

A Semi-Quantitative Method

to

Assess Occupational Exposure

to

Harmful Chemicals



**MINISTRY OF
MANPOWER**

**Ministry of Manpower
Occupational Safety and Health Division
18 Havelock Road
#03-02
Singapore 059764**

Email: mom_oshd@mom.gov.sg

All rights reserved. No part of this publication may be reproduced or transmitted in any form or by any means, without the prior permission of the copyright holder.



Introduction

Risk may be defined as the likelihood of occurrence of an event resulting in certain consequences. Different chemicals have different properties and toxicity. Exposure to toxic chemicals can result in different effects depending on the routes and levels of exposure.

A risk assessment of toxic or harmful chemicals determines the risk levels they present to the users. It also enables decisions to be made on whether measures need to be taken to safeguard or protect persons against the chemicals. Under the Factories Act, factory occupiers or employers must take measures to ensure the safe use of chemicals. To discharge this duty, an assessment of all chemicals used in the workplace must be carried out in order to identify, evaluate and control any health risk associated with work activities involving the use of the chemicals.

The purpose of these guidelines is to provide guidance to factory occupiers, employers, health and safety personnel, as well as users of chemicals on the methods and procedures of assessing health risks arising from the use of toxic or harmful chemicals. These guidelines are not mandatory and may be used to complement other risk assessment methods. The guidelines do not address flammable and other hazardous chemicals, which may pose fire or explosion and other hazards.

These should be separately assessed by appropriate methods.



Objectives

The purposes of conducting a risk assessment of harmful chemicals are to

- identify the hazards posed by each chemical used or handled
- evaluate the degree of exposure to the toxic or harmful chemicals
- determine the likelihood of the adverse effects from exposure to the chemicals

The main outcome of the risk assessment is to assign a risk rating to different work tasks involving exposure hazards. The hazard scenarios are then ranked and the ranking is used for prioritizing actions to address the hazards and to reduce the risk.

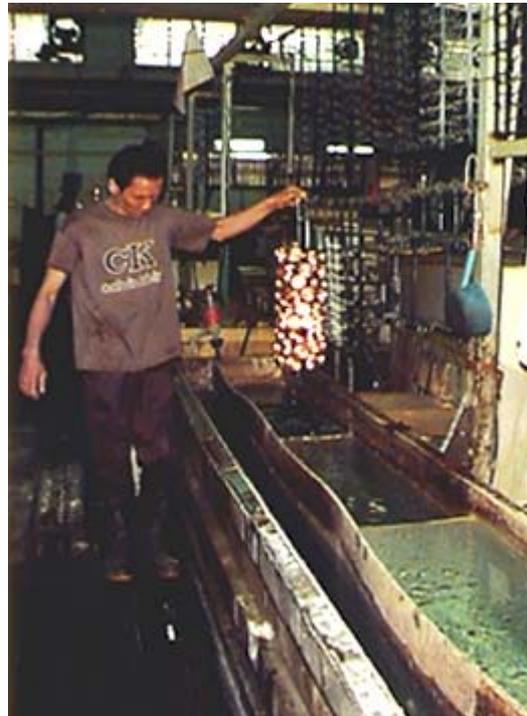
Without a system that ranks hazards according to their potential risk, time and resources could be diverted to addressing low-risk hazards while more significant ones could be neglected.

Scope

- In these guidelines, the assessments are concerned only with the health risks to people in the workplace.
- These guidelines are applicable to plants handling toxic or harmful chemicals including raw materials, products, ingredients and by products.
- These guidelines provide guidance on the steps of deciding who should do the assessments, and determining what work should be assessed.
- These guidelines outline a general process for the assessment of risk in work releasing or generating toxic or harmful chemicals.
- These guidelines also describe the actions that should be taken following an assessment and the requirements for recording and reviewing assessments.
- These guidelines may be used by health and safety practitioners and others who might be involved with risk assessment.
- The assessment can provide an indication of relative risk if the parameters used for assessment are known. However, the results can be questionable if meaningful information and data are not available or if human errors are made in the process of assessment.
- These guidelines do not address the risk related to failure of any

machine, equipment and control system that may eventually lead to an accident or incident.

- They also do not address the risks to those in the immediate neighbourhood, to the public or to the environment.
- The assessment does not take into account persons with hypersensitivity.
- The assessment does not take into account dermal exposure and ingestion. However, sample calculations of dermal exposure is included in Annex 1.



Definitions

Hazard is the general term for anything that has the ability or potential to cause injury. The hazard associated with a potentially toxic chemical is a function of its toxicity.

Risk is the term applied to the predicted or actual frequency or likelihood of occurrence of an adverse effect of a chemical or other hazard.

Risk assessment is the identification and quantification of the risk resulting from a specific use of a chemical, taking into account the possible harmful effects on people using the chemical in the amount and manner proposed and all the possible routes of exposure.

Toxic is the adjective applied to any chemical or substance able to cause injury to living organisms.

Toxicity of a chemical is its ability to cause injury to a living organism.

Semi-Quantitative Risk Assessment

This method systematically identifies the chemical hazards, evaluates the exposure or likelihood of exposure, determines the risk level, and prioritises actions to address the risks.

There are eleven steps involved in a semi-quantitative risk assessment

Commitment of Management:

- 1 Formation of a workgroup

Hazards/Identification and Rating:

- 2 Breakdown of work process
- 3 Identification of chemicals
- 4 Determination of hazard rating
- 5 Conducting work inspection and interviews

Exposure Evaluation:

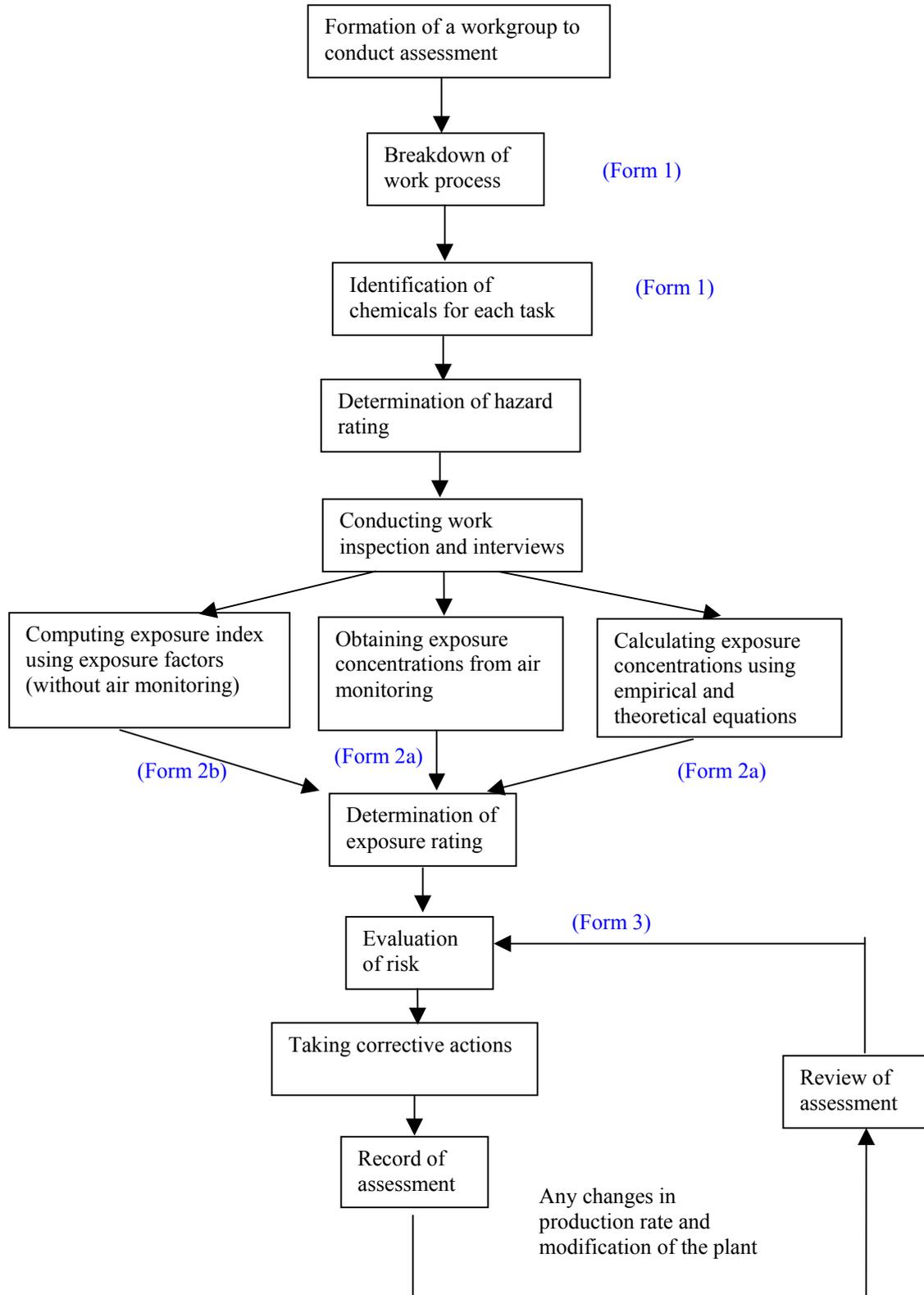
- 6 Obtaining information on frequency and duration of exposure
- 7 Determination of exposure rating

