indication of how and where skin contact might occur. However, they are not a direct measure of exposure and cannot readily be compared with any exposure limits.

8.3 In-Situ XRF Metal Analysis

An XRF spectrometer uses primary radiation from an X-ray tube to excite secondary emission from a sample. The radiation emerging from the sample includes the characteristic X-ray peaks of major and trace elements present in the sample. Dispersion of these secondary X-rays into a spectrum, usually by X-ray diffraction, allows identification of the elements present. The height of each characteristic X-ray peak relates to the concentration of the corresponding element in the sample, allowing quantitative analysis of samples for most elements in the concentration range 1 ppm to 100%.

In recent years small hand-held XRF analysers have been developed which are extremely useful for measurements of samples within the field. One such application is their use to measure elements in contaminated soils and unknown bulk materials. This is particularly useful for metal analysis.

It should be noted that particle size and surface preparation can influence results. Improved analysis can be achieved if the sample is dried, sieved, ground or pressed.

Dost (1996) evaluated a field XRF unit in relation to the measurement of dusts from surfaces in workplaces and commented on the ease with which the elemental nature and level of contamination in the workplace could be determined. Dost also concluded that the XRF technique had a distinct advantage over the traditional wipe method where the contaminant material was on a rough and porous surface (e.g., concrete). Conversely, it was not suitable on surfaces such as steel as it picked up the elements of this surface as well as the overlaying contaminant material.

A common use for XRF instruments is in the evaluation of coatings for the likely presence of significant amounts of lead.

8.4 Skin Exposure

Dermal exposure can present a significant pathway for some contaminants to enter the body. This is especially the case with pesticides, but other compounds can be absorbed this way.

Dermal exposure evaluation methods have been broadly categorized into direct and indirect methods.

8.4.1 Direct

Direct means assessing what is deposited on to the skin; indirect means estimating dermal dose either as attributable to some biologic indicator that is actually measured or that which could potentially result from a contaminant measured on an accessible surface.

The most common direct method is the use of dermal dosimeters in the form of patches. Other direct evaluation methods include skin washes and wipes, and the video detection of fluorescent tracers.

8.4.2 Indirect

Indirect methods refer primarily to measuring a biologic response such as cholinesterase activity in blood or urinary excretion, but also include measuring surface contamination.

In comparison to air sampling and even biological monitoring, dermal dosimetry is not a simple or routine procedure.

An individual applying dermal dosimeters should be thoroughly trained regarding the placement and retrieval of the dosimeters and recording of observations and other information about the activity.

In addition to objective parameters, observed work practices can also have statistically significant important influences on dermal exposure.

Each patch dosimeter is a sandwich holding a passive matrix (like a cotton gauze sponge) flat and to protect it from skin perspiration. Either one or two sets of patch dermal dosimeters can be used. The most important is the set placed against the skin under the clothing. It is believed that errors will result from using patch dosimeters attached to the inside of clothing that is free to move relative to the skin; such dosimeters will neither collect contaminants reaching the skin via penetration through openings (such as the neck, sleeves, or cuffs) nor be affected by the air motion carrying contaminant through the weave of the fabric. A second set of dosimeters may be placed outside of any clothing; it is also important that no inner dosimeter is placed beneath an outer dosimeter.

After dosimeters have been in place throughout an activity involving exposure, they are carefully removed, prepared for extraction (the quantitative removal of the chemical from the collection matrix), and the extract is analysed for the mass of chemical.

Whole body dosimeters are typically a set of long cotton underwear that minimizes the effect of non-uniform depositions within a body part, but suffers from the lack of a barrier between the skin and dosimeter and may add heat stress to the wearer. After use, the whole-body dosimeter may still be dissected into portions covering individual body parts.

As with all other approaches to assessing dermal exposures, there are limitations to the use of dermal dosimeters. Among the most important of these limitations (not restricted to dermal dosimeters) is the difficulty in accurately collecting depositions of volatile chemicals.

Biological monitoring to assess dermal exposure is a common technique (e.g., cholinesterase activity in blood for pesticides); however, it may be invasive and unless correct sample collection techniques are observed may grossly underestimate exposure. In such cases dermal dosimetry (patches) may be a good alternative.

In other cases, such as chromium VI, Styrene or (Tetraethyl lead) where skin absorption can be a significant route of exposure, a combination of environmental monitoring and biological monitoring may give the most accurate picture of employee exposure.

Irrespective of the circumstances, dermal monitoring should only be undertaken by persons trained and experienced in the appropriate monitoring techniques.

8.4.2.1 Tool Kit for Dermal Risk Assessment and Management - RISKOFDERM

The European Research Project RISKOFDERM – Risk Assessment of Occupational Dermal Exposure – has developed a conceptual model for dermal risk assessment and a simple to use tool kit for assessment and management of health risks from dermal exposures and is currently undergoing final evaluation. The tool kit can be downloaded at:

http://www.eurofins.com/research- development/occupational hygiene/risofderm.asp

The tool kit was constructed by analysing the major determinants of dermal hazard and control exposure. The results were combined in the form of a decision tree. The tool kit does not show all the details behind the assessment, but asks the user a series of questions that are translated by the system into hazard and exposure categories that lead to an estimate of health risk from dermal exposure together with suggested control strategies.

8.4.2.2 Hazard

The user is asked to enter the identification of the chemical and the risk phrases and any additional information such as pH and the physical state of the chemical.

The information is translated into two hazard categories – one concerning local effects, the other systemic effects after uptake through the skin. The hazards are rated – negligible, low, moderate high, very high or extreme.

8.4.2.3 Exposure

User asked to enter information to identify the workplace or process that is assessed and which one of the Dermal Exposure Operational units' best fits with the sub category of exposure to solid or liquid:

- Handling of contaminated objects – solid or liquid

- Manual dispersion – solid or liquid
- Hand tool dispersion – solid or liquid
- Spray dispersion – solid or liquid
- Immersion – solid or liquid
- Mechanical treatment – solid or liquid

From the information the tool kit will apply default exposure rates, take into account duration and the exposed body areas and the actual exposure score from local effects and the internal exposure score from systemic effects are then calculated separately and ranked as health risk scores with suggested controls ranging from no action required up to substitute in either case and stop working.

The toolkit is an attempt to adapt elements of exact science to a situation where the necessary input data are of limited quality and are only estimates. The purpose is to enable the user to estimate the order of magnitude of hazard, exposure and risk and to encourage the user to deal with issues of dermal hazard, exposure and control.

The RISKOFDERM project has been the subject of significant controversy and more detail can be found in an overview by Oppl et al (2003).

8.5 Confined Spaces

8.5.1 Identification and Nature of Hazards

Confined spaces have various legal definitions in different parts of the world and while a full list of such definitions is not appropriate for this course, all contain the same (or similar) key elements. These include:

- They are enclosed or partially enclosed spaces at atmospheric pressure during occupancy.
- May have a deficiency or an excess of oxygen.
- May have an atmosphere which has potentially harmful levels of contaminants.
- May contain a product which could cause engulfment.
- Could have restricted means of entry and exit.

Please be sure to understand the definition of a confined space in your jurisdiction, as definitions and air monitoring requirements may vary.

Examples of confined spaces include:

- Storage tanks, boilers, silos, pressure vessels, etc.

- Pits, pipes, sewers, ducts, etc.

A confined space is determined in part by the hazards associated with entry into such a space and not just work performed in a physically restrictive location.

The presence of chemical agents (alone or in combination) may present a risk to personnel in a confined space that would not otherwise occur in the general atmosphere.

Some of the hazards that may be associated with work in confined spaces are:

- Hazardous Substances: This includes the use of chemicals, previously stored substances or their by-products (e.g., H2S from decomposing plant material), fumes from welding, painting, etc.
- Flammable Atmospheres: This includes gases, vapours and dusts which are present in the explosive range.
- Unsafe Oxygen Level: This includes oxygen deficient atmospheres as a result of oxidation, combustion, displacement, absorption, consumption by some process and, excess oxygen as a result of a leaking oxygen supply fitting, oxy-propane cutting, oxygen injection and the use of chemicals that liberate oxygen (e.g., hydrogen peroxide).
- Engulfment: Asphyxiation caused by a stored supply of material immersing workers within the confined space.
- Physical and Other Factors: This includes manual handling, ignition hazards, electrical hazards, mechanical hazards, noise, radiation, biological hazards and heat stress.

8.5.2 Monitoring in Confined Spaces

The human senses should never be trusted to determine if the atmosphere within a confined space is safe. Many toxic gases and vapours (such as carbon monoxide) cannot be seen or smelt, nor can the level of oxygen be established accurately without appropriate instrumentation.

As permit to enter procedures for confined spaces invariably involve a risk assessment, this process should ensure that appropriate arrangements are put in place to test the atmosphere within the confined space.

Where appropriate the atmosphere should be tested for:

- Oxygen content; and/or
- Airborne concentration of flammable contaminants; and/or
- Airborne concentration of potential harmful contaminants.

The common means of sampling the air to assess the risk of adverse health effects is to test for specific materials with a suitable portable analyser. There are many different kinds of analysers available but the results are only as good as the operator’s skill and the state of analyser

maintenance. An explosimeter, used for measuring the percent Lower Explosive Limit (LEL) in a confined space, should be tested against a known standard gas, both before and after a test for vessel entry, to ensure that an accurate reading is obtained. It should be noted that a reading below the LEL could still mean that hundreds or even thousands of ppm of contaminants are present in the atmosphere.

Instruments used for testing the atmosphere in a confined space should be selected for their ability to measure hazardous concentrations and should be calibrated in accordance with the manufacturer's guidelines or manuals.

