DEPARTMENT OF OCCUPATIONAL
SAFETY AND HEALTH

GUIDELINES ON MONITORING OF AIRBORNE CHEMICAL HAZARDOUS TO HEALTH 2022

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PREFACE

The purpose of this guideline is to provide guidance to employer or person conducting chemical exposure monitoring to comply with the requirements of Regulation 26 of the Occupational Safety and Health (Use and Standards of Exposure of Chemicals Hazardous to Health) (USECHH) Regulations 2000 or as amended. This guideline specifies monitoring procedure, sampling technique and monitoring strategy for airborne chemicals hazardous to health. An employer who uses or handles chemicals hazardous to health specified in Regulation 3 of the USECHH Regulations, and in which there exists potential that any workers may be exposed to chemicals hazardous to health at work, is advised to refer to this guideline.

This guideline is to be used by competent persons or employers who wish to conduct exposure monitoring for chemicals hazardous to health in compliance with the USECHH Regulations. The competent persons must be registered with the Department of Occupational Safety and Health. The competent persons are expected to be familiar with this guideline.

Director General
Department of Occupational Safety and Health
Malaysia
2022

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We also wish to thank individuals who have directly or indirectly contributed in the preparation of this guideline.

CONTENT

GLOSSARY

Accredited Laboratory	Laboratory accredited under *Skim Akreditasi Makmal Malaysia (SAMM)* by Department of Standards Malaysia or any equivalent recognised international body.
Action Level	Half of the value of the eight-hour time weighted average limit.
Aerodynamic Equivalent Diameter (AED)	The diameter of a hypothetical sphere of unit density (i.e. 1 g/cm^3) that has the same terminal settling velocity in air as the actual airborne particle, regardless of its geometric size, shape and true density.
Blank-Corrected	Describes data that have had trace contamination amounts deducted from the total amount of contaminant detected in the sampling media.
Hygiene Technician or Hygiene Technologist	A worker or any other person appointed by the employer and registered with the Director General to carry out chemical exposure monitoring or to carry out any inspection, examination or test on engineering control equipment installed at the place of work under the USECHH Regulations. For the purpose of this guideline, the term of hygiene technician or hygiene technologist is referring to the scope of work related to air monitoring.
Inhalable Particulates	Particles that are hazardous when deposited anywhere in the respiratory tract which the particle aerodynamic diameter is 100 micrometres (μm) and smaller.
Integrated Sampling	Samples taken by drawing air through the sampling medium, which is then analysed by a laboratory to determine the amount of contaminant present.
Limit of Detection (LOD)	The lowest concentration level of a contaminant that can be determined to be statistically different from zero concentration. It is defined as three (3) times the standard deviation.
Limit of Reporting (LOR)	The concentration above which quantitative result maybe obtained with a specific degree of confidence.

Maximum Exposure Limit (MEL)	A fifteen-minute time-weighted average airborne concentration limit which is three times the eight-hour time-weighted average limit of the chemicals specified in Schedule I of USECHH Regulations.
Passive Sampling	Sampling that relies on diffusion of the contaminant from the air onto a solid sorbent.
PEL-TWA	Permissible exposure limit for eight-hour time-weighted average limit specified in Schedule I of USECHH Regulations.
Periodic Monitoring	Monitoring of airborne chemicals hazardous to health as the frequency specified under USECHH Regulations as per the following: a) not more than six months for exposure at or above the permissible exposure limit; or b) not more than twelve months for exposure at or above half of the eight-hour TWA but below the eight-hour TWA.
Permissible Exposure Limit (PEL)	Occupational exposure limits specified by USECHH Regulations.
Personal Samples	Samples that are obtained at the breathing zone when a worker wears a sampling train for some interval during the work shift.
Respirable Particulates	Particles that are hazardous when deposited in the gas-exchange region which is generally smaller than 10 micrometres (μm).
Short Term Exposure Limit (STEL)	A fifteen-minutes time-weighted average airborne concentration limit specified in Schedule I of USECHH Regulations.
Time Weighted Average (TWA)	An average airborne concentration over a specified period of time.
TWA_8	Calculated eight-hour time-weighted average for airborne concentration measured for duration of eight (8) hours.
Validated Method	Any monitoring and analysis method evaluated by Department of Standards Malaysia or any internationally recognized body but does not include non-standard method.

ABBREVIATION

AED	Aerodynamic Equivalent Diameter
APF	Assigned Protection Factor
CHTH	Chemicals Hazardous to Health
CL	Ceiling Limit
COC	Chain of Custody
DMSO	Dimethyl Sulfoxide
DOP	Degree of Protection
DOSH	Department of Occupational Safety and Health
HT	Hygiene Technician or Hygiene Technologist
LOD	Limit of Detection
LOR	Limit of Reporting
MCE	Mixed Cellulose Ester
MEL	Maximum Exposure Limit
NMAM	NIOSH Manual of Analytical Method
OES	Occupational Exposure Standard
PEL-TWA	Permissible Exposure Limit-Time Weighted Average
PTFE	Polytetrafluoroethylene
PVC	Polyvinyl Chloride
SEG	Similar Exposure Group
STEL	Short Term Exposure Limit
US NIOSH	United States National Institute for Occupational Safety and Health
US OSHA	United States Occupational Safety and Health Administration
USECHH Regulations	Occupational Safety and Health (Use and Standard of Exposure of Chemicals Hazardous to Health) Regulations 2000 or as amended

CHAPTER 1: INTRODUCTION

1.1 Background

Chemical exposure monitoring is used to measure the level of exposure of workers to chemicals hazardous to health (CHTH) and to evaluate adequacy of existing control equipment. Workers' exposure to CHTH through inhalation can be measured by conducting air monitoring. Air monitoring is the process of quantifying or determining the identity of a chemical by the use of standard sampling instruments, techniques and strategies. A sampling device is used to separate and collect the contaminant from a measured volume of the atmosphere. The contaminant can be quantified instantaneously with the use of direct reading instrument. Integrated air sampling instrument can be used to measure airborne CHTH according to validated methods. The chemical levels in the atmosphere are then established in terms of mass or number concentration for particulate, or volume concentration for gases and vapours.

1.2 Purpose and Scope of Guidelines

This guideline is to provide guidance on conducting monitoring of airborne CHTH at the workplace. The guideline describes on the steps of air monitoring, monitoring methodology, sampling technique, monitoring strategy, sample management, sampling results management and interpretation and report writing.

This guideline applies to monitoring of workers' exposure to airborne CHTH through inhalation at the workplace.

1.3 Legal Requirements

The main legislation governing the use of CHTH at the workplace is the Occupational Safety and Health (Use and Standard of Exposure of Chemicals Hazardous to Health) Regulations 2000 (USECHH Regulations) or as amended.

CHTH is defined in USECHH Regulations as any chemical or preparation which is:

a) Listed in Schedule I or II of the USECHH Regulations;

b) Classified in any hazard class specified under Health Hazards of First Schedule of the Occupational Safety and Health (Classification, Labelling and Safety Data Sheet of Hazardous Chemicals) Regulations 2013 [P.U.(A) 310/2013] or as amended;

c) A pesticide as defined under the Pesticides Act 1974 [Act 149] or as amended; or

d) Listed in the First Schedule of the Environmental Quality (Scheduled Wastes) Regulations 2005 [P.U. (A) 294/2005] or as amended.

The USECHH Regulations stipulates that an employer must conduct a health risk assessment for each work activity involving the use and exposure of CHTH to workers at workplace. The assessment of risk to health is to be carried out by an assessor appointed by the employer and registered with DOSH. Among the responsibility of an assessor is to determine the necessity of exposure monitoring for each work unit assessed.

Under the USECHH Regulations, exposure monitoring is to be conducted where an assessment of risk to health indicates that:

a) Monitoring of exposure is required to ensure workers exposure does not exceed Permissible Exposure Limit (PEL) or lowest practicable level; or

b) It is requisite for ensuring the maintenance of adequate control measure of the exposure of workers to CHTH.

The PELs of CHTH is as specified in Schedule I of the USECHH Regulations.

The monitoring of exposure is to be conducted in accordance with validated method of monitoring and analysis by a HT appointed by the employer and registered with DOSH. In this guideline, the role and scope of work of HT is related to monitoring of airborne CHTH which are to:

a) Conduct air monitoring of CHTH in accordance with validated method of monitoring and analysis; and

b) Furnish and present a full report of the air monitoring to the employer within one month of the completion of the monitoring.

The monitoring of exposure conducted by HT does not include checking of the presence of toxic and flammable gases and the level of oxygen in a confined space before entry where the scope falls under the Industry Code of Practice for Safe Working in Confined Space 2010 or as amended. The analysis of monitoring samples must be carried out by a laboratory accredited by the Department of Standards Malaysia through *Skim Akreditasi Makmal Malaysia (SAMM)* or any equivalent recognised international body.

1.4 Purpose of Air Monitoring

Generally, the purposes of air monitoring conducted at the workplace include:

a) To help towards the design of exposure control measures and to evaluate the effectiveness of control measures;

b) Evaluation of exposure level relative to an exposure limit;

c) As periodic monitoring to meet regulatory requirements;

d) Measurement of initial or baseline exposure data;

e) Providing a historical record of worker's exposures for company and worker's records;

f) Identification of potential overexposure situations or high-exposure activities; and

g) Identification of contaminants in an emergency situation (such as a hazardous chemical spill), or in an unknown atmosphere (as in a confined space).

1.5 Physical States

Airborne chemicals can be divided into three (3) broad groups depending on their physical characteristics. These are:

a) Particulate - solid particles or liquid droplets suspended in the air as dust; fumes; mist or fibres;

b) Gases; and

c) Vapour.

Types of airborne CHTH are:

a) **Dusts** are solid particles suspended in air generated by mechanical action which include respirable particles and inhalable particles;

b) **Fumes** are solid particles suspended in air, generated by condensation from gaseous state, generally after volatilisation from molten metals. Size of the particulate formed are usually less than 1 micron in diameter;

c) **Fibres** are a special type of particle with its length and width ratio of 3:1 or more (the ratio of particle length to diameter is known as its aspect ratio);

d) **Mists** are airborne liquid droplets suspended in the atmosphere which is formed through condensation of vapour back to the liquid state or through spraying of liquids. Examples are an oil mist produced during cutting and grinding operations and paint spray mist in painting operations;

e) **Gases** are formless fluids that expand to occupy the space or enclosure in which they are confined. Examples are nitrogen, oxygen and formaldehyde; and

f) **Vapours** are volatile form of chemicals that are usually in the liquid or solid state at room temperature and pressure.

1.6 Type of Monitoring

The deployment of samplers will depend on the purpose of monitoring, whether concerning chemical emissions or concerning chemical exposures to workers. For monitoring emissions, the device is located at a fixed point and for monitoring workers' exposure, the sampler is placed within the breathing zone of exposed worker. Basically, there are two (2) types of monitoring:

a) Area monitoring - located at fixed points in the vicinity of chemical sources; and

b) Personal monitoring - attached to workers with the sampler within the breathing zone over specified duration.

1.6.1 Area Monitoring

Area monitoring or source sampling is to obtain information on the likely sources contributing to the exposure. However, this monitoring does not usually reflect the amount that workers could breathe in, which determines the risk to health. It is not generally acceptable methods for evaluating worker's exposure as PEL specified in the USECHH Regulations refer to personal exposures.

Area monitoring is carried out to -

a) Obtain average concentrations of chemical at particular work area;
b) Evaluate overall quality of the surrounding air;
c) Evaluate the effectiveness of control measures;
d) Identify and select workers for the purpose of personal monitoring;
e) Evaluate the air after CHTH removal or clean up activity; and
f) Establish trends in air concentrations.

The monitoring device or sampling medium should be positioned at about 1.2 to 1.8 m (3 to 4 ft) from the floor and adjacent to a source of the chemicals as illustrated in **Figure 1**. Make sure that the sample collection medium is not in direct contact with, or placed too close to any settled dust or spilled chemical.

Figure 1: Sampling Position for Area Monitoring

1.6.2 Personal Monitoring

Personal monitoring is typically used where the chemical exposure of a worker due to inhalation is of greatest concern and can be used to demonstrate which tasks performed during a shift are leading to the highest levels of exposure. The results of personal monitoring are later compared against permissible exposure limit (PEL). PEL relates to personal exposure to airborne chemicals in the worker's breathing zone, which is defined as a hemisphere of radius 30 cm extending in front of the face, measured from the midpoint of an imaginary line joining the ears as illustrated in **Figure 2**.

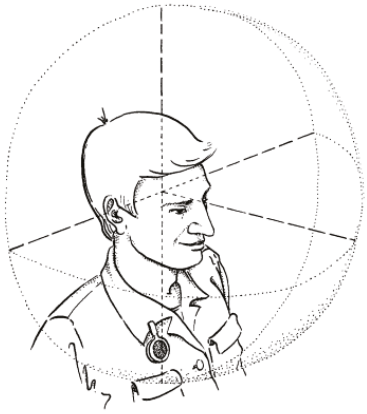

Figure 2: Breathing Zone

The sampling media is positioned in the breathing zone of the workers as shown in **Figure 3**, so that the sampler collects samples of air in the breathing zone continuously even if the worker is moving around while working. Sampling should be carried out while the work activity is in operation.

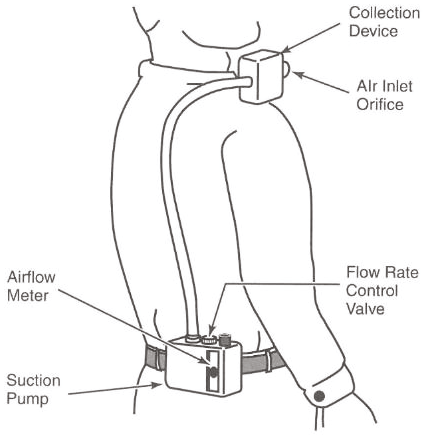

Figure 3: Personal Sample Collector Attached to The Worker's Shirt Collar

Personal monitoring should measure exposure or allow assessment of exposure throughout the work shift.

CHAPTER 2: AIR MONITORING PROCEDURE

This chapter briefly explains the procedure need to be taken by the HT in conducting air monitoring at the workplace as shown in **Figure 4**. The procedure of air monitoring consists of nine (9) steps which are:

2.1 Step 1: Preliminary Survey

Conduct preliminary survey to obtain a general overview of the workplace, its layout and work operations. Identify the work area or work unit and chemicals to be monitored. Gather information on health risk assessment, hazard information of the chemicals to be monitored, tasks carried out, task duration and frequency, work pattern and control measures in place, considering how these might affect exposures. The preliminary survey includes walk-through to the work area with direct-reading instruments, if available, to observe work activities and trend of exposure and communicate with employer and workers involved.

Note: Work unit is a group of workers with similar exposure with respect to similar tasks and similar exposure to the same CHTH.

2.2 Step 2: Identify Similar Exposure Group (SEG) and Variation of Exposure

A group of workers subject to a similar degree of exposure is known as a "similar exposure group" (SEG). Identify a SEG in each work area or work unit where chemicals are to be monitored and divide selected worker into SEG. The workers may be divided according to the process, chemical, activity, equipment, task, etc.

Refer to paragraph 4.4 on determination of SEG and selection of workers for sampling.

2.3 Step 3: Identify Sampling Technique

Identify the sampling technique to conduct the air sampling. Selection of sampling technique is based on the physical state of chemicals to be monitored. Refer to Chapter 3 for further details.

2.4 Step 4: Monitoring Strategy

Decide on the monitoring strategy to be used in conducting the air sampling. Monitoring strategy includes determination of sampling duration, number of sampling media needed and number of workers to be sampled. Refer to Chapter 4 for further details.