Assessing Risk:

- 8 Evaluation of risk
- 9 Taking corrective actions
- 10 Record of assessment
- 11 Review of assessment

There are three methods to conduct exposure evaluation. The assessor can use the actual exposure levels to determine the exposure rating and risk level. If exposure levels are not available, exposure factors or parameters can be used to determine the exposure index and rating. For risk assessment of exposure hazard at plant or process design stage, the exposure may be estimated using empirical or theoretical formulas.

Process Flow Chart of Semi-Quantitative Method



STEP 1 Formation of a workgroup

A workgroup or team consisting of representatives of both the management and the employees as well as a competent person could be set up to conduct the risk assessment. Alternatively, a safety

The competent person could be an employee or any person who has adequate training and experience in management of hazardous substances and in risk assessment and risk management.



consultant or an industrial hygienist could be engaged to carry out the assessment.

There should be consultations between the management and the employees. The employees who actually carry out the work should be of great help. The participation of both the employees and their representatives in the committee can help in obtaining information about the way the task is carried out, the substances used and the different routes of exposure to the substances. The management should be committed to conduct the risk assessment and to implement any control measures or corrective actions to manage the risk.

STEP 2 Breakdown of work process

It is useful to group employees by job tasks in the following sequence:

- List the different departments in the company
- List the different processes in each department
- Divide the processes into different tasks
- Group the employees who perform the same task in the same area.

- For those whose jobs require movement around the plant, consider their jobs individually. Tasks like maintenance should also be included although these may not be done daily or frequently.
- Ensure that all persons who are or may be exposed to the substances are included. These include employees involved in production, repairs, maintenance, research or development, cleaning and any on-site contractors.

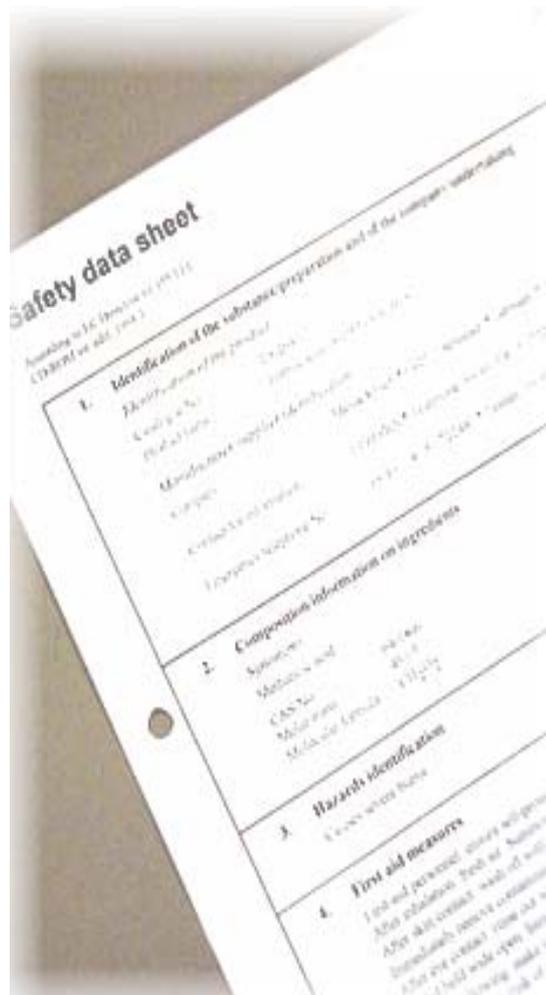
It is necessary to visit the workplace, and to follow the floor plans to ensure that all work areas are covered. The task is usually separated by physical or geographical sections. Process flow diagrams and process instrumentation diagrams may be used to identify the tasks for risk assessment.

For example, a company may have a premix department, an adjustment department, and a packaging department. In the premix department, there are processes like mixing, pretreatment and colour matching. The process of mixing involves tasks like collecting raw materials, weighing, pouring raw materials into tanks, auto/manual stirring, checking and sampling.

Form 1 should be used to document the breakdown of the work process.

STEP 3 Identification of chemicals

Identify all the chemicals that are used or produced, e.g. raw materials, intermediates, main products and secondary products. A chemical might be in the form of a solid, liquid, gas, vapour, dust, mist or fume. All chemicals must be included regardless of any control that may be in place.



The presence of chemicals may be identified by:

- looking at the stock lists, inventories, registers, material safety data sheets (MSDS) and container labels
- inspecting all locations where chemicals are stored or used
- considering the substances that may be produced during any work process as intermediates,
- by-products, finished products or given off as wastes, residues or fugitive emissions
- considering all substances that are used, or may arise from work such as maintenance and repair, cleaning or testing.

For example, formaldehyde might be emitted during injection moulding and ethyl acetate is used to remove grease on the injection moulding machine. Therefore these chemicals should be included for risk assessment.

For each work process or task identified, list the chemical(s) involved using Form 1.

STEP 4 Determination of hazard rating

Having identified the chemicals used or present, the next step is to determine if they are toxic or harmful to health. The hazard of a chemical depends on its toxicity, routes of exposure and other factors. The hazard rating can be determined from the toxic or harmful effects of the chemical (Table 1). Alternatively, the rating can be determined from the acute toxicity of the chemical in terms of lethal dose (LD_{50}) and lethal concentration (LC_{50}) – Table 1A. Information on the toxic effects of a chemical, its LD_{50} and LC_{50} can be obtained from the MSDS.

Table 1 : Hazard Rating

Hazard Rating	Description of Effects/Hazard Category	Example of chemicals
1	<ul style="list-style-type: none"> – No known adverse health effects – ACGIH* A5 carcinogens – Not classified as toxic or harmful 	sodium chloride, butane, butyl acetate, calcium carbonate
2	<ul style="list-style-type: none"> – Reversible effects to the skin, eyes or mucous membranes, not severe enough to cause serious health impairment – ACGIH A4 carcinogens – Skin sensitisers and skin irritants 	acetone, butane, acetic acid (10% concentration), barium salts, aluminium dust
3	<ul style="list-style-type: none"> – Possible human or animal carcinogens or mutagens, but for which data is inadequate – ACGIH A3 carcinogens – IARC* Group 2B – Corrosive (pH 3 to 5 or 9 to 11) , respiratory sensitizers, harmful chemicals 	toluene, xylene, ammonia, butanol, acetaldehyde, acetic anhydride, aniline, antimony
4	<ul style="list-style-type: none"> – Probable human carcinogens, mutagens or teratogens based on animal studies – ACGIH A2 carcinogens – NTP* Group B – IARC Group 2A – Very corrosive (pH 0 to 2 or 11.5 to 14) – Toxic chemicals, 	formaldehyde, cadmium, methylene chloride, ethylene oxide, acrylonitrile, 1, 3-butadiene
5	<ul style="list-style-type: none"> – Known human carcinogens, mutagens or teratogens – ACGIH A1 carcinogens – NTP Group A – IARC Group 1 – Very toxic chemicals 	benzene, benzidine, lead, arsenic, beryllium, bromine, vinyl chloride, mercury, crystalline silica

*Please refer to Annex 2 for the classification of carcinogens.