If atmospheres that are to be sampled are potentially explosive, intrinsically safe monitoring equipment will be necessary. Initial monitoring should be performed from outside the confined space by inserting a sample probe at appropriately selected openings. Telescopic extension probes or probes attached to a line can be used to reach remote regions.

Some gases or vapours are heavier than air (for example, hydrogen sulphide) and in unventilated areas will settle to the bottom of a confined space. Also, some gases are lighter than air (for example, methane) and will be found around the top of the confined space. As it is possible for contaminants to settle at different levels, the top, middle and bottom of a space should be sampled. Horizontal spaces should also be sampled at representative intervals along their length. Sampling should be such as to reflect accurately the conditions within the confined space.

When considering the appropriate time to monitor the atmosphere, it should be understood that unless monitoring is undertaken immediately prior to entry, the results may not be relevant and an unsafe condition may potentially exist.

While pre-entry testing indicates whether the atmosphere in the confined space is acceptable for entry, atmospheric conditions in the confined space can change, therefore the atmosphere should be re-tested during the work day.

Testing the atmosphere within the confined space while work is in progress will indicate whether or not the ventilation system is adequate or if the work processes are making the atmosphere unsafe.

Continuous monitors provide constant surveillance of atmospheric conditions in a confined space. Personal direct reading monitors can be used to initially test the space, and then can be worn by an employee during work to detect atmospheric changes during entry. These monitors should be fitted with visual and audible alarms to warn employees of the hazard and the need for further action as set out in the entry procedure and permit.

Re-testing and continuous monitoring of the atmosphere may be necessary:

- If determined under the risk assessment;
- As indicated from the initial testing of the atmosphere;
- Because of the potential for later release or disturbance of hazardous material. Such material includes sludge, scale or other deposits, brickwork and liquid traps. The hazardous material may be released if disturbed or if heat is applied. Where harmful

contaminants are released, control measures should be based on the assumption that any further disturbance of the sludge will release more vapours; or

- Because of the work undertaken in the space. For example, heat or fumes from processes such as welding can build up rapidly in a confined space.

No matter what type of instrumentation is used to assess a confined space (or any other workplace), it is important that the operator clearly understands the limitations of that equipment. For example, an explosimeter exhibits different sensitivities towards different flammable gases or vapours and thus to give accurate results it should be calibrated with known concentrations of the gas or vapours likely to be present in the atmosphere being assessed.

Moreover, most chemical sensors used for the measurement of contaminant gases are fitted with filters to minimize cross sensitivity from other contaminants. These filters need to be replaced according to the manufacturer's instructions and the potential problems of cross sensitivity well understood by the instrument operator.

It should also be noted that monitoring is never a substitute for the systematic and verified isolation of the confined space from any outside source of hazardous material.

8.5.3 Breathing Air Quality

Air supplied or self-contained breathing apparatus (SCBA) relies on the use of air generated by air compressors to provide the air source. It is important to ensure that the quality of this air is assessed at regular intervals to check for contaminants such as carbon monoxide and oil mist, which may have been inadvertently generated by the compressor. If significant pipework is used to direct the breathing air around a plant, it is not uncommon for condensation to occur in the pipes, leading to corrosion. Under some circumstances such corrosion can give rise to an astringent taste in the air.

In most commercial systems filters are installed to control moisture, oil mist and carbon monoxide, but these have a finite life and need to be changed when expended.

There are varying approaches to monitoring these contaminants in the air but the advent of direct reading devices has made the inline analysis of carbon monoxide on site relatively easy.

In modern systems continuous monitoring instrumentation for carbon monoxide and built-in filtration are common. For older systems it may be necessary to sample the breathing air using external procedures. In such cases air is drawn into a gas sampling bag from which it is extracted and presented to the instrument (carbon monoxide monitor or indicator tube) for measurement. Oil mist is usually sampled by passing a known volume of air through a small pore size filter. The collect oil is either analysed gravimetrically or more accurately by infra-red or gas chromatographic means.

Chapter 9 Presentation of Results

This chapter addresses the basics of how to analyse and present the results of occupational exposure measurements

9.1 Background

Accurate reporting of data is as important as sample collection as they provide a record of what was done, where, when, why and by whom. It is therefore important to be clear on the objectives of exposure monitoring effort, and to keep careful and detailed field notes in a consistent fashion. Besides reporting findings made, reports should address the meaning of the data and should include recommendations (including whether further sampling is necessary) as appropriate. Note that in some jurisdictions such as the US, an exposure evaluation report is considered an exposure record for which there are specific requirement regarding how long an employer is required to retain the report.

Preparing an exposure monitoring report requires identifying the intended audience and affected stakeholders such as:

- Management or person/group requesting the survey.
- Statutory authorities – if involved in the exercise.
- Workforce representatives (unions) – if involved in the process.
- Persons monitored– It stands to reason that individuals who participate in exposure monitoring be informed of the results and what they mean. This is best done in person by someone familiar with their interpretation so that concerns can be addressed.

The BOHS also published a guidance document for clear and concise report writing (see https://www.bohs.org/information-guidance/bohs-resources/), which builds on previous documents prepared by AIOH 2006. This guidance is the basis for BOHS assessment of reports as part of personal learning portfolios (PLPs) for BOHS certificate and or diploma candidates.

There are also two national standards that address occupational exposure assessment report structure and content: British Standard BSEN689 and Australian Standard AS 2985 (see text boxes).

9.2 General Report Content

A well-based occupational hygiene report should be written in easy-to-read language, address all questions raised in the original scope of work and be able to satisfy an experienced occupational hygienist that the work was properly conducted and appropriate conclusions drawn. It may take many forms depending on the objectives of the survey. However, they should generally address the following:

- Introduction - What the objectives of the survey were. Who did the work and where. What were the limitations?

- Methods and Materials - How were the samples collected? When did the work take place? What equipment was used? How was it calibrated? Who analysed the samples? Attach the lab report to sample report.

- Results and Discussion - What was the process investigated? What did the lab report? Calculate 8h-TWAs as needed. What do the results mean? What was observed on site that could explain the results?

- Recommendations - What should be done about the findings? Is additional sampling needed? Are there regulatory consequences?

- Conclusions - What did the study find?

It's always a good idea to have a colleague review your report before sending it out. The checklist provided in the current BOHS guidance is very useful.

BSEN689: Guidance for Assessment of Exposure by Inhalation to Chemical Agents

"Reports shall be written of the occupational exposure assessment and of any periodic measurement. Each report should give reasons for the procedures adopted in the particular workplace.

- The report has to contain:

- The name of the person(s) or institutions undertaking the assessment and the measurements;

- The name the substances considered;

- Name and address of company;

- The description of the workplace factors including the working conditions during the measurements;

- The purpose of the measurement procedure;

- The measuring procedure;

- The time schedule (date, beginning and end of sampling);

- The occupational exposure concentrations;

- All events or factors liable to influence appreciably the results;

- Details of quality assurance if any;

AS2985 Workplace Atmospheres: Method for Sampling and Gravimetric Determination of Dust for requires test reports to include:

- Identification of sample either as name of person wearing sample or sampler location.
- Activities being conducted during sampling.
- Any personal protective equipment worn.
- Name of laboratory or authority which performed the test.
- Date on which the test was carried out and sampling duration.
- If uncertainties are not formally derived, for sampling periods greater than 60 minutes the concentration should be reported to two decimal places and three significant figures for six place microbalances, and to one decimal place and two significant figures for five-place microbalances.
- Net weight of dust on filter.
- The identity of any reference material used to assist in the validation of the test results.
- Any observation, in relation to either the test sample or the performance of the test, which may assist in the correct interpretation of the test results.
- References to the test method used."

9.3 Notes on Process Description

Where a survey of an area, plant or process is conducted, the following should be described:

- Area/plant/process surveyed, e.g.," a survey of the area known as cold press or CP was conducted".
- Conditions at the time (i.e., personnel, process conditions, risk controls in place) e.g., "usual operator unavailable", "shutdown", "worst case situation, with no controls", "as normal, believed to be a representative working day", "only Blender No.2 was operating", "protective equipment worn other than overalls".
- Identify any items examined, e.g., "Toolmaster serial number 123", "machine called the hot block curer".
- Number of employees, duration of work shift(s) and task frequency and duration, e.g., "9 employees work an 8-hour day, 5-day week with 2 hours overtime worked infrequently", "it takes about 30 minutes for 5 bags to be opened and poured daily".

Diagrams and photographs are useful for clarifying sampling locations and conditions.

9.4 Notes on Results and Discussion

- Results may be presented in the body of the report or as appendices. The level of information, considering the complexity of the processes, tasks and risks, should satisfy the technical reader but not unnecessarily complicate the report. Results should be traceable to the original field notes to enable verification of supporting data (e.g., identity of equipment used, calibration, etc.) should this be needed.

- Results of personal sampling should be compared with the relevant exposure standard. If there is no relevant exposure standard, it will be necessary to either modify or adapt an existing guideline or develop a guideline. The rationale justifying the guideline used should be provided.

- Time weighted average (TWA) and short-term excursions limits (STEL), or

- TWA and general excursions limits (if no STEL is set), or

- Peak/ceiling limits.

- Results should be compared with any previous surveys at the premises and data from similar premises if available, e.g., “The process produced results that are similar to other coating operations”. An explanation of general trends and unusual high or low trends should be included.

- The level of risk should be determined (preferably quantitatively) to allow for the adequacy of controls to be assessed and the prioritization of control options.

9.5 Notes on Conclusions and Recommendations

Conclusions should be drawn about whether or not the relevant exposure standard(s) have been exceeded and if the work could harm employee health, e.g., “Exposure is likely to approach and may exceed the exposure standard and there is a significant risk”, “It is believed that exposures are unlikely to approach the exposure standard and the risk is not significant”, “The risk is uncertain due to the state of knowledge (or level of exposure)”.