2.5 Step 5: Conduct Air Sampling

Take at least three (3) samples for each of chemical at each of the SEG to be monitored. If the number of workers is less than three (3), HT need to replicate the monitoring in other day or another shift. It is difficult to draw conclusion about trend of exposure in the work area on the basis of a single sample because of the variation in the task, work or process. Next step to be taken will be based on the results of the three (3) samples which are:

a) If all three (3) results are less than 10% of PEL, it can be assumed that the PEL is complied with and can proceed to Step 8 for conclusion and recommendation; or

b) If any result is more than PEL, employer must improve control measures to reduce the exposure. Attention should be given to the exposure of the particular SEG, perhaps by redesign of work practices or improvement of engineering control measures; or

c) If any result is at or more than 10% of PEL but at or below PEL ($0.1\ PEL \leq x \leq PEL$), take another six (6) more samples (Step 5 (d)). Proceed to Step 6.

Refer to **Appendix 1** for example of worker's sampling.

2.6 Step 6: Perform Statistical Analysis

For Step 5 (d) of **Figure 4**, use all the nine (9) results for statistical analysis. Refer to paragraph 6.3 for further details.

2.7 Step 7: Perform Compliance Test

Based on monitoring results from Step 5 (c), compare directly with PEL to determine if any of the results exceed PEL. In the case no results from Step 5 (c) exceed PEL, the compliance test is performed by using monitoring results from Step 5 (a) and Step 5 (d). Refer to paragraph 6.3.2 for further details.

If the compliance test failed, employer must improve control measures to reduce the exposure, particularly on the work practices or improvement of engineering control measures. The HT may also wish to look again at sources of exposure and efficiency of control measures, using direct-reading instruments for example. Information on control measures can be referred to the Guidelines on The Control of Chemicals Hazardous to Health 2002 or as amended.

2.8 Step 8: Conclusion and Recommendation

HT is required to conclude the result and recommend actions to be taken by the employer for all outcomes of the monitoring (Step 5 (b), Step 5 (c) and Step 7). In the case of a work unit or work area that has failed a compliance test, the employer must review the existing control measures and improve the control in the work unit or work area before conducting periodic monitoring. Refer to Chapter 7 : Report Writing, paragraph 9.0 Conclusion.

2.9 Step 9: Prepare and Submit Report

Prepare the monitoring report according to report writing format elaborated in Chapter 7. The report should be presented and submitted to employer within one (1) month after the completion of the monitoring.

Whatever results obtained from the monitoring, the HT needs to prepare report to be submitted to the employer. Employer can make improvement after receiving the sampling results.

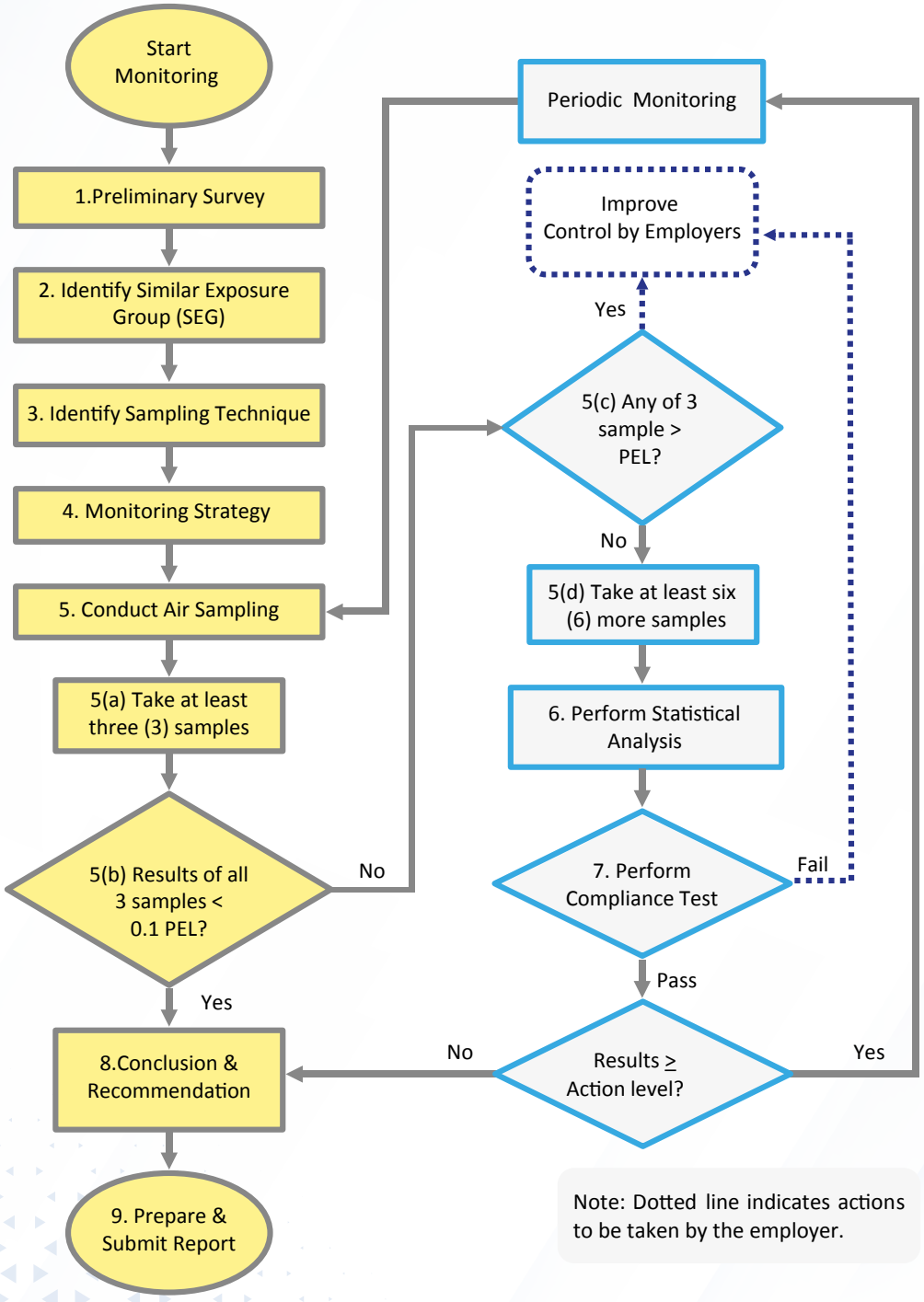

Figure 4: Air Monitoring Procedure

CHAPTER 3: SAMPLING TECHNIQUE

Instruments used for sampling of airborne CHTH can be categorised as integrated air sampling instruments and direct reading instruments. Integrated air sampling instruments are non-real time instruments because the results of the measurements made are not known immediately as the samples have to be sent for analysis to a laboratory. Direct reading instruments are also known as real time instruments because they give instantaneous read-out of the measurements made.

3.1 Integrated Air Sampling

An integrated air sampling is a method which air is drawn through or across a collector called sampling media by force (active sampling) or by nature (passive sampling). The sampling media is then analysed at the laboratory to determine the amount of contaminant that is present in the collector. The sampling media used is depending on the type of contaminant to be collected.

a) **Active sampling** is a common method using a pump, typically a flow controlled, battery operated pump. A known volume of air is drawn through a sampling media. It is often worn for an entire shift to measure the eight hour time-weighted average (TWA_8) airborne concentration. The sampling media may be a filter, a sorbent tube or impinger.

   In order to collect the samples, an instrument set up must be performed. This set up is called sampling train. It is composed of three (3) elements which are:

   (i) Sampling Pump

   The pump acts as an air mover and causing the necessary suction to be created at the face of the filter holder. For personal sampling, the pump must be lightweight, slim, hip-hugging style, battery operated, and capable of producing constant flow rate.

   (ii) Collecting Media

   The media is used to collect the intended airborne CHTH. It may varies depend on the type of chemical to be collected.

   (iii) Holder and/ or Connecting Tube

   Holder is to hold or to provide housing for the collecting media. The connecting tubes are used to connect holder and pump and are usually made up of silicon rubber, polymer, thermoplastic or PTFE.

The component of the sampling train is dictated by the requirements of the sampling method, which will specify the sampling media to be used, and volume of air that must be sampled to yield accurate analytical results. **Figure 5** is a diagrammatic representation of a sampling train.

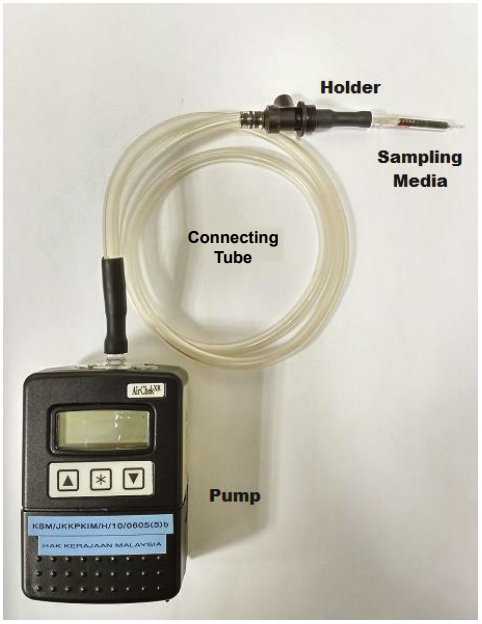

Figure 5: Sampling Train

Sampling pumps come in a range of sizes with different flow capabilities. Pumps used for measuring individual exposures are usually small. Low flow rates pumps are generally used for personal sampling while high flow rates are used to take samples in a fixed location in the work area. However, the selection of the pump should meet the flow rate specified by the method of monitoring and analysis. The pump unit must be capable of maintaining a constant flow of the specified rate throughout the sampling period.

b) **Passive sampling** is a simple alternative to active sampling whereby airborne CHTH are adsorbed onto a sorbent by diffusion. The surface area may be large as in the case of badges or cylinders, or small as for tubes. The rate at which the CHTH is absorbed, the uptake rate, must be derived for each chemical on each type of sampler and sorbent.

Not all commercially available passive samplers meet the requirements for precision and accuracy. For the purpose of worker's personal exposure monitoring, only the validated passive samplers are accepted. The supplier of the passive samplers must provide complete documentation on its validation i.e. performance testing.

3.2 Direct-Reading or Real-Time Monitoring

Direct-reading monitoring, also known as real time monitoring, give instantaneous read-out of measurements made. This type of monitoring permit real-time or near real-time measurements of airborne CHTH concentrations in the field, thus eliminating the lag time encountered when samples are collected on media and analysed by a laboratory. Using direct-reading instruments, airborne CHTH are sampled and analysed within the instrument in a relatively short time (seconds to minutes). Direct-reading monitors can profile fluctuations in airborne CHTH concentrations that are lost when performing traditional integrated sampling. Thus, measurements can estimate

instantaneous exposures, short-term exposures and time integrated exposures to compare with exposure standards.

However, this type of monitoring has constraints such as:

a) Detection and/or measurement for specific classes of chemicals.

b) Direct-reading instrument that have been designed to detect one particular substance also detect other substances (interference) and, consequently, may give false readings.

When direct-reading instruments are used, all potential sources of error should be minimized to ensure proper quality control practices. All instruments require calibration according to the manufacturer's instructions before and after every use.

Example of real-time or direct reading monitors are:

a) Electronic direct-reading instruments - Computerized data acquisition and processing systems are integrated into the instruments, allowing the exposure doses to be displayed for variable periods.

b) Colorimetric direct-reading devices - The operating principle is based on the fact that the intensity of the developing chips is proportional to the concentration of airborne CHTH or a family of CHTH.

3.3 Sampling for Particulate

Sampling for particulate can be achieved by two (2) techniques:

a) Integrated air sampling
b) Direct-reading monitoring

Note: If there are other techniques, it may be accepted according to recommendation from recognised agency/ body.

3.3.1 Integrated Air Sampling for Particulate

3.3.1.1 Sampling for Inhalable Particulate

Sampling solely concerns with particulates that are able to enter the respiratory system by inhalation through the nose or mouth. This sampling is carried out when the airborne particulates are soluble in tissue fluids or of an acutely toxic or irritant nature and the primary health effect of the particulate is not on the lungs.

Instruments required for inhalable particulate sampling are:

a) Sampling Pump
b) Connecting Tube
c) Filter Cassette

Filter cassettes are commonly made of polystyrene, but other material may also be used. A filter support screen is usually placed beneath the filter in the cassette. There are two (2) techniques of sample collection using filter cassette. It will be specified by the method that has been chosen.

Table 1: Technique of Sample Collection Using Filter Cassette

Open Face Cassette	Closed Face Cassette
Top portion of the cassette is removed during sampling	Plastic plug is removed
Filter and filter support screen are held in place by ring section that fits into female section	Air enters the cassette through small hole in the centre
Used when the distribution across the surface of the filter is important for the analytical method, e.g. Asbestos Fibres.	Used when the entire filter is analysed to determine total amount of airborne CHTH present, e.g. metal fume

Figure 6: Sample of Filter Cassette and Filter Cowl

d) Filter Media

The filter media for particulate sampling is made up of various materials such as plastic fibre, cellulose, organic membrane, silver membrane and glass fibre. The characteristics of these filters are shown in **Table 2**.

Fume is normally collected using a sampling head or filter holder loaded with media made of glass fibre or membrane with pore size less than 2 µm.

Table 2: The Characteristics of Filters

Type of Filter	Characteristics
Plastic Fibre	Weak, friable, electrostatic charge and low moisture pick-up
Cellulose	Considerable tensile strength and rapid uptake of moisture
Organic Membrane	Brittle and very low moisture pick-up
Silver Membrane	Tough and flexible
Glass Fibre	Moderately strong and low moisture pick-up

Recommended filter to be used for various type of particulate are shown in **Table 3**.

Table 3: Recommended Filter to be Used for Various Type of Particulate

Particulate	Filter Used
Asbestos Fibres	0.45 to 1.2 µm MCE
Elements (e.g. Arsenic)	0.8 µm PVC
Lead	0.8 µm MCE
Silica	0.8 µm or 5 µm PVC or MCE
Wood Dust	5 µm PVC
Welding Fumes	Glass fibre or 0.8 µm MCE

However current validated methods should be referred to specific particulate.

Other accessories include a waist-strap to hold the pump in place, a sampling head holder, and a cellulose band to shrink-wrap the cassettes.

3.3.1.2 Sampling for Respirable Particulate

Measurement is solely concerned with insoluble particles that may reach the pulmonary air spaces and potentially causing lung damage (due to the very slow rate of particle removal in the alveolar region). This type of sample is taken for exposure assessment of any particulate known to cause pneumoconiosis such as silica, talc and coal dust. Respirable dust is dust particles with AED less than 10 µm.

In order to assess effectively the potential risk of lung damage, it is necessary to make use of a dust sampling instrument which is able to select and retain that portion of the dust cloud which is capable of entering and residing for long periods within the alveolar region.

This is the form of a two-stage sampler in which an initial collector simulates the action of the respiratory tract by arresting the larger particles (elutriator or cyclone) in the airborne dust sample while passing the finer, respirable particles for subsequent collection in a second and final collector, usually in the form of a high efficiency filter.

For sampling respirable dust, the following instruments are necessary:

a) Personal sampling pump
b) Connecting tube
c) Filter holder
d) Filter media
e) Initial stage collector or respirable dust separator

Other accessories include waist-strap to hold the pump in place; a sampling head holder; and a cellulose band to shrink-wrap the cassettes.

Respirable dust separator as illustrated in **Figure 7** is either an elutriator or a miniature cyclone connected to the sampling head to separate the non-respirable from the respirable portion of the inhalable dust.

