RISK ASSESSMENT OF HAZARDOUS CHEMICALS- A CASE STUDY IN CHEMISTRY RESEARCH LABORATORIES OF USM

By

MAAZZA YOUSUF ABDULAH MOHAMED

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LIST OF ABBREVIATIONS

ACGIH	American Conference of Governmental Industrial Hygienists
AIHA	American Industrial Hygienist Association
ANSI	American National Standard Institute
AS	Australian System
BC	Benzyl Chloride
BMI	1, 1-(Methylenedi-4, 1-phenylene) bismaleimide
Bz	Benzene
C	Ceiling
CAS	Chemical Abstract Service Registry Number
CB	Chlorobenzene
CF	Chloroform
CSDS	Chemical Safety Data Sheet
DA	Degree of Absorption
DAPM	4, 4, Diaminodiphenylmethane
DCP	Dicumyl peroxide
DHB	2,4-di-hydroxybenzaldehyde
DR	Duration Rating
DRs	Degree of Release
ER	Exposure Rating
EU	European Union
HCS	Hazard Communication Standard
HR	Hazard Rating
IARC	International Agency for Research on Cancer
ICS	International Chemical Safety card
ING	Ingestion
INH	Inhalation
IPCS	International Programme on Chemical Safety
LC_{50}	Lethal Concentration

LD_{50}	Lethal Dose
LEV	Local Exhaust Ventilation
MPDA	4-methyl-1, 2-phenylenediamine
MR	Magnitude Rating
MSDS	Material Safety Data Sheet
NIOSH	National Institute for Occupational Safety and Health
OECD	Organization for Economic Co-operation and Development
OEL	Occupational Exposure Limit
OSHA	Occupational Safety and Health Administration
PDA	*o*-Phenylene diamine,
PEL	Permisible Exposure Limit
PPE	Personal Protective Equipment
R	Risk phrase
RR	Risk Rating
RVC	Reticulated vitreous carbon
S	Solubility
SCE	Saturated Calomel Electrode
SK	Skin notation
STEL	Short-Term Exposure Limit
TEOS	Tetraethyl orthosilicate
TLVs	Threshold Limit Values
Tol	Toluene
TWA	Time-Weighted Average
VP	Vapour Pressure
WEEL	Workplace Environmental Exposure Level
WHMIS	Canada's Workplace Hazardous Material Information System

LIST OF UNITS

fpm	Feet per minute
kPa	Kilo pascal
mg	Milligram
mg/L	Milligram per litter
mg/m^3	Milligram per cubic meter
mL	Milliliter
º C	Celsius (degree temperature unit)
ppm	per part of million

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PENILAIAN RISIKO TERHADAP BAHAN KIMIA BERBAHAYA – SATU KAJIAN KES DI MAKMAL PENYELIDIKAN KIMIA DI USM

ABSTRAK

Kajian ini telah dijalankan bagi menilai risiko berkaitan pendedahan para pelajar ijazah tinggi terhadap enam belas jenis bahan kimia berbahaya dalam makmal penyelidikan kimia dalam salah sebuah institut pengajian di Malaysia. Empat pelajar penyelidikan dari Universiti Sains Malaysia, Pulau Pinang melibatkan diri dalam kajian ini. Enam belas bahan kimia berbahaya yang disebut di atas merupakan bahan kimia yang diguna oleh para pelajar beserta dengan bahan kimia lain yang kurang berbahaya yang diguna dalam sepanjang projek penyelidikan mereka. Penilaian ini dijalankan dalam tempoh masa melebihi bulan dan kajian adalah berdasarkan pemerhatian semasa para pelajar menjalankan peyelidikan makmal mereka; sama ada para pelajar tersebut mematuhi peraturan keselamatan serta mengikut langkah keselamatan ang sewajarnya semasa mengendalikan bahan kimia. Antara parameter-parameter primer yang digunakan untuk menganalisis risiko-risiko temasuk pendedahan, kemudaratan serta tahap risiko. Kaedah yang digunakan dalam kajian ini adalah berdasarkan Akta Keselamatan dan Kesihatan Pekerjaan Malaysia (AKKP). Namun demikian, terdapat sedikit pengubahsuaian yang wajar dibuat terhadap AKKP dalam pengiraan tahap pendedahan (ER) dalam kajian ini agar satu kaedah yang lebih efektif dan sesuai dapat diguna dalam menganggar risiko. Langkah yang diubahsuai ini menunjukkan kredibiliti dan kewajaran yang lebih jika dibanding dengan AKKP yang sedia ada kerana anggaran risiko parameter dalam kajian ini adalah berdasarkan faktor fiziko kimia yang mempengaruhi tahap risiko secara langsung. Tekanan wap, dos kematian (LD_{50}) serta keterlarutan dianggap faktor fiziko kimia yang paling efektif dalan penganggaran darjah pelepasan dan