Conclusions should also be drawn about adequacy of control and any further practical actions to eliminate or reduce the assessed risk so far as is practicable, e.g., “existing controls adequate if maintained”,” existing controls not adequate and need to be upgraded”.

Recommendations should be selected using the hierarchy of control approach (personal protective equipment being the last resort) and guidance on an appropriate implementation time frame (e.g., urgent, short, medium or long term) should be provided. e.g., “Temporarily cease work on No.123 process until corrective actions (see below) have been implemented”, “Personal protection is a short-term interim control. In the longer-term engineering controls…”, “A preventive maintenance programme should be implemented as soon as practicable”, “Periodic reviews to determine if control measures need to be modified should occur at least once a year”.

Recommendations arising from regulatory requirements or similar guidelines should reference the relevant source document(s), e.g., "The xxx Occupational Health and Safety (Noise) Regulations 1992 require that…", "xxx Standard 4114 Spray Painting Booths states that a minimum velocity of …". "

What is fundamental in all cases is that the information collected and evaluated is communicated to all the stakeholders involved in the exercise in a manner and format that meets their needs or expectations. In almost all cases this will be different for each of the stakeholders.

9.6 Statistical Analysis Primer

Occupational hygienists may be called upon to use evaluate air sampling measurements, typically to determine whether measured exposures exceed an OEL, or in some cases, other internal criteria (often half of a recognized OEL). As suggested in Chapter 4, a collection of results represent a population of data, and the issue becomes how to evaluate it collectively rather than value by value. In the case of a prescribed standard, there may be specific approaches and requirements for data collection and analysis but this is not usually the case.

This primer is intended to provide a brief overview of statistics and statistical tools in the context of occupational hygiene data. OHTA 501 Students are expected to be familiar with the general concepts but will not be required to apply them as part of this course. However, competence and board certifications in occupational hygiene will require a deeper understanding and application of these and other concepts.

The following is suggested for further reading: Milz S, and J Mulhausen (2015) "*Appendix IV: Descriptive Statistics, Inferential Statistics, and Goodness of Fit*" In A Strategy for Assessing and Managing Occupational Exposures, 4th edition, AIHA, Fairfax, VA.

A 2021 BOHS Webinar on YouTube also provides further information (see https://www.youtube.com/watch?v=THWxgHoJwU0). Search for BOHS statistics if link does not work.

In the absence of prescribed approaches, occupational hygienists have used professional judgement to evaluate air sample results. For example, if all measured exposures are well below an exposure criterion (half of the OEL is used by many hygienists), the process would be considered under reasonable control and the results would be judged to be acceptable. This does not mean that exposures could not exceed the criterion, however if they did, this would be due to unusual circumstances (e.g., maintenance). Results that approximate the criterion would require further evaluation and potentially the introduction of better controls since it is more likely to exceed the desired criterion. A process would be considered out of control if exposures exceeded the criterion. This should prompt an exposure mitigation program, including temporary use of respiratory protection until process emissions can be better controlled.

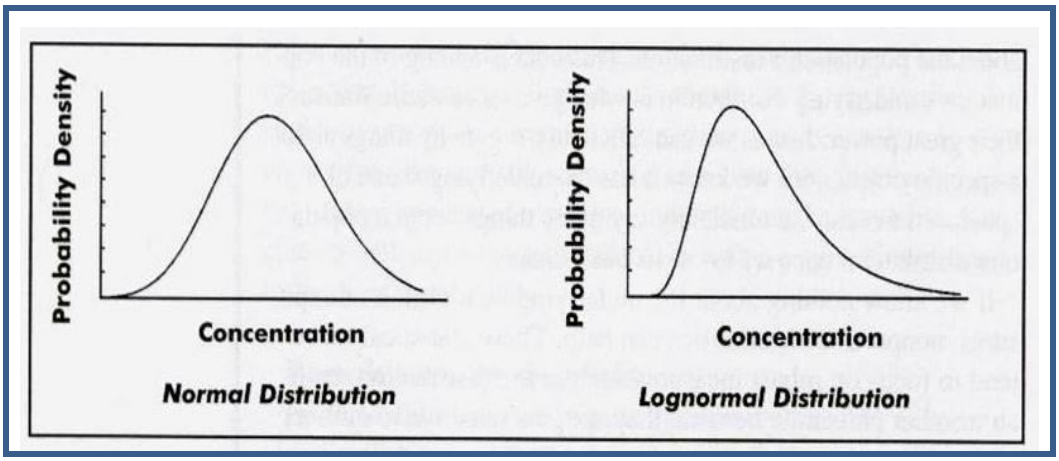
Note that statistical analysis assumes random sample collection, which may not always be the case in occupational hygiene work. Often, processes vary, or anomalies may occur on the day of sampling. Moreover, Nonetheless, statistical analysis provides useful insight.

9.6.1 Statistical Distribution

According to parametric statistical theory, most data sets (i.e., measurements) represent a universe of values that conform to some form of definable distribution. For occupational hygiene work, we are mostly interested in normal and log normal distribution of data. The latter is where the data is equally distributed around a central mean, which yields a bell-shaped curve. However, data distribution becomes skewed when there cannot be negative results, as occurs with air sampling data. This type of data distribution is known as a log normal distribution, because plotting log values of the data yields a normal distribution. Figure 9-1 illustrates the difference between these two types of distribution.

When examining occupational hygiene data, it is reasonable to assume lognormal distribution unless there is a compelling reason to believe otherwise. This should be verified through online data analysis tools (e.g., AIHA's IH Stat) or can be determined by plotting data on log probability paper (see below).

Figure 9-1 Normal and Lognormal Distributions



(Source: AIHA 1998 – Used with the permission of the American Industrial Hygiene Association 2007)

9.6.2 Mean and Standard Deviation

A collection of data can be defined by their mean values, as well as standard deviation. Normal and lognormal distributions each have their own versions as shown in

Table 9-1. The equations shown below can be used to calculate those values, although most spreadsheet programs calculate parameters such as mean and standard deviations easily, as does the AIHA's IHSTAT spreadsheet (see https://www.aiha.org/public-resources/consumer-resources/topics-of-interest/ih-apps-tools).

Table 9-1 Normal vs Log Normal Parameters

Normal	Log Normal
Arithmetic Mean (AM)	Geometric Mean (GM)
Standard Deviation (SDev)	Geometric Standard Deviation (GSD)

The equations for these parameters are shown below

Arithmetic Mean (AM)

$$\bar{x} = \frac{1}{n}\sum x \qquad \text{…Equation 9-1}$$

Where x = result
n = number of sampler
$\bar{x}$ = arithmetic mean

Standard Deviation (SDev)

$$SDev = \sqrt{\frac{\sum(x-\bar{x})^2}{n-1}} \qquad \text{…Equation 9-2}$$

Where SDev = standard deviation

Geometric Mean (GM)

$$\ln(GM) = \frac{1}{n}\sum \ln x$$

$$GM = e^{\frac{1}{n}\sum ln(x)} \qquad \text{…Equation 9-3}$$

Where GM = geometric mean

Geometric Standard Deviation (GSD)

$$\ln GSD = \frac{1}{n-1}\sum(\ln(x) - \ln(\bar{x}))^2$$

$$GSD = e^{\frac{1}{n-1}\sum(ln(x)-\ln(\bar{x}))^2}$$ …Equation 9-4

Where GSD = geometric standard deviation

Care needs to be taken when analysing data that contains some results reported as less than a specified quantity (i.e., results are reported as non-detect, ND, or < LOD). Non detect results represent neither zero nor a value just less that the limit of detection so should necessarily be discarded when evaluating a collection of data. The University of Montreal has created an online tool to address this issue (https://espum.umontreal.ca/lespum/departement-de-sante-environnementale-et-sante-au-travail/production-scientifique/utilitaires/ndexpo/).

The Arithmetic means (AM and GM) scan be compared to OELs directly but are not informative as to how likely it is that the criterion might be exceeded. Examination of Figure 9-1 indicates that it is hypothetically possible to exceed any given value, so it is of value to get a sense of how likely that might be. Standard deviations (SDev) and geometric standard deviations (GSD) provide some insight into this.

Standard deviations essentially indicate how widely spread the underlying data is. Geometric standard deviation values also can provide an insight into the nature of the underlying data as shown on Table 9-2.

Table 9-2 Rules of Thumb GSD Values

GSD Value	Comment
1.0	No variability
1.5-2.0	All data are same values-why?
2.0-3.5	Very little variability
> 3.5	Moderate variability

Nowadays, these means and standard deviations (normal and log normal) are easily calculated in most spread sheet applications. Online tools such as AIHA's IHSTAT (https://www.aiha.org/public-resources/consumer-resources/topics-of-interest/ih-apps-tools) simplify statistical calculations and encourage the application of statistical concepts for evaluating data.

Knowledge of AM and SDev, as well as GM, and GSD, allow inferential analysis of the underlying data by estimating various parameters such as confidence levels, and MVUE.

9.6.3 Confidence Levels

Means and standard deviations allow an estimation of likely values within the populations they define. For example, it possible to derive a point estimate below which one could expect 95% of measurements. This would be termed a 95% upper confidence limit (95% UCL).