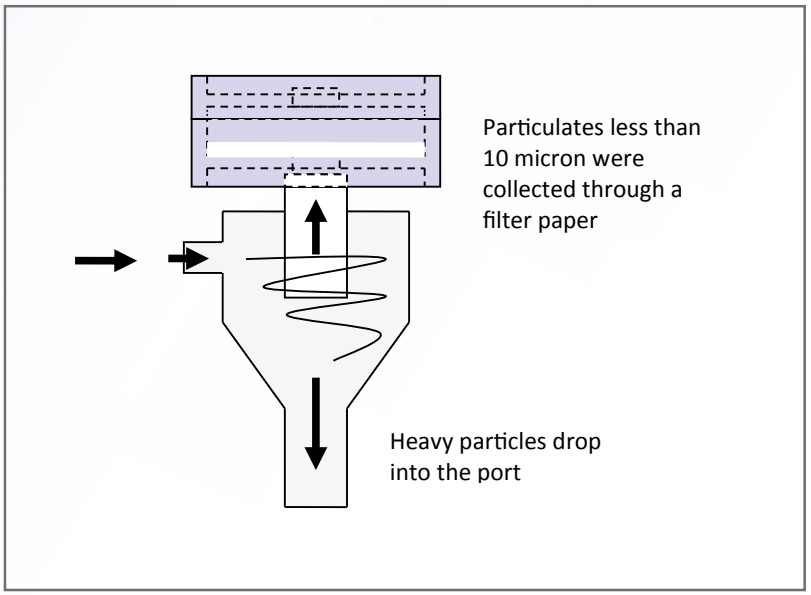

Figure 7: Respirable Dust Separator

3.3.1.3 Sampling of Respirable Fibres

Respirability of fibres is principally a function of the actual diameter of the particle and is largely independent of its length up to the point where direct interception intervenes in the separation process (diameter < 3 μm and length > 5 μm).

There is a need to use a counting method to determine the fibre concentration since:

a) AED size selection is unable to differentiate between fibrous and non-fibrous portions of sample; and
b) AED size selection unable to exclude non-respirable fibre aggregates from the sample.

Instruments required for fibre sampling are:

a) Sampling Pump
b) Filter Holder: 25 mm filter holder with cowl
c) Filter Media

General characteristic of filter and recommended filter can be found in **Table 2** and **Table 3**. However current validated methods should be referred for specific particulate.

d) Connecting Tube

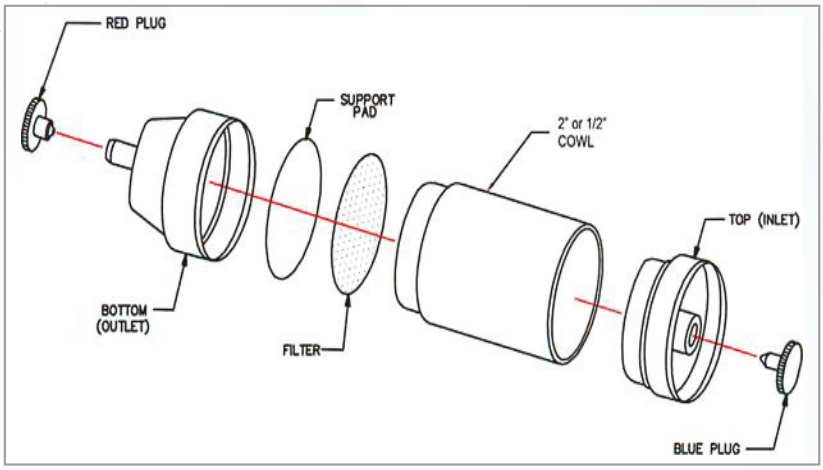

Figure 8: Filter Holder With cowl

A sample is collected by drawing a known volume of air through a membrane filter by means of a sampling pump. The filter is rendered transparent and mounted on a microscope slide. Fibres on a measured area of the filter are counted visually using phase-contrast optical microscopy (PCOM), and the number concentration of fibres in the volume of air is calculated. **Figure 8** and **Figure 9** show sampling train for respirable fibres.

Figure 9: Sampling Train for Respirable Fibres

3.3.2 Direct-Reading Instruments for Particulates

Direct-reading instruments are compact, portable devices that combine sampling and analytical functions designed to measure respirable particle mass concentrations. Refer paragraph 3.2 for further explanation for the general requirement of direct-reading sampling.

3.4 Sampling for Gas and Vapour

Sampling for gas and vapour can either be achieved by continuous or grab samplings through:

a) Integrated air sampling
b) Direct-reading monitoring

3.4.1 Integrated Air Sampling for Gas or Vapour

3.4.1.1 Active Sampling

The following instruments are used for the active sampling of gas and vapour:

a) Sampling Pump

The pump used should be able to deliver low flow rates to allow time for contact between the gas and absorbent or the vapour with the adsorbent.

b) Collector

(i) Sorbent Tubes

Sorbent tubes are made of glass. The ends must be broken off before sampling. Most sorbent tubes have arrows on them to indicate the direction of airflow. If there is no directional arrow on the tube, the end nearer the small back up the section of sorbent tubes should be placed into the sampling tube or holder. It can contain adsorbent media such as charcoal or silica gel.

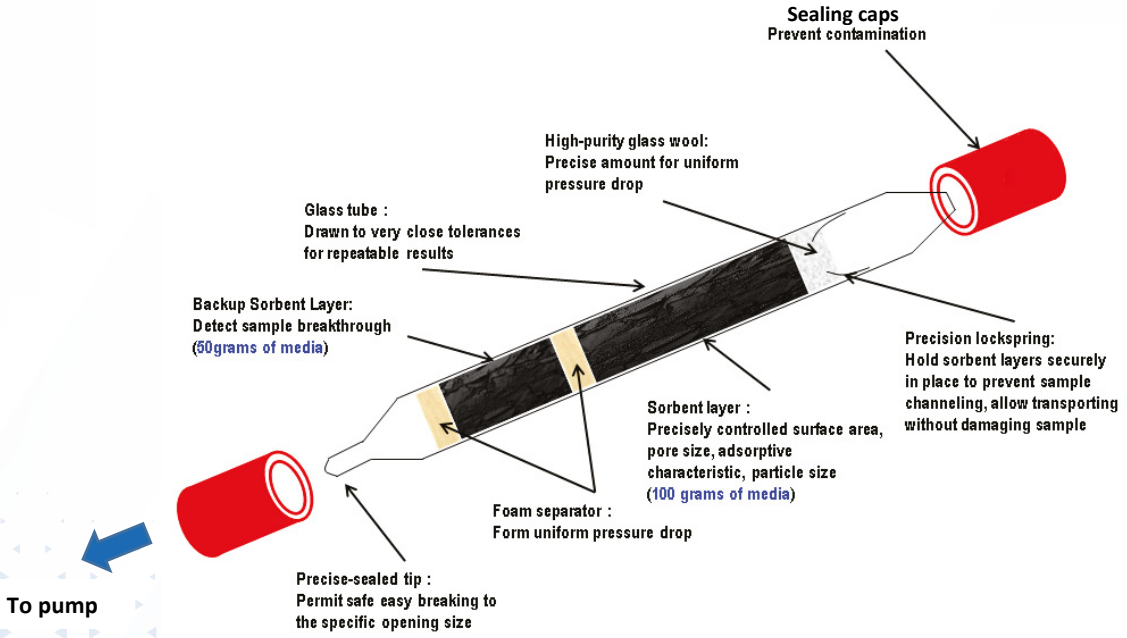

Figure 10: The Construction of Typical Sorbent Tubes

The backup section of the sorbent tube has an important role, which is to capture any CHTH that pass through the front section. The air will enter the front section first. If the laboratory analysis of the backup section of sorbent tube shows that it contains an amount of contaminant equal to 20-25% of the amount of CHTH captured in the front section, it is an indication that the front section of the sorbent was possibly completely saturated during sample collection. This condition is called a breakthrough. When this happened, the sample results underestimate the actual concentration of the contaminant.

(ii) Impingers

A nonreactive and highly soluble air contaminant in a specific solution may be collected by using an impinger. Impinger is a glass container, also known as a bubbler or a gas-wash bottle resembles a graduated cylinder with a long inlet tube fitted into a stopper.

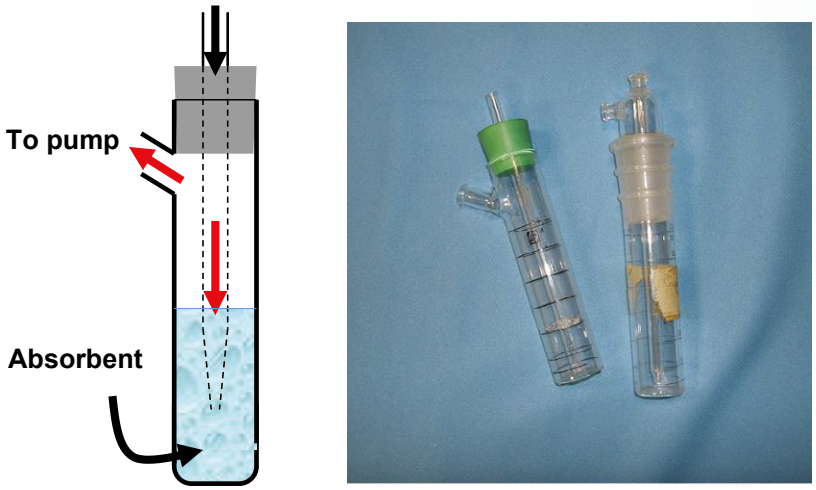

Figure 11: Impingers

The sampling pump is connected so that a partial vacuum is created inside the impinger, drawing air through the inlet tube, where it exits into the solutions. The air bubbles up through the solutions, and this contact between air and liquid allows the contaminant to dissolve in the liquid. After sampling, the solution may be sealed in the impinger cylinder or placed into a different container and sent to the laboratory for analysis.

(iii) Adsorbent and Absorbent Media

Adsorbent and absorbent media are used to collect the intended air contaminant. The common adsorbent and absorbent media are shown in **Table 4**. However, current validated methods should be referred for specific gas or vapour.

Charcoal is the most widely used solid sorbent for CHTH sampling. Charcoal contains microscopic opening where molecules are trapped while silica gel provides a surface on which contaminants may condense or to which they might simply adhere.

Sorbent also sometimes coated with a chemical compound to enhance collection efficiency for a specific contaminant, for example, sulphuric acid with treated silica gel.

Table 4: Common Adsorbent and Absorbent Media

Gas or Vapour	Absorbent / Adsorbent	Sampling Media/ Collector
Acids, inorganic	Washed silica gel (400/200) mg	Solid sorbent tube
Ammonia	Sulphuric Acid-treated silica gel	Solid sorbent tube
Formaldehyde	20 ml + 20 ml 1% sodium bisul-phite solution	2 impingers + 1 micro m PTFE filter
Hydrocarbon-boiling point (36-126) °C (e.g. benzene, toluene)	Coconut shell charcoal (100 mg / 50 mg)	Solid sorbent tube
Hydrogen Cyanide	Soda lime (600 mg / 200 mg)	Solid sorbent tube
Isocyanates	Trytamine/DMSO; 20 ml	Impinger
Methanol	Silica gel (100 mg / 50 mg)	Solid sorbent tube

c) Connecting tube

Connecting tube is used to connect the pump and the media. It is usually made of flexible thermoplastic PVC-based material or polymer or PTFE.

For further information on measurement of gas and vapour can be referred to **Appendix 2**.

3.4.1.2 Passive Sampling

Passive sampling is conducted without an air sampling pump. The airborne CHTH is collected through diffusion rather than through forcing the air into the sampling device. Often called sample badge, it is a small clip-on device that contained solid sorbent tube and can be used for the collection of a wide variety of airborne CHTH. These devices are very easy to use; it is simply clipped to the workers' lapel and worn throughout the shift. When the sampling is completed, the sampler is sealed in a container and sent to the laboratory for analysis. Other passive sampler provides user-interpreted results in the form of a colour change in response to the presence of a particular CHTH.

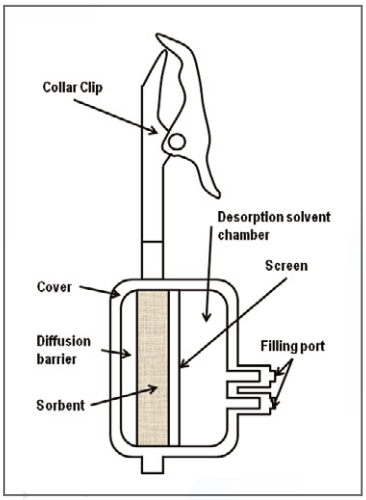

Figure 12: Passive Sampler

Generally, two (2) types of sampler commonly used are:

a) Badge sampler;

b) Tube sampler.

Figure 13: Badge Sampler

Figure 14: Tube Sampler

3.4.2 Direct-Reading Instruments for Gas or Vapour Sampling

Direct-reading instruments for measuring gases and vapours are devices that sample CHTH either continuously or intermittently, quantitatively analyse the sample, and display the results in the form that gives an immediate indication of the atmospheric concentration of the analyte (the chemical that is analysed).

These direct-reading instruments are also useful in tracing sources of contaminant emission, the immediate detection of unacceptable conditions, and the rapid assessment of the efficiency of control measures.

Some of the most common direct-reading instruments are:

a) Gas Analyser
Based on the photometric principle, i.e. solutions of air mixtures of gaseous contaminants absorb a specific wavelength of light in the infrared regions of the electromagnetic spectrum.

b) Portable Gas Chromatography (GC)
Mixtures of chemical compounds are separated from one another by selective partition between a stationary liquid phase and a mobile phase.

c) Gas Detector Tubes
Make use of the chemical properties of the gaseous contaminant to promote a reaction between the gas or vapour and a specific reagent which results in the formation of a coloured product.

Refer paragraph 3.2 for further explanation for the general requirement of direct-reading sampling.

3.5 Measuring Atmospheric Conditions

Atmospheric conditions to be measured during sampling are temperature, pressure, relative humidity and air velocity. There are various methods of measuring equipment such as whirling hygrometer, anemometer, thermometer and others. For example, anemometer or thermometer can be used to determine the absolute average ambient air temperature during sampling to convert the volume of air sampled at standard condition while whirling hygrometer can be used to measure relative humidity.

It is necessary to correct the volume of air sampled for barometric pressure, where the difference in altitude is more than 1000 ft (305 meter) or the temperature difference is more than 14°C. Refer to 6.2.1 for detail calculation.

3.6 Calibration of Sampling Instruments

The purpose of calibrating sampling instrument is to set the pump to the recommended flow rate to get an accurately measured volume of air over the sampling duration. There are two (2) types of calibrator, i.e. the primary calibrator and the secondary calibrator. The most commonly used primary calibrator is the bubble meter. The accuracy of a primary calibrator should be within ± 5%. The secondary calibrator is less accurate, and it is used to check the flow rate of the pump during sampling. Calibration frequency for the calibrator should be referred to manufacturer's specifications and recommendation.

The pumps need to be calibrated before every air monitoring. When carrying out pump calibration, the sample media/ collector needs to be connected between the pump and the calibrator. The pump flow rate is adjusted so that the desired flow rate is obtained. When the desired flow is achieved, the pump flow meter or rotameter is marked, to indicate the set value.

Before calibration, make sure that the pump is fully charged and in good order. The bubble meter uses the principle of cylindrical air displacement meter with nearly frictionless piston. The interior surface is wetted with a detergent solution to make it frictionless. A soap-film bubble is placed, and suction is provided from the pump to be calibrated. The bubble in the cylinder will be drawn up. The column displacement per unit time can be determined by measuring the time required for the bubble to pass between the two-scale marking which encloses a known volume.