penyerapan bahan kimia. Walaupun tren yang diperolehi melalui parameter fizikal dan tahap risiko adalah hampir sama, akan tetapi keputusan yang diperoleh daripada tekanan wap dan LD_{50} didapati lebih rasional dalam menganggar tahap risiko. Tahap risiko bahan kimia didapati menurun menurut turutan seperti berikut. Natrium Sianida (NaCN) > Benzene (Bz) > Kalium Aurum Sianida ($KAu(CN)_2$) > Benzyl Klorida (BC) > 1-1-(metiledi-4,1-feniline)bismaleimide (BMI) > Toluene (Tol) = Klorobenzene (CB) >4,4 Diaminofenilmetana (DAPM) > Kuprum Nitrate Trihidrat ($Cu(NO_3)_2$) > Tetraetil Ortosilikat (TEOS) > Kloroform (CF) > 1,2 Fenilediamina (PDA) = Asid Sulfurik (H_2SO_4) >2,4 Dihydroksibenzaldehide (DHB) >4-Metil-1,2-Fenildiamina (MPDA) = Salicaldehid. Keputusan hasil kajian ini menunjukkan pelajar penyelidik berkemungkinan terdedah kepada risiko kesihatan yang memudaratkan hasil daripada kesan bahan kimia yang asalnya memudaratkan, kekurangan pengetahuan dalam penggunaan Risalah Data Keselamatan Bahan (MSDS) serta penggunaan alat pelindung keselamatan. Tambahan pula, mereka tidak didedahkan kepada latihan berkaitan kaedah pengendalian serta aplikasi yang betul serta selamat semasa menjalankan kerja-kerja makmal yang selanjutnya menambahkan risiko terhadap kesihatan mereka.

RISK ASSESSMENT OF HAZARDOUS CHEMICALS - A CASE STUDY IN CHEMISTRY RESEARCH LABORATORIES OF USM

ABSTRACT

This study was conducted to assess the risk from exposure to sixteen hazardous chemicals by postgraduate students in chemical laboratories of one of the academic institutions in Malaysia. Four research scholars from Universiti Sains Malaysia, Penang, volunteered themselves for this study. The sixteen hazardous chemicals were handled by the students, along with other less hazardous chemicals, during their laboratory works. The assessment was conducted for a period of more than 6 months, and it was based on observation while the students were performing their normal experimental works i.e. whether they followed the safety parameters and considered the appropriate precautions for handling the chemicals. The primary parameters used to evaluate the risk were: exposure, hazard and risk ratings. The method applied was adopted from Occupational Safety and Health Administration OSHA (Malaysia). However, an appropriate modification was made in OSHA method for the calculation of the exposure rating (ER) in this study, in order to come-up with more effective and adequate method for estimating the risk. The modified method showed more credibility and reasonability when compared to conventional OSHA model because the estimation of risk parameters in this case were based on physicochemical properties which directly influence the risk rating parameters. The vapour pressure (VP), lethal dose (LD_{50}) and solubility (S) were considered the most effective physicochemical properties for estimating the degree of chemical release and the degree of chemical absorbed. Although the trend obtained from these physical parameters and the risk rating were almost similar, but the results attained from vapour pressure and LD_{50} were found to be more rational for estimating the risk rating. The risk rating of the chemicals was found to decrease in the order: sodium cyanide (NaCN) > benzene (Bz) > gold potassium cyanide ($KAu(CN)_2$) > benzyl chloride (BC) > 1,1-(Methylenedi-4,1-phenylene) bismaleimide (BMI) > toluene (Tol) = chlorobenzene (CB) > 4,4-Diaminodiphenylmethane (DAPM) > cupper nitrate trihydrate ($Cu(NO_3)_2$) > Tetraethyl orthosilicate (TEOS) > Chloroform (CF) > 1,2-phenylenediamine (PDA) = Sulphuric acid (H_2SO_4) > 2,4-Dihydroxybenzaldehyde (DHB) > 4-Methyl-1,2-phenylenediamine (MPDA) = Salicylaldehyde. The results of this study indicated that the students could be in adverse health risks due to the nature of hazard of the chemicals, lack of knowledge regarding the use of material safety data sheets (MSDS) and the use of proper safety protective equipments. Furthermore, there was inadequate training on chemical handling or application of the correct safety parameters while doing any laboratory work which increases the risk to their health.

Chapter 1

Introduction

The reduction of hazards improves the safety and quality of life for human and for the environment, these hazards can be minimized through researches that are currently being performed by toxicologists and environmental scientists. Therefore performance of risk assessment of hazardous chemical is an important process to organize the management of hazards of these chemicals.

Chemicals are found in nature in different physical forms like gas, liquid, or solid. These chemicals have many applications in different aspects of life. In particular, they are widely used and handled by human beings in many occupational institutions in areas such as universities, schools, hospitals, factories, companies and even at houses. The hazardous effects caused by these chemicals differ widely according to the types of chemicals. These effects vary from being toxic, corrosive, explosive, flammable, radioactive or reactive.