Table 1A – Hazard Rating by Acute Toxicity

Hazard Rating	LD ₅₀ absorbed orally in rat mg/kg body weight	LD ₅₀ dermal absorption in rat or rabbit mg/kg body weight	LC ₅₀ absorbed by inhalation in rat, mg/litre per 4 h Gases and Vapors	LC ₅₀ absorbed by inhalation In rat, mg/litre per 4 h Aerosols and particulates
2	> 2000	> 2000	> 20	> 5
3	> 200 to ≤ 2000	> 400 to ≤ 2000	> 2.0 to ≤ 20	> 1 to ≤ 5
4	> 25 to ≤ 200	> 50 to ≤ 400	> 0.5 to ≤ 2.0	> 0.25 to ≤ 1
5	≤ 25	≤ 50	≤ 0.5	≤ 0.25

Determine the hazard rating (HR) of each chemical identified and record it in Form 1.

STEP 5 Conducting work inspection and interviews

Conduct a 'walk-through' inspection according to the work tasks listed in Form 1 and interview the employees.



The aim of the interview is to find out if all the tasks are listed in Form 1 and whether all the worker groups are accounted for. In order to assess whether the workers are exposed to toxic or harmful chemicals, it is important to talk to the employees regarding their work practices and procedures. For example, they could describe what happens during a breakdown, maintenance, manpower shortage, changes in personnel or volume of production, or other changes that

could affect the work involving toxic or harmful chemicals.

If a new job, process or work unit is being planned but not yet in operation, evaluation of the relevant work process, plan or design is required, and it should be included in Form 1.

A checklist for inspection is attached in Annex 3. The inspection checklist addresses these four areas:-

- 1) Work unit where toxic or harmful chemicals are used or generated
- 2) Work practices
- 3) Emission of contaminants
- 4) Areas of concern

STEP 6 Obtaining information on frequency and duration of exposure

For employees who are or might be exposed to toxic or harmful chemicals, estimate the degree of exposure, taking into account the level, frequency and duration of exposure, as well as the different routes of exposure.

If air monitoring results are available for certain tasks, Form 2a should be used. Where air monitoring results are not available, exposure factors could be used for hazard rating and Form 2b should be used instead.

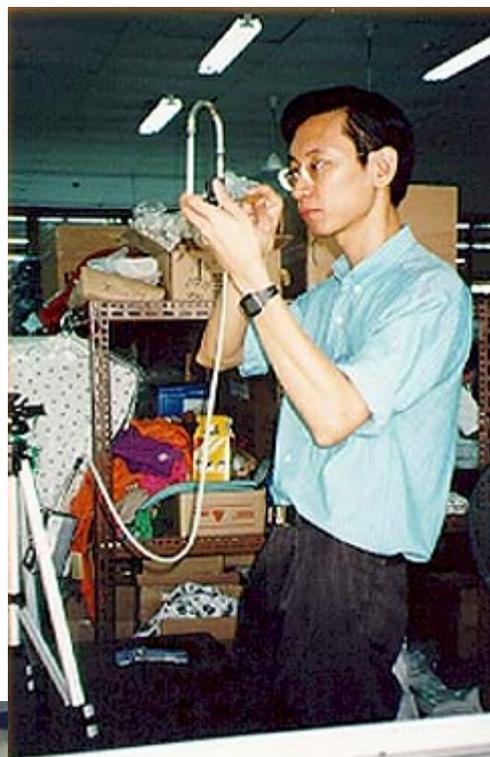
Form 2a (monitoring results are available)

In Form 2a, the duration of the specific task must be known. If the duration of the task is less than 8 hours, the frequency must be specified. For example, weighing of raw material takes about 2 hours (D = 2), but its frequency is twice a day or 10 times a week (F = 10 per week). Injection moulding takes full shift, that is 8 hours (D =8) and its frequency is once a day or 5 times a week (F = 5).

If there is exposure to two or more chemicals having similar health effects, fill in the row that indicates 'Chemicals with similar effects' with 'Y'. Information on health effects of chemicals can be obtained from MSDS.

Form 2b (monitoring results are not available)

In Form 2b, there are five factors that determine the exposure rating. These are vapour pressure, detectable odour/permissible exposure level, hazard control measure, amount of chemical used and duration of work per week. However, not all the factors will be utilized in a risk assessment, depending on whether the parameters are available.



Step 7 Determination of exposure rating

Exposure rating can be determined using actual exposure level or exposure index.

Using exposure level

Where air monitoring results are available, the weekly time weighted average exposure may be estimated using the following equation.

$$E = \frac{F \times D \times M}{W} \quad (1)$$

where

E	=	weekly exposure (ppm or mg/m ³)
F	=	frequency of exposure per week (no. per week)
M	=	magnitude of exposure (ppm or mg/m ³)
W	=	average working hours per week (40 hours)
D	=	average duration of each exposure (hours)

Equation (1) assumes that there is no exposure when the task is not carried out. The assumption must be tested in each case to confirm that it is true.

Exposure Rating (ER)

The exposure (E) is then compared to the PEL (Long Term) and the exposure rating can then be determined using the following Table.

Table 2 : Exposure Rating

E / PEL	Exposure Rating (ER)
< 0.1	1
0.1 to < 0.5	2
0.5 to < 1.0	3
1.0 to < 2.0	4
≥ 2.0	5

Combined Exposure

For exposure to two or more chemicals having similar effects, the combined exposure (E_{combined}) has to be considered i.e. for those chemicals in Form 2a where there are indications of 'Y' (yes to additive effect), the following equation should be used to determine the degree of exposure.

$$E_{\text{combined}} = \frac{E_1}{\text{PEL}_1} + \frac{E_2}{\text{PEL}_2} + \dots + \frac{E_n}{\text{PEL}_n} \quad (2)$$

where

E is the exposure and PEL is the corresponding permissible exposure level.

Exposure Exceeding 40 hrs/week

The PEL (Long Term) value has to be reduced for exposure of more than 40 hours per week. A weekly reduction factor (f) must be multiplied to the PEL(Long Term) value and it is obtained using the following equation:

$$f = \frac{40}{H} \times \frac{(168 - H)}{128} \quad (3)$$

where

H = number of hours worked per week

The above equation uses a conservative approach and results in the most reduction. There are other techniques available such as the OSHA model and Pharmacokinetic models. When adjustments are necessary, it is recommended that a competent person be consulted to ensure that the adjustment is appropriate and applicable as the models are theoretical and involve assumptions that may not apply to every chemical. An understanding of the chemical is needed and care must be taken where toxicity data is limited. However, the benefits of adjusting exposure limits outweigh the uncertainty of the models. Where unusual work schedules are common, the need to adjust exposure limits should be explored and the most appropriate model selected.

For short term exposure of up to 15 minutes during any time of the day, the magnitude of exposure should be compared with the PEL (Short Term) value. Record the exposure rating in Form 3.

Using exposure index

Where air monitoring results are not available, the exposure rating can be determined from the exposure index (EI) using the following equation:

$$ER = [EI_1 \times EI_2 \times \dots \times EI_n]^{\frac{1}{n}} \quad (4)$$

where

n is the number of factors used.

The exposure indexes are rated on a five-scale rating from 1 to 5 in an increasing order of magnitude i.e. 1 means very low, 5 means very high and 3 is medium.

