A HEALTH HAZARD EVALUATION OF WORKERS EXPOSED TO SOLVENTS DURING THE RE-FURBISHING OF CHEMICAL RAIL-TANKERS

H.W. VERGOTINE Hons. B.Sc. (Med)

Dissertation submitted in partial fulfilment of the requirements for the degree Magister Scientiae in Occupational Hygiene at the Potchefstroomse Universiteit vir Christelike Hoër Onderwys

Supervisor: **Mnr. M.N. Van Aarde**
Co-supervisor: **Mnr. V. Yousefi**

2003

Potchefstroom

ACKNOWLEDGEMENTS

I would like to thank my supervisors, Mr. M.N. van Aarde from the Potchefstroomse Universiteit vir Christelike Hoër Onderwys and Mr. V. Yousefi from the National Institute for Occupational Health, for their patience, encouragement, time and support given during the study.

The workers from the different companies that participated in the study deserve thanks for their willingness to give up their time to answer questions, as well as, allowing me to taking photographs, biological and personal air samples.

The management from the various companies needs to be thanked for allowing access to the work areas, and allowing the study to be undertaken.

I would also like to thank my previous Head of Department, Mr. V. Yousefi, for making special arrangements for me to undertake this study and to complete the degree, and my colleagues for being patient and showing support. A special thanks to all the staff at NIOH, for their assistance and advice and in particular to Kalavati Chana for conducting the analyses of all samples collected.

Very special thanks to my wife, Glynnis, for her tolerance, support, interest and belief in my abilities to complete this course.

ABSTRACT

This study was aimed at evaluating the health hazards of workers exposed to solvents during the re-furbishing of chemical rail-tankers. The process of re-furbishing comprises of three main and sub processes that requires the application of three different solvent products at various time intervals. Two of the three main processes were conducted within the tanker, defined as a confined space, and the third was conducted on the dome area, situated on the outside middle top area of tanker. The main chemical composition of the solvent products used included; xylene, toluene, trichloroethylene, methylene chloride, methyl ethyl ketone (MEK) and petroleum solvent.

Various different combinations of chemical compositions, per solvent product, were found. During the assessment of the solvent exposures, as prescribed by the National Institute for Occupational Safety and Health Manual of Analytical Methods (NIOSH Manual of Analytical Methods)[7], results for both personal and environmental / area air samples were found to be in violation of the occupational exposure limit (OEL) for mixtures, as it has exceeded the unity of one (1). This result was further supported by the high urine content of biological markers, which are reflected in the biological exposure index, for the majority of solvents.

The most frequent complaints experienced among the majority of exposed workers included; headaches, dizzy spells, a feeling of fatigue, drunkenness and eye irritation. A lesser percentage experienced nausea (feeling like vomiting), had a sense of irritability and breathing problems. Control measures, aimed at limiting exposures, were found to be inadequate or non-existent as some workers indicated that they were required to purchase their own personal protective equipment. No training or awareness in the safe use, handling, storage and associated health effects has been provided to workers exposed to solvents.

The study highlights numerous limitations and concerns, which sets the platform for future studies within similar work environments.

OPSOMMING

Hierdie studie is daarop gemik om die gesondheidsrisiko te evalueer waaraan werkers blootgestel word as hulle tydens die opknapping van chemise spoortenkwaens met oplosmiddels werk. Die opknappingsproses bestaan uit drie hoof- en sub-prosesse, waarvoor drie verskillende oplosmiddels op verskillende tye aangewend moet word. Twee van die drie hoofprosesse vind binne-in die tenkwa plaas, wat as 'n beknopte ruimte gedefinieer is, terwyl die derde bo-op die koepel aan die buitekant van die boonste gedeelte van die tenkwa plaasvind. Die chemiese samestelling van die oplossmiddels was hoofsaaklik die volgende: xileen, toluene, trichloro-etileen, metileenchloried, metiel-etielketoon (MEK) en petroleum oplossmiddel.

Verskillende kombinasies van chemiese komposisies is vir elke oplosmiddel gevind. Tydens die evaluasie van die blootstelling aan oplosmiddels, soos deur die Nasionale Instituut vir Beroepsveiligheid en Gesondheid se Handleiding vir Ontledingsmetodes (NIBVG- Handleiding vir Ontledingsmetodes) [7] voorgeskryf, is gevind dat die resultate vir die persoonlike sowel as die omgewingslugmonsters / area meer as 'n enkele eenheid (1) – en dus bo die blootstellingsgrens was. Hierdie resultate is verder gesteun deur die hoë inhoud van biologiese merkers in die urienmonsters, wat vir die meeste oplosmiddels in die biologiese blootstellingsindeks aangedui word.