Poisons and related health effects mainly resulted from the acute and chronic contacts of human to a chemical, either as a pure substance, or as an ingredient in a product. Treatment of these health effects is possible if the entire ingredients in the product are known. However, the knowledge about the ingredients of the chemicals is one of the important basis for poison centres as well as its importance for general risk assessment.

1.1 Risk assessment

According to international organizations such as International Programme on Chemical Safety (IPCS) and Organization for Economic Co-operation and Development (OECD) (2003), risk assessment is a process to calculate or estimate the risk of an agent to a targeted organism, system or population following exposure to that agent. It includes hazard identification, hazard characterization, exposure assessment, and risk characterization. The primary purpose of hazard assessment is to avoid injury and harmfulness as well as to reduce the risk. Ruden (2006) stated that the scientific principle of risk assessment depends on scientific data on exposures and effects, and these data are usually obtained from three main sources: standardized experiments (i.e. animal models), studies of exposed humans (epidemiology data) and from non-standardized experiments (i.e. toxicological research data).

The toxicity assessment is the process of determination of the relationship between the exposure to a contaminant and the increased likelihood of the occurrence or severity of adverse effects to people; this includes hazard identification and dose response evaluation. However, all the data used in hazard identification are derived from animal studies. These studies can only detect risks of the order of 1 percent. In order to extrapolate the data taken from animals exposed to high doses to humans, since humans are exposed to doses several orders of magnitude lower than animals, toxicologists employ mathematical models (Davis and Cornwell 2008). Nevertheless, there are some limitations of animal studies, since no species provides exact duplicate of human response, and only certain effects that occur in common lab animals generally occur in people. Epidemiological study is also used to determine toxicity in human, but it also has limitations because of large population required to detect the toxicological effect and the long latency period between the exposure to the toxicant and a measurable effect.

1.2 Exposure

Public health scientists and physicians are challenged to protect populations from harmful exposures to environmental chemicals and to recognize exposures that are not of health concern. When human beings are exposed to the environmental chemicals, these chemicals will enter the body through different routes of entry. These include inhalation through respiratory tract, ingestion through gastrointestinal tract and dermal contact through the skin. However, the effects of corrosive agents is in the point of entry, while for the other toxic substance the exposure indication to the beginning of the physiological (metabolic) processes of the human body interact to absorb, distribute, store, transform and eliminate of the substance. However, as stated by LaGrega *et al*. (2001), to produce a toxic effect, the chemical or its biotransformation products must reach the targeted organ at a sufficiently high concentration and for a sufficient length of time.

1.3 Chemical mixture

Humans are exposed sequentially to a large number of chemicals by various routes of exposure and from a variety of sources which increases the demand for chemical mixtures assessment. Risk assessments of chemical mixtures or chemical reactions are complex, due to the physical and chemical changes which occur during the formulation or the chemical reactions. The physical transformations, chemical reactions, as well as the processing among ingredients are suspected to modify the characteristic and hazard of the final products of the mixtures (Hamilton *et al*. 2006).

The classification of chemical mixtures has been established by different systems such as the European Union (EU), Australian Systems (AS), Occupational Safety and Health Administration (OSHA) and Canada's Workplace Hazardous Material Information System (WHMIS). The EU and AS classifications depend on the variation of the components and their concentration in the mixture, therefore it was found that hazard of mixtures decreases with the decrease in concentrations of the component. While OSHA and WHMIS established that the presence of a hazardous component of 1% and above makes the overall entire mixture hazardous with similar classification of the contributing individual component (Ignatowski *et al.* 1995).

1.4 Objective

This research was conducted in chemical research laboratories at USM (Malaysia) to study the risk of using 16 hazardous chemicals by four postgraduate students. However, the primary objectives of the study are:

- To determine the risk rating of using hazardous chemicals and the effects of these chemicals to the users.
- To estimate the risk rating caused by handling hazardous chemicals in the workplace.
- To suggest suitable actions need to be taken to reduce the estimated risk.

Chapter 2

Literature Review

2.1 Use of chemicals in higher institution

Education is a continuous process that transforms the level of knowledge and wisdom of individuals and involves the learning as well as the teaching processes. However, the accelerated changes in society and technology add a new design of education. Chemistry is widely taught in higher schools, colleges and universities. It includes theory as well as practical experiments in the laboratories. These experimental practices are targeted for educating students in solving problems in industry or research studies. The practical experiments involve the use of chemicals compounds with a wide range of classes and toxicity (Anastas and Warner 2005). The use of chemicals requires understanding of what makes these chemicals dangerous, as well as appreciative of acute and chronic hazards (Fivizzani 2005). The ability of a chemical to affect the body as noted by Blaauboer (2003) depends on the route of exposure, the quantity (or concentration) of the chemical, the way in which the compound is taken up, distribution and elimination from the organism.