Table 3: Exposure Factors and Index

Exposure Index Exposure Factor	1	2	3	4	5
Vapour pressure or particle size (aerodynamic diameter)	< 0.1 mmHg	0.1 to 1 mmHg	>1 to 10 mmHg	> 10 to 100 mmHg	>100 mmHg
	Coarse, bulk or wet material	coarse and dry material	dry and small particle size > 100 µm	dry and fine material 10 to 100 µm	dry and fine powdered material < 10 µm
Ratio of *OT/PEL	<0.1	0.1 to 0.5	> 0.5 to 1	>1 to 2	≥2
Hazard control measure	Adequate control with regular maintenance	Adequate control with irregular maintenance	Adequate control without maintenance ; moderately dusty	Inadequate control; dusty	No control at all; very dusty
Amount used per week	Almost negligible amount used (< 1 kg or l)	Little amount used (1 to <10 kg or l)	Medium amount used, workers are trained on handling the chemical (10 to < 100 kg or l)	Large amount used, workers are trained on handling the chemical (100 to 1000 kg or l)	Large amount used, workers are not trained on handling the chemical (> 1000 kg or l)
Duration of work per week	<8 hrs	8 to 16 hrs	16 to 24 hrs	24 to 32 hrs	32 to 40 hrs

* Odour threshold (OT) divided by the permissible exposure level (PEL)

In the first row of the above Table, when the chemical is a liquid at room temperature, its exposure hazard depends on its vapour pressure which can be obtained from the MSDS. Vapour pressure depends on temperature. When the liquid is at a different temperature from the one stated in the MSDS, its vapour pressure can be determined using the Antoine equation. When the chemical is a solid, its inhalation hazard depends on the size of the solid particles. This might require an on site judgement. The particle size refers to its aerodynamic diameter, and is given by this formula:

$$Da = Dp \sqrt{s.g} \quad (5)$$

where

Da = aerodynamic diameter
Dp = diameter of the particle
s.g = specific gravity of the bulk chemical

The exposure rating depends on the permissible exposure level and the detectable odour threshold (second row) of the specific chemical. They can be found in Annex 4 and Annex 5 respectively.

The likelihood of exposure to a chemical is largely determined by the presence of engineering control measures and their effectiveness. A properly designed and well-constructed local exhaust system will greatly reduce the exposure risk, whereas an open process or poorly designed and maintained system can result in high exposures. The differences are reflected in the hazard control measure ratings (third row of Table 3). Examples of adequate control measures are process containment or enclosure with no direct contact, no visible contaminant release or emission, adequate capture velocity. The provision of personal protective equipment is not a form of control.

The degree of exposure to a chemical also depends on the amount of chemical used and the duration of work or exposure. These are shown in the fourth and fifth rows of Table 3 respectively. A weekly work shift (usually 40 hours) is used as the basis for assigning exposure rating as the PEL values are based on 40-hour exposures.

Example, fine powdered silica dust (EI = 5) is generated during weighing and this task takes 1 hour per day or 7 hours per week (EI = 1). There is moderate dust by visual inspection (EI = 3). The amount used is little (EI = 2).

$$\begin{aligned} ER &= (5 \times 3 \times 2 \times 1)^{1/4} \\ &= 2.3 \end{aligned}$$

Step 8 Evaluation of risk

The risk can be expressed in the following form:

$$\text{Risk} = \sqrt{(\text{HR} \times \text{ER})} \quad (6)$$

where

HR = hazard rating on the scale of 1 to 5 (see Table 1)
ER = exposure rating on the scale of 1 to 5

The square root is to limit the risk value within the scale of 1 to 5. When the risk rating is not a whole number, it should be rounded up to the nearest whole number.

Example.

HR = 4, ER = 3, Risk = $\sqrt{4 \times 3} = 3.5$ round up to 4.

Significance of Risk

Determine the risk of each task and rank it in accordance with the following Table:

Table 4 : Risk Rating

Risk Rating	Ranking
1	Negligible
2	Low
3	Medium
4	High
5	Very High

Alternatively, the matrix below can be used to determine the risk level.

Risk Rating Matrix

HR ER	1	2	3	4	5
1	1 1	1. 4	1. 7	2	2. 2
2	1. 4	2	2. 4	2. 8	3. 2
3	1. 7	2. 4	3	3. 5	3. 9
4	2	2. 8	3. 5	4	4. 5
5	2. 2	3. 2	3. 9	4. 5	5

Legend

	= negligible
	= low
	= medium
	= high
	= very high

The risk rating scaling of 1 to 5 is in increasing order of magnitude. Rating of 1 implies negligible risk and a rating of 5 implies very high risk. Record the risk rating and rank it in Form 3. This ranking will enable a prioritization of action plans to reduce the risk of exposure.

STEP 9 Taking corrective actions

If the assessment shows that there is a significant risk to health, the appropriate actions should be taken to reduce the risk. These include:

- a) Select appropriate measures to eliminate or minimize the risk eg substitution of the toxic chemicals, installation of local exhaust ventilation or dilution ventilation, implementing administrative control and issuing of personal protective equipment
- b) Arrange induction and training of employees

- c) Determine if monitoring is required. Please refer to MOM's Guidelines on Sampling Strategy and Submission of Air Monitoring Report.
- d) Determine if medical examinations are required. Please refer to the Factories (Medical Examinations) Regulations.
- e) Establish emergency and first-aid procedures if indicated

It is the responsibility of the employer to ensure that the risk is acceptable. Here are some possible actions for the different risk levels.

Risk Level 1 – Negligible risk

- End assessment
- Review assessment every five years

Risk Level 2 – Low risk

- Maintain control
- Determine if air monitoring is required
- Review assessment every four years

Risk Level 3 – Medium risk

- Implement and maintain control
- Determine if air monitoring is needed
- Determine if employee training is needed
- Review assessment every three years

Risk Level 4 – High risk

- Implement effective engineering control
- Conduct air monitoring
- Conduct training for employees
- Adopt Respiratory Protection Programme (please see Annex 6)
- Provide suitable personal protective equipment e.g. goggles, apron, gloves etc.
- Develop and implement safe and correct work procedures
- Establish first-aid and emergency procedures if necessary
- Reassess the risk after all the above have been done

Risk Level 5 – Very High risk

- Implement effective engineering control
- Conduct air monitoring
- Conduct training for employees
- Adopt Respiratory Protection Programme (please see Annex 6)

- Provide suitable personal protective equipment
- Develop and implement safe and correct work procedures
- Establish first-aid and emergency procedures if necessary
- Reassess the risk (carry out a detailed risk assessment) after all the above have been done

STEP 10 Record of assessment

All assessments should be properly recorded in a permanent form, either in writing or on a computer. The record should be concise. It should include:

- a) name of assessment team
- b) description of work unit
- c) personnel involved
- d) work area and time
- e) a list of hazardous substances used or produced in that work unit and a notation to indicate whether MSDS are available
- f) hazard information
- g) summary of process
- h) risk identification
- i) conclusion about risks
- j) recommendations
- k) signature, date and position of the assessment team
- l) signature, date and position of the employer accepting the assessment

STEP 11 Review of assessment

A review is required if any of the following situations arises:

- There are significant changes in the volume of production, materials, processes or control measures (management of change)



- Work-related ill health is reported
- Accidents or near misses have occurred which may be due to inadequate control
- Monitoring or health surveillance indicates a loss of control
- There is new evidence about hazards of substances, perhaps resulting in a reviewed standard, a change in the value of the PEL, or any properties of the chemicals
- New or improved control technology becomes practicable

Some of the common errors in the risk assessment are:

- 1) Errors of facts : e.g procedures, and location of usage of substances
- 2) Inadequate identification of hazards
- 3) Claims that consequences will be of limited range or effect, without convincing justification.
- 4) The uncertainties of 'Black Box' methodologies, models and assumptions for calculations.

Exposure Assessment Estimation

This section is applicable for factories at the design phase when air monitoring data is not available. Theoretically, the risk assessment techniques can give precise results, however, the scarcity of meaningful data and equation parameter coupled with human error and inaccuracy makes the calculated results questionable.

This assessment involves detailed computations of exposure level in ppm or mg/m³.