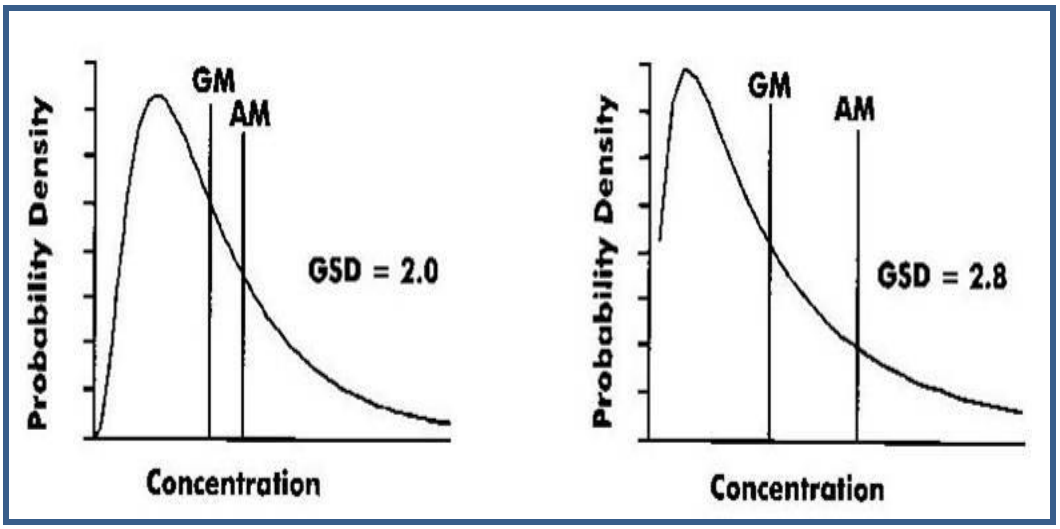
In some instances, estimated 95% UCL values are compared to exposure criteria to determine whether a process is adequately controlled, particularly where the process involves substances that exhibit acute toxicity.

It is easier to use spreadsheets or online tools such as AIHA's IHSTA to estimate confidence limits. However, they can also be estimated using log probability plots of data

9.6.4 Minimum Variance Unbiased Estimate (MVUE)

Minimum variance unbiased estimate (MVUE) is especially useful in those cases when the data is heavily influenced by high results. The MVUE provides an unbiased estimate of the true arithmetic mean of a lognormal dataset. When the data has little variability (GSD <2.0) the GM and MVUE (AM) will be close together, however as variability increases (GSD 2.0 – 3.5) the MVUE (AM) will give a better estimate of the central point of the exposure profile (Figure 9-2).

Figure 9-2 AM and GM of Lognormal Distributions



(Source: AIHA 1998 – Used with the permission of the American Industrial Hygiene Association 2007)

MVUE values are difficult to calculate because of the iterative nature of its calculation.

9.6.5 Log Probability Plots

Log probability can be sued to evaluate whether a data set is log normally distributed.

The plot can be done manually by ranking the results, 1 being used for the lowest value, determining their plotting position as follow:

$$Plotting\ Position\ (\%) = \frac{Rank}{n+1}\ x\ 100\% \qquad \text{...Equation 9-5}$$

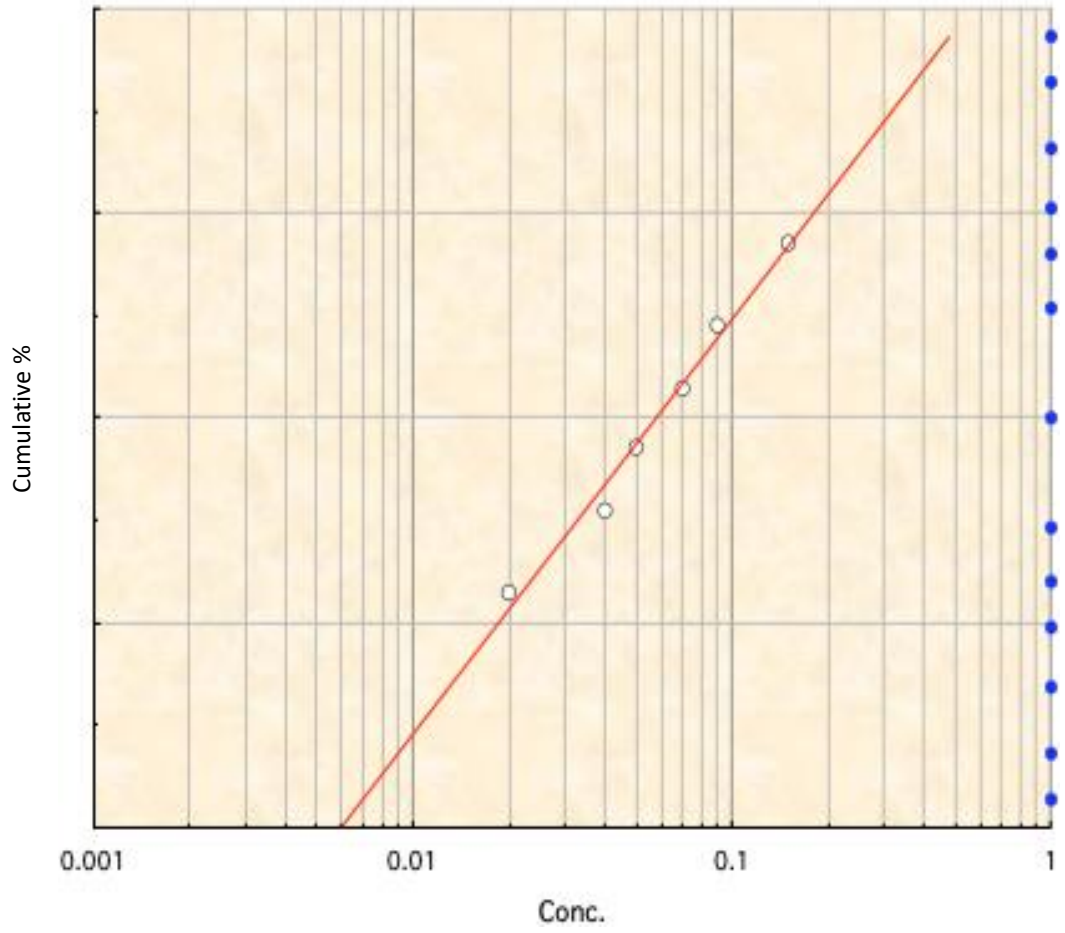
Where Rank is rank of result with lowest = 1

and, n = number of results

The resulting data can then be plotted on log normal paper, with % position on the y-axis, and corresponding result on the x-axis. A linear plot indicates the data is log normally distributed. See

Figure 9.2 below:

Figure 9.2: Example of Log Probability Plot



The GM can be found by reading off the concentration at the 50th percentile, so in the above case, it would be 0.06 ppm (assuming the plot data is in ppm).

Deriving the GSD requires either dividing the concentration at the 84th percentile by that of the 50th percentile, or by that of the 50th percentile by the 16th percentile. Results may not always be symmetrical due to calculations to plot best fit line. In the above example, GSD is around 4. This indicates a fair amount of variability. Perhaps there are outliers, or perhaps the group sampled is not as homogeneous as anticipated.

The 95th percentile (used as a measure of compliance by some organisations) can also be read off the graph (around 0.40 ppm in the example above)

Log probability plots are easily done on software available on line such as AIHA's IH Stat (https://bit.ly/3SVKEfQ). They can also be done on linear plots on Excel, though you may need to work with log converted concentrations, and will need to convert back when trying to derive actual values (e.g., GM, 95%-ile) off the chart.

Chapter 10 Biological Monitoring

10.1 Fundamentals of Biological Monitoring

Biological exposure monitoring, or biological testing, is a way of determining how much of a particular contaminant has actually entered, and has been taken up by, the body from all routes of exposure. A number of substances can be measured in this way. It can also provide information on cumulative exposures experienced over a long period of time or environments where air sampling presents challenges such as due to equipment limitations or scheduling difficulties (e.g., firefighter exposures during live fire response). The advantages of such an approach include:

- It provides additional information where there is a respiratory hazard
- It can be used where the main route of exposure is not inhalation
- It can highlight deficiencies in the wearing of personal protective equipment, i.e., respirators and gloves and/or clothing
- It provides evidence for medical assessment

In contrast, workplace air monitoring and comparison of the results with exposure standards provides information about the probable exposure of workers to inhalation hazards. It does not provide information about the other exposure routes of skin absorption, ingestion, nor information about any non-work-related exposures.

Biological monitoring is one of the three tools used in the prevention of disease from hazardous substances in the work environment, the other two being occupational hygiene or environmental monitoring and health surveillance.

Biological monitoring means the assessment of exposure to chemicals (substances) that are present in the workplace, through the measurement of appropriate determinants in biological specimens from exposed workers. In most cases, the specimen used for biological monitoring is urine, blood or exhaled air.

The risks associated with the obtaining and handling of bodily fluids, in terms of potential exposure to possible pathogens, i.e., HIV, Hepatitis, viruses etc. have to be considered.

In many countries only a qualified doctor or nurse can obtain such samples. Local advice must be sought before such work is to be carried out.

Biological monitoring can be divided into:

- Direct biological monitoring also referred to as biological monitoring of exposure
- Biological effect monitoring

10.2 Direct Biological Monitoring

The purpose of direct monitoring is to assess the health risk through the evaluation of internal dose of the chemical in question with the aim of ensuring the exposure does not reach levels that can cause adverse effects.

The direct analysis of the contaminant is undertaken in the specimen:

- Blood – e.g., for lead and mercury
- Urine – e.g., for cadmium and MOCA (methylene bis-orthochloroaniline)
- Hair and nails - e.g., for arsenic
- Breast milk– e.g., for pesticides and Polychlorinated Biphenyls (PCBs)
- Expired air – e.g., for carbon monoxide and organic solvents – e.g., benzene or analysis of its metabolites
- Blood – carboxyhemoglobin from carbon monoxide
- Urine – mandelic acid from styrene

10.3 Biological Effect Monitoring

Biological effect monitoring is aimed at identifying early and reversible biochemical changes resulting from exposures, i.e., no detrimental effect has occurred but one or more measurable biochemical changes has occurred. The degree of change is less than that which leads to injury and is not associated with a known irreversible pathological effect.