By adjusting the flow rate of the pump, the required flow rate as derived from the bubble meter can be found. The temperature of the room and the barometric pressure must be recorded during the calibration. After sampling, the pump has to be recalibrated to check the flow rate and to calculate the error. If the error is more than 10%, the sample must be rejected. Calibration set-up for inhalable particulates sampling is shown in **Figure 15** while calibration set-up for the respirable particulates is shown in **Figure 16**.

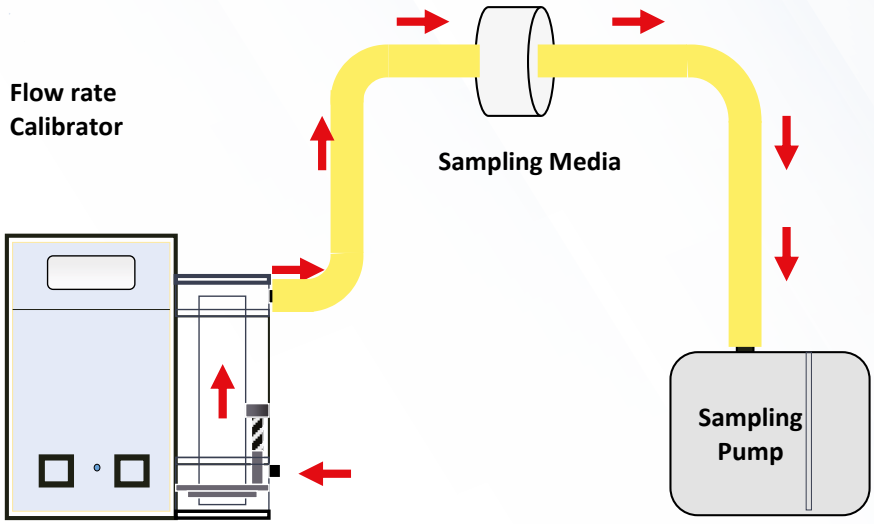

Figure 15: Example of Calibration Set-Up for Inhalable Particulates Sampling

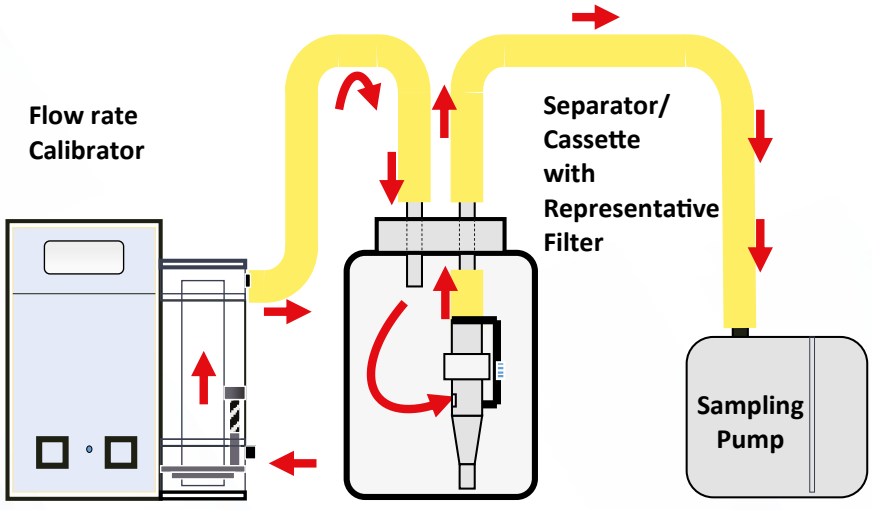

Figure 16: Example of Calibration Set-Up for Respirable Particulates Sampling

CHAPTER 4: MONITORING STRATEGY

This chapter explains monitoring strategy that can be taken by HT during airborne CHTH sampling including sampling strategy, sample preparation, duration of sampling and selection of workers to be sampled.

4.1 Sampling Reference Period

Results of air sampling are intended for comparison with PEL in USECHH Regulations. In the absence of PEL in USECHH Regulations, Occupational Exposure Standard (OES) can be used. For an 8-hour time-weighted average limit (PEL-TWA), the reference period is eight (8) hours; for short term exposure limit (STEL) and maximum exposure limit (MEL), it is 15 minutes and for a ceiling limit (CL), it depends on the sampling method for respective chemicals.

When evaluating or determining compliance with the PEL-TWA, samples representing a full-shift exposure should be collected. All work hours during which workers are subjected to exposure should be monitored to eliminate errors associated with fluctuations. PEL-TWA calculation is only applied for sampling duration not more than eight hours, refer to paragraph 6.2.2. For extended working hours, refer to paragraph 6.4 on the calculation of adjusted PEL-TWA.

4.2 Sampling Strategy for Eight-Hour Time Weighted Average Limit

Sampling strategy can be classified into one of these three categories:

a) Full period - Continuous single sample monitoring
b) Full period - Consecutive samples monitoring
c) Partial period - Consecutive samples monitoring

The full period consecutive samples monitoring is considered the best option as it yields the narrowest confidence limits on the exposure estimate. The full period continuous single sample monitoring is considered as the second best option if sampling/analytical method is available.

4.2.1 Full Period - Continuous Single Sample Monitoring

Full period continuous single sample monitoring is where the sample is taken for full period of the standard i.e. PEL or OES. If the monitoring is for PEL-TWA, where the reference period is eight (8) hours, the sampling is taken for eight (8) hours. For example, to measure worker exposure to respirable dust, a personal sampling pump with a respirable dust sampler is attached within the breathing zone of the worker. His shift starts at 8.00 am and end at 5.00 pm with lunch break from 12.00 pm to 1.00 pm. **Figure 17** represents full period-continuous single sample monitoring.

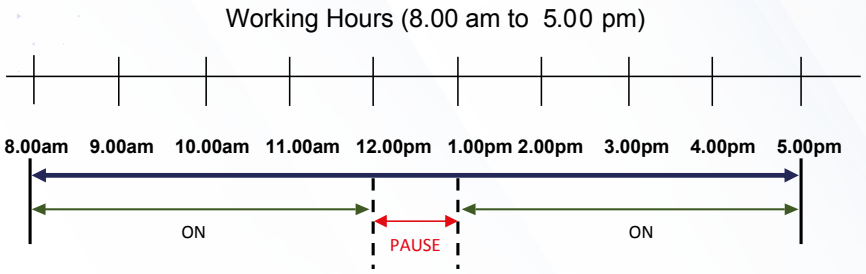

Figure 17: Full Period- Continuous Single Sample Monitoring

The sample collected constitutes a full period sample for determination of respirable dust exposure because it covers the entire time period appropriate to the reference period of eight (8) hours.

4.2.2 Full Period - Consecutive Samples Monitoring

Full period consecutive samples monitoring is where several samples (equal or unequal time duration) are obtained during the entire period appropriate to the standard i.e. PEL or OES. The total time covered by the sample must be eight (8) hours for PEL-TWA. For example, personal samples for asbestos workers are collected as follows:

Shift starts at 8.00 am, lunch for 60 minutes at 12.00 pm and finishes at 5.00 pm

Sample 1: 8.00am to 9.00 am
Sample 2: 9.00 am to 10.00 am
Sample 3: 10.00 am to 11.00 am
Sample 4: 11.00 am to 2.00 pm (pause for 1-hour lunch)
Sample 5: 2.00 pm to 5.00 pm

The monitoring obtained is a full period consecutive samples as it covers the entire time period appropriate to the standard PEL-TWA and the samples are taken consecutively or serially. **Figure 18** represents full period-consecutive samples monitoring.

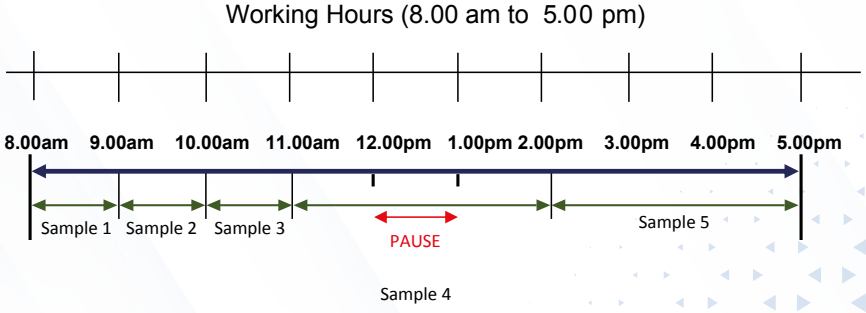

Figure 18: Full Period-Consecutive Samples Monitoring

4.2.3 Partial Period - Consecutive Samples Monitoring

Partial period consecutive monitoring is where one (1) or several samples (equal or unequal time duration) are obtained for only a portion of the period appropriate to the standard i.e. PEL or OES. The sampled portion should cover at least 70% to 80% of the full reference period i.e. eight (8) hours. Professional judgement is needed to judge the unsampled portion of the period. Reliable knowledge concerning the operation is required to make this judgement. For the unsampled portion of the period, two (2) assumptions must be decided whether it is zero or similar exposure. The unsampled period is considered zero exposure when there is no work activity being done or during breaks, or no exposure to the monitored workers. Similar exposure can be assumed for work activity when there is exposure to workers considering worst case scenario in protecting the workers.

For example, personal sampling for lead exposure was carried out, starting from 8.30 am to 3.30 pm with one (1) hour lunch break from 12.00 pm to 1.00 pm. The sampling is considered as partial period consecutive samples monitoring since it covers only six (6) hours compared to the appropriate eight (8) hours reference period. **Figure 19** represents partial period-consecutive samples monitoring.

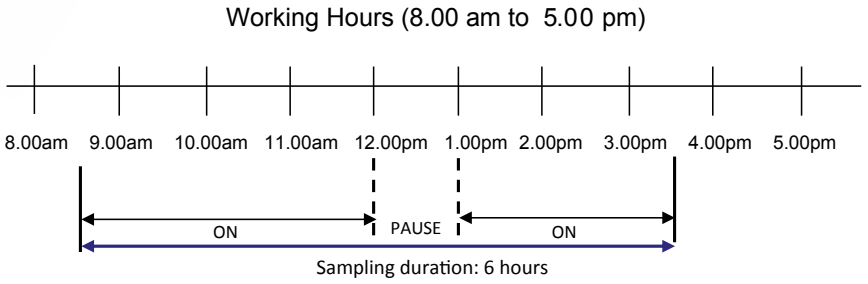

Figure 19: Partial Period-Consecutive Samples Monitoring

4.3 Sampling Strategy for Short Term Monitoring

A sampling that was done to determine the ceiling limit (CL), short term exposure limit (STEL) or maximum exposure limit (MEL) is treated in similar manner to sampling for comparison with PEL-TWA. However, two (2) criteria that should be considered when sampling for comparison with CL, STEL or MEL are:

a) The samples are best taken in non-random fashion. All available information related to the work area, individual, work task and process being sampled should be utilized to obtain sample during periods of expected maximum concentration of the chemicals.

b) The duration for sampling is much shorter than those taken for calculating TWA's.

4.3.1 Short Term Exposure Limit (STEL) and Maximum Exposure Limit (MEL)

For STEL and MEL, each measurement should consist of a 15-minutes sample (or series of consecutive samples totalling of 15 minutes) taken in the employee breathing zone. The sampling duration will refer to the following situation:

a) If task duration is 15 minutes or less, the total work duration should be sampled.
b) If task duration is more than 15 minutes, sampling should be conducted for the 15 minutes task that is assumed to have maximum exposure.
c) If task duration is more than 15 minutes and the maximum exposure duration cannot be assumed, or when the exposure may be considered as fairly constant, sampling of the total work hour may be an option (Example: For 30 minutes work or task, sampling should be done for 30 minutes). In this case, the time weighted average (30-minute average concentration) is regarded as the maximum value of the 15-minute time weighted average during the work hours and is compared with the STEL or MEL.

The sample taken is not limited to one (1) sampling period of 15 minutes. The determination of number of samples must take into account the trend of exposure of CHTH to the worker. A minimum of three (3) measurements should be taken for STEL or MEL.

4.3.2 Ceiling Limit (CL)

Measurements for the purpose of determining workers exposure to ceiling limit should be taken during the period of expected maximum airborne concentrations, based on the trend of exposure relating to the area, workers, and process being sampled. A minimum of three (3) measurements should be taken in one (1) work shift, and the highest of all the results is a good estimation of the worker's maximum exposure for that shift.

To calculate the minimum duration of the sample, refer to sampling method of the particular chemical. Even though samples taken for comparison with CL are best taken in a non-random fashion, there may be situations where the process appears constant during the work shift. In this case, the number of time period that should be sampled can be estimated so that representation is assured from the desired exposures.

Explanation on ceiling limit, MEL and TWA is shown graphically in **Figure 20**.

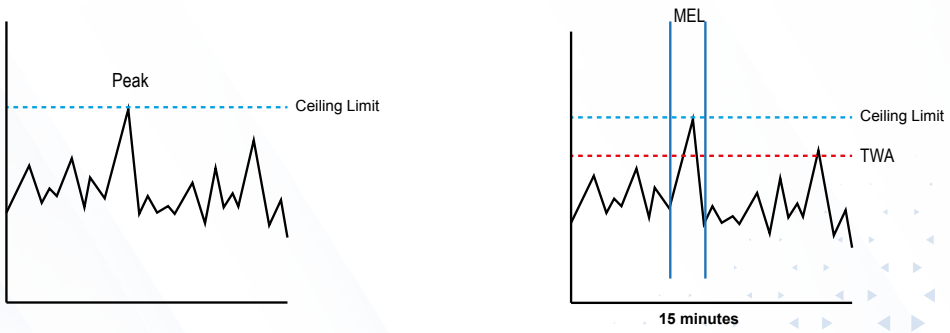

Figure 20: Explanation on Ceiling Limit, MEL and TWA

4.4 Workers to be Sampled

Selection of worker who has maximum exposure is important to determine the overall worker's exposure. There are few factors to be considered in selection of workers to be sampled such as maximum expected risk, exposure to CHTH at high concentration, nearest to the source, maximum risk of exposure and difference in work pattern. Sampling of worker maybe based on identified SEG and the variability of worker's exposure.

4.4.1 Work Unit and Similar Exposure Group

Work unit is a group of workers with similar exposure with respect to similar tasks and similar exposure to the same CHTH. Usually, the chemical risk assessor has identified work unit which exposure monitoring is necessary.

Similar exposure group (SEG) refers to a group of workers who are assumed to have a similar degree of exposure. Generally, the size of SEG (number of workers constituting an SEG) will be considered in many cases to be three (3) or more. There are some cases of an SEG having only one (1) or two (2) workers; conversely some large SEG consist of several tens of workers. For example, workers assigned to operate forklift in a warehouse may be grouped as having similar potential exposures to carbon monoxide.

For air monitoring purpose, the identified work unit may be considered as one (1) SEG or subdivided into a few SEGs depending on the variation of exposure. Selection of workers for monitoring will be randomly selected within the identified SEG.

4.4.2 Variation of Exposure

Variation of exposure includes variation in the process, job or tasks being carried out which can be by hour, day or week. Type of variation of exposure can be categorised as:

a) Worker-to-worker variance – two workers doing the same task or job will not have same exposure because of minor differences in work pattern and equipment; or

b) Day-to-day variance – exposure varies from shift to shift or day to day.
   (i) Day-to-day variance I
   (ii) Day-to-day variance II

Variances in the eight-hour time-weighted average of workers in an SEG are divided into between-worker and within-worker variability. Here, the worker-to-worker variance shall be the variance among workers of the geometric mean of each worker's day-to-day distribution (assembly of daily eight-hour time weighted averages for one worker). Since an SEG is a group of workers with similar exposure, the geometric mean of each worker should be essentially the same, although, of course, not exactly identical.