Research students in universities and higher institutes use many chemicals for their experimental work, and also organic solvents are extensively used in these academic laboratories. In addition, the organic solvents are employed in a wide variety of applications in industrial processes as well as commercial household products. They are being used for the dissolution of one substance of a mixture or as a feed stock for the production of synthetic compounds. The exposure of users to organic solvents can cause many health hazards including the central nervous system toxicity and respiratory effects (Schenker and Jacobs 1996).

2.2 Handling of chemical

Protection of students or any chemical users from exposure to hazardous chemicals depends on handling of chemicals in laboratory. Important information about handling chemicals can be found in Material Safety Data Sheets (MSDS), which is available for all chemicals (Foster 2007) and should be kept in laboratory to be used before handling any hazardous chemicals. Moreover MSDS explains the inhalation and contact health risks as well as the flammability and toxicity of the chemicals.

The exposures of students to chemicals should be kept to a minimum level to avoid hazards; however traditional risk assessment as well as monitoring should be employed to prevent extreme exposures (Fivizzani 2005), in addition to apply the correct type of personal protective equipment (PPE) and the use of fume hood. On the other hand elimination or substitution of hazardous chemicals can also reduce the risk (Elston 2000). Furthermore, the chemicals of unknown toxicity should be treated as toxic with respect to exposure during laboratory work and appropriate precautions should be taken by taking into consideration the risk of most toxic chemical in the mixture. However, students should avoid skin contact with chemicals and they should wash the exposed skin and hands as well as removing all the protective clothes before leaving the laboratory. In addition, students must avoid eating, drinking and smoking inside the laboratory (Wickman *et al.* 2007).

On the other hand, chemical safety should be an inherent value for every working chemist graduates in schools and colleges. The students should bring with them strong safety ethics and should be educated in hazard recognition, risk assessment, risk control and risk management. Further, the safe method of using chemicals in any laboratories depends on the teaching of chemistry in the undergraduate level (Hill 2003; Penas *et al.* 2006). Senkbeil (2004), Hill and Nelson (2005), Hendershot *et al*. (1999) and Nelson (1999) suggested that adding a safety course in chemistry curriculum will increase the students knowledge and thinking about the safe usage of chemicals in laboratories. It was also pointed out by Foster (2003) and Foster (2007) that periodical inspections of laboratory will enhance the safety program in academia.

2.3 Permissible Exposure limit (PEL)

An exposure limit is the concentration of a chemical in the workplace air to which most workers may be repeatedly exposed without adverse health effects. Permissible exposure limit is a guideline for determining the toxicity of the substance. As stated by Cote *et al*. (1998) and Liu and Wai (1996) there are many organizations which published PEL values based on past experience and laboratory testing data.

Threshold limit values (TLVs) are exposure guidelines developed by the American Conference of Governmental Industrial Hygienists (ACGIH). Permissible exposure limits (PELs) are legal exposure limit in the United States, from the Occupational Safety and Health Administration (OSHA) and Workplace Environmental Exposure Level (WEEL) from the American Industrial Hygienist

Association (AIHA) are some well-recognized exposure guidelines in industrial hygiene applications. However, there are three different types of exposure limits in common use:

1) Time-weighted average (TWA) exposure limit is the time-weighted average concentration of a chemical in air for a normal 8-hour work day to which nearly all workers may be exposed day after day without harmful effects.
2) Short-term exposure limit (STEL) is the average concentration to which workers can be exposed for a short period (15 minutes) without experiencing irritation, long-term or irreversible tissue damage.
3) Ceiling exposure limit (C) is the concentration which should not be exceeded at any time.

2.4 Lethal Concentration (LC_{50}) and Lethal Dose (LD_{50})

Lethal Concentration (LC_{50}) is a value usually refers to the concentration of a chemical in air but in environmental studies it can also means the concentration of a chemical in water. For inhalation experiments, LC_{50} is the concentrations of the chemical in air that kills 50% of the test animals in a given time usually for inhalation four hours and for water 96 hours. It is usually expressed as parts per million (ppm) or milligrams per cubic metre (mg/m^3) and the duration of exposure should be stated (Ecobichon 1992).

Lethal Dose (LD_{50}) is the amount of a material, given all at once, which causes the death of 50% of a group of experimental animals, often testing is done with rats and mice in the first 24 hours period. The LD_{50} is designed to measure the acute toxicity of a material. It is usually expressed as milligrams of chemical per kilogram of body weight. The LD_{50} can be found for any route of entry or administration but dermal which applied to the skin and oral (given by mouth) administration methods are most common (Ecobichon 1992). However, the smaller LD_{50} value illustrates more toxicity of the chemical.

2.5 Material Safety Data Sheet (MSDS)

A Material Safety Data Sheet (MSDS) is a document that contains information on the potential health effects of exposure and how to work safely with the chemical product. It is an essential starting point for the development of a complete health and safely program. It contains hazard evaluations on the usage, storage, handling and emergency procedures all related to that material. MSDS also contains more information about the material than the label of that material (Greenberg *et al*. 1996).