Some examples of biological effect monitoring are:

- Zinc protoporphyrin in blood – these levels increase with exposure to lead, because lead inhibits the biosynthesis of heme.
- Cholinesterase activity in red blood cells and plasma – exposure to organophosphate pesticides depresses cholinesterase activities.

Biological effect monitoring is not health surveillance through which individuals with early signs of adverse health effects are identified.

10.4 General Considerations

The extent and rate of absorption of a chemical after exposure depend on the properties of the chemical, especially its solubility in lipids and water, and the route of exposure. It is also important to select the appropriate specimen for the determinant of interest. For example, blood may be more appropriate than urine for a determinant with a biological half-life of many months, while breath may be more appropriate for volatile determinants.

Once absorbed, a chemical is distributed and spreads into various tissues depending on the susceptibility of the tissue due to variations in pH, permeability etc. Very water-soluble chemicals may be distributed throughout the total body water, while lipophilic (attract non polar organics such as fats and oils) may concentrate in the body fat, or in other lipid tissues such as the brain.

The loss of chemical from the body or elimination depends on metabolism and excretion. Chemicals may be eliminated by numerous routes including fecal, urinary, exhalation, perspiration and lactation.

A chemical may be excreted from the body without metabolism, i.e., the particular chemical can be measured directly. In other cases, the chemical may be metabolized through oxidation, reduction, hydrolysis or combination of these followed by often very complex biochemical reaction in the body. Hence the choice of the indicator of exposure and even the timing of when to take a sample is critical.

10.5 Biological Half-Life

The biological half-life of a substance is the time required for half of that substance to be removed from the body by either a physical or a chemical process. The half-lives for different substances vary significantly and hence the importance of the correct sampling time cannot be over emphasized.

10.6 Sampling Time

The timing of biological samples can be very important. Substances absorbed into the body are removed at different excretion rates. The concentration of some determinants can change rapidly, so in these cases sampling time must be observed and recorded carefully. On the other hand, a determinant that accumulates slowly may not need a specific sampling time.

An exposure that occurs through the ingestion route typically takes longer to enter the blood stream than an exposure through the inhalation route. So, it is possible to collect the sample too soon after the exposure occurs, although this is not usually an issue in relation to workplace exposures.

Table 10-1 Recommended Sampling Times

Sampling Time	Recommended Collection
Prior to shift	16 hours after exposure ceases
During the shift	Any time after 2 hours of exposure
End of shift	As soon as possible after exposure ceases
End of the work week	After 4 or 5 consecutive working days with exposure
Discretionary	At any time

Practical guidance on the interpretation of sampling times is given by the ACGIH (2007). While the ACGIH provides the recommendations as listed in Table 10-1 Recommended Sampling Times, it is important to understand that this information is for guidance only and an understanding of the substance being monitored is critical if accurate and meaningful results are to be achieved.

The UK Health & Safety Executive (HSE) in the Guidance Note EH56 "Biological Monitoring for Chemical Exposures in the Workplace" (HSE 1992) uses the following Table 10-2 Optimum Time for Collecting Samples) to provide advice on the timing of sample collection.

Table 10-2 Optimum Time for Collecting Samples

Half Life	Optimum Time for Taking Samples
<2 Hours	Concentration changes too fast – not suitable
2 to 10 Hours	End of shift or next morning
10 to 100 Hours	End of shift at end of week
>100 Hours	Random sampling acceptable

Source: HSE – Reproduced with permission

10.7 Urine Specimen Acceptability

The concentration of urine can have a marked effect on the results of the analysis of the contaminant. Sample results can be corrected for urine concentration in one of two ways:

- By adjusting for the specific gravity of the sample; or
- By correcting for the creatinine level in the urine, as creatinine excretion from the body occurs naturally at a nearly constant rate.

The World Health Organisation has adopted the following guidelines for acceptable limits to assist in overcoming the issues associated with highly diluted and highly concentrated urine samples:

$$\text{Creatinine concentration:} \quad > 0.3 \text{ g/L and} < 3 \text{ g/L}$$

or

$$\text{Specific Gravity:} \quad > 1.010 \text{ and} < 1.030$$

Samples outside these guidelines should be discarded and another sample collected.

Some Biological Exposure Indices BEIs® for determinants whose concentrations is dependent on urine output are expressed as relative to creatinine concentration. For other determinants correction for urine output is not appropriate.

10.8 Biological Standards

10.8.1 Biological Exposure Indices

Similar to TLVs®, the results of biological monitoring are compared against Biological Exposure Indices or BEIs®. The main source of BEIs® is from the ACGIH in their handbook Threshold Limit Values and for Chemical Substances and Physical Agents and Biological Exposure Indices (ACGIH 2019).

Biological Exposure Indices (BEIs®) are guidance values for assessing biological monitoring results. BEIs® represent the levels of determinants that are most likely observed in specimens collected from healthy workers who have been exposed to chemicals to the same extent as workers with inhalation exposure at the TLV®.

In a similar fashion to TLVs®, BEIs® are to be used as guidelines in the evaluation of occupational hygiene health hazards. BEIs® do not indicate a sharp distinction between hazardous and nonhazardous exposures. Due to the often-varied nature of concentration in biological specimens' great care and caution must be exercised in the interpretation of the results from a single specimen.

BEIs® apply to 8-hour exposures, 5 days per week. The BEI® Committee does NOT recommend adjusting or applying a correction factor to the BEIs® for altered or extended shift patterns.

Use of BEIs® should only be done by experienced occupational health professionals in consultation with the associated documentation for them. The BEI® is a guideline for the control of potential health hazards for workers and the values are inappropriate for use for the general public and for non-occupational exposures. In the application of BEIs® reference must be made to the current edition of the Documentation of the Threshold Limit Values and Biological Indices from the ACGIH®.

10.8.2 Notations

A notation is a designation that appears as a component of the adopted BEI® value to provide additional information with respect to the particular chemical:

$$\text{“B”} = \text{Background}$$

The determinant may be present in biological specimens collected from subjects who have not been occupationally exposed, at a concentration which could affect the interpretation of the result.

$$\text{“Nq”} = \text{Non-quantitative}$$

Biological monitoring should be considered for this compound based on the review; however, a specific BEI® could not be determined due to insufficient data.

$$\text{“Ns”} = \text{Non-specific}$$

The determinant is non-specific, since it is also observed after exposure to other chemicals.

$$\text{“Sq”} = \text{Semi-quantitative}$$

The biological determinant is an indicator of exposure to the chemical, but the quantitative interpretation of the measurement is ambiguous.

These determinants should be used as a screening test if a quantitative test is not practical or as a confirmatory test if the quantitative test is not specific and the origin of the determinant is in question.

10.8.3 UK Limits

In the UK the HSE has established a system of non-statutory biological monitoring guidance values as an aid in the interpretation of biological monitoring data.

Biological Monitoring Guidance Values (BMGVs) are set where they are likely to be of practical value, suitable monitoring methods exist and there are sufficient data available. The type of data that are available will vary between substances and therefore the route taken to deriving the BMGV will vary between substances. BMGVs are either based on a relationship between biological concentrations and health effects, between biological concentrations and exposure at the level of the WEL or are based on data collected from a representative sample of workplaces correctly applying the principles of good occupational hygiene practice. The technical basis for each BMGV will be clearly described in supporting documentation such as an EH64 summary or other guidance.

BMGVs are non-statutory and any biological monitoring undertaken in association with a guidance value needs to be conducted on a voluntary basis (i.e., with the fully informed consent of all concerned). BMGVs are intended to be used as tools in meeting the employer’s primary duty to ensure adequate control under COSHH. Where a BMGV is exceeded, it does not necessarily mean that any corresponding airborne standard has been exceeded nor that ill health will occur. It is intended that where they are exceeded this will give an indication that investigation into current control measures and work practices is necessary.

Of course, that is not necessarily to say that because biological monitoring results are below a particular guidance value an employer need take no further action to reduce exposure; but it should be noted that BMGVs are not an alternative or replacement for airborne occupational exposure limits.

10.9 Confidentiality

There are several ethical and confidentiality issues that must be considered and implemented before commencing a biological monitoring programme.

- The method should be appropriate for the requirements of the investigation.
- The procedures should not threaten the health of the participant.

- The risk of using invasive methods must be justified by the benefits.
- The informed consent from the participants is needed. This consent must only be given when the participant feels no fear of reprisals if their consent is not given.
- Results of the monitoring should be kept confidential and shared only with the occupational health professional and the participant.

Appendix A Introduction to Physiology and Toxicology

This section contains a basic review of physiology and toxicology. This subject is covered in greater detail in student manual of the OHTA module W507 Health Effects of Hazardous Substances.

A.1 The Human Body

The human body has many different interacting sub-systems. It is important to have some understanding of the function and features of these systems to appreciate the effects that exposure to occupational hygiene hazards and in particular exposure to hazardous substances may have.

A.1.1 Cardiovascular System

The main components of the cardiovascular or circulatory system are the heart, the blood and the blood vessels. The blood vessels consist of arteries, capillaries and veins.

Arteries bring the oxygenated blood, pumped from the heart, to the tissues and the veins bring the deoxygenated blood back to the heart. Blood passes from arteries to veins through capillaries, which are the thinnest and most numerous of the blood vessels.

A.1.2 Digestive System

The digestive system takes in food, digests it to extract energy and nutrients for the body and expels the remaining waste. It consists of:

- Upper gastrointestinal tract – mouth, esophagus and stomach
- Lower gastrointestinal tract – small and large intestine.
- Related organs including liver, gall bladder and pancreas.