On the other hand, the day-to-day variance is further subdivided into variance due to daily variance of workplace environments (day-to-day variance I) and variance due to daily variance of the work movement of workers themselves and their transfer route (day-to-day variance II). Thus, variances in the eight-hour time weighted average of workers in an SEG can be divided into three (3) groups: worker-to-worker variance, day-to-day variance I, and day-to-day variance II.

The variables affecting the airborne concentration of chemicals close to the workers are:

a) The numbers of sources from which chemicals are released
b) The production rate in relation to production capacity
c) The rate of release from each source
d) The type and position of each source
e) The dispersal of the chemical by air movement
f) The type and effectiveness of exhaust and ventilation system

The variables related to workers' action and behaviour are:

a) How close the worker is to the sources
b) Duration spent in the area
c) Workers' work practices

4.4.3 Number of Workers to be Sampled

The minimum number of samples collected for each SEG and each chemical should be at least three (3) samples. The numbers of samples to collect is important as it relates to the confidence that can be placed in the exposure estimate. The number of samples needed for an accurate and reliable exposure assessment depends on the purpose of the sampling, the number of processes, work tasks or jobs to be evaluated, the variance of exposure, sampling and analytical variability, and other factors.

Workers to be sampled are selected at random from among a SEG and should be from those who are on duty during the given working day. It is advisable that the work schedule for the monitoring day should be verified with the supervisor and/or the workers to be monitored.

4.5 Number of Sampling Media Needed

4.5.1 Eight-Hour Time Weighted Average Sampling

a) Determine maximum volume, V_{max} and sampling flowrate, Q recommended for each sampling media from validated methods such as from US OSHA (OSHA Reference Method), US NIOSH (United States NIOSH Manual of Analytical Methods) or other validated methods.

b) Calculate maximum sampling duration, t_{max} for each sampling media using the following equation:

$$t_{max} = \frac{V_{max}}{Q}$$

c) Identify total sampling duration, t_{total} based on sampling method (refer to paragraph 4.1)

d) Calculate number of sampling media, n needed as follows:

$$n = \frac{t_{total}}{t_{max}}$$

Example: Number of Sampling Media Calculation

a) From US NIOSH Method 0500 for inhalable dust monitoring:

$$V_{max} = 333 \text{ L @ } 15 mg/m^3$$
$$Q = 1 - 2 \text{ L/min}$$

b) Maximum sampling duration, t_{max} for each sampling media for sampling flow rate 1 L/min :

$$t_{max} = \frac{333 L}{1 \text{ L/min}} = 333 \text{ min}$$

c) For sampling of full period eight-hour time-weighted average, samples are taken throughout worker's working shift from 8.00 am to 5.00 pm and paused during his meal break at 1.00 pm to 2.00 pm:

$$\text{total sampling duration, } t_{total} = 480 \text{ min}$$

d) Number of sampling media, n needed as follows:

$$n = \frac{480}{333} = 1.4$$
$$\sim 2 \text{ sampling media}$$

4.5.2 Short-Term Sampling

a) Take at least three (3) measurements in one (1) work shift. Determine minimum volume, V_{min} , sampling flowrate, Q and limit of detection (LOD). The estimated LOD for each sampling media can be obtained from validated methods such as US OSHA (OSHA Reference Method), US NIOSH (NIOSH Manual of Analytical Methods) or others.

b) Calculate minimum sampling duration, t_{min} for each sampling media using the following equation:

$$t_{min} = \frac{V_{min}}{Q_{max}}$$

Note:
i. This equation is only applicable for ceiling limit.
ii. For STEL and MEL sampling duration is 15 minutes.

Example 1: Determination of Sampling Duration for Ceiling Limit

a) From US NIOSH Method 2541 for airborne formaldehyde monitoring
V_{min} = 1 L @ 3 ppm
V_{max} = 36 L
Q = 0.01 – 0.10 L/min
estimated LOD = 1 µg per sample
Ceiling limit (USECHH Regulation) = 0.3 ppm

b) Minimum sampling duration, t_{min} for each sampling media using the following equation:

$$t_{min} = \frac{V_{min}}{Q_{max}}$$

$$t_{min} = \frac{1L}{0.10\ L/min} = 10\ min$$

c) Sample needs to be sent to laboratory with LOD of 1 µg per sample or below to enable chemical concentration detection during analysis.

Example 2: Determination of Sample Volume when t = 15 minutes

a) From US NIOSH Method 1300 for airborne acetone monitoring
V_{min} = 0.5 L
V_{max} = 3 L
Q = 0.01 – 0.20 L/min
estimated LOD = 0.02 mg per sample
PEL-TWA (USECHH Regulation) = 500 ppm

b) When sampling duration, *t equal* to 15 minutes:

V = (*Q max*) x *t*
V = 0.20 L/ min x 15 minutes
V = 3 L, within the range

Note: Breakthrough will occur once volume exceeds 3 L

c) Sample needs to be sent to laboratory with LOD of 0.02 mg per sample or below to enable chemical concentration detection during analysis.

4.6 Preparation of Sample

Generally, the preparation of sample will be based on the validated methods referred such as from US OSHA (OSHA Reference Method), US NIOSH (NIOSH Manual of Analytical Methods) or others. The methods provide detail instructions about collecting and analysing of the sample. The method contains the following information but not limited to:

a) The sampling media to be used
b) The sampling flow rate
c) The volume of air that is to be sampled
d) Instructions for sample preservation and handling
e) Detailed procedures to be followed for the analysis

Refer to **Appendix 3** for an explanation of US NIOSH Manual of Analytical Methods.

4.7 Blanks

Certain number of blanks are required by the analytical laboratory for each set of samples to be analysed. The specific method being used should be consulted concerning the number and type of blanks required.

Blanks are used to detect any potential contamination that could be introduced during monitoring as well as to detect problems with preparation and analysis of the samples. A particular analysis may involve several types of blanks measurement including reagent blanks, media blanks or field blanks.

4.7.1 Field Blanks

A field blank consists of sample media that are exposed to the same conditions as the media used for the actual sampling, but are not connected to a sampling pump. Field blanks measure the signal contribution from the collection media (e.g. impinger solution, filter, sorbent tube). For example, during a solvent sampling activity involving fives (5) samples, two (2) charcoal tubes are opened and immediately capped, sealed, and labelled. The required number of field blanks is specified in the method used.

The field blanks are subjected to the same chain of custody and other sample handling procedures as the rest of samples. This is the quality control step intended for detection of any potential contamination that could be introduced into the process through sample handling. Analysed field blanks that contain measurable levels of contaminant may indicate problems with sampling or handling of the media, or existence of unsuspected source of interference or contamination.

4.7.2 Reagent Blanks

Reagent or laboratory blanks are sample media that are not sampled but are prepared and analysed by the laboratory. Reagent blanks also measure the signal contribution from solvents, acids or other reagents used by the laboratory in preparing samples for analysis. This is another quality control step that is taken to detect problems with preparation and analysis of the samples.

Blank values are sometimes deducted from sample values – this procedures data that are said to be blank-corrected. If both field blanks prepared in the example above had contamination at a level of two (2) micrograms, it would be assumed that all the samples contained this extra amount. The analytical data for the samples would then be blank corrected by subtracting two (2) micrograms from the total amount of contaminant found on each of the tubes.

4.8 Sources of Error in Air Monitoring

The results of air monitoring can be affected by many things, some of which cannot be controlled. Uncontrollable sources of error are usually assumed to be self-correcting or self-limiting though randomness. It is also possible to introduce error into any sampling process through actions or through the failure to take certain actions. These sources of error are not random and controllable. Standard sampling and analytical methods are developed to include steps that, if followed, will assure sampling accuracy, such as the calibration of sampling pumps. Direct-reading methods are also subjected to operator-introduced error. Some examples of sampling error are:

a) Systematic Error

(i) Using inappropriate sample collection media.
(ii) Using a direct-reading instrument outside of its limitations and applications.
(iii) Use of incorrect flow rates, resulting in a sample volume that is too large or too small to allow accurate quantitation of the contaminant.
(iv) Failing to perform calibrations or functional checks on direct reading instruments.
(v) Overloading the sample collector.
(vi) Errors in calculations – flow rates, sample volumes, resulting concentrations.
(vii) Sampling in the presence of interfering compounds.
(viii) Failure to follow special handling procedures such as protecting samples from light or heat.
(ix) Placement of sample collectors.
(x) Neglecting to keep complete and accurate records.

Once samples have been received at the laboratory, they are again subjected to possible mishandling or other situation that can affect the results which include:

(i) Improper storage or handling of samples while awaiting analysis.
(ii) Delays in analysis that exceed time limits for stability of samples (holding times).
(iii) Use of incorrect analytical techniques, including use of instruments that are not set up according to the parameters specified in the analytical method.
(iv) Failure to properly prepare the samples for analysis.
(v) Contamination of samples with other samples or laboratory chemicals.
(vi) Errors in calculations.
(vii) Mix-ups such as incorrect labelling of samples and transposing numbers.
(viii) Loss of samples due to breakage, spillage, or other events.

b) Random Error

Random error is always present in a measurement and caused by variations in the readings of the instrument due to precision limitations or HT interpretations. Random errors cannot be predicted because every repeated value is different from the previous value. Unlike systematic errors, random errors can be reduced by averaging a large number of observations. Examples of random error are errors due to sampling device, analytical method and inter-day or intra-day environmental fluctuations.

CHAPTER 5: SAMPLE MANAGEMENT

The duties and responsibilities of HT does not end at sampling stage. HT is also responsible for laboratory selection and sample management throughout the process until the final stage. In sample management, sample handling and selecting an accredited laboratory at the early stage of the process is crucial. HT plays a vital role in ensuring sample management is in line with this guideline.

5.1 Selection of Laboratory

In selecting a laboratory for sample analysis, HT should ensure that the laboratory has been accredited by the Department of Standards Malaysia under the SAMM or any equivalent recognised international body. The laboratory should be equipped with technical expertise to support the problems most likely encountered in the field and can demonstrate competence. Laboratories may have sampling protocols, which assures that the techniques used to collect samples are compatible with their established analytical procedures. They may also provide a collecting media.

The selected laboratory should demonstrate general competence by participating in appropriate external quality assurance, proficiency test and certification programs initialised by the Department of Standards Malaysia. They should be capable of producing a set of standard operating procedures, chain of custody practices, sample handling and control procedures, instrument calibration and maintenance records, internal and external testing programs, and quality control of individual methods.

The selected laboratory should also review the methodology used to verify the accuracy, precision, sensitivity, temperature, humidity, and storage effects of the procedure. Both the HT and the laboratory management should be concerned with maintaining the integrity of the sample through a chain of custody (COC) procedure.

5.2 Sample Handling

Generally, sample management needs to follow specific instruction or procedure required by reference method accordingly. Otherwise, the handling procedure should contain:

a) Sample handling
b) COC

5.2.1 Sample Preparation, Labelling and Identification

Procedure should indicate the proper care and handling of the samples to ensure integrity. Proper laboratory documentation that tracks the disposition of samples through preparation is just as important as the documentation after sampling. Care must be taken to properly mark all samples to ensure unambiguous identification throughout the sample handling.

Any information that can be used to assess sample integrity should be recorded at the time of sample collection. Any necessary marking can be marked on the side of the container with a permanent marker or other methods of identification such as bar coding or any computerised label.

5.2.2 Sample Collection

All collected samples must be carefully removed from the monitoring device, placed in labelled, nonreactive containers, and sealed to avoid possibility of invalid results. Use of tamper-evident custody seals are suggested and may be required in certain cases. The sample label must adhere firmly to the container to ensure that it cannot be accidentally removed. Custody seals on sample containers serve two (2) purposes: to prevent accidental opening of the sample container and to provide visual evidence should the container be opened or tampered with. The best type of custody seal depends on the sample container; often, a piece of tape placed across the seal and signed by the HT is sufficient; for other containers, wire locks or tie wraps may be the best choice. Collected samples must be kept at specific temperature requirement from reference method.

5.2.3 Sample Shipment

Samples should be delivered to the laboratory for analysis as soon as possible after collection. It is recommended that this be done on the same day that the sample is taken from the monitor. If this is impractical, all the samples should be placed in transport containers (e.g., carrying case, cooler, shipping box) for protection from breakage, contamination, and loss and in an appropriate controlled-temperature device (i.e., refrigerator or freezer) if the samples have specific temperature requirements as required from reference method or laboratory analysis. It is recommended for each transport container to have a unique identification, such as sampling location, date, and transport container number, to avoid interchange and to aid in tracking the complete shipment. The number of the transport containers should be subsequently recorded on the COC form along with the sample identification numbers of the samples included within each transport container.

It is advised that the container be sealed using an appropriate tamper-evident method, such as with custody tape or a wire lock. Precautions should be taken to eliminate the possibility of tampering, accidental destruction, and/or physical and chemical action on the sample during shipment. The person who has custody of the samples must be able to testify that no tampering occurred. After delivery to the laboratory, the samples must be maintained according to reference method and kept in a secured place.

5.2.4 Sample Analysis

Collected sample must be analysed according to the referred validated method. If the sample undergoes several steps such as preparation, equilibration, extraction, dilution, analysis and others, and if these steps are performed by different individuals, there should be a mechanism in place to track the sample through the steps. This is to ensure established procedures are followed and the integrity of the sample is maintained.

5.2.5 Storage and Archival

Samples must be properly handled to ensure that there is no contamination and that the sample analysed is actually the sample taken under the conditions reported. For this reason, whenever samples are not under the direct control of the sample custodian, they should be kept in a secured

location. This may be a locked vehicle, locked refrigerator, or locked laboratory with limited access. It is highly recommended that all samples be secured until discarded. These security measures should be documented by a written record signed by the handlers of the sample on the COC form or in any manners indicating the storage location and conditions. Any samples not destroyed during the analysis process should be archived as directed by the reference method or any recognized requirements.

5.3 Chain of Custody (COC)

Samples need to be managed in such a way to maintain the integrity of the sample through a COC procedure. The COC is necessary to show the integrity of the samples. A written record must be available which list the location of the samples. COC record sheet with the names and signatures of the receivers is used to track the handling of the samples through various stages of storage, processing, and analysis at the laboratory.

Each person handling the samples must be able to state from whom and when the item was received and to whom and when it was delivered. If using professional services to transport physical samples, only transport provider equipped with a tracking number should be used. Information describing the enclosed samples should be placed. A copy of the shipping receipt and tracking number should be kept as a record. A procedure must be in place to ensure that samples are delivered to the appropriate person without being opened or damaged.

Once the samples arrive at their destination and at every custody change, the samples should first be checked to ensure that their integrity is intact. The contents of the shipment should be checked against the COC form to ensure that all samples listed were included in the shipment.

Refer to **Appendix 4** for a sample of COC form.

CHAPTER 6: SAMPLING RESULTS MANAGEMENT AND INTERPRETATION

6.1 Receiving Result From Laboratory

Upon receiving result from the laboratory, HT should prepare the following:

a) Review the certificate of analysis (COA) for:
   (i) outliers data
   (ii) laboratory's analytical LOD or Limit of Reporting (LOR)
   (iii) verification by laboratory's authorised person
   (iv) sample identification (ID) and analyte name
   (v) mass, if applicable
   (vi) volume and concentration if volume is provided
   (vii) concentration unit
   (viii) front section and backup section result
   (ix) name of analytical method adopted for the analysis

If any information in 6.1 a) is not available, HT should request the laboratory personnel to provide the required information.

b) Blank Correction
   The analytical data for the samples would then be blank corrected by subtracting the value of the blank. If there are more than one (1) blank used during sampling, the average weight of the blank used must be calculated.