Material Safety Data Sheets are regulated by the Occupational Safety and Health Administration (OSHA) through the Hazard Communication Standard at 1986 (HCS 1986). The OSHA standard stipulates that the MSDS must report the physical and chemical characteristics of the product, precautions for a safe product handling, and health hazards from exposure to the product. However, as stated by Foster (2007) the American National Standard Institute (ANSI) established 16 standard sections of MSDS format (Appendix B) which are:

1. Material identification.
2. Composition.
3. Hazards identification.
4. First aid measures.
5. Fire fighting measures.

6. Accidental release measures.

7. Handling and storage.

8. Exposure controls and personal protection.

9. Physical and chemical properties.

10. Stability and reactivity.

11. Toxicological information.

12. Ecological information.

13. Disposal consideration.

14. Transport information.

15. Regulatory information.

16. Additional information.

Studies in a group of engineering students for the purpose of determination of the accuracy of information retrieval was done by Lehto (1998), he found that material safety data sheets is more useful in getting the information compared to the easy access to the chemical labels. While Bluff (1997) considered that the availability of MSDS was high in South Australia workplace, more than half of the workers in his study had accessed to the MSDSs for the hazardous chemicals they used, whereas the MSDSs for the rest of the workers were not available.

Other studies on workers understanding and acceptability of MSDS found that most of the workers reported that it is acceptable and easily accessible, while the rest of them disagreed that MSDS is easy to read and understand. Further, they have not been asked to see it during working with chemicals as noted by Phillips *et al*. (1999). In addition, the MSDS in some workplaces were not requested at the time of receiving the chemicals or kept on the workplace due to the lack of knowledge and understanding of the MSDS, as well as the use of difficult words in the MSDS (Seki *et al.* 2001). However, there are four major limitations of MSDSs as suggested by Bernstein (2002):

- Elimination of basic information regarding the general chemical names and formulas of hazardous agents.
- Omission of the listing of potential respiratory and skin sensitizing agents that are known to induce reactions through a specific immune response.
- Failure to update current permissible exposure levels (PELs) for many agents that are higher than the PELs set by OSHA in 1989.
- Failure to require documented clinical information regarding specific occupational lung diseases (occupational asthma) associated with a specific agent is also a major limitation.

Greenberg *et al*. (1996) reviewed the MSDS from the physician point of view and confirmed that the MSDS is a useful source of information to treat patients who are exposed to hazardous chemical, but it also has limited information for the emergency physician. However, the accuracy and completeness of MSDS documents has been studied by several investigators (Kolp *et al.* 1995; Kolp *et al.* 1993). Frazier *et al*. (2001) suggests that investigation of the accuracy of health information on MSDSs for hazardous chemicals and periodic review of MSDSs also required every two years.

The purpose of a MSDS is to tell the physical properties or fast-acting health effects that make it dangerous to handle, the level of protective equipment needed, the first aid treatment is to be provided when exposed to a hazard, the preplanning needed for safely handling spills, fires, and daily operations and how to respond to accidents (Greenberg *et al.* 1996). Noteworthy, there has been little research on MSDSs in last years, most of them in workplaces and a few in academic areas.

2.6 Steps to minimize the exposure and control hazards of chemicals

There are different steps to minimize the exposure to chemicals and control the hazards; these include the personal protective equipment, the engineering control equipments as well as the availability of the first and initial medical aids.

2.6.1 Personal protective equipment (PPE)

Personal protective equipments (PPE) are clothing or devices worn to help isolating a person from direct exposure to a hazardous materials or situations and reducing the illnesses and injuries. They are used in many occupational environments to protect employees and they were found on a variety of brands. Chemical protective equipments are recommended to be used by all personnel who work in the laboratory and are often listed on Material Safety Data Sheet (MSDS).

Some types of protective clothing were disposable, while the rest were reusable depending on durability and cost. The clothing and suit materials were made from both natural and synthetic materials such as latex, cotton and neoprene (Henry 2007). Although, a major factor for failure of worker to use PPE during their work, is lack of its comfort. Akbar Khanzadeh and Bisesi (1995) reported that the workers feel a high degree of discomfort while using their PPE due to the added weight, improper fit, out of fashion style or colour and some times limiting the movements of the worker.

However, PPE should not be used as an alternative for engineering controls or work practice; rather it should be used in conjunction with these controls to provide the employee safety and health in the workplace (Blais1999a). On the other hand, PPE lose its proper functionality after being used for long time and hence it can not perform the anticipated job. Moreover, storage conditions and the manufacturer expiration date also influence the efficiency of PPE (Wood-Black & Pasquarelli 2007).

The subsequent subsections discuss the major PPE which are recommended to be used by any chemical user. These equipments include body protection, respiratory protection, hand protection as well as eye and face protection equipments.