A.1.3 Endocrine System

The endocrine system is a control system of ductless glands that secrete “instant messengers” or hormones that circulate within the body via the bloodstream to affect distant cells within specific organs. Endocrine glands secrete their products immediately into the blood or interstitial fluid, without storage of the chemical.

Hormones act as messengers and are carried by the bloodstream to different cells in the body which then interpret the message and act on them. Examples include the pituitary gland, the thyroid gland, adrenal gland and the pancreas and gonads.

A.1.4 Immune System

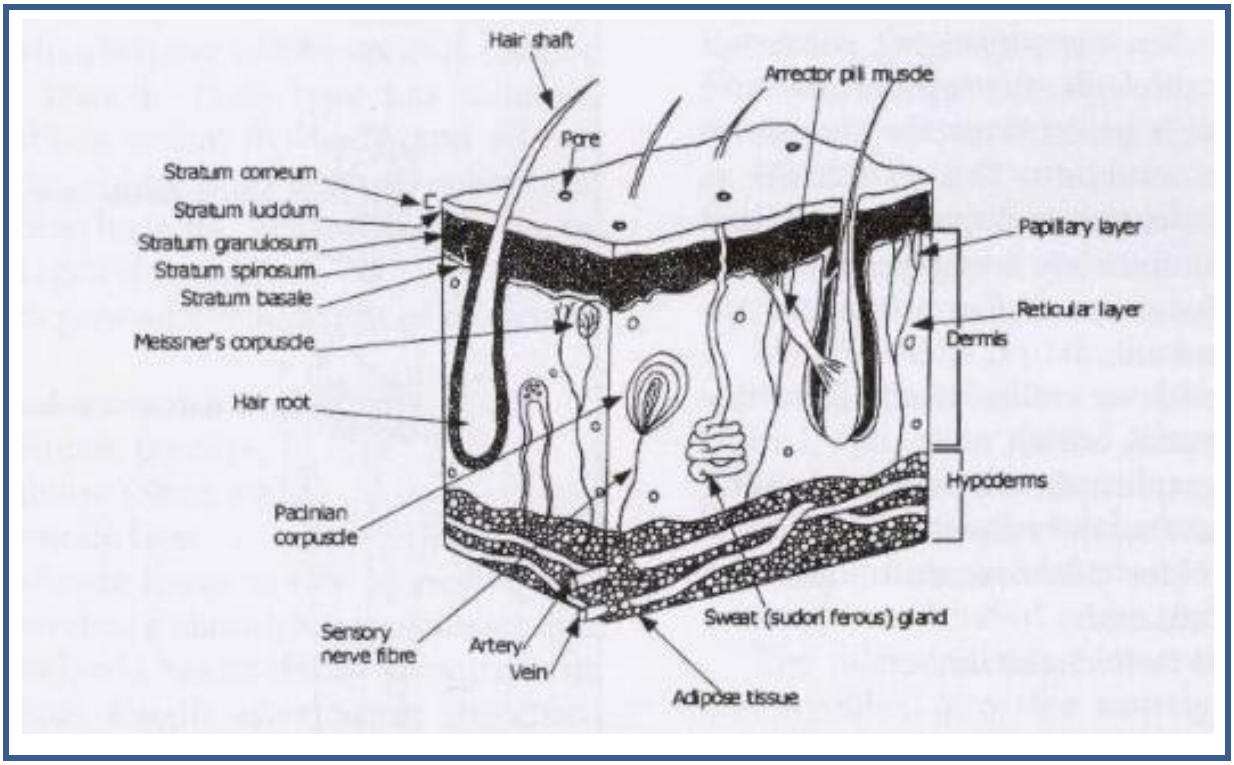
The immune system protects the body from infection by creating and maintaining barriers that protect bacteria and viruses from entering the body. If a pathogen breaches the barriers and gets

into the body the innate immune system is equipped with specialized cells that detect, and often eliminate, the invader before it is able to reproduce, potentially causing serious injury to the host. A pathogen that successfully invades the innate immune cells faces a second, adaptive immune system. It is through the adaptive response that the immune system gains the ability to recognize a pathogen and to mount stronger attacks each time that pathogen is encountered. Examples of disease that arise from damage or impairment of the immune system are Hepatitis, Ebola, Acquired Immune Deficiency Syndrome (AIDS), Influenza, Cholera, Typhoid and Malaria.

A.1.5 Integumentary System

The integumentary system comprises of the skin (cutaneous membrane) and its accessory structures of hair, nails and exocrine glands. There are three layers of skin – epidermis, dermis and subcutaneous tissue. The cutaneous glands include the sweat glands, oil glands, glands of the ear and the mammary glands.

Figure 10-1 Diagram of the Layers of the Human Skin



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The skin is often known as the largest organ of the body and as the interface with the surroundings it provides protection against the physical hazards such as heat, radiation and abrasion, chemicals and bacteria. Its other important functions are insulation and temperature regulation, sensation and Vitamin D and B synthesis.

A.1.6 Lymphatic System

The lymphatic system is a complex network of lymphoid organs, lymph nodes, lymph ducts and lymph vessels that produce and transport lymph fluid from tissues to the circulatory system. It is a major component of the immune system.

The lymphatic system has three interrelated functions:

- Removal of excess fluids from body tissues.
- Absorption of fatty acids and subsequent transport of fat to the circulatory system.
- Production of immune cells (such as lymphocytes, monocytes and antibody producing cells called plasma cells).

A.1.7 Muscular System

The muscular system is the biological system that allows us to move. It is controlled by the nervous system, although some muscles (such as the cardiac muscle within the heart) can be completely autonomous.

In general, the function of muscle is to produce movement, maintain posture, stabilize joints and to generate heat.

Muscles are attached to bone by tendons and other tissues. They exert force by converting chemical energy into force. Nerves link the muscles to the central nervous system.

A.1.8 Nervous System

The nervous system is often divided into the central nervous system (CNS) and the peripheral nervous system (PNS). The CNS consists of the brain and the spinal cord and functions as the body's control centre. The PNS consists of all of the other nerves and neurons in the body that do not lie within the CNS and carry electrical impulses to and from the spinal cord and cranial nerves that carry electrical impulses to and from the brain.

The peripheral nervous system is divided into the somatic nervous system and the autonomic nervous system.

The somatic nervous system is responsible for coordinating the body's movements, and also for receiving external stimuli. It is the system that regulates activities that are under conscious control.

The autonomic nervous system is then split into the sympathetic division, parasympathetic division, and enteric division. The sympathetic nervous system responds to impending danger or stress, and is responsible for the increase of one's heartbeat and blood pressure, among other physiological changes, along with the sense of excitement one feels due to the increase of adrenaline in the system. The parasympathetic nervous system, on the other hand, is evident when a person is resting and feels relaxed, and is responsible for such things as the constriction of the pupil, the slowing of the heart, the dilation of the blood vessels, and the stimulation of the digestive and genitourinary systems.

The role of the enteric nervous system is to manage every aspect of digestion, from the esophagus to the stomach, small intestine and colon.

A.1.9 Reproductive System

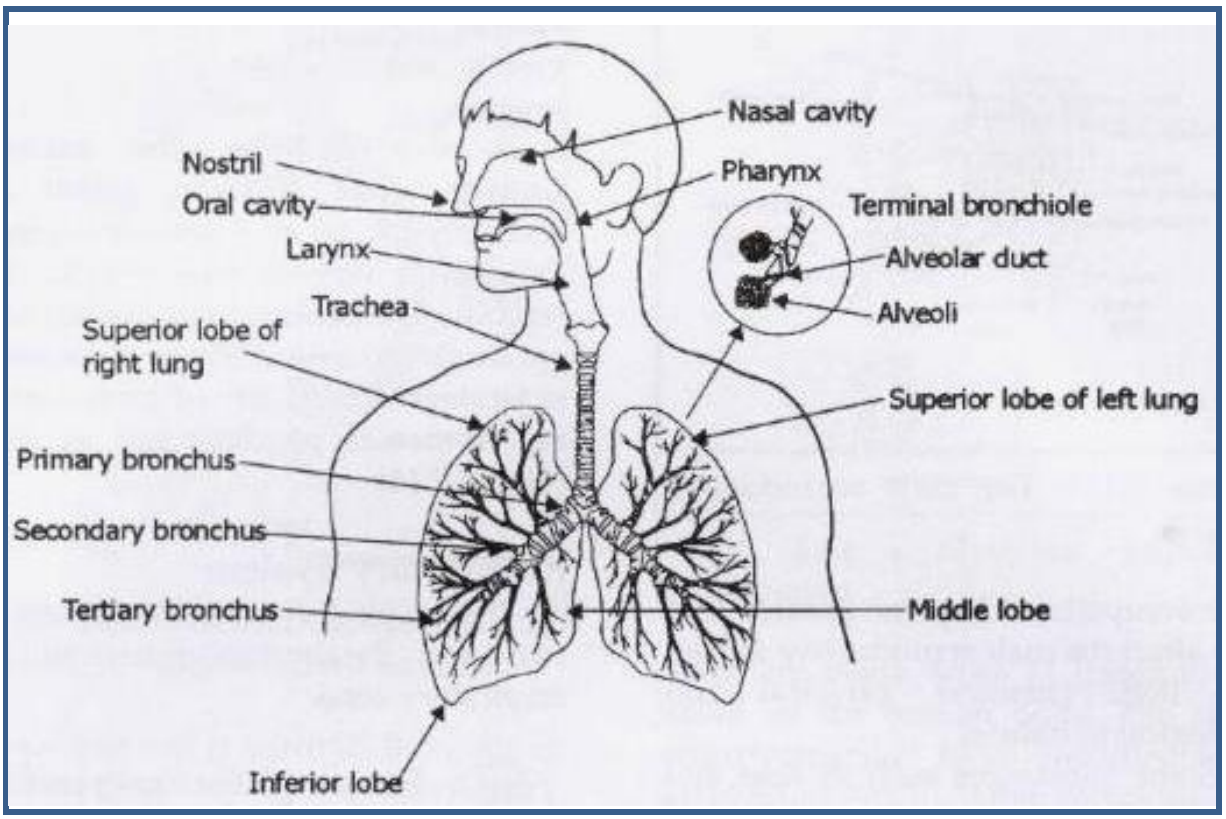
The role of male and female reproductive systems is to produce offspring. The male reproductive organs include the sperm producing region – the testes located inside the scrotum and the duct system comprising the epididymis, the vas deferens and the urethra.