Die mees algemene klagtes van die meerderheid blootgestelde werkers het die volgende ingesluit: hoofpyn, duiseligheid, 'n gevoel van moegheid, 'n dronk gevoel en oogirritasie. 'n Kleiner persentasie het naarheid, 'n gevoel van geirriteerheid en asemhalingsprobleme ondervind. Beheermattreëls wat daarop gemik is om blootstelling te beperk was ontoereikend of het glad nie bestaan nie en sommige werkers het aangedui dat hulle hul eie persoonlike beskermingstoerusting moes koop. Werkers wat aan oplosmiddels blootgestel is, het geen gebruiks- of bewustheidsopleiding in die veilige gebruik, hantering, bewaring en verwante gesondheidseffekte ontvang nie.

Die studie beklemtoon talle beperkings en probleme wat as basis vir toekomstige studies in soortgelyke werksomgewings kan dien.

TABLE OF CONTENTS

CHAPTER 4

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Millions of workers are exposed to solvents on a daily basis. Solvents constitute an indispensable ingredient of modern living. The principal classes of components are the chlorinated and non-chlorinated hydrocarbons. The major routes of absorption of these compounds are through the lungs and the skin[1].

Solvents are used in a wide range of industries that includes construction, maritime, retail, general industry, etc. They are used in the extraction of fats and oils, in degreasing, in dry cleaning and in the manufacture of many items including paints, varnish, lacquers, paint removers, plastic, adhesives, textiles, impregnation agents, printing inks, rubber products, floor polishes, and waxes[2]. It has been estimated that in 1981 there were approximately 350 different solvents commonly used in the United States[2]. The National Institute for Occupational Safety and Health (NIOSH) estimates that there are almost 10 million workers potentially exposed to organic solvents in the workplace, and that this number is likely to increase over time[3].

This study is a health hazard evaluation of workers' exposure to solvents, which are used while refurbishing chemical rail-tankers. This refurbishing activity can be categorized into three main processes and three-sub processes (A more detailed discussion about the processes and sub-processes will follow). The following are the main processes of the refurbishing activity:

- full reline,
- patch work, and
- dome work.

The three sub-processes are similar for all the main processes, and they are the following:

- smearing tank,
- smearing rubber panels, and
- stitching rubber panels.

Each main process, coupled with its sub-processes, requires the application of various solvents at various time intervals. These solvents, listed by their product name, main composition of ingredients, main process and sub-process are presented in the following table:

Table 1.1 Product name, its main composition of solvents used during the main process and the corresponding sub-process

PRODUCT NAME	MAIN COMPOSITION	MAIN PROCESS	SUB PROCESS
TY-PLY UP	• Methyl ethyl ketone (MEK); • Xylene	Full reline	Smearing tank
TY-PLY RC	• Petroleum solvent; • Xylene	Full reline	Smearing tank
CHEMLOCK 286	• Toluene	Full reline	1. Smearing tank; 2. Smearing rubber panels; 3. Stitching rubber panels
TY PLY 2033	• Trichloroethylene; • Methylene Chloride; • Toluene	Patch and Dome Work	1. Smearing tank; 2. Smearing rubber panels; 3. Stitching rubber panels
WD 473 & 472	• Methyl ethyl ketone; • Toluene	Patch and Dome Work	1. Smearing tank; 2. Smearing rubber panels; 3. Stitching rubber panels

Objectives

Objectives of study was five fold:

- To identify and list all solvents used in the refurbishing process;
- To define the toxicity and health effects of solvents;
- To assess workers' exposure by means of personal monitoring, environmental / area sampling and biological monitoring;
- To determine health effects of solvents exposure by biological monitoring and administration of a health questionnaire, and
- To prescribe a safe operational procedures for refurbishing.

Research questions

- What are the solvent concentration, which workers are exposed to while performing a refurbishing task;
- Are workers, currently engaged in the process of re-furbishing, being exposed to chemical stress higher than those prescribed by the Regulations for Hazardous Chemical Substances, Government Notice R.1179 of 25 August 1995[11b];
- Can any health deficiency correlation be drawn from the results obtained of the air and urine samples as well as those from the self-administrated health questionnaires.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

Many individual solvents or groups of solvents have unique properties, there are also common chemical, physical, and biological features shared by large numbers of solvents[4]. Due to this it is possible and prudent to develop and implement control strategies aimed at reducing inhalation and skin contact to solvents in general. In addition many solvent groups or individual substances have special properties requiring more specialised control measures.

2.1.1 Health effects

There are both acute and chronic health effects associated with the exposure to solvents.

2.1.1.1 Acute effects

Acute effects of solvent exposure are usually reversible and generally dependent upon the concentration levels. Symptoms frequently disappear, following an exposure free interval. Exposed employees often report feeling better on their days off when they are away from workplace and exposure[5]. Commonly reported acute symptoms are:

- Headaches;
- Dizziness;
- Fatigue;
- Tingling;

- Vomiting;
- Feeling of being drunk;
- Memory problems;
- Concentration problems;
- Depression;
- Anxiety;
- Irritability;
- Eye irritation, and
- Breathing problems.

2.1.1.2 Chronic effects

Chronic effects are more serious and even permanent conditions can occur with long term solvent exposure[5]. Chronic health effects most typically associated with organic solvents exposure include nervous system damage (central and peripheral), kidney and liver damage, adverse reproductive effects such as sperm changes and infertility, skin lesions, and cancer[4]. Individual solvents may cause one or more of the following:

- Solvents that may cause damage to the nervous system include n-hexane, perchloroethylene, and n-butyl mercaptan etc.[6];
- Solvents associated with liver or kidney damage include toluene and carbon tetrachloride, 1.1.2-2-tetrachloroehtane, chloroform etc. [6];

- Solvents known or thought to pose reproductive hazards include, 2-methoxyethanol, 2-ethoxyethanol, and methyl chloride etc.[7];

- Known or suspected solvent carcinogens include, carbon tetrachloride, trichloroethylene, 1.1.2.2-tetrachloroethane, perchloroethylene, methylene chloride etc.[7]

In recent years there have been many research studies and several international meetings to determine the long-term neurotoxic effects of organic solvents[8]. These effects were grouped into three categories, based on their severity:

- The mildest level of disorder ("organic affective syndrome / Type 1) is characterized by fatigue, memory impairment, irritability, difficulty in concentrating and mild mood disturbance;

- The second level of disorder ("mild chronic toxic encephalopathy"/ Type2) involves symptoms of neurotoxicity, as well as abnormal performance on neuropsychological testing. Symptoms may include sustained mood or personality changes, such as emotional instability and loss of motivation, or impaired memory, concentration and learning ability;

- The third level of disorder ("severe chronic toxic encephalopathy / Type 3) involves symptoms such as intellectual and memory loss (dementia) that may be irreversible, or at best poorly reversible.

Type 1 and 2 disorders have been reported in solvent – exposed workers. The most severe disorders (Type 3) have been reported only in people who have consciously abused solvent –containing products by inhaling them intentionally[8].

2.1.1 Exposure Limits

The Occupational Safety and Health Administration (OSHA) has established permissible exposure limits (PELs) for over 100 solvents, including those most commonly used[6]. Most of these were established in 1971 and are considered to be out-of-date. The National Institute for Occupational Safety and Health (NIOSH) has Recommended Exposure Limits that are more stringent than the OSHA PELs for over 35 solvents[9]. The American Conference of Governmental Industrial Hygienists (ACGIH) has recommended Threshold Limit Values more stringent than the OSHA PELs for over 25 solvents.[10]

In the South African context, these solvent are enforced by the Department of Labour with the Occupational Health and Safety Act, 1993 (Act no. 85 of 1993) [11(a)], and its Regulations for Hazardous Chemical Substances, Government Notice R.1179 of 25 August 1995[11(b)]. Furthermore, it is also regulated by the Hazardous Substances Act, 1973 (Act no. 15 of 1973) [12], which is enforced by the Department of Health.

There are two statutory limits assigned under the Regulations for Hazardous Chemical Substances, namely Occupational Exposure Limit Recommended Limit (OEL-RL) and Occupational Exposure Limit Control Limit (OEL-CL). OEL-RL and OEL-CL are set by the Chief Inspector on recommendation of the Advisory Council for Occupational Health and Safety following assessments by the Standing Committee No.7 (TC 7).