2.6.1.1 Body protection

Protection of human body and clothes from corrosive chemicals splash are made by using body protection clothes. Such protection like lab coats, aprons and coveralls are well known body protection materials. However, in academic laboratories students were given lab coats or asked to purchase it for the required laboratory courses (Manufacturing Chemists Association 1972).

The common one is disposable coveralls and has a various grade depending on the level of protection needed. However, the most common material for disposable coveralls is Tyvek, which normally protects against dry chemicals. But Tyvek or polyvinyl chloride (PVC) or its equivalent is needed when more hazardous chemicals are used whereas the disposable garments reduce the potential of contamination from reuse (Henry 2007). Aprons are generally used when mixing chemicals to protect against chemical splashes; they are commonly made of nitrile, PVC, or other resistant materials and are less likely to be considered as disposable items (Purschwitz 2006).

2.6.1.2 Respiratory protection

Respirators are used to provide protection against hazard from exposure to chemicals vapours and fumes. They are classified into two categories: air purifying respirators, and atmosphere supplying respirators. An air purifying respirator protects the user by removing the contaminants from inhaled air, while atmosphere supplying respirators provides the user with a supply of air or oxygen (Hodson *et al.* 2002). Chemical respirators have a cartridge of activated carbon and have standard colour code for ease of identification; it is black for organic vapours (Purschwitz 2006).

2.6.1.3 Hand protection

Gloves are one of the means of protection against exposure to hazardous chemicals during the handling of these chemicals in the workplace; however the protection level depends on the selection and use of the right type of protective gloves. Chemical resistant gloves are commercially made of polymeric materials such as nitrile and neoprene. However, nitrile gloves are suitable for solvents, whereas vinyl gloves are good for peroxides and amines. Polychloroprene is protecting against peroxide, alcohols and phenols. Whereas, polyvinyl alcohol glove type is good for the protection against aromatics and chlorinated solvents, ketones and esters. Viton is protecting from exposure to chlorinated and aromatic solvents, aliphatics and alcohols while the butyl gloves are used for ketones, aldehydes and esters. (Kwon *et al.* 2006)

2.6.1.4 Eye and face protection

Eyes are extremely sensitive and require protection. Many types of glasses even ordinary glasses are better than no glasses at all, while the use of contact lenses in the laboratory is prohibited. Several varieties of chemical splash goggles exist and are suitable for protection in laboratory, while the face shields completely covering the front of the face also provides protection if needed. However, the visitor's goggles are a form of eye protection that must be worn by the visitors while they are in the lab (Green and Turk 1978, Manufacturing Chemists Association 1972).

2.6.2 Engineering Control Equipments

Control equipment is equipment used for controlling risks such as safety showers and eye wash stations, fire extinguisher, general ventilation and local exhaust ventilation system.

2.6.2.1 Safety showers and eye wash stations

Safety showers and eye wash stations are an emergency facility which should be available in every chemical laboratory. It is used by laboratory workers in case of splash of toxic or corrosive chemicals or fire. However, the easy access to the safety showers and eye wash station and clear signal is important to treat the affected laboratory workers (Green and Turk 1978). An eye wash stations or safety shower should deliver automatically a copious and continuous stream of water once turn on and the temperature of the water should be kept within a comfortable range, since high temperature may increase absorption of chemicals.

However, for the eyewash units, a frequent water replacement or weekly flushing for a minimum of three minutes should be done (Walters 2000) to remove the harmful micro organisms from the units which can cause severe infection and loss of sight (Stricoff and Walters 1990). Several researches have been published about microbial contamination in eyewash stations and explained that routine flushing is not sufficient to control microbial contamination; also disinfection should be included in a routine maintenance program. Regular maintenance, disinfection, and monitoring of emergency eyewash and shower stations are important in preventing potential microbial infections (Paszko- Kolva *et al*. 1998)

The location of the eye wash and safety shower should be near to the laboratory exits (Green and Turk 1978) or close to the hazardous materials using area (Stricoff and Walters 1990) and the floor should slope towards a drain. Whereas an emergency blanket should be available near the shower to prevent from shock and cover the place for removal of clothes.

2.6.2.2 Fire extinguisher

Fire extinguishers are important items of safety equipment used to prevent life and property losses caused by fires. However, there are four classes of fire that can occur in the laboratories (Stricoff and Walters 1990; Thomson 2001):

Class A: Fires involving solid materials (Combustible material such as wood, cloth, paper, rubber, plastic).

Class B: Fires involving liquids or liquefiable solids (oil, greases, flammable gases).

Class C: Fires that are generated by energized electrical equipment.

Class D: Fires in combustible metals such as magnesium, zirconium, sodium, lithium, potassium etc.

Although understanding the type of fire hazard is important for the choice of fire detection and suppression equipment; however, the extinguisher should be located in accessible area, suitable type and size of extinguisher should be selected and also need to consider the strength of personnel who might use it in case of fire.