   Example: Calculating blank-corrected

   (i) Sample
   Weight front portion: 0.2 mg
   Weight back portion: 0 mg

   (ii) Blank
   Weight front portion: 0.01 mg
   Weight back portion: 0 mg

   So, the corrected weight is: 0.2 mg – 0.01 mg = 0.19 mg

c) Breakthrough Identification
   For sampling using sorbent tube, result obtained from laboratory will not identify the occurrence of breakthrough and only stated the weight on both front and back portion of the sample. Therefore, HT is responsible to determine any breakthrough occurred by taking into consideration the reading on the back portion of the sampling media. Breakthrough and possible sample loss is occurred if $W_b > \frac{W_f}{10}$ where W_f and W_b is the weight of the front and back portion of sorbent sections respectively.

Example: Breakthrough determination

Determine whether breakthrough has occurred for the following sample.

For sample:
Weight front portion: 0.1 mg
Weight back portion: 1.5 mg

* $W_b > \frac{W_f}{10}$: Breakthrough occurred

Since breakthrough has occurred, the sample is considered void.

d) Calculate the concentration of the sample
HT need to calculate the concentration of the sample based on its properties as the laboratory result does not include any calculations. The laboratory will determine the total amount of sample collected on the sampling media and will normally report the result in total mass or weight of the specified sample. Refer to 6.2 for detail calculation.

6.2 Calculations and Interpreting Results

Generally, sampling is conducted at approximately the same temperature and pressure as calibration, in which case no correction for temperature and pressure is required and the sample volume reported to the laboratory is the volume actually measured. Where sampling is conducted at a substantially different temperature or pressure than calibration, an adjustment to the measured air volume may be required depending on the sampling pump used, in order to obtain the actual air volume sampled.

For conversion without adjustment for temperature and pressure at the sampling site, use the following equation to convert concentration in mg/m^3 to ppm:

$$ppm_{act} = \frac{mg/m^3\ (24.45)}{\text{molecular weight}}$$

24.45 - molar volume of air at 25°C (298K) and 760 mmHg

If there is a requirement or necessity to know the actual concentration at the sampling site, it can be derived from results using the following equation:

$$\text{Adjusted concentration} = \text{Actual concentration} \times \frac{P}{760} \times \frac{298}{T}$$

$$ppm_{adj} = ppm_{act} \times \frac{P}{760} \times \frac{298}{T}$$

where,
P = Sampling site pressure (mmHg)
T = Sampling site temperature (K)
ppm_{act} = Actual concentration (ppm)
ppm_{adj} = Adjusted concentration (ppm)

6.2.1 Calculation of Airborne Concentration

The concentration of sample can be calculated as follows:

$$Concentration = \frac{corrected\ sample\ weight,\ M\ (mg)}{corrected\ volume\ of\ air\ sampled,\ V\ (m^3)}$$

Corrections for the blank must be made for each sample.

For particulates, the difference between the weight of the conditioned filter after sampling and the weight of the conditioned filter before sampling represents the weight found in the filter.

M = weight found in the sample filter-average weight in the blanks filter

Correction of Volume Air Sampled

It is necessary to correct the volume of air sampled for barometric pressure, where the difference in altitude is more than 1000 ft or the temperature difference more than 14°C.

$$V = \frac{Q_c \times t}{1000}\left[\frac{P_c \times T}{P \times T_c}\right]^{1/2}$$

Actual volume of air sampled (cubic metre) for pumps with linear scale

where,
Q_c = Calibrated flow rate (litre per minute)
t = Sample duration (minutes)
P_c = Barometric pressure at calibration location (mmHg)
P = Barometric pressure at the sampling location (mmHg)
T = Absolute average ambient air temperature during sampling (K)
T_c = Absolute ambient temperature during calibration (K)

Note: for pumps without rotameter, the correction of volume air sampled does not apply.

Conversion Volume of Air Sampled to Standard Condition

The formula used to convert the volume of air sampled to standard condition of 25˚C (298K) and 760 mmHg is:

$$V_s = V\ \frac{\mathrm{P}}{760} \times \frac{298}{\mathrm{T}}$$

where,
V_s = Volume of air sampled at standard condition
V = Actual volume of air sampled
P = Volumetric pressure at sampling location (mmHg)
T = Absolute average ambient air temperature during sampling (K)

6.2.2 Calculation of TWA

$$\text{TWA} = \frac{\sum_{i=1}^{n} Citi}{\sum_{i=1}^{n} ti} = \frac{C1t1 + C2t2 + \ldots + Cn\ tn}{t1 + t2 + \ldots\ldots + tn}$$

where, *Ci* is the measured exposure concentration in mg/m^3 or ppm;
ti is the measured exposure time in minutes.

The 8-hour TWA (TWA$_8$) may be represented mathematically by:

$$\text{TWA}_8 = \frac{\sum Ci\ ti}{480} = \frac{C1t1 + C2t2 + \ldots + Cn\ tn}{480}$$

where, *Ci* is the measured exposure concentration in mg/m^3 or ppm;
ti is the measured exposure time in minutes.

When sampling periods do not correspond to the average time of exposure limits, some assumptions must be made about the unmeasured portions of the work period.

Example : Calculation of TWA$_8$

The operator is engaged in tasks which he is exposed to a CHTH. His normal working time is from 9.00 am to 5.00 pm. His rest is 45 minutes for meal, 15 minutes each for morning and afternoon breaks. PEL-TWA for the chemical is 0.52 mg/m^3.

Result of measured exposure concentration is as below:

Working period	Concentration, C (mg/m^3)	Sampling duration, t (min)
09.00 – 10.30	0.32	90
10.45 – 12.45	0.07	120
13.30 – 15.30	0.20	120
15.45 – 17.00	0.10	75

i) Assumption: Zero exposure for unmeasured period.

Apply equation under paragraph 6.2.2. Calculated 8-hr TWA is:

$$\text{TWA}_8 = \frac{(0.32\text{x}90) + (0.07\text{x}120) + (0.20\text{x}120) + (0.10\text{x}75) + (0\text{x}75)}{480} = 0.14 \text{ mg/m}^3$$

Which could be concluded as the exposure is below the PEL-TWA.

ii) Assumption: Similar exposure for unmeasured period.

Apply equation under paragraph 6.2.2. Calculated 8-hr TWA is:

$$\text{TWA for 405 minutes} = \frac{(0.32\text{x}90) + (0.07\text{x}120) + (0.20\text{x}120) + (0.10\text{x}75)}{405} = 0.17 \text{ mg/m}^3$$

$$\text{TWA}_8 = \frac{(0.32\text{x}90) + (0.07\text{x}120) + (0.20\text{x}120) + (0.10\text{x}75)}{405} + \frac{0.17}{75} = 0.17 \text{ mg/m}^3$$

Which could be concluded as the exposure is below the PEL-TWA.

6.2.3 Interpretation of Results

Many laboratories calculate the concentration as a service to the HT; however, their calculation assume that the HT has provided all the correct information. It is expected for HT to provide data sheet calculations to support his or her results.

Interpretation of sampling results requires an understanding of the accuracy of the validated method. It is possible that data may be shown to be inconclusive at proving whether or not an overexposure exist. In this situation, the HT should assume the worst and proceed as if there were an overexposure or over the PEL condition.

If the results from the laboratory indicates as non-detected (ND), concentration must be based on LOD or LOR that can be reliably measured by an analytical procedure stated in the laboratory report. E.g. estimated LOD: 0.075 mg per sample. The value of ND should be 0.075 mg.

The HT must be aware that there are many issues associated with the use of airborne concentration as representing the absorbed dose of the exposed worker. Age, gender, fitness level, pre-existing medical conditions, exposure to a combination of chemicals, and the physical demands of the work are all factors that can influence the body's absorption of a CHTH. The HT must also consider the representativeness of the data obtained during sampling.

6.3 Statistical Analysis of Sampling Result

Multiple samples generally allow for better understanding of the variation in exposure, and thus provide more detailed information to assessing confidence that the results represent the 'true' exposure profile or determining compliance to PELs or OES. Statistical analysis of the sampling results will give better indication of the variability in exposure and the extent of compliance with PELs. For example, the mean (average) exposure calculated may be below a PEL, but random variation, sampling and analytical error will introduce some uncertainty around that average.

A set of monitoring data can be summarised by calculating the arithmetic average (mean), geometric mean and geometric standard deviation. These summary statistics should only be calculated if the measurements are representative of long term (8 hours) or short term (10 or 15 minutes) average exposure over a workday and are from the same SEG. Samples collected for different durations or from different scenarios should not be considered together when calculating simple statistics.

There are various statistical tools in analysing the occupational exposure such as IHStat™ (AIHA), HYGINIST (Scheffers, TSAC), IHDataAnalyst (Paul Hewett, USA) or Altrex Chimie (France). Analysis can be done using generic statistical software which require knowledge and experience in statistics, such as SPSS® Statistics, Math Lab or GraphadPrism.

As mentioned in Step 5 (paragraph 2.5), three (3) shift-length exposure measurements on workers selected at random from the SEG to determine whether measurements exceed 10% of the PEL. If there are fewer than three (3) workers in the SEG, the measurements will have to be spread over more than one (1) shift, and one (1) or more workers measured twice or need to replicate the monitoring in another day. If any result from three (3) measurements were more than 10% but below PEL, take six (6) more samples and proceed with statistical analysis to determine the compliance. This will be explained in detail in paragraph 6.3.1 and paragraph 6.3.2.

6.3.1 Descriptive Statistics

Table 5 lists the descriptive statistics used in statistical analysis which is useful for characterizing the location and shape of the underlying distribution of exposures. Descriptive statistics characterize the sample's distribution such as the central tendency (e.g. mean, median) and the spread (such as the range, standard deviation, variance).

Table 5: Descriptive Statistics

Minimum (min)	The minimum value in the sample set.
Maximum (max)	The maximum value in the sample set.
Range	The difference between the largest and smallest values in a sample set.
Percent above the PEL	The fraction of the sample set (in percent) that exceeded the occupational exposure limit.
Mean	The arithmetic average of a set of data.
Median	The measurement that divides a sample set into two equal parts.
Standard deviation	The parameter for measuring the dispersion about the mean.
Geometric mean	The median of the lognormally distributed data.
Geometric standard deviation	The antilog of the standard deviation of the log transformed data, which measures the variability for a lognormal distribution.

For the purpose of this guidelines, only geometric mean (GM) and geometric standard deviation (GSD) are used. The geometric mean (GM) and geometric standard deviation (GSD) are descriptive statistics that are used to estimate parameters of a log-normal distribution. The GM is the antilog of the arithmetic mean of the log-transformed values. The GM is the value below and above which lie 50% of the elements in the population (i.e., the population median). The GSD is the antilog of the standard deviation of the log-transformed values. The GSD is unitless and reflects variability in the population around the GM; therefore, confidence intervals will have a larger spread as the GSD increases.

6.3.2 Compliance Test

The compliance test is applied as follows:

1) **STEP ONE**
Calculate the geometric mean (GM) and the geometric standard deviation (GSD) of all of the exposure measurements in the SEG. If the ŋ individual shift exposure levels are a_1, a_2, a_3, ...a_n, these are:

$$\log GM = \frac{(\log a_1 + \log a_2 + \log a_3 \ldots\ldots + \log a_n)}{\eta}$$

(equation 1)

$$\log GSD = \sqrt{\frac{(\log a_1 - \log GM)^2 + (\log a_2 - \log GM)^2 + (\log a_3 - \log GM)^2 + (\log a_n - \log GM)^2}{\eta - 1}}$$

(equation 2)

These can be worked out using a scientific calculator; or the method in **Appendix 5** can be applied.

2) STEP TWO

Calculate the parameter U, with the following equation:

$$U = \frac{[log\ (PEL) - \ log\ GM]}{log\ GSD}$$

(equation 3)

3) STEP THREE

The value of U is then compared with the limiting values given in **Table 6**.

If calculated U is more than the limiting value of U, PEL is complied. The PEL is not complied with, if U calculated from equation 3 is less than the limiting value given.

Table 6: Limiting Values of U

Number of exposure measurements	Limiting value of U
9	2.035
10	2.005
11	1.981
12	1.961
13	1.944
14	1.929
≥ 15	1.917

Note: It assumes that the exposures are log-normally distributed.

If the PEL is not complied with, employer should review and improve the existing control measures to ensure the exposure is below the PEL assigned for the chemical or to as low as reasonably practicable (ALARP). Refer to the Guidelines on The Control of Chemicals Hazardous to Health for controlling the exposure. The exposure should be continuously and periodically monitored, with frequency depending on the monitoring results (*x*):

a) For action level < *x* ≤ PEL, at interval of not more than 12 months; or
b) For *x* > PEL, at interval of not more than 6 months.

Note : Action level is equal to 50% of PEL-TWA.

6.4 Adjustment of PEL for Extended Working Hours

PEL-TWA are derived on an eight-hour workday or 40-hour workweek. When shifts are longer than this, either over a day or a week, the PEL-TWA needs to be adjusted to account for the longer period of exposure and shorter recovery time using this equation:

$$\text{Adjusted PEL-TWA} = \text{PEL-TWA} \times \left(\frac{8}{h} \times \frac{24-h}{16}\right)$$ where h is hours worked per day

Note: The adjusted PEL-TWA is only applicable to certain chemicals.

Example : Extended working hours

A worker is working on 12-hour shift each week doing spray painting. Personal sampling was conducted to measure the exposure of the worker to CHTH. Result obtained from the monitoring of the chemical is 10 ppm. The PEL-TWA of the chemical is 25 ppm. To evaluate compliance, the PEL for eight-hour time-weighted average (PEL-TWA) have to be adjusted:

Apply equation under paragraph 6.4.

$$\text{Adjusted PEL-TWA} = \text{PEL-TWA} \times \left(\frac{8}{h} \times \frac{24-h}{16}\right) \quad \text{where h is hours worked per day}$$

$$= 25 \times \left(\frac{8}{12} \times \frac{24-12}{16}\right) = 12.5 \text{ ppm}$$

10 ppm < 12.5 ppm, which could be concluded as the exposure is below the PEL-TWA.

6.5 Mixed Exposure

Generally, PELs are applicable to airborne concentration of a single chemical or a range of compounds. If workers are exposed simultaneously or consecutively to more than one (1) chemical, the effect of mixed exposures should be taken into consideration. Such effects are:

a) Independent Effects
If there is evidence to suggest that the actions of hazardous chemicals on the body are independent, the concentrations of each individual chemical should be compared directly with its own PEL value (TWA, STEL, or CL as appropriate).

This is most obvious when two or more chemicals have different toxic actions and cause adverse effects on different target organs.

b) Additive Effects
If two or more hazardous chemicals have similar toxicological effects on the same target organ or system, their combined effect should be considered. In this case the combined exposures need to be compared against the PEL of the mixture, as well as each individual chemical against its specific PELs.

$$\frac{TWA_1}{PEL_1} + \frac{TWA_2}{PEL_2} + \ldots + \frac{TWA_n}{PEL_n} \leq 1$$

Where,
TWA_1, TWA_2 .. TWA_n : the average measured airborne concentrations of the particular chemical

PEL_1, PEL_2 .. PEL_n : the appropriate exposure standards for the individual chemical.

The PEL is complied with, if the combine exposure is at or below one (≤1).