The female reproductive system consists of the internal organs including the ovaries, fallopian tubes, uterus, cervix and vagina.

A.1.10 Respiratory System

The respiratory system consists of the airways, the lungs and the respiratory muscles that mediate the movement of air into and out of the body. Inhaled air passes from the nose and mouth through the trachea and into the branched structures of the lungs called bronchi.

Figure 10-2 Respiratory System



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Air then travels along the bronchioles to its ending (the terminal bronchiole) which is covered in tiny multi lobed sacs called alveoli where most of the gas exchange occurs.

A.1.11 Skeletal System

The human skeleton is made of 206 individual or joined bones, such as the skull, supported and supplemented by a structure of ligaments, tendons, muscles, cartilage and other organs.

The most obvious function of bone is to support the body. It is also the site of hematopoiesis, the manufacture of blood cells that takes place in bone marrow and why bone marrow cancer is very often a terminal disease. The skeleton is also necessary for the protection of vital organs. Human

movement is dependent on the skeletal muscles which are attached to the skeleton by tendons. Without the skeleton to give leverage movement would be greatly restricted. Bone also serves as a storage deposit in which fat and minerals such as calcium and phosphorous can be stored and retrieved.

A.1.12 Urinary System

The urinary system is the organ system that produces, stores and eliminates urine. In humans it includes two kidneys, two ureters, the urinary bladder, two sphincter muscles and the urethra.

The kidneys are one of the various organs (together with the lungs, intestine and skin) that participates in the elimination of the wastes of the organism. The kidneys are bean-shaped organs about the size of a bar of soap. They are near the middle of the spine, just below the ribcage. They are situated behind the organs of digestion within the abdominal cavity. Situated on the superior surface of each kidney is an adrenal gland.

A kidney consists of about 1 million filtering units termed nephrons, each consisting of a glomerulus, ball-shaped network of capillaries, and a network of tubules. Blood plasma is filtered by the glomerulus, and the resultant "prourine" passes through the tubular system where water, and nutrients are reabsorbed under the supervision of hormone activity and the autonomic nervous system.

Humans produce about 1.5 litres of urine over 24 hours, although this amount may vary according to circumstances. Increased fluid intake generally increases urine production, while increased perspiration and respiration may decrease the amount of fluid excreted through the kidneys. A reduced intake of water will normally result in less urine production as well. Some medications interfere directly or indirectly with urine production, such as diuretics.

The kidney plays a crucial role in regulating electrolytes in the human blood (e.g., sodium, potassium, calcium). pH balance is regulated by the removal of excess hydrogen ions (H+) from blood. In addition, they remove urea, a nitrogenous waste product from the metabolism of proteins from amino acids. The metabolism process forms ammonia which is transported by blood to the liver and detoxified to a less harmful byproduct called urea.

A.2 Routes of Entry

There are four primary routes of entry for contaminants into the human body;

Inhalation: The requirements of a man in a normal day are approximately 3.4 kg food and water (water is obtained in the food we eat and as direct ingestion). For light physical work an average person breathes in between 1-1.2 m^3 of air per hour. This rate would be much higher for heavy physical exertion.

Therefore, it is easy to understand why inhalation is by far the most common route of entry due to both the volume of air coming into contact with the large surface area of the lungs and the thin cell layer in the lungs separating the air from the blood, with skin absorption next (especially pesticides) and ingestion last. Inhalation is the major route of entry of dusts, fumes, mists, gases and vapours into the body.

Skin Absorption (includes injection): Skin absorption via direct contact with chemicals especially organic solvents and organophosphate pesticides is the second most important route of entry to the body.

Eye: The eye is a relative minor route of entry into the body. It should also be noted that the eye is also at risk from direct contact with chemicals.

Ingestion: Ingestion is usually a relatively minor route of absorption of chemicals in the workplace. It is commonly as a result of an accidental ingestion, or from poor personal hygiene e.g., eating with dirty/contaminated hands. In some workplaces inadvertent ingestion or skin absorption can result from contact with contaminated surfaces.

It should be noted that insoluble aerosols can end up in the digestive tract from where they can be absorbed into the body. Additionally, involuntary ingestion as a result of clearance mechanisms in the upper respiratory tract can also be another route of entry, especially in the case of large particles of toxic substances.

A.3 Target Organs and Systems

There are numerous target organs for contaminants in the human body such as:

- Heart
- Liver
- Bones
- Lungs
- Brain
- Thyroid
- Kidneys
- Central Nervous System
- Blood

Target organs are defined as organs in which critical effects are observed as the result of exposure to a harmful input. There are many identifiable instances of inputs which affect a number of critical organs. Which they affect depends upon the circumstances of exposure, the interplay of defense processes and the susceptibility of the individual, as well as the tissues of the target organ. Thus, in discussing effects it is required that all possible target organs are considered.

The definition of 'target organs' must, necessarily, be wide, and must include, where appropriate, systems and tissues as well as organs.

For example, the target organ of hydrogen sulphide, which attacks the nerve tissue and causes respiratory paralysis, might be categorized as the central nervous system.

Crocidolite induces serious disease of the pleura and peritoneum (the tissue lining in the inner surface of the chest wall, and the lungs or the inner surface of the abdominal cavity and the abdominal organs). In this instance the pleura and peritoneum are the target organs.

A series of target organs and an outline of their principal functions are given in Table A-3.

Table A-3 Target Organs, With an Outline of Their Principal Functions

Target Organ	Principal Functions	
Skin	Protects against friction, water/fluid loss, entry of harmful inputs; thermal insulation; self-greasing by means of sebaceous glands; thermoregulatory by means of sweat glands; receives afferent information.	
Respiratory tract	Oxygen and carbon dioxide exchange; defense against aerosols; warming and moistening of incoming air; excretion of gases, vapours.	
Blood, plasma, blood-forming organs: circulatory system	Metabolism: transformation and conjugation. Chief transport system for oxygen, carbon dioxide nutrients, heat and fluids.	
Kidney, urinary tract	Excretion:	Water, salts and nitrogenous wastes (includes homeostasis as well as bio- dumping).
	Secretion:	Hormones for controlling blood pressure and production of red blood cells.
	Metabolism:	Transportation and conjugation.
Liver	Secretory:	a) Bile - contains waste non-nutrients, aids digestion
		b) Heparin - anti-coagulant for blood
	Storage:	a) Vitamins
		b) Iron (for hemoglobin)
		c) Glycogen-energy store substance
	Metabolism:	Transformation and conjugation
Brain and nervous system	Information processing and control of bodily activities.	
Bone	Support framework for movement and protection (certain bones house blood-forming organs; but those are functionally separate from bone).	
Gut	Input of nutrients; digestion; excretion of non-nutrients; defensive processes of gastric-acid barrier.	
Lymphoid system and lymphatics	Tissue drainage; filtration; site of defensive processes such as immune response and phagocytosis.	
Ductless glands	Such as thyroid, parathyroids, adrenals (suprarenal); produce hormones - substances exercising key control over function and morphology.	

A.4 Concept of Dose Response

"No substance is a poison by itself, it is the dose that makes a substance a poison." Paracelsus 1540.

Ideally dose should be defined as the concentration of a substance at the site of effect, regard being made for the time for which the substance concentration is maintained. For practical

purposes dose refers to the amount of a substance to which a person is exposed and is a combination of the amount or concentration of exposure and the duration of exposure. Exposure can arise from inhalation (most common route) or skin absorption (common with some substances) or via eye absorption (rare).

In simplistic terms dose can be expressed as:

$$\text{Dose} = \text{Concentration of exposure x duration of exposure} \quad \text{...Equation A-1}$$

This simplistic equation does not account for the following factors:

- Dose may be less than the amount inhaled if most is exhaled without any absorption (e.g., many gases).
- Heavy physical workload results in higher breathing rates than light workloads and thus have higher doses.
- Dose may depend on an individual being a mouth or nose breather.
- Additional exposure may come from non-occupational sources (carbon monoxide from smoking).

Effect can be any observable, biological change associated with the input concerned, and ideally it should be quantifiable. It is implicit in dose-effect relations that effect is related to and caused by the dose.

Effect does not necessarily denote an adverse biological change, but embraces any biological change. Certain effects can be beneficial and only become adverse if the dose is excessive or remains for a critical period of time.

Types of toxic effects include acute, chronic, local and systemic.

Acute or immediate effects occur during or immediately after exposure and last for a short period of time. Examples of acute effects include the immediate eye and respiratory tract response to exposure to, and inhalation of, chlorine or burns to the skin caused by direct contact with strong acids or alkalis.

Chronic effects are long lasting and may be, but not necessarily, permanent. Some examples of chronic exposures are pneumoconiosis from long term exposure to coal dust, silicosis after exposures to quartz dusts.

Local effects occur at the point of entry to the body of the toxin and systemic effects are associated with distant target organs (e.g., with lead the main route of entry is by inhalation but the toxic effect is upon the blood forming process, nervous system, kidneys and reproductive functions).