While the extinguisher should be located near any place containing hazard and installed not more than 5 ft above the floor with its operating instructions on the front of it. On the other hand, regular inspection and maintenance of extinguishers should be conducted to insure that they have been placed and worked properly. However, unification of risk phrases is important in dealing with chemical fire hazard. It is important to note that the knowledge about the chemical safety card is demanded particularly for the chemical that it is highly flammable or explosive because it contains main and effective information to help the users and fire fighters to choose suitable extinguishing agent (Zawierko 1996).

2.6.2.3 Ventilation

Ventilation is the movement of air and the main purpose of ventilation is to remove contaminated air from the workplace. Ventilation systems in laboratory protect people inside the laboratory from exposure to chemicals. The well designed and maintained ventilation systems can remove flammable vapours from the workplace and reduce the risk of fire and health problems. Moreover, they are considered a disposing route for unwanted materials. The unit for measuring ventilation is air changes per hour. Whereas, chemical laboratories require about 10 air changes per hour, a chemical preparation room requires about 12 to 15 air changes per hour. The main purposes of general ventilation in laboratory is to replace stale air and dilute offensive odours, remove heat, remove water vapour and prevent condensation and dilute harmful vapours and poisonous chemicals (Pitt and Pitt 1985). Normally, there are two common systems of ventilation these are general ventilation and local exhaust ventilation. However, these ventilation systems can be operated naturally through the natural moving wind or mechanically by using any of air moving devices such as ceiling fans, exhausting fans, etc. However, the mechanical means of ventilation are the most likelihood applied when handling hazardous chemicals because they are highly efficient.

2.6.2.3.1 General ventilation

General ventilation is the removal of contaminated air from the general area and bringing in a clean air. This dilutes the concentration of contaminant in the work environment. The general ventilation is usually suggested for non-hazardous materials as well as for controlling humidity and temperature.

2.6.2.3.2 Local exhaust ventilation

Local exhaust ventilation is the removal of contaminated air directly at its source. This type of ventilation can help to reduce the exposure to airborne materials more effectively than general ventilation because it does not allow the material to enter the work environment. It is usually recommended for hazardous airborne materials.

Laboratory chemical hoods are local ventilation systems which are operated mainly through the mechanical means of ventilation. These hoods are also one of the most important engineering controls designed to protect laboratory workers from hazardous chemical inhalation exposure. However, there are variety of hood systems found in different laboratories such as chemical, biomedical, pharmaceutical, micro-electronic, academic and government research laboratories, while the protection of people working with hazardous materials ranging from negligible to immediately dangerous to life and health (Smith 2004).

American National Standard Institute (ANSI) reported the average face velocities of chemical hoods are ranged from 80 to 120 ft per minute (fpm) with 100 fpm being an appropriate value for laboratory ventilation (Deluga 2000, Diberardinis 2002). In addition to regular periodic monitoring and annual maintenance, all tests should be documented, especially if corrosive or hazardous materials are concerned (Diberardinis 2002, Stricoff and Walters 1990, Klein *et al.* 2003). Moreover, the fume hood should be used only for experiments; it is neither being used for storage nor for sharing. It is also reported that the excess numbers of fume hoods in particular lab do not improve the safety rather than the efficiency of the fume hood (Mathew *et al.* 2007).

The concentration of the vapour inside the hood which is released from volatile liquid spills of organic solvents was studied by Klein *et al.* (2004) and was found dependent on the solvent vapour pressure. Notable, it is expected that future laboratory chemical fume hoods will be safer, computerized, better in controlling the airflow and the level of contaminants. Moreover they are expected to be more automated (Walters 2001).

2.6.3 First aid

As defined by OSHA (Blais 1999a), first aid is the emergency treatment of injuries before regular medical care is available. Although over many years only few reports were published for first aid treatments, but useful and effective information for each chemical can be found in MSDS.

There is universal agreement that the best response to chemical exposure for eyes and skin is the immediate irrigation with large volumes of water. It was reported by Segal (2007) and Blais (1999b) that for skin and eye exposures, the past and present standard first aid is to flush the infected areas with copious amounts of water for 15 min and then seek medical attention. Clark (2002) reported that the washing of the eye with water should be started within seconds, even before calling for emergency assistance because chemical injury to the eye is serious and potentially threatening to vision and it should be followed by complete medical evaluation for every chemical eye injury.

2.7 Chemical storage

Chemicals should be separated and stored according to hazard category and compatibility in order to prevent laboratory workers and students form the risk of these chemicals. Moreover, when purchasing the chemical, it is always preferable to buy the requested quantity to avoid the hazard effects from storing the extra chemical, saving the spaces in the storage room and to minimize the waste to the lowest possible level. On the other hand, storing chemical needs a good understanding about its hazard.