An OEL-RL can be assigned to a substance, if all of the following criteria are met:

- Criteria 1 – There is no risk at the exposure limit;
- Criteria 2 – Likely excursions above the exposure limit are unlikely;
- Criteria 3 – Compliance is reasonable practicable.

An OEL- CL can be assigned to a substance, if it does not meet the above criteria's and in addition must meet the following criteria:

- Criteria 4 – Available evidence on the substance does not satisfy criterion 1 and/2 for an OEL-RL and exposure to the substance has, or is liable to have serious health implications for workers; or
- Criteria 5 – Socio-economic factors indicate that although the substance meets criteria 1 and 2 for an OEL-RL, a numerically higher value is necessary if the controls associated with certain users are to be regarded as reasonably practicable.

2.2 DESCRIPTION OF SOLVENT PRODUCTS USED

During the refurbishing process a number of different solvent and mixtures bearing different trade names are used

2.2.1 TY-PLY UP

This product is a mixture of two solvents, methyl ethyl ketone and xylene, which is used during the full reline work process[13]. The following table contains more information about this solvent.

Table 2.2.1: The product/trade name, main product composition and its exposure limits for chemicals used during the full-reline work process.

PRODUCT OR TRADE NAME	MAIN PRODUCT COMPOSITION	EXPOSURE LIMITS ppm & mg/m³			
		TWA OEL-RL		SHORT TERM OEL-RL	
		ppm	mg/m³	ppm	mg/m³
TY-PLY UP	a) Methyl ethyl ketone	200	590	300	885
	b) Xylene	100	435	150	650

Toxicological effects

Effects of over exposure to this mixture may cause eye and skin irritation and can also lead to dermatitis. Possible irritation of the respiratory system can occur causing a variety of symptom such as dryness of the throat, tightness of the chest and shortness of breath[13]. May cause central nervous system depression characterized by the following progressive steps[13]:

- Headache
- Dizziness;
- Staggering gait;
- Confusion;
- Unconsciousness or coma

May further cause respiratory sensitization. May cause liver or kidney damage and repeated or prolonged solvent overexposure may result in permanent central nervous system damage. May also affect the gastrointestinal system and blood and blood-forming organs[13].

2.2.2 TY-PLY RC

This product is a mixture of two solvents petroleum solvent and xylene, which is used during the full reline work process[14]. The following table contains more information about this solvent.

Table 2.2.2: The product/trade name; main composition and exposure limits for chemicals used during the full reline work process.

PRODUCT / TRADE NAME	MAIN PRODUCT COMPOSITION	EXPOSURE LIMITS ppm & mg/m^3			
		TWA OEL-RL		SHORT TERM OEL-RL	
		ppm	mg/m^3	ppm	mg/m^3
TY-PLY RC	a) Petroleum solvent	N.E	N.E	N.E	N.E
	b) Xylene	100	435	150	650

• N.E. – not established

Toxicological Effects

The effects of overexposure to this product were found to be similar to that of the preceding product, TY-PLY UP[13], as both are classed as rubber to metal bonding agents.

2.2.3 CHEMLOCK 286

This product mainly contains toluene, which is also used during the full reline work process[15].

Table 2.2.3: The product/trade name, main composition and exposure limits for chemicals used during the full reline work process.

PRODUCT / TRADE NAME	MAIN PRODUCT COMPOSITION	EXPOSURE LIMITS ppm & mg/m^3			
		TWA OEL-RL		SHORT TERM OEL-RL	
		ppm	mg/m^3	ppm	mg/m^3
CHEMLOCK 286	Toluene	50	188	150	560

Toxicological Effects

The effects of overexposure to this product were found to be similar to that of the preceding products, TY-PLY UP[13]and TY-PLY RC[14].

2.2.4 WD 472 & 473

This product is a mixture of two solvents, methyl ethyl ketone and toluene, which is used during the patch and dome work processes[16]. The following table contains more information about this solvent.

Table 2.2.4: The product/trade name, main composition and exposure limits for chemicals used during the Patch and Dome work processes.

PRODUCT / TRADE NAME	MAIN PRODUCT COMPOSITION	EXPOSURE LIMITS ppm & mg/m^3			
		TWA OEL-RL		SHORT TERM OEL-RL	
		ppm	mg/m^3	ppm	mg/m^3
WD 472 & 473	a) Methyl ethyl ketone	200	590	300	885
	b) Toluene	50	188	150	560

Toxicological Effects

Acute health effects include being very hazardous in the case of skin (irritant, permeater) and eye contact (irritant), ingestion and inhalation. Severe overexposure can result in death. Inflammation of the eye is characterised by redness, watering and itching. Skin inflammation is characterised by itching, scaling, reddening, or occasionally blistering[16].

2.2.5 TY-PLY 2033

This product is a mixture of three solvents, trichloroethylene, methylene chloride and toluene, which is used during the patch and dome work processes[17]. The following table contains more information about this solvent.

Table 2.2.5: The product/trade name, main composition and exposure limits for chemicals used during the patch and dome work processes.

PRODUCT / TRADE NAME	MAIN PRODUCT COMPOSITION	EXPOSURE LIMITS ppm & mg/m^3			
		TWA OEL		SHORT TERM OEL	
TY-PLY 2033		ppm	mg/m^3	ppm	mg/m^3
	a) Trichloroethylene (Control Limit)	100	535	150	802
	b) Methylene chloride (RL)	100	350	250	780
	c) Toluene (RL)	50	188	150	560

Toxicological Effects

Effects of over exposure to this mixture may cause eye and skin irritation and can also lead to dermatitis. Possible irritation of the respiratory system can occur causing a variety of symptom such as dryness of the throat, tightness of the chest and shortness of breath[17]. May cause central nervous system depression characterised by the following steps[17]:

- Headache
- Dizziness;
- Staggering gait;
- Confusion;
- Unconsciousness or coma

In elevated temperature applications, product may release vapours that may produce cyanosis in the absence of sufficient ventilation or adequate respiratory protection. May cause liver or kidney damage and repeated or prolonged solvent overexposure may result in permanent central nervous system damage. May also affect the gastrointestinal system and blood and blood-forming organs[17].

2.3 INDIVIDUAL CHEMICAL OVERVIEW

In this operation, chemicals of MEK, methylene chloride, trichloroethylene, xylene, toluene and petroleum solvent in different forms of mixtures are used. Following is the physical properties, uses, sources of potential exposure, health hazard information and exposure concentrations in both animal and human studies, for each of the solvents used.

2.3.1 Methyl Ethyl Ketone (MEK)

2.3.1.1 Physical Properties

- MEK is a colorless volatile liquid that is soluble in water[18].
- The odor threshold for MEK is 5.4 ppm, with an acetone-like odor[19].
- The chemical formula for MEK is C_4H_8O and the molecular weight is 72.10 g/mol[20,21].
- The vapor pressure for MEK is 95.1 mm Hg at 25 °C, and it has a log octanol/water partition coefficient (log K_{ow}) of 0.261[21].
- MEK is also referred to as 2-butanone[22].

2.3.1.2 Uses

- The primary use of MEK is as a solvent in processes involving gums, resins, cellulose acetate, and cellulose nitrate[23].
- MEK is also used in the synthetic rubber industry, in the production of paraffin wax, and in household products such as lacquer and varnishes, paint remover, and glues[23].
- In this operation it is used in patch, dome and full reline work processes as a major ingredient of TY PLY UP and WD 473 & 472 products (refer to table 1.1).

2.3.1.3 Sources and Potential Exposure

- As MEK is used in a variety of places, one may be exposed at work and home environments.

- MEK has been detected in both indoor and outdoor air. MEK can be produced in outdoor air by the photooxidation of certain air pollutants, such as butane and other hydrocarbons[23].
- MEK has been found in drinking water and surface water at a number of sites[18].
- Exposure to MEK could also occur at the workplace and through exposure to household products containing the chemical[23].

2.3.1.4 Health Hazard Information

Acute Effects

- Acute exposure of humans to high concentrations of MEK produces irritation to the eyes, nose, and throat[23,24].
- Other effects reported from acute inhalation exposure in humans include central nervous system depression, headache, and nausea[23,24].
- Dermatitis has been reported in humans following dermal exposure to MEK[23].
- Tests involving acute exposure of rabbits has shown MEK to have high acute toxicity from dermal exposure, while acute oral exposure of rats and mice has shown the chemical to have moderate toxicity from ingestion[25].
- Acute inhalation tests in rats indicate low toxicity from MEK exposure via inhalation[25].

Chronic Effects (Noncancer)

- Limited information is available on the chronic effects of MEK in humans from inhalation exposure. One study reported nerve damage in individuals who sniffed a glue thinner containing MEK and other chemicals[23].
- Slight neurological, liver, kidney, and respiratory effects have been reported in chronic inhalation studies of MEK in animals[23].
- The Reference Concentration (RfC) for MEK is 1 milligram per cubic meter (mg/m^3) based on decreased fetal birth weight in mice. The RfC is an estimate (with uncertainty spanning perhaps an order of magnitude) of a continuous inhalation exposure to the human population (including sensitive subgroups) that is likely to be without appreciable risk of deleterious noncancer effects during a lifetime. It is not a

direct estimator of risk but rather a reference point to gauge the potential effects. At exposures increasingly greater than the RfC, the potential for adverse health effects increases. Lifetime exposure above the RfC does not imply that an adverse health effect would necessarily occur[22].

Reproductive/Developmental Effects

- No information on the reproductive or developmental effects of MEK in humans was located.
- An inhalation study in mice exposed to MEK reported decreased fetal weight and fetal malformations. Developmental effects have also been reported in rats following oral and inhalation exposures[24,20].

Cancer Risk

- No information on the carcinogenicity of MEK in humans was located.
- No studies were available on the carcinogenicity of MEK by the oral or inhalation routes. In a dermal carcinogenicity study, skin tumors were not reported from MEK exposure[23,22].
- EPA has classified MEK as a Group D, not classifiable as to human carcinogenicity, based on a lack of data concerning carcinogenicity in humans and animals[22].

2.3.1.6. Exposure Concentrations in Animal and Human Studies

Animal studies

- The oral LD_{50} in rats for MEK has been reported to be 6.86 ml/kg body weight[26].
- Signs of eye and nasal irritation developed rapidly in guinea pigs exposed at 10,000 ppm and narcosis occurred after 5 hours[27].
- It was further found that guinea pigs tolerated 3000 ppm for several hours, whereas humans found this concentration irritating to the nose and eyes [28].

- Exposure of rats to 6000 ppm MEK, 8 hours/7day, 7 days/week did not result in any obvious motor impairment, however all rats died from bronchopneumonia in the seventh week [29].
- Pregnant rats exposed at 800 ppm and 1500 ppm of MEK had an increased frequency of abortions as compared with unexposed controls [29].
- Pregnant rats exposed at 1000 and 3000 ppm during days 6-15 of gestation produced litters with extra ribs and retarded ossification of fetal bones [30,31].

Human Studies

- Studies designed to determine comfortable working conditions for exposure to MEK, reported slight nose and throat irritation at 100 ppm and mild eye irritation in some subjects at 200 ppm [32].
- It was found that low-grade intoxication occurred from exposures at 300 to 600 ppm of MEK [33].
- Trained panelists found 4.68 ppm for a 50% response and 10 ppm for 100 % response to odor detection. A further threshold for eye and nose irritation was approximately 200 ppm, by 50 % of respondents [34].
- Central nervous system (CNS) effects and peripheral neuropathy have been reported in industrial settings following exposures to mixtures of organic substances that included MEK [35-40].
- An epidemiological study of cancer mortality among 446 workers in two dewaxing plants revealed no excess risk for cancer [41].

2.3.2 Methylene Chloride

2.3.2.1 Physical Properties

- A common synonym for methylene chloride is dichloromethane [42,43].
- Methylene chloride is a colorless liquid with a sweetish odor [42, 44].

- The chemical formula for methylene chloride is CH_2Cl_2, and the molecular weight is 84.93 g/mol[42].
- The vapor pressure for methylene chloride is 349 mm Hg at 20 °C, and it has a log octanol/water coefficient (log K_{ow}) of 1.30[42].
- Methylene chloride has an odor threshold of 250 parts per million (ppm)[45].
- Methylene chloride is slightly soluble in water and is nonflammable[42, 44].

2.3.2.2 Uses

- Methylene chloride is predominantly used as a solvent in paint strippers and removers; as a process solvent in the manufacture of drugs, pharmaceuticals, and film coatings; as a metal cleaning and finishing solvent in electronics manufacturing; and as an agent in urethane foam blowing[42].
- Methylene chloride is also used as a propellant in aerosols for products such as paints, automotive products, and insect sprays[42].
- It is used as an extraction solvent for spice oleoresins, hops, and for the removal of caffeine from coffee. However, due to concern over residual solvent, most decaffeinators no longer use Methylene chloride[42].
- Methylene chloride is also approved for use as a post harvest fumigant for grains and strawberries and as a degreening agent for citrus fruiy[42].
- In this operation it is used in patch and dome work processes as a major ingredient of the TY PLY 2033 product (refer to table 1.1).

2.3.2.3 Sources and Potential Exposure

- The principal route of human exposure to methylene chloride is inhalation of ambient air[42].
- Occupational and consumer exposure to methylene Chloride in indoor air may be much higher, especially from spray painting or other aerosol uses. People who work in these places can breathe in the chemical or it may come in contact with the skin[42].
- Methylene Chloride has been detected in both surface water and groundwater samples taken at hazardous waste sites and in drinking water at very low concentrations[42].

2.3.2.4 Health Hazard Information

Acute Effects

- Case studies of methylene chloride poisoning during paint stripping operations have demonstrated that inhalation exposure to extremely high levels can be fatal to humans[42, 46].
- Acute inhalation exposure to high levels of methylene chloride in humans has resulted in effects on the central nervous system (CNS) including decreased visual, auditory, and psychomotor functions, but these effects are reversible once exposure ceases. Methylene Chloride also irritates nose and throat at high concentrations[42, 46].
- Tests involving acute exposure of animals have shown methylene chloride to have moderate acute toxicity from oral and inhalation exposure[47].

Chronic Effects (Noncancer)

- The major effects from chronic inhalation exposure to methylene chloride in humans are effects on the CNS, such as headaches, dizziness, nausea, and memory loss[42, 46].
- Animal studies indicate that the inhalation of methylene chloride causes effects on the liver, kidney, CNS, and cardiovascular system[42, 46].
- EPA has calculated a provisional Reference Concentration (RfC) of 3 milligrams per cubic meter (mg/m^3) based on liver effects in rats. The RfC is an estimate (with uncertainty spanning perhaps an order of magnitude) of a continuous inhalation exposure to the human population (including sensitive subgroups) that is likely to be without appreciable risk of deleterious noncancer effects during a lifetime. It is not a direct estimator of risk but rather a reference point to gauge the potential effects. At exposures increasingly greater than the RfC, the potential for adverse health effects increases. Lifetime exposure above the RfC does not imply that an adverse health effect would necessarily occur[48].
- The Reference Dose (RfD) for methylene chloride is 0.06 milligrams per kilogram body weight per day (mg/kg/d) based on liver toxicity in rats[43].

Reproductive/Developmental Effects

- No studies were located regarding developmental or reproductive effects in humans from inhalation or oral exposure[42, 46].
- Animal studies have demonstrated that methylene chloride crosses the placental barrier, and minor skeletal variations and lowered fetal body weights have been noted[42, 46].

Cancer Risk

- Several studies did not report a statistically significant increase in deaths from cancer among workers exposed to methylene chloride[42, 46].
- Animal studies have shown an increase in liver and lung cancer and benign mammary gland tumors following inhalation exposure to methylene chloride[42, 43, 46].
- EPA considers methylene chloride to be a probable human carcinogen and has ranked it in EPA's Group B2[43].
- EPA uses mathematical models, based on animal studies, to estimate the probability of a person developing cancer from breathing air containing a specified concentration of a chemical. EPA calculated an inhalation unit risk estimate of 4.7×10^{-7} $(\mu g/m^3)^{-1}$. EPA estimates that, if an individual were to continuously breathe air containing methylene chloride at an average of 2.0 $\mu g/m^3$ (0.002 mg/m^3) over his or her entire lifetime, that person would theoretically have no more than a one-in-a-million increased chance of developing cancer as a direct result of breathing air containing this chemical. Similarly, EPA estimates that breathing air containing 20 $\mu g/m^3$ (0.02 mg/m^3) would result in not greater than a one-in-a-hundred thousand increased chance of developing cancer, and air containing 200 $\mu g/m^3$ (0.2 mg/m^3) would result in not greater than a one-in-ten thousand increased chance of developing cancer. For a detailed discussion of confidence in the potency estimates, please see IRIS[43].
- EPA calculated an oral cancer slope factor of 7.5×10^{-3} $(mg/kg/d)^{-1}$ [43].

2.3.2.5 Exposure Concentrations in Animal and Human Studies

Animal Studies

- The acute oral LD_{50} of methylene chloride in rats is about 200 mg/kg.
- A slight narcosis occurs at 4000-6100 ppm in several species of animals [49].
- The lethal concentration for an exposure of 7 hours is about 15 000 ppm [49-51].
- Rats exposed 8 hours/day for 75 days at 1300 ppm methylene chloride showed slight liver changes that were not found at 50 days [49].
- Cats exposed 4-8 days at 7200 ppm for 4 weeks were found to have kidney and liver changes.
- A study on hamsters, observed no oncogenic or toxicological effects in a 2-year study. No advert effects on malignancies in groups of 95 hamsters of each sex expose 6 hours/day, 5 days/week at 500, 1500, or 3500 ppm [52].
- No teratogenic effets were observed in pregnant rats that inhaled 4500 ppm methylene chloride during critical periods of gestation [53].
- Exposure of rats at concentrations as high as 1500 ppm vapour 6 hours/day, 5 days/week did not affect any of the reproductive parameters examined in a two-generation reproduction study [54].

Human Studies

- Despite the wide spread usage of methylene chloride, reports of human injury are few.
- Two cases of poisoning in painters who suffered from headaches, giddiness, stupor, irritability, numbness, and tingling in the limbs, has been reported [55].
- Complaints of headache, fatigue, and irritation of the eyes and respiratory passages by workers exposed at concentrations up to 5000 ppm [56].
- A chemist developed toxic encephalosis with acoustical and optical delusions and hallucinations after being exposed to methylene chloride for a year. Concentrations levels during time of exposure frequently exceeded 500 ppm values and recorded 660, 800 and 3600 ppm [57].

- In the early 1940's methylene chloride was considered the least toxic of the chlorinated hydrocarbon solvents when a safe industrial air limit of 500 ppm was proposed which was later adopted by the TLV Committee a protective enough to prevent any significant narcotic effects or liver injury [58].

2.3.3 Trichloroethylene

2.3.3.1 Physical Properties

- Trichloroethylene is a nonflammable colorless liquid with a sweet odor similar to ether or chloroform[59].
- The odor threshold for trichloroethylene is 28 ppm[60].
- The chemical formula for trichloroethylene is C_2HCl_3, and the molecular weight is 131.40 g/mol[59].
- The vapor pressure for trichloroethylene is 74 mm Hg at 25 °C, and it has a log octanol/water partition coefficient (log K_{ow}) of 2.42[59].
- Trichloroethylene is not a persistent chemical in the atmosphere; its half-life in air is about 7 days[59].

2.3.3.2 Uses

- The main use of trichloroethylene is in the vapor degreasing of metal parts[59].
- Trichloroethylene is also used as an extraction solvent for greases, oils, fats, waxes, and tars, a chemical intermediate in the production of other chemicals, and as a refrigerant[59].
- Trichloroethylene is used in consumer products such as typewriter correction fluids, paint removers/strippers, adhesives, spot removers, and rug-cleaning fluids[59].
- Trichloroethylene was used in the past as a general anesthetic[59].
- In this operation it is used in patch and dome work processes as a major ingredient of the TY PLY 2033 product (refer to table 1.1).

2.3.3.3 Sources and Potential Exposure

- Trichloroethylene has been detected in ambient air at levels less than 1 part per billion (ppb). Ambient air measurement data from the Aerometric Information Retrieval System (which has 1,200 measurements from 25 states from 1985-1995) give a range of ambient air values from 0.01 to 3.9 micrograms per cubic meter ($\mu g/m^3$) [59,61].
- Because of its moderate water solubility, trichloroethylene in soil has the potential to migrate into groundwater. The relatively frequent detection of trichloroethylene in groundwater confirms its mobility in soils[61].
- Drinking water supplies relying on contaminated groundwater sources may contain trichloroethylene. The Agency for Toxic Substances and Diseases Registry's (ATSDR) [59, 61] reports that trichloroethylene is the most frequently reported organic contaminant in groundwater. It estimates between 9 and 34 percent of drinking water supply sources have some trichloroethylene contamination but that most municipal water supplies are in compliance with the maximum contaminant level of 5 $\mu g/L$[59, 61].
- Workers may be exposed to trichloroethylene in the factories where it is manufactured or used. In addition, persons breathing air around these factories may be exposed to trichloroethylene[59