Critical organ concentration seems, given the present state of knowledge, to be the parameter of greatest utility in estimating dose. Whole body concentration provides a less useful criterion, because the organs in which greatest accumulation occurs may not be critical organs.

Bone, for example, accumulates lead, but the critical organ is bone marrow, which is functionally separate from the bone which surrounds it.

At some time in the future, it will, no doubt, be possible to estimate dose in terms of critical cell concentrations - or subcellular concentration - but at present this is impracticable.

There are complexities in the specification of effect, since certain effects, such as death, are of an all-or-none character, while others are of a graded nature, such as occupational deafness.

Specification is further complicated by the fact that certain all-or-none effects (cancer, for example) require only a trigger. Once triggered they continue by self-propagation or by the other processes independent of the dose of the triggering input. On the other hand, many observable and gradable effects are both trivial and reversible.

However, the complexities do not end here. The specification of dose needs to take account of all possible modes of input, and the non-occupational as well as the occupational possibilities. For example, in the case of metals like lead, in most if not in all countries, input by ingestion from the normal diet is inevitable. Any occupational exposure, probably by inhalation, will be supplemented by the non-occupational dose. Combination of the two may cause a critical organ concentration to be reached in the bone marrow or in other organs.

A.4.1 Dose Response

Dose response is that proportion of a human population which experiences a specific effect following exposure of the total population to specified harmful contaminant. The correlation of the response with estimates of the dose provides a dose-response relation, which is normally expressed as a graph, with percentage of population affected on the y axis and estimated dose on the x axis (Figure 10-3 Dose Response Curve).

A.4.2 No Observed Adverse Effect Level

The “no observed adverse effect level” (NOAEL) is the term used to define that point below which adverse effects cannot be observed. Effects, particularly adverse effects, are generally manifestations of the change in an organ and particularly the cells of the organ.

In toxicology, the NOAEL is specifically the highest tested dose or concentration of a substance at which no adverse effect is found in the exposed test species (usually animals or cells).

This level is commonly used in the process of establishing a dose response relationship, a fundamental component in most risk assessment strategies.

Another important toxicological concept is “lowest observed adverse effect level” (LOAEL) or the lowest dose or concentration that causes any observed adverse effect. Thus, by definition the NOAEL is less than the LOAEL.

As these determinations of exposure and effect have generally been established in species other than humans, various safety factors or uncertainties are applied before this data is used in the establishment of workplace exposure standards.

A.4.3 Threshold

The term "threshold" is used in toxicology to describe the dividing line between no-effect and effect levels of exposure. It may be considered as the maximum quantity of a chemical that produces no effect or the minimum quantity that does produce an effect. Every change produced by a chemical, whether it is beneficial, indifferent, or harmful, has a threshold. (Perhaps the word "change" should be qualified with an adjective such as "biological" or "clinical" to anticipate the reader with a literal bent who will say that the mere exposure of an organism to a chemical represents a change and that such a change obviously does not have a threshold).

The precise threshold for a given effect can, and usually does, vary within certain limits with species, with individuals within a species, and perhaps even with time in the same individual.

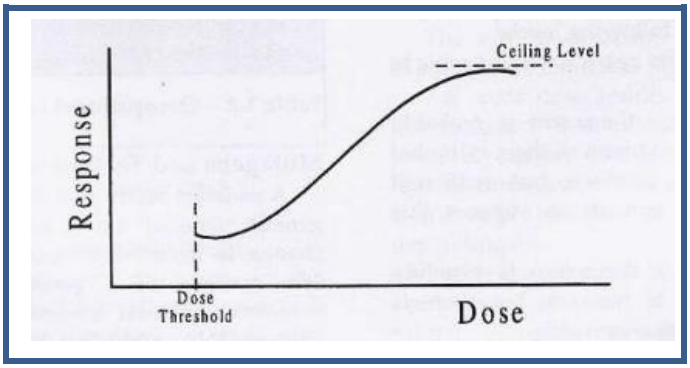
For a given population, as illustrated by the dose response relationship (see Figure 10-3 Dose Response Curve), it is clear that thresholds exist because it can be determined experimentally that certain low levels of exposure will produce no detectable effect, and that as the dosage is increased the effect appears.

Since the dose-response relationship is a continuum, somewhere between the experimental no-effect and effect levels is the turning point known as the threshold.

Dose-response curves typical of those plotted from data obtained in chronic toxicity experiments exist for a number of contaminants. It is very important to recognize that such a curve is drawn from only several points, one for each exposure group in the experiment. The greater the number of exposure groups, the greater the number of points, and hence, the greater the accuracy of the curve that is drawn. But without an infinite number of points, the precise shape of the dose-response curve cannot be known.

The curve is interpreted as follows: with chronic exposure of increasing doses up to the threshold, no effect is detectable because some biochemical or physiologic mechanism, handles the chemical in a manner that prevents an effect from occurring. At the threshold, the defense mechanism is saturated, or in some manner overwhelmed, for the more susceptible individuals and the effect begins to appear. With increasing doses, increasing numbers of individuals show the effect until finally a dose is reached where all of the members of the population show the effect (ceiling level).

Figure 10-3 Dose Response Curve



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The threshold concept is of great importance to toxicologists because it permits them to make judgements about the potential hazard, or lack thereof, to humans from exposure to chemicals.

Another toxicologic question relates to the shape of dose-response curves for carcinogens as they approach zero dose. The inability of toxicology to answer this question by experiment has given

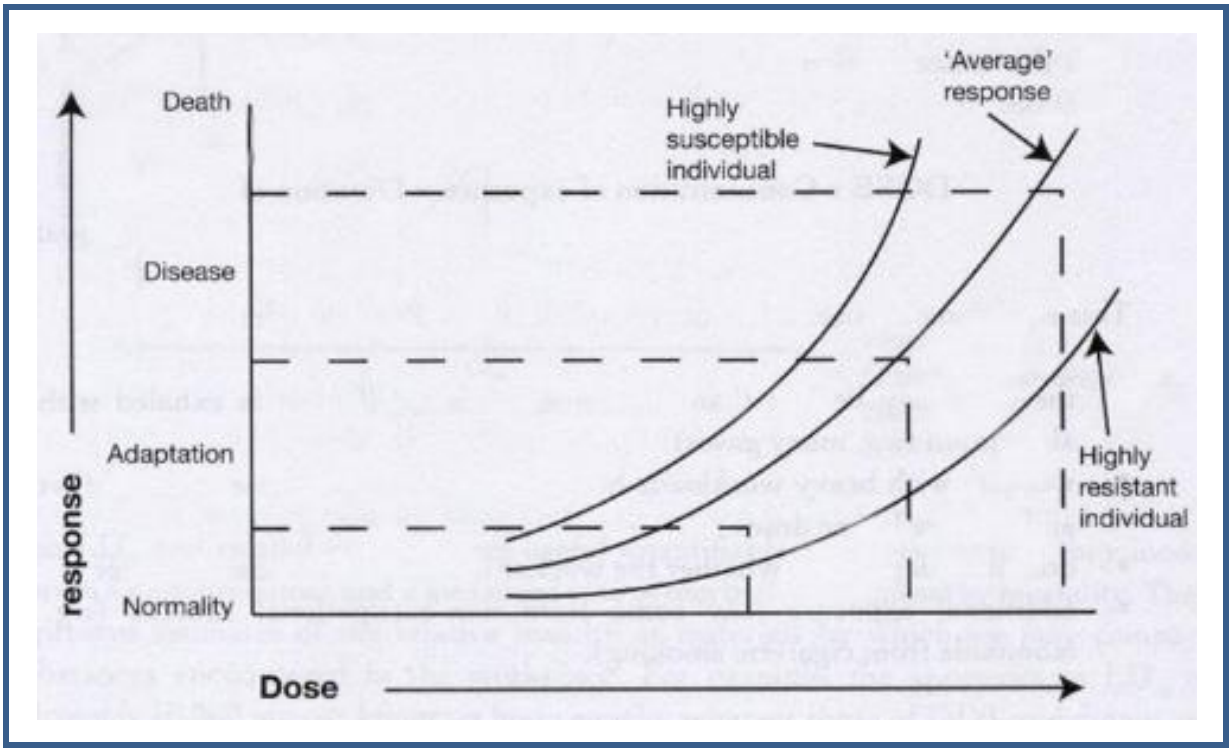
rise to a scientific controversy concerning whether or not there is a threshold (no-effect level) for carcinogenic effects. If there is no threshold, extension of the experimentally derived dose-response curve to zero effect would yield a line that would go through the origin (zero dose). If there is a threshold, the extended line would meet the abscissa [x axis] at some point greater than zero dose.

In regard to carcinogens, it is important to note that it is rare to have any data except for high doses, so the estimate of the shape of the dose response curve below the lowest actual data point must typically cover many orders of magnitude. Where a threshold cannot be identified, limits are generally risk based and dependent upon the dynamics of the particular substance.

It is extremely important, as background to all considerations of the threshold, to recognize that detectable biological effects are not universally adverse.

What should be recognized is that in any group of test subjects there are some susceptible individuals (hypersensitive) who are affected at low concentrations of the test contaminant and there are also some highly resistant individuals (hyposensitive) who are not affected at high concentrations but there are the vast majority of “average” individuals in the middle (Figure 10-4 Variability of Human Exposure to Dose).

Figure 10-4 Variability of Human Exposure to Dose



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Consequently exposure standards tend to be based on dose response relationships applicable to “average” individuals and thus it is important to recognize that some hypersensitive individuals may be in a work group and that they may suffer adverse health effects at exposures below the recognized exposure standard.

A.4.4 Threshold of Intoxication

For each substance, no matter how toxic, there exists a dose level called the threshold of intoxication, which the human body is capable of accepting and detoxifying without injury to itself. It is this principle that the major exposure standards used within the western world are based upon.