Becker and Elston (2004) conducted a surveying study for storing hazardous chemicals in secondary schools. He concluded that the chemical storages in these schools were inappropriate and therefore, high percentages of chemical reagents increase the severity of the risk through accidental reactions.

Sarquis (2003) and Hill (2003) reported that it is the responsibility of the teachers and the supervisors to teach the student about proper chemical storage, as well as to enhance their safety knowledge. Cournoyer *et al.* (2005) illustrated that the easy way to develop chemical storage is to use the chemical inventory software programs which can organize the chemicals according to their compatibility and minimize the hazard. However, the efficiency of this software depends mainly on the accuracy of input data. Moreover, Gibbs (2005) reported that such systems can organize hazard reports and offer MSDSs, besides it can also show the chemical expiration date.

There are many concerns in the literature regarding ventilation of the chemical storage room because the ventilation can reduce the hazard associated with storing some chemicals such as flammable liquids. In addition, good ventilation can also eliminate odour of some volatile hazardous chemicals (Simmons *et al.* 2008).

As mentioned previously, chemicals should not be stored in the fume hood because they can interrupt proper airflow in the fume hood and hence increase the risk of personal injury or property damage in the event of a fire explosion within the hood. Moreover, chemicals should not also be stored on the lab floor, hallways or on the bench tops. In addition, the storage should be away from heat and direct sunlight. However, good chemical storing process includes the proper labelling of all chemical containers then storing them in a well ventilated storage room. In case of chemical being transferred to a second container, secondary container label should contain the chemical name, hazard warning, manufacturer's name, the name of the researcher in charge and the date of the transferring to the new container. On the other hand, the condition of the containers in the storage area should be checked frequently and the damage ones have to be removed to prevent or minimize the occurrence of hazard as well as saving spaces (Manufacturing chemists association 1972).

However, to avoid accidents, chemicals should not be stored in five feet height open shelves and chemical resistant trays should be used where appropriate. Laboratory-grade explosion-proof refrigerators and freezers should be used to store chemicals which require cool storage. Nevertheless, the domestic refrigerators can possess ignition sources and cause dangerous fire and explosions. It is also important to note that chemical laboratory refrigerators should not be used as storage for food and beverages (Foster 2005).

2.8 Biomonitoring

Biomonitoring is an abbreviation for biological monitoring, which is defined as the assessment of human exposure to environmental chemical via the measurement of its metabolites or reaction products usually in human blood and/or urine. It could also be detected in the tissues of individuals. However, this measurement of the biomarker of exposure to a chemical is often linked to the concentration of the internal dose (Needham *et al.* 2007). On the other hand, the availability of a particular environmental chemical in blood or urine does not mean that it can cause disease, but rather this is dependent on the exposure level of this chemical in blood or urine.

It was reported by Needham *et al.* (2005) that the environmental chemicals can enter the body through ingestion, inhalation as well as dermal contact, and then absorbed into the blood stream and this followed by possible metabolism and distribution within the body.

The metabolites of some environmental chemicals, which are used in this research, are reported here as examples and to indicate for the expected influences caused from exposing to these chemicals. However, actual biomonitoring approach for the chemicals under study was not conducted in this project.

2.8.1 Benzene

The tests for compounds produced through the metabolism of benzene, which has been entered to the human body by any means of exposure, illustrated the presence of many compounds. In urine, S-phenylmercapturic acid and trans-muconic acid could be detected for benzene exposures as low as 0.1 ppm. The urinary benzene is excellent biomarker and showed a relationship with airborne benzene at all levels of exposure studied including 0.1 ppm benzene. Hydroquinone and phenol are also used for bio-monitoring of benzene exposures but they are not good markers below 5 ppm (Bird *et al.* 2005).

2.8.2 Toluene

The bio-monitoring of toluene after human exposure, followed by metabolism in human body was studied by several researchers. These studies found that the hippuric acid, which is the main result from toluene metabolite, was a marker for estimating individual exposure in the shoe and footwear industry as they are extensively using toluene and other organic compounds. Also this hippuric acid is good marker even at lower concentrations of toluene and in organic chemical mixtures. Beside the hippuric acid, the workers also showed a reduction in blood haemoglobin levels (Pitarque *et al*. 1999, Vanina *et al*. 2007).

2.8.3 Benzyl chloride

Biotransformation of benzyl chloride by means of its metabolism was studied by Ryan *et al*. (1995). They detected benzyl glutathione conjugate (IV) through the NMR techniques from the biliary excretion. They reported that benzyl chloride is a compound that is easily converted to benzyl-glutathione conjugate in the liver. Nevertheless, many xenobiotic undergo biotransformation in the liver before excreted through the bile, but the benzyl chloride is excreted at a relatively high concentration in comparison to these components.

2.8.4 Chlorobenzene

The metabolism of chlorobenzene mainly gives the chlorobenzene-3, 4-epoxide and 2, 3-epoxide. These epoxides later rearrange to chlorophenols. Moreover, the