Example : Mixed exposure

The workers are exposed to toluene and methyl ethyl ketone (MEK) which effect on the same target organ i.e. the central nervous system. PEL-TWA of toluene is 50 ppm and MEK is 200 ppm. The calculated result of 8-hr TWA of toluene is 25 ppm and MEK is 120 ppm.

Apply equation under paragraph 6.5:

$\frac{25}{50} + \frac{120}{200} = 1.1 > 1;$

Which could be concluded as the combined exposure is exceeding the PEL-TWA even though the exposure to individual chemical do not exceed the PEL-TWA.

6.6 Compliance with PEL Using Respirator

Where the worker is provided with respirator, the degree of protection (DOP) afforded by the respirator for the periods during which the respirator is worn should be considered to determine compliance with the PEL. Period of exposure should be averaged with the exposure level of the airborne concentration during the period when respirators are not worn.

Assigned Protection Factor (APF) means the workplace level of respiratory protection that a respirator or class of respirators is expected to provide to employees when the employer implements a continuing, effective respiratory protection program. APF is the term used to indicate DOP of the respirator.

Example: Determination of Compliance Using Respirator

Chemical used : Acetone
PEL-TWA : 500 ppm
Measured exposure concentration : 1788 ppm
Assigned Protection Factor (APF) : 10
The worker work shift is 8 hours and the respirator is worn for only 4 hours.

Apply equation under paragraph 6.2.2. Actual exposure:

$$TWA_8 = \frac{(1788 \text{ x } 4) + \left(\frac{1788}{10} \text{ x } 4\right)}{8} = 983.4 \text{ ppm}$$

Which could be concluded as non-compliance as the exposure is exceeding the PEL-TWA.

To ensure compliance to PEL using respirator with APF 10, how long should the respirator be worn?

The respirator should be worn for:

$$500 \text{ ppm} = \frac{(1788\text{ppm x } (8 - t_2)) + \left(\frac{1788\ ppm}{10} \text{ x } t_2\right)}{8 \text{ hours}} \quad , t_1 = 8\text{-}t_2$$

$4000 = (14304\text{-}1788t_2) + (178.8t_2)$

$1788\ t_2 - 178.8\ t_2 = 14304 - 4000$

$t_2 = 6.4$ hours

The respirator should be worn for period of at least 6.5 hours.

CHAPTER 7: REPORT WRITING

Findings from the exposure monitoring conducted by the hygiene technician should be finalised and documented in the form of a report. The report should be presented to the employer or employer's representative of the workplace and should be submitted within one (1) month after completion of the monitoring (refer attached HT Notification Form). The monitoring report should contain the following information but not limited to:

a) Report title page
b) Executive summary
c) Introduction
d) Specific objective
e) Process description
f) Methodology
g) Findings
h) Discussion
i) Recommendation on action to be taken
j) Conclusion
k) Appendices

1.0 Report Title Page

The front page should be the report title page and contain the following information:

(i) The title of the report
(ii) Type of monitoring (Area/Personal monitoring)
(iii) Report reference number that contains hygiene technician's name and competency registration number
(iv) Place of monitoring
- Name and address of workplace
- DOSH registration number (if any)

(v) Date of monitoring

2.0 Executive Summary

Executive summary should provide a summary of the purpose, main activities, findings, recommendation and conclusions of the monitoring activity that has been conducted.

3.0 Introduction

Introduction should provide the following:

(i) Background information on a workplace, process description and work activity at the monitored area
(ii) If the monitoring is done in stages, i.e. different from chemical risk assessor's recommendation, please specify with justification
(iii) Objective of monitoring
(iv) Date of monitoring
(v) Name of hygiene technician and competency registration number
(vi) No of shift and no of worker for every work unit

4.0 Methodology:

Description on:

(i) Method used
(ii) List of equipment used (serial number, calibration and expiry date)
(iii) Type of sampling media used
(iv) Selection of worker from Similar Exposure Group (SEG)
(v) Justification on monitoring duration and number of samples
(vi) Type of monitoring (Personal or area)
(vii) Statistical analysis tool used, if applicable

5.0 Findings

The result and finding of the monitoring may be presented as follows:

(i) Monitoring Area Information:

Area	Name of chemical	Work specification	No. of worker exposed	No. of worker monitored

(ii) Monitoring Result (Personal/ Area)

Name of chemical / sample no.	Work area	Work specification	Sampling Duration (Minutes)	Result (TWA_8/ MEL/ CL/ STEL)	PEL/ OES	Adjusted/ Mixed Exposure PEL (If applicable)	Compliance to PEL/OES

Note : The result of TWA_8 / MEL / CL / STEL is the TWA calculated from mean or statistical analysis.

(iii) Descriptive Statistical Data and Compliance Test

Chemical Name	Result			
	Sample No. 1	Sample No. 2	Sample No. 3	Sample No. n
Geometric mean				
Geometric standard deviation				
Compliance Test Result				

6.0 Discussion

Discussion on the findings of the monitoring result and relates to:

(i) Compliance with PEL
(ii) Factors contribute to the exposure such as work practice, standard operating procedures, unsafe act or unsafe condition
(iii) Adequacy of existing control measures
(iv) Justification on sampling strategy including its limitation such as limited samples, due to the nature of work activity or task frequency

7.0 Summary of The Previous Monitoring Report (If Available)

Summary on the findings not limited to:

(i) Result and finding
(ii) Frequency of monitoring
(iii) Compliance with PEL
(iv) Adequacy of existing control measures
(v) Summary of recommendations

8.0 Recommendation and Action to Be Taken

The hygiene technician should give recommendation and justification on the actions to be taken based on the result of findings, which includes:

(i) Necessity of further monitoring
(ii) Necessity to review the control measures
(iii) Necessity of periodic exposure monitoring

If non-compliance, the HT should advise the employer to refer to Chemical Risk Assessor for further action regarding the following:

The frequency of air monitoring should be based on the level of exposure which are:

a) Not more than six months for exposure at or above the permissible exposure limit; or

b) Not more than twelve months for exposure at or above half of the eight-hour TWA but below the eight-hour TWA.

The air monitoring may discontinue if the result for at least two consecutive measurements taken at least seven days apart show that the exposures are below:

a) Half of the eight-hour TWA;

b) Maximum exposure limit/STEL; or

c) Ceiling limit.

9.0 Conclusion

HT should conclude whether the monitoring objective is achieved and determine the workers exposure in compliance with the PEL. Overall finding and action to be taken should be summarised in this report.

10.0 Appendix

Appendices should include the following but not limited to:

(i) Copy of certificate of competency
(ii) HT notification form (attached)
(iii) Process flowchart
(iv) Method Used (eg: *US NIOSH Method*)
(v) Calibration certificate
(vi) Data and calculation form
(vii) Certificate of Analysis from laboratory
(viii) Plan layout with monitored workers location
(ix) Descriptive statistics calculation and related data

HT Notification Form

Date : .....

Workplace : .....
.....
.....
.....

Contact Person: .....

Ref: REPORT ON MONITORING OF AIRBORNE CHEMICAL HAZARDOUS TO HEALTH

This is to certify that monitoring of airborne chemical hazardous to health for the above premise has been ***conducted and explained*** to the Safety and Health Committee members/ employer's representative of the workplace on the ***(date of presentation)***.

2. The report has been submitted to the employer on ..... (Date of submission)

.....
Signature of Hygiene Technician
DOSH Registration No.

Monitoring Report Received by: (To be filled by employer)

Name : .....

Designation : .....

Date of report received : .....

Signature : .....

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APPENDIX 1 - EXAMPLE OF WORKER'S SAMPLING

1) Sampling for TWA_8

SEG at workplace XYZ consist of 3 workers. A report from chemical health risk assessment recommend that airborne monitoring of benzene must be conducted.

The number of samples to be collected for TWA_8 are as follows:

Method NMAM 1501 for aromatic hydrocarbon is referred.

From the method it is stated that for benzene:

Flowrate, Q ≤ 0.2 L/min
Volume, V = min 5 L
max 30 L

For a worker, the number of samples calculated are as follows: -

$$Flowrate,\ Q = \frac{Volume,\ V}{Time,\ t}$$

Use Q = 0.1 L/min, V = 12 L

Sampling time for a sample is:

$$Time,t = \frac{Volume,\ V}{Flowrate,\ Q}$$

$$= \frac{12\ L}{0.1\ L/min}$$

$$= 120\ min$$

For 8 hours monitoring, the number of samples need for a worker are:

$$\frac{480\ min}{120\ min} = 4\ samples\ needed\ per\ worker$$

For 3 workers, 12 samples are needed.

From the method, a blank sample must be included for at least 10% of the total sample.

10% of 12 samples = 1.2 ≈ 2

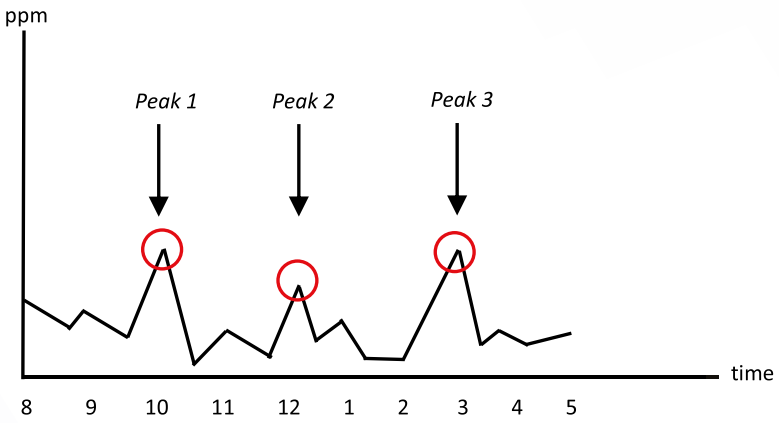
As a conclusion, the total number of samples to be prepared for benzene air monitoring are at least 14 samples including the blank.

2) Sampling for Ceiling Limit

At workplace ABC, there are 2 workers that have been identified to be monitored for airborne chemical exposure monitoring. A CHRA report recommends that a ceiling limit value for formaldehyde at the SEG needs to be measured.

Before conducting the air sampling, a HT needs to identify the trend of exposure at the SEG since a sampling for the ceiling limit is not conducted throughout the entire working hours. HT needs to anticipate when the workers are exposed to the highest exposure (peaks) of formaldehyde during the working hour.

Alternately, a HT can use direct reading measuring instrument to identify the number of peaks occurred throughout the working hours.
Let say, the peaks identified as follows: -



From the graph, it shows 3 peaks throughout working hours. So, HT needs to conduct a sampling at the 3 peaks.

NMAM 2016 for formaldehyde is referred.

From the method it is stated that for formaldehyde:

Flowrate, Q = 0.03 – 1.50 L/min
Volume, V = min 1 L – max 15 L

For a worker, the number of samples calculated as follows: -

$$Flowrate, Q = \frac{Volume, V}{Time, t}$$

Use Q = 1 L/min, V = 10 L

So, sampling time for each sampler is

$$Time, t = \frac{Volume, V}{Flowrate, Q}$$

$$= \frac{10\ L}{1\ L/min}$$

$$= 10\ min$$

*t value is acceptable since it is less than 15 minutes

If the sampling time (t) is more than 15 minutes, the flowrate or volume should be adjusted within the range stated by the method.

Since there are 3 peaks per worker to be measured, so the number of samplers need to be prepared are: -

3 peaks x 2 workers = 6 sampler

From the method, it states that, 2-10 field blank per set and 6-10 media blank per set must be prepared.

As a conclusion, total number of samplers to be prepared to conduct air monitoring for formaldehyde is at least 6 + 2 field blank + 6 media blank = 14 samplers including the blank.

APPENDIX 2 - MEASUREMENT FOR GAS OR VAPOUR

Measurement for gas or vapour can either be undertaken using the:

a) Reservoir sampling

In reservoir sampling, the whole of the air sample obtained is stored in a container until required for analysis, and no attempt is made to separate the gaseous CHTH at this stage. The containers for storing the gaseous CHTH are as follows:

(i) Evacuated containers

It consists of a glass bulb from which the air has been removed by a vacuum pump and the neck of which has been sealed by heating and drawing to a tip during the final stage of evacuation. This type of collection is suitable for gases such as carbon dioxide, oxygen, methane and nitrogen.

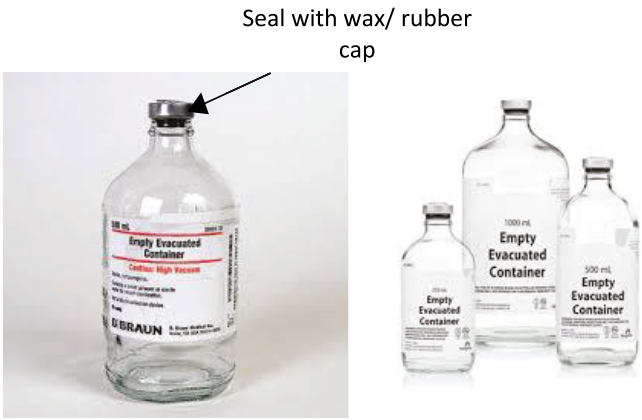


Figure 21: Evacuated Containers

It is not suitable for collection of very reactive gases such as hydrogen sulphide, oxides of nitrogen or sulphur dioxide. This is because such gases may react with dust particles, moisture, wax sealing compound, and to some extent even with the glass of the container, so that by the time the sample is analysed the proportion of these gases will have been altered. In such situation, an absorbing fluid for the particular gas or vapour is contained in the evacuated container.

(ii) Displacement collectors

These are in the form of gas tube or ordinary heavy-wall bottles. The gas sample tube may be metal or glass and may be closed with stopcocks or screw clamps and rubber tubing if the sample does not react with the rubber. Metal containers are not suitable for sampling many gases, which will react with the metal, such as hydrogen sulphide, sulphur dioxide, or oxides of nitrogen.

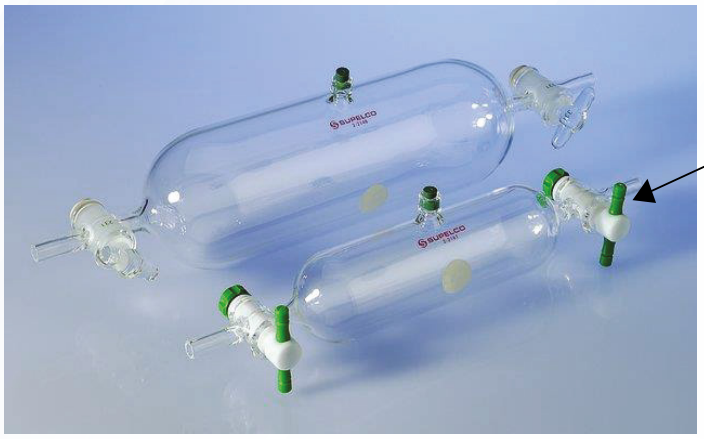


Figure 22: Displacement Collector

To fill any of the containers, it is necessary for its original air or gas content to be completely swept out and replaced by the air to be sampled. For this purpose, an aspirating device is usually necessary. The most convenient devices are a double-acting rubber bulb aspirator or a double-acting foot pump.

(iii) Gas bags

The typical material used is Aluminised Scotch Pak, Scotch Pak, Saran and Mylar. Entry into the bag can be accomplished with tygon, teflon or glass tubing or an ordinary tyre valve, a sample is introduced into the bag by a hand operated pump or a squeeze bulb. Bags can be reused after purging with clean air and checking for residue components. Certain airborne CHTH, such as styrene, cannot be sampled or stored in any plastic bag due to their reactivity with surrounding chemicals or themselves. Sampling is carried out at atmospheric pressure, and the final pressure inside the bag must be equal to the atmospheric pressure. Temperature variations must be avoided since these would lead to condensation inside the bag.