The exposure level can then be compared to the PEL (Long Term) values. To obtain the exposure rating (ER), if the exposure is less than 8 hours, then the following equation should be used to convert to the 8-hours time-weighted-average (C_{TWA}) before comparison.

$$C_{TWA} = \frac{C_1T_1 + C_2T_2 + \dots + C_nT_n}{8} \quad (7)$$

where

C = concentration of exposure and T is the corresponding exposure time

Equation to predict Inhalation Exposure- Transfer Operation^A

This equation is suitable for any transfer operations like tank car loading and drumming.

$$C_{ppm} = \frac{(1.67 \times 10^4)(VP V fr)}{QK} \quad (8)$$

where

C_{ppm} = airborne concentration at equilibrium, ppm
 VP = vapor pressure, atm

Default input value:	Container Types		
	Drums	Tank Trucks	Tank Cars
V, volume of container, m ³	0.21	19	76
f, saturation factor, dimensionless	0.5 ^{B,C} , 1.0 ^{D,E}	0.5 ^{B,C} , 1.0 ^{D,E}	0.5 ^{B,C} , 1.0 ^{D,E}
r, fill rate, units/hour	20 ^B , 30 ^D	2	1
Q, ventilation rate, m ³ /min	85 ^B , 14 ^D	6700v ^{B,F} , 750v ^{D,F}	6700v ^{B,F} , 750v ^{D,F}
k, mixing factor, dimensionless	0.5 ^B , 0.1 ^D	0.5 ^B , 0.1 ^D	0.5 ^B , 0.1 ^D

^AAssumes the temperature of the liquid and the temperature of the air are equivalent, extinction of the substance is negligible, only one generation source is present, steady state conditions are reached, and that the ideal gas law is applicable. Spillage during filling operations is neglected. The value 1.67×10^4 incorporates conversion to more conventional units (i.e., from cm^3 to m^3 for V, units/sec to units/hr for r, and cm^3/sec to m^3/min for Q).

^BDefault input value for “what-if” hypothetical estimates is the value that lies in the central portion of the range for the value.

^CAssumes bottom filling technique is used

^DDefault input values for bounding estimates are selected such that the resulting estimates will be higher than that incurred by the individual in the population with the highest exposure.

^EAssume splash filling technique is used

^FOutdoor ventilation rate in units of m^3/min is calculated using this unit’s conversion for the estimated wind speed, “v” in mph.

Equation to predict Inhalation Exposure- Open surface Operation^A

This equation may be used for processes like furniture stripping in a dip or immersion tank, degreasing and cleaning of metal parts.

$$C_{eq} = \frac{(720)VP[1/MW + 1/29]^{0.25} A}{MW^{0.165} Qk \Delta x^{0.25}} \quad (9)$$

where

C_{eq} = airborne concentration at equilibrium, ppm

VP = vapor pressure, atm

MW = molecular weight, g/g-mole

Default input values:	Operation	
	Sampling	Other Open Surface
A, area, cm^2	$40^B, 80^C$	^D
Q, ventilation rate m^3/min	$85^B, 14^C$	$85^B, 14^C$
k, mixing factor, dimensionless	$0.5^B, 0.1^C$	$0.1^B, 0.5^C$
Δx , pool length in the direction of air flow, cm	$7^B, 10^C$	^D

^AAssumes that the temperature of the substance and the ambient temperature of the air equals 298K, that the overall pressure equals 1 atmosphere, and that the air velocity equals 50.8 cm/sec (100ft/min) and is flowing parallel to the pool of liquid. Assumes steady state conditions are reached, heat of evaporation is provided by the surroundings, diffusion at the edge of the pool and in the direction of the air stream is negligible, there is no mixing in the area above the pool of liquid, no local exhaust or physical barriers are present at the edges of the pool, and that the ideal gas law is applicable. This equation is applicable for substances with low to moderate vapour pressures (i.e., less than 0.05atm). The value 720 incorporates conversion to more conventional units (i.e., from cm^3/sec to m^3/min for Q)

^BDefault input value for “what-if” hypothetical estimates is the value that lies in the central portion of the range for the value.

^CDefault input values for bounding estimates are selected such that the resulting estimates will be higher than that incurred by the individual in the population with the highest exposure.

^DTo be estimated based on the operation

Please refer to the article on Evaluation of the Mass Balance Model used by the Environmental Protection Agency for Estimating Inhalation Exposure to New Chemical Substances from the American Industrial Hygiene Association Journal, 1996, Volume 57, page 526-536.

Estimating Worker Exposures to Liquid pool Evaporation or Boiling

Released liquids are assumed to form a pool from which chemicals are released into the atmosphere. This equation is used to estimate the vaporization rate of volatile from an open vessel.

$$Q_m = \frac{MKAP_{sat}}{R_g T_L} \quad (10)$$

where

- Q_m = evaporation rate (kg/s)
- M = molecular weight of contaminant (kg/kg-mole)
- K = mass transfer coefficient (m/s)
- A = area of exposure or liquid pool (m²)
- P_{sat} = saturated vapour pressure of the liquid (Pa or N/m²)
- R_g = ideal gas constant (8.314 Pa m³/mol K)
- T_L = temperature of liquid (K)

To find mass transfer coefficient of the contaminants:

$$K = K_o \left(\frac{M_o}{M} \right)^{1/3} \quad (11)$$

where

- K_o = mass transfer coefficient of reference substance, water (0.0083m/s)
- M = molecular weight of contaminant (kg/kg-mole)
- M_o = molecular weight of water (kg/kg-mole)

Estimating Worker Exposures to Toxic Vapours – Dilution Ventilation

The average concentration C_{ppm} of any volatile liquids or substances in an enclosure given a source term Q_m and ventilation rate Q_v . It can be applied to workers standing near a pool of volatile liquid, an opening to a storage tank or an open container of volatile liquid. Q_m can be obtained from equation 10.

$$C(ppm) = \frac{Q_m R_g T}{k Q_v PM} \times 10^6 \quad (12)$$

where

- C_{ppm} = average concentration of volatile vapour in the enclosure [ppm]
- Q_m = evolution rate of volatile material [kg/s]
- k = non ideal mixing factor ($k = 0.1$ to 0.5); for perfect mixing ($k = 1$)
- R_g = ideal gas constant ($8.314 \text{ Pa m}^3/\text{mole K}$)
- T = temperature of the source (K)
- M = molecular weight of the escaping vapour (kg/kg-mole)
- Q_v = ventilation rate (m^3/s)

Assumptions:

1. The vapour concentration calculated is an average concentration in the enclosure. However, the localized conditions will result in higher concentrations; e.g. workers directly above an open container will be exposed to higher vapour concentrations.
2. Steady state conditions assuming there is no accumulation of vapours.

Example

An open toluene container in an enclosure is weighed as a function of time and it is determined that the average evaporation rate is 0.1 gm/min . The ventilation rate is $100 \text{ ft}^3/\text{min}$. The temperature is 80°F and the pressure is 1 atm . Estimate the concentration of toluene vapor in the enclosure and compare to the PEL (Long Term) for toluene of 100 ppm .

Solution

$$Q_m = 0.1 \text{ gm/min} = 2.20 \times 10^{-4} \text{ lbm/min}$$

$$R_g = 0.7302 \text{ ft}^3 \text{ atm/lb-mole } ^\circ\text{R}$$

$$T = 80^\circ\text{F} = 540^\circ\text{R}$$

$$Q_v = 100 \text{ ft}^3/\text{min}$$

$$M = 92 \text{ lbm/lb-mole}$$

$$P = 1 \text{ atm}$$

$$k\text{C}_{\text{ppm}} = \frac{(2.20 \times 10^{-4} \text{ lbm/min})(0.7302 \text{ ft}^3 \text{ atm/lb-mole } ^\circ\text{R})(540^\circ\text{R})}{100 \text{ ft}^3/\text{min}(1 \text{ atm})(92 \text{ lbm/lb-mole})} \times 10^6$$

$$k\text{C}_{\text{ppm}} = 9.43 \text{ ppm}$$

Since k varies from 0.1 to 0.5, the concentration is expected to vary from 18.9 to 94.3 ppm. Actual vapor sampling is recommended to ensure that the PEL (Long Term) is not exceeded.

Reference Documents

1. Guidance Note for the Assessment of Health Risks Arising from the use of Hazardous Substances in the Workplace [NOHSC: 3017 (1994)]
2. Assessment of the Health Risks Arising from the Use of Hazardous Chemicals in the Workplace [Department of Occupational Safety and Health, Ministry of Human Resources, Malaysia, 2000]
3. Workplace Risk Assessment Course notes [Liberty]
4. Chemical Process Safety: Fundamentals with Applications by Daniel A. Crowl/Joseph F. Louvar

DETERMINATION OF EXPOSURE RATING

(This form is used if air monitoring results are available)

FORM 2a

Process:

Task:

	Chemical 1	Chemical 2	Chemical 3	Chemical 4
Duration of exposure, D				
Frequency of exposure, F				
Magnitude of exposure (from air monitoring results), M				
Chemicals with similar effects (Y/N)				
Exposure level, E				
Exposure Rating, ER				

DETERMINATION OF EXPOSURE RATING

(This form is used if air monitoring results are not available)

FORM 2b

Process:

Task:

	Chemical 1	Chemical 2	Chemical 3	Chemical 4
Vapour pressure or particle size				
Ratio of OT/PEL				
Hazard control measure				
Amount used per week				
Duration of work per week				
Exposure Index, EI				
Exposure Rating, ER				

RESULTS REPORT OF RISK ASSESSMENT

FORM 3

Process	Task	Hazard Rating	Exposure Rating	Risk Level	Action/Follow-up

Signature of assessor/date

Signature of employer representative /date

Estimation of Dermal Exposure to Liquid

Dermal : Exposure to Liquid

The daily total dose resulting from dermal absorption of liquid exposure, D_{dl} can be calculated from: -

$$D_{dl} = \frac{W_x S_x A_x E_x F}{BW} \text{ [mg/kg/day]} \quad (13)$$

where

- 10% W = weight fraction of substance in product eg. 0.1 for a solution
- S = skin absorption rate (taken as 0.32 mg/cm²/hr from experiment)
- A = skin surface exposed (cm²)
- E = exposure duration = $\frac{[hr / day][days / yr]}{365 days / yr}$
- F = skin contact time (as fraction of exposure duration eg F= 2 for 20% of time for intermittent dermal exposure or F=0.01 for incidental exposure as skin contact)
- BW = average body weight of worker (kg),

The standard skin surface areas (A) for an adult male are:-

Arms	2280 cm ²
Upper arms	1430 cm ²
Forearms	1140 cm ²
Hands	840 cm ²
Head	1180 cm ²

The dose obtained can then be compared against the lethal dose (LD₅₀) for skin adsorption of the specific chemical.

Example:

Skin absorption rate, S	= 0.32 mg/cm ² /hr
Skin contact (assume incident), F	= 0.01
Area of skin exposed (hand and forearm), A	= 1,000 cm ²
Exposure duration, E	= 4 hr /day for 30days/yr
Weight fraction 90 % of substance in product, W=	0.9
Average body weight of an adult, BW	= 70 kg

For dermal exposure:

$$D_{dl} = \frac{WxSxAxExF}{BW}$$
$$= \frac{0.9 \times 0.32 \text{ mg/cm}^2/\text{hr} \times 1000 \text{ cm}^2 \times 4 \text{ hr /day} \times 30 \text{ days/yr} \times 0.01}{70 \text{ kg} \times 365 \text{ days}}$$
$$= 0.014 \text{ mg/kg/day}$$

Categories of Carcinogenicity

ACGIH: American Conference of Governmental Industrial Hygienists

- A1 – Confirmed human carcinogen
- A2 – Suspected human carcinogen
- A3 – Confirmed animal carcinogen
- A4 – Not classifiable as a human carcinogen
- A5 – Not suspected as a human carcinogen

IARC: International Agency for Research on Cancer

- Group 1: Carcinogenic to humans
- Group 2A: Probably carcinogenic to humans
- Group 2B: Possibly carcinogenic to humans

NTP: National Toxicology Program, Public Health Service, U.S. Department of Health and Human Services

- Group A: Known to be human carcinogens
- Group B: Reasonably anticipated to be human carcinogens

Inspection Checklist

Questions	Observations	Remarks	
Chemicals			
a) Are any raw materials, products released or emitted into the work area?		If yes to any of these, remember to include the chemicals in Form 1.	
b) Are there other chemicals used for different products?			
c) Will the process generate any by-products?			
Work practices			
a) Is there any non-routine activity?		If yes, it must be included in Form 1.	
b) Do current work practices ensure safe handling?		If no to any, other routes of exposure must be considered. Risk level obtained in these guidelines may not be a representative of the actual situation as it only addresses inhalation.	
c) Are appropriate personal protective clothing and equipment used?			
d) Are facilities for changing, washing and meal areas maintained in good conditions?			
e) Are good housekeeping practices in place?			
f) Are there any possibility of skin contact?			If yes, assess the extent of skin absorption using equation 13

Emission of contaminants		
a) Any evidence of contamination (e.g. dust or fumes visible in the air or on surfaces, substance visible on a person's skin or clothing, odour of chemical, visible leaks, spills or residues, chemical splashes)?		If yes to any, this could mean that control is inadequate (for Form 2b), or if the risk rating is low after assessment, consider other routes of exposure.
b) Are any employees experiencing any symptoms of exposure?		
c) Any employees' medical reports showing abnormal results?		
d) Any air monitoring conducted at the workplace?		If yes, Form 2a could be used. The results are also an indication of whether the control is adequate.
Establish areas of concern		
a) Are there any workers who are required to work directly with harmful substances, work near or pass through areas in which the substances are used, produced (including discharge of emissions), stored, transported or disposed of?		If yes to any, remember to include tasks and workers in Form 1.
b) Do workers need to enter a confined space in which the substance might be present?		
c) Do workers clean, perform maintenance or other work in areas where the substance might be present?		

Permissible Exposure Levels of Toxic Substances

Toxic Substance	Permissible Exposure Level (PEL)			
	PEL (Long Term)		PEL (Short Term)	
	ppm ^a	mg/m ³ ^b	ppm ^a	mg/m ³ _b
Acetic acid	10	25	15	37
Acetic anhydride	5	21	-	-
Acetone	750	1780	1000	2380
Acrylonitrile (Vinyl cyanide)*	2	4.3	-	-
Aluminium dust	-	10	-	-
Ammonia	25	17	35	24
Aniline*	2	7.6	-	-
Antimony and compounds, as Sb	-	0.5	-	-
Arsenic, elemental and inorganic compounds, as As	-	0.01	-	-
Arsine	0.05	0.16	-	-
Asphalt (petroleum) fumes	-	5	-	-
Barium, soluble compounds, as Ba	-	0.5	-	-
Benzene*	5	16	-	-
Beryllium and compounds, as Be	-	0.002	-	-
Bromine	0.1	0.66	0.2	1.3
1,3-Butadiene	2	4.4	-	-
Butane	800	1900	-	-
n-Butanol*	-	-	50	152
sec-Butanol	100	303	-	-
n-Butyl acetate	150	713	200	950
Cadmium, elemental and compounds, as Cd	-	0.05	-	-
Calcium carbonate (Limestone, Marble)	-	10	-	-
Calcium hydroxide	-	5	-	-
Calcium silicate	-	10	-	-

Calcium sulfate	-	10	-	-
Carbon black	-	3.5	-	-
Carbon dioxide	5000	9000	30,000	54,000
Carbon disulfide*	10	31	-	-
Carbon monoxide	25	29	-	-
Carbon tetrachloride (Tetrachloromethane)*	5	31	10	63
Chlorine	0.5	1.5	1	2.9
Chloroform (Trichloromethane)	10	49	-	-
Coal tar pitch volatiles (Polycyclic aromatic hydrocarbons), as benzene solubles	-	0.2	-	-
Cobalt, elemental and inorganic compounds, as Co	-	0.02	-	-
Copper				
Fume	-	0.2	-	-
Dusts & mists, as Cu	-	1	-	-
Cotton dust, raw	-	0.2	-	-
Cresol*	5	22	-	-
Cyclohexane	300	1030	-	-
Cyclohexanol	50	206	-	-
Cyclohexanone*	25	100	-	-
Cyclohexene	300	1010	-	-
Diborane	0.1	0.11	-	-
Ethanol (Ethyl alcohol)	1000	1880	-	-
Ethyl acetate	400	1440	-	-
Ethylene glycol	-	-	50	127
Ethylene oxide	1	1.8	-	-
Ethyl ether (Diethyl ether)	400	1210	500	1520
Ethyl mercaptan (Ethanethiol)	0.5	1.3	-	-

Fibrous glass dust	-	10	-	-
Fluorides, as F	-	2.5	-	-
Fluorine	1	1.6	2	3.1
Formaldehyde	-	-	0.3	0.37
Formic acid	5	9.4	10	19
Furfural*	2	7.9	-	-
Furfuryl alcohol*	10	40	15	60
Gasoline	300	890	500	1480
Grain dust (oat, wheat, barley)	-	4	-	-
Graphite, respirable dust	-	2	-	-
Heptane	400	1640	500	2050
Hexane (n-Hexane)*	50	176	-	-
Hydrazine*	0.1	0.13	-	-
Hydrogen bromide	-	-	3	9.9
Hydrogen chloride	-	-	5	7.5
Hydrogen cyanide*	-	-	4.7	5
Hydrogen fluoride	-	-	3	2.6
Hydrogen peroxide	1	1.4	-	-
Hydrogen sulfide	10	14	15	21
Iodine	-	-	0.1	1.0
Iron oxide dust & fume, as Fe	-	5	-	-
Iron salts, soluble, as Fe	-	1	-	-
Isobutyl acetate	150	713	-	-
Isobutyl alcohol	50	152	-	-
Isophorone	-	-	5	28
Isopropyl acetate	250	1040	310	1290
Isopropyl alcohol	400	983	500	1230
Lead, inorganic dusts and fumes, as Pb	-	0.15	-	-

L.P.G. (Liquified petroleum gas)	1000	1800	-	-
Malathion*	-	10	-	-
Maleic anhydride	0.25	1.0	-	-
Manganese, as Mn				
Dust and compounds	-	5	-	-
Fume	-	1	-	3
Mercury				
Alkyl compounds*	-	0.01	-	0.03
Aryl compounds*	-	0.1	-	-
Inorganic forms* eg. metallic mercury	-	0.025	-	-
Methanol (Methyl alcohol)*	200	262	250	328
Methyl acetate	200	606	250	757
Methyl acrylate*	10	35	-	-
Methyl n-butyl ketone (2-Hexanone)*	5	20	-	-
Methylene bisphenyl isocyanate (MDI, Diphenyl methane diisocyanate)	0.005	0.051	-	-
Methylene chloride (Dichloromethane)	50	174	-	-
Methyl ethyl ketone (MEK, 2-Butanone)	200	590	300	885
Methyl ethyl ketone peroxide	-	-	0.2	1.5
Methyl isobutyl ketone (Hexone)	50	205	75	307
Methyl mercaptan (Methanethiol)	0.5	0.98	-	-
Mineral wool fiber	-	10	-	-
Molybdenum, as Mo				
Soluble compounds	-	5	-	-
Insoluble compounds	-	10	-	-
Naphtha	300	1370	-	-
Naphthalene*	10	52	15	79
Nickel				
Metal	-	1	-	-
Insoluble compounds, as Ni	-	1	-	-
Soluble compounds, as Ni	-	0.1	-	-

Nickel carbonyl, as Ni	0.05	0.12	-	-
Nickel sulfide, as Ni	-	1	-	-
Nicotine*	-	0.5	-	-
Nitric acid	2	5.2	4	10
Nitric oxide	25	31	-	-
Nitrogen dioxide	3	5.6	5	9.4
Nitrous oxide	50	90	-	-
Nuisance particulates	-	10	-	-
Octane	300	1400	375	1750
Oil Mist, mineral	-	5	-	10
Ozone	-	-	0.1	0.20
Parathion*	-	0.1	-	-
Pentane	600	1770	750	2210
Perchloroethylene (Tetrachloroethylene)	25	170	100	685
Phenol*	5	19	-	-
Phosgene	0.1	0.40	-	-
Phosphine	0.3	0.42	1	1.4
Phosphoric acid	-	1	-	3
Phosphorus	0.02	0.1	-	-
Phthalic anhydride	1	6.1	-	-
Platinum				
Metal	-	1	-	-
Soluble salts, as Pt	-	0.002	-	-
Portland cement	-	10	-	-
Potassium cyanide	-	-	-	5
Potassium hydroxide	-	-	-	2
n-Propyl acetate	200	835	250	1040
n-Propyl alcohol*	200	492	250	614
Propylene oxide (1,2- Epoxypropane)	20	48	-	-

Selenium and compounds, as Se	-	0.2	-	-
Silica-Amorphous				
Diatomaceous earth (uncalcined)	-	10	-	-
Precipitated silica	-	10	-	-
Silica, fume, respirable dust	-	2	-	-
Silica, fused, respirable dust	-	0.1	-	-
Silica gel	-	10	-	-
Silica-Crystalline				
Cristobalite, respirable dust	-	0.05	-	-
Quartz, respirable dust	-	0.1	-	-
Tridymite, respirable dust	-	0.05	-	-
Tripoli, respirable dust	-	0.1	-	-
Silicon	-	10	-	-
Silver				
Metal	-	0.1	-	-
Soluble compounds, as Ag	-	0.01	-	-
Sodium cyanide	-	-	-	5
Sodium hydroxide	-	-	-	2
Stoddard solvent	100	525	-	-
Styrene, monomer (Phenylethylene, Vinyl benzene)	50	213	100	426
Sulfur dioxide	2	5.2	5	13
Sulfuric acid	-	1	-	3
Talc	-	2	-	-
Tantalum, metal and oxide, as Ta	-	5	-	-
Tetraethyl lead, as Pb*	-	0.1	-	-
Tetrahydrofuran	200	590	250	737
Tetramethyl lead, as Pb*	-	0.15	-	-

Tin	Metal	-	2	-	-
	Oxide inorganic compounds, as Sn	-	2	-	-
	Organic compounds, as Sn*	-	0.1	-	0.2
Titanium dioxide		-	10	-	-
Toluene (Toluol)*		50	188	-	-
Toluene-2,4-diisocyanate (TDI)		0.005	0.036	0.02	0.14
1,1,1-Trichloroethane (Methyl chloroform)		350	1910	450	2460
1,1,2-Trichloroethane*		10	55	-	-
Trichloroethylene		50	269	100	537
2,4,6-Trinitrotoluene (TNT)*		-	0.5	-	-
Tungsten, as W					
	Insoluble compounds	-	5	-	10
	Soluble compounds	-	1	-	3
Turpentine		100	566	-	-
Vegetable oil mists		-	10	-	-
Vinyl chloride (Chloroethylene)		5	13	-	-
Welding fumes		-	5	-	-
Wood dust					
	Hard wood	-	1	-	-
	Soft wood	-	5	-	10
Xylene		100	434	150	651
Zinc oxide					
	Fume	-	5	-	10
	Dust	-	10	-	-
Zirconium and compounds, as Zr		-	5	-	10

Note:

a ppm means parts of the substance per million parts of contaminated air by volume;

b mg/m³ means milligrammes of the substance per cubic metre of contaminated air;

*** means the chemicals can contribute to significant exposure through skin adsorption.**

The following formula can be used to convert mg/m³ to ppm at standard temperature (25°C) and pressure (760mmHg)

$$(\text{ppm}) = (\text{mg/m}^3) \times 24.5 / \text{molecular weight}$$

Odour Thresholds and Irritation Concentrations of Chemicals

Chemical Compound	Low Odour mg/m ³	High Odour mg/m ³	Description of Odour	Irritating Concentration on mg/m ³
Acetaldehyde	0.0002	4	Green, sweet, fruity	90
Acetic acid	2.5	250	Sour, vinegar-like	25
Acetic anhydride	0.6	1.5	Sharp odour, sour acid	20
Acetone	48	1,614	Minty chemical, sweet	475
Acetonitrile	70	70	Ether-like	875
Acrolein	0.05	38	Burnt, sweet	1.3
Acrylic acid	0.3	3	Rancid, sweet	-
Acrylonitrile	8	79	Onion-garlic pungency	-
Allyl alcohol	2	5	Pungent, mustard	13
Allyl chloride	1.4	75	Green, garlic, onion	75
Allyl glycidyl ether	44	44	Sweet	1,144
Ammonia	0.03	40	Pungent, irritating	72
Aniline	0.0002	350	Pungent, amine-like	-
Arsine	0.8	2	Garlic-like	-
Benzene	4.5	270	Sweet, solventy	9,000
Boron trifluoride	4.5	4.5	Pungent, irritating	-
Bromine	0.3	25	Bleachy, penetrating	2
1,3-Butadiene	0.4	3	Mild, aromatic	
n-Butyl acetate	33	95	Fruity	473
n-Butyl alcohol	0.4	150	Sweet	75
Butyl cellosolve	0.5	288	Sweet, ester	-
Butyl cellosolve acetate	0.7	1.3	Sweet, ester	-
Carbon disulfide	0.02	23	Disagreeable, sweet	-
Carbon tetrachloride	60	128	Sweet, pungent	-
Cellosolve	2	185	Sweet, pleasant	-
Cellosolve acetate	0.3	270	Sweet, musty	-
Chlordane	0.008	0.04	Pungent, chlorine-like	-
Chlorine	0.03	15	Bleachy, pungent	9
Chlorine dioxide	0.3	0.3	Sharp, pungent	15
Chlorobenzene	1	280	Sweet, almond-like	933
Chloroform	250	1,000	Sweet, pleasant	20,480
Cresol	0.001	22	Sweet, creosote, tar	-
Cumene	0.04	6	Sharp, aromatic	23
Cyclohexane	1.4	1.4	Sweet, aromatic	1,050
Cyclohexanol	400	400	Camphor-like	200
Cyclohexanone	0.5	400	Sweet, peppermity	100

Diborane	2	4	Repulsively sweet	-
o-Dichlorobenzene	12	300	Pleasant,aromatic	150
p-Dichlorobenzene	90	180	Mothballs	240
Dichloroethane	446	810	Chloroform-like	-
Diethylamine	0.06	114	Fishy, ammonical	150
Diisobutyl ketone	0.7	2	Sweet, ester	150
Dimethyl formamide	300	300	Fishy,unpleasant	-
1,1-Dimethylhydrazine	12	20	Ammonical, amine-like	-
1,4-Dioxane	0.01	612	Ethyl-like	792
Epichlorohydrin	50	80	Chloroform-like	325
Ethanolamine	5	11	Ammonia	13
Ethyl acetate	0.02	665	Fruity, pleasant	350
Ethyl alcohol	0.3	9,690	Sweet, alcoholic	9,500
Ethyl amine	0.5	396	Sharp, ammonical	180
Ethyl benzene	9	870	aromatic	870
Ethyl ether	1	3	Sweet, ether-like	300
Ethyl mercaptan	3×10^{-5}	0.09	Garlic	-
Ethylene diamine	2.5	28	Ammonical, musty	250
Ethylene dibromide	77	77	Mild, sweet	-
Ethylene dichloride	24	440	sweet	-
Ethylene glycol	63	63	sweet	-
Ethylene oxide	520	1,400	Sweet, olefinic	-
Fluorine	6	6	Pungent, irritating	50
Formaldehyde	1.5	74	Pungent, hay	1.5
Formic acid	0.05	38	Pungent, penetrating	27
Furfural	0.02	20	Almonds	48
Hydrazine	3	4	Ammonical, fishy	-
Hydrochloric acid	7	49	Irritating, pungent	49
Hydrofluoric acid	0.03	0.1	Strong, irritating	4
Hydrogen bromide	7	7	Sharp, irritating	10
Hydrogen cyanide	0.9	5	Bitter almond	-
Hydrogen sulfide	0.0007	0.01	Rotten eggs	14
Iodine	9	9	Irritating	2
Isophorone	1	50	Sharp, objectionable	50
Isopropyl alcohol	8	490	pleasant	490
Maleic anhydride	1.8	2	Acrid	6
Methyl acetate	610	915	Fragrant, fruity	30,496
Methyl acrylate	70	70	Sharp, sweet, fruity	263

Methyl alcohol	13	26,840	Sweet	22,875
Methyl bromide	80	4,000	Sweetish	
Methyl cellosolve	0.3	288	Mild, non-residual	368
Methyl cellosolve acetate	1.6	240	Sweet, ester	-
Methyl chloroform	543	3800	Chloroform-like	5,429
Methyl ethyl ketone	0.7	148	Sweet, acetone-like	590
Methyl isobutyl ketone	0.4	193	Sweet, sharp	410
Methyl mercaptan	4 x 10 ⁻⁵	0.08	Sulfidy	-
Methyl amine	0.03	12	Fishy, pungent	-
Methylene chloride	540	2,160	Sweet	8,280
Mineral spirits	157	787	Kerosene-like	-
Naphthalene	1.5	125	Mothball, tar-like	75
Nickel carbonyl	0.2	21	Musty	-
Nitric acid	0.8	2.5	Acrid, choking	155
Nitric oxide	0.4	1.2	-	-
Nitrobenzene	0.02	9.5	Shoe polish, pungent	230
Nitroethane	620	620	Mild, fruity	310
Nitrogen dioxide	2	10	Sweetish, acrid	20
Nitromethane	250	250	Mild, fruity	360
1-Nitropropane	1080	1,080	Mild. fruity	360
2-Nitropropane	18	1,029	Fruity	-
Octane	725	1,208	Gasoline-like	1,450
Ozone	0.001	1	Pleasant, clover-like	2
Pentane	7	3,000	Gasoline-like	-
Perchloroethylene	31	469	Mildy sweet	1,340
Phenol	0.2	22	Medicinal, sweet	182
Phosgene	2	4	Musty hay, green corn	8
Phosphine	0.03	3.6	Decaying fish	11
n-Propyl alcohol	0.08	150	Sweet, alcohol	-
Propyl alcohol	75	500	Sharp, musty	13,750
Propylene	40	116	Aromatic	-
Propylene oxide	25	500	Sweet, alcoholic	1,125

Pyridine	0.009	15	Burnt, sickening	90
Stoddard solvent	5	156	Kerosene-like	2,100
Styrene	0.2	860	Solvently, rubbery	430
Sulfur dioxide	1.2	12.5	Pungent, irritating	5
Sulfuric acid	1	1	-	1.1
Tetrachloroethane	21	35	Sickly sweet	1,302
Tetrahydrofuran	7	177	Ether-like	-
Toluene	8	150	Rubbery, mothballs	750
Toluene 2,4-diisocyanate	3	17	Sweet, fruity, acrid	4
Trichloroethylene	1	2,160	Etheral, chloroform like	864
Turpentine	560	1,120	Pine-like	560
Vinyl acetate	0.4	1.7	Sour, sharp	-
Naphtha	4	4	-	435
Xylene	0.4	174	Sweet	435

Respiratory Protection Programme

These are the key issues which should be included in the respiratory protection programme:

1. Is there a documented respiratory protection programme?
2. Are the respirators in use suitable?
3. Are workers trained in the use and maintenance of respirators?
4. Is fit-testing carried out once every two years?
5. Are medical fitness tests carried out for workers wearing respirators once every three years?
6. Are there signs displayed designating respiratory protection areas?
7. Are there regular inspections and evaluations of respirator usage?
8. Are respirators maintained in good working condition?
9. Are airline respirators used?
10. Is the air supply tested and of suitable quality?

Acknowledgement

Contributors:

Occupational Safety and Health Division, Ministry of Manpower

Mr Tan Kia Tang
Deputy Director (Hygiene)

Miss Oei Hun Ping
Industrial Hygiene Engineer

Mr George Na
Senior Officer

Miss Ng Lee Penn
Industrial Hygiene Engineer

Mr Salim Shaik
Industrial Hygiene Engineer

Mdm Veronica Chow
Industrial Hygiene Engineer

The Division would like to thank the following for their invaluable inputs:

- Committee on Management of Chemical Hazards
- Singapore Confederation of Industries
- National Safety Council of Singapore
- Singapore Institute of Safety Officers