Figure 23: Gas Bags

b) Extractive sampling

In extractive sampling, the collection and contaminant separation occur simultaneously. In principle, a continuously moving atmospheric sample is brought into collection media that separates contaminant by the mechanism of absorption and adsorption:

(i) Absorption

Absorbents for collection of gases and vapours are usually liquids in which the gaseous absorbate dissolves. The process of solution is often accompanied by a chemical reaction between absorbent and absorbate. Absorbers to be used depend on the solubility or the reactivity of the gases or vapours with the absorbents. The type of the absorbent can be referred to respective method.

Generally, for gases and vapours readily soluble in, or react with, the absorbing solution use simple bubblers (or impingers). While, for gases and vapours which are less soluble in, or reactive with, the absorbing solution use:

- bubblers with diffusers;
- spiral absorbers; or
- packed towers.

The contaminant content of the absorbent liquid can be determined by standard analytical methods including Visible; Infrared and Ultraviolet Spectrophotometers; and Gas, Thin Layer, and High Performance Liquid Chromatography (HPLC).

(ii) Adsorption

Adsorption is a process that occurs when a gas or liquid solute accumulates on the surface of a solid or liquid (adsorbent), forming a molecular or atomic film (adsorbate). This effect is particularly marked when the adsorbing material is porous and has an extensive surface area for a given mass.

There are two (2) types of application which are: -

- Solid sorbent tube

  Adsorbent tubes are used to collect samples in the gaseous and vapour states such as solvent vapours, some gases, and acids. These tubes may contain activated charcoal, silica gel, or certain polymers.

Figure 24: Solid Sorbent Tube

- Passive sampler

  A passive sampler relies instead on molecular diffusion to bring gaseous CHTH into contact with an adsorbent medium because no external air mover or power source is required for it to function successfully.

Figure 25: Passive Sampler

APPENDIX 3 - HOW TO USE NMAM

The methods are arranged alphabetically by method name, and some method names may refer to a group of related substances.

1. Method Finder

The easiest and fastest way to locate a method is to refer to the Method Finder inside the front cover of the Manual. The Method Finder is an alphabetical listing of common chemical names and their associated methods with information on Compound, Method Number, Method Name, Sampling Rate, Minimum Volume, Maximum Volume, Extraction Solvent, Analytical Technique, and Sampler for quick reference.

2. Method Numbering System

Substances having the same sampler, sample preparation and measurement technique may be grouped together in one method (note that this numbering system is unchanged from the Third Edition):

Method #	Substances
0001-0799	General air samples
0800-0999	Bioaerosols
1000-1999	Organic vapors on charcoal
2000-3499	Organic vapors on other solid sorbents
3500-3999	Organic vapors on other samplers (e.g., liquids, direct-reading)
4000-4999	Organic vapors on diffusive samplers
5000-5999	Organic aerosols
6000-6999	Inorganic gases
7000-7999	Inorganic aerosols
8000-8999	Biological samples
9000-9999	Bulk samples

3. Indexes

There are three (3) indexes in the back of the Manual which can be used in locating methods:

a) Fourth Edition Methods – An index of current US NIOSH methods in order of method number (Note: The fourth edition uses the same numbering system as the third edition. This Index also lists the disposition of all third edition methods).

b) First and Second Edition Method Numbers – An index of the first and second edition "P&CAM" and "S" methods, from which many of the current methods were derived. This index shows the disposition of all these methods, whether they were revised into current methods.

c) Names and Synonyms – An alphabetical listing of all chemical names and synonyms used in the current methods, including Chemical Abstracts Service numbers.

4. Method Format

The methods consist of three (3) major parts:

a) Front page - The first page of each method concisely summarizes sampling and measurement parameters, and gives estimates of limit of detection, working range, overall and measurement precision, and interferences. References to other methods are given. New to the fourth edition are: Method Classification, US NIOSH Registry of Toxic Effects of Chemical Substances (RTECS) number, and an estimate of method accuracy (See Figure 1).

b) Instructions – The second page of each method begins with lists of required reagents and equipment. Please note that these reflect the conditions under which the methods were evaluated, and that there may be some latitude for variation. Commercial versions of the samplers may differ slightly from the methods. The user of the methods is responsible for assuring accuracy of the results (e.g., to determine that breakthrough and recovery are acceptable for each lot of samplers used). Typical tolerances are:

   (i) Glass tubing used to contain solid sorbents: inside diameter is usually not critical within the range 4 to 6 mm; length should be sufficient to contain the specified mass of sorbent.

   (ii) Contents of sorbent tubes: mass of sorbent within ±10% of specification; separators of either glass wool or cleaned polyurethane foam unless otherwise indicated; sorbent mesh size of 20/40 unless sampling efficiency dictates otherwise. Filled sorbent tubes should be sealed to protect from contamination.

CHEMICAL NAME **METHOD #**

FORMULA Molecular Weight Chemical Abstracts Service # RTECS #

Method numbers are the same as those in the 3rd edition. **Evaluation** (Full, Partial, Unrated, N/A) is assigned as described in Method Classification of these "blue pages." **Issue date** reflects current version (e.g., August 15, 1994) and previous 3rd edition versions, if any.

US OSHA: These exposure limit values are
US NIOSH: those in effect at the time of
ACGIH: printing of the method.

PROPERTIES: Boiling/melting points, equilibrium vapor pressure, and density help determine the sample aerosol/vapor composition.

SYNONYMS: Common synonyms for the substance. These are all listed alphabetically in the **Index of Names and Synonyms** ("yellow pages" in this Manual).

SAMPLING

SAMPLER: Brief description of sampling equipment

FLOW RATE: Acceptable sampling range, L/min

VOL-MIN: Minimum sample volume (L); corresponds to Limit of Quantitation (LOQ) at US OSHA PEL

-MAX: Maximum sample volume (L) to avoid analyte breakthrough or overloading

BLANKS: Each set should have at least 2 field blanks, up to 10% of samples, plus 6 or more media blanks in the case of coated sorbents, impinger solutions, or other special samplers.

ACCURACY

Data are for experiments in which known atmospheres of the substance were generated and analyzed according to the method. Target accuracy is less than 25% difference from actual concentration over the range of the method.

MEASUREMENT

TECHNIQUE: The measurement technique used

ANALYTE: The chemical species actually measured

A summary of the measurement equipment, sample preparation, and measurement steps appearing on the second page of the method is given here.

CALIBRATION: Summary of type of standards used

RANGE: Range of calibration standards to be used; from **LOQ** to **upper limit of measurement** (Note: More concentrated samples may be diluted in most cases to fall within this calibration range.)

ESTIMATED LOD: Limit of detection (background + 3)

PRECISION ($_r$): Experimental precision of spiked samplers

APPLICABILITY: The conditions under which the method is useful, including the working range in mg/m^3 (from the LOQ to the maximum sampler loading) for a stated air volume aregiven here.

INTERFERENCES: Compounds or conditions which are known to interfere in either sampling or measurement are listed.

OTHER METHODS: Methods from the 2nd edition ("P&CAM" and "S" methods) and current methods which are related to this one, as well as similar US OSHA and literature methods are keyed to references.

Figure 26. Layout of Front Page of Methods

(iii) The special precautions section gives safe practices to be observed during sampling and measurement. Next are the step-by step instructions for sampling, sample preparation, calibration and quality control, measurement, and calculations. Any lengthy instructions for sampler preparation or standardization of stock solutions appear in appendixes to the method. Nomenclature is consistent with the Glossary of Abbreviations, Definitions and Symbols.

Note: Additional general information relating to sampling and measurement is contained in the chapters on quality assurance and sampling.

c) Supporting information laboratory and field data relating to the method are summarized in the evaluation of method section and on the summary page, along with pertinent references.

5. Method Classification

Methods in the fourth edition of the NMAM are classified into Evaluation categories: Full, Partial, Unrated, and Not Applicable. Classification is based on the results of laboratory testing and evaluation criteria as described in Chapter E, Development and Evaluation of Methods, NMAM.

The data from these evaluations are summarised in the evaluation of method section in each method. This section may also contain other corroborating data, e.g., collaborative testing, Proficiency Analytical Testing (PAT) data, or field data from US NIOSH Sequences. For Partially Evaluated methods, this section will state which evaluation points were not tested, thus providing the user with information on which to make a reasonable judgment on the quality of the data obtained.

a) Evaluation: Full

Fully evaluated methods are methods that have been tested and have met all the factors of the US NIOSH evaluation protocol as presented in Chapter E.

b) Evaluation: Partial

Partially evaluated methods are methods that have been subjected to some of the evaluation experiments but have not received a full evaluation (i.e., Short-term Method Development). These may also include methods that were fully tested but did not meet one (1) or two (2) of the evaluation criteria, e.g., some of the earlier-developed methods that do not meet the current ±25% accuracy criterion.

c) Evaluation: Unrated

Unrated methods have not been tested by US NIOSH, but have been developed by a recognized independent source such as the United States Occupational Safety and Health Administration (US OSHA).

d) Evaluation: N/A

The designation, Not Applicable (N/A), is applied to methods where no quantitative data are collected:

(i) Procedures for sample collection only. The collected samples are analysed subsequently by an appropriate analytical method, e.g., the Lead Wipe procedure (NMAM 9100) where the samples are analysed by one of the three lead analysis methods.

(ii) Qualitative methods that indicate results as positive or negative, e.g., Lead spot test (NMAM 7700), or Mycobacterium Tuberculosis by PCR (NMAM 0900).

APPENDIX 4 - SAMPLE OF COC FORM

Sample reference No. :.....

(Name and Address of Laboratory)

SAMPLE INFORMATION FORM

(i) COLLECTION OF SAMPLES/ MEDIA FROM LABORATORY FOR SAMPLING (IF APPLICABLE)

	NAME	ORGANIZATION	SIGNATURE	TIME AND DATE
Received By		Company Name		

(ii) SUBMISSION OF SAMPLES TO LABORATORY AFTER SAMPLING

LABORATORY REFERENCE NO. : _____ **COMPANY REFERENCE NO:** _____
(To be filled by the laboratory) (To be filled by sender)

	NAME	ORGANIZATION	SIGNATURE	TIME AND DATE
Submitted By		Company Name		
Received By		Laboratory Name		

(iii) SAMPLE INFORMATION

a) Packaging marking (envelope/ plastic) of the sample :

b) Monitoring Personal/ Area :

NO.	SAMPLE MARKING

APPENDIX 5 - CALCULATIONS FOR COMPLIANCE TEST USING STATISTICAL TOOLS

These appendix gives calculation method for compliance test as described in paragraph 6.3.2.

Example 1

Exposure of toluene is measured in a printing factory among three maintenance workers (SEG) on Monday and result indicated more than 10% PEL but below PEL as shown below. Due to that, another 6 more sample is taken on Thursday and Friday to determine the compliance. Given PEL for toluene is 50 ppm. Apply compliance test for this scenario.

	Raj	Ali	Chin
Monday	4.45	7.54	5.95
Thursday	9.67	10.11	6.34
Friday	8.18	6.21	10.51

Steps

1. First, calculate the logarithm of each of these values in the above table. Logged data are assumed to be log normally distributed. Use the logged value to do analysis because the analysis applies with values that are normally distributed.

	Logged value		
	Raj	**Ali**	**Chin**
Monday	0.65	0.88	0.77
Thursday	0.99	1.00	0.80
Friday	0.91	0.79	1.02

2. Calculate the geometric mean (GM) and the geometric standard deviation (GSD) of all the exposure measurements in the SEG. Using equation 1 and equation 2 in paragraph 6.3.2.

a) Geometric mean (GM)

$$\log GM = (\log a_1 + \log a_2 + \log a_3 \ldots + \log a_n)/n \qquad \textit{(equation 1)}$$

$$\log GM = \frac{(0.65+0.88+0.77+0.99+1.00+0.80+0.91+0.79+1.02)}{9}$$

$$= 0.87$$

b) Geometric standard deviation (GSD)

$$\log GSD = \sqrt{\frac{(\log a_1 - \log GM)^2 + (\log a_2 - \log GM)^2 + (\log a_3 - \log GM)^2 + (\log a_n - \log GM)^2}{n - 1}}$$

(equation 2)

$$\log GSD = \sqrt{\frac{(0.65-0.87)^2+(0.88-0.87)^2+(0.77-0.87)^2+(0.99-0.87)^2+(1-0.87)^2+(0.8-0.87)^2+(0.91-0.87)^2+(0.79-0.87)^2+(1.02-0.87)^2}{8}}$$

$$\log GSD = 0.13$$

3. Then calculate the parameter U with the following equation:

$$U = \frac{[log\,(PEL) - log\,GM]}{log\,GSD} \qquad \textit{(equation 3)}$$

$$= \frac{[(\log 50)-(0.87)]}{0.13}$$

$$= 6.38$$

4. The value of U is then compared with the limiting values given in **Table 6**. The calculated U (i.e. U=6.38) is more than the limiting value of U (2.035) with 9 measurements. Hence, PEL is complied with and the compliance test is considered pass in this case.

Example 2 (Calculation with Microsoft Excel)

Two of the workers were measured four times but Chloe was not working in the SEG on Tuesday and Wednesday, so there are only two measurements for her. The measurements will only represent the exposure if there is no systematic variation of exposure with the day of the week, and the measurements must be representative of the usual exposure if the results are to be valid. Given PEL for cotton dust is 1.7 mg/m3.

	Greg	Joe	Chloe
Monday	0.16	0.51	0.18
Tuesday	0.38	0.6	-
Wednesday	0.2	0.35	-
Thursday	0.44	0.7	0.65

Steps

1. First, calculate the logarithm of each of these values in the above table. Logged data are assumed to be log normally distributed. Use the logged value to do analysis because the analysis applies with values that are normally distributed.

Logged Value			
	Greg	Joe	Chloe
Mon	=LOG(B23)		-0.74
Tue	-0.42	-0.22	
Wed	-0.70	-0.46	
Thur	-0.36	-0.15	-0.19

2. Calculate the geometric mean (GM) and the geometric standard deviation (GSD) of all the exposure measurements in the SEG. Using equation 1 and equation 2 in paragraph 6.3.2.

a) Geometric mean (GM)

Logged Value			
	Greg	Joe	Chloe
Mon	-0.80	-0.29	-0.74
Tue	-0.42	-0.22	
Wed	-0.70	-0.46	
Thur	-0.36	-0.15	-0.19
log M_G	=AVERAGE(N23:P26)		

b) Geometric standard deviation (GSD)

Logged Value			
	Greg	Joe	Chloe
Mon	-0.80	-0.29	-0.74
Tue	-0.42	-0.22	
Wed	-0.70	-0.46	
Thur	-0.36	-0.15	-0.19
log M_G	-0.43		
log S_G	=STDEV(N23:P26)		

3. Then calculate the parameter U with the following equation:

$$U = [\log(PEL) - \log GM] / \log GSD \qquad \textit{(equation 3)}$$

Logged Value			
	Greg	Joe	Chloe
Mon	-0.80	-0.29	-0.74
Tue	-0.42	-0.22	
Wed	-0.70	-0.46	
Thur	-0.36	-0.15	-0.19
log M_G	-0.43		
log S_G	0.24		
U value	=(LOG (1.7)-N28)/N29		

4. The value of U is then compared with the limiting values given in **Table 6**. The calculated U (i.e. U=2.79) is more than the limiting value of U (2.005) with 10 measurements. Hence, PEL is complied with and the compliance test is considered pass in this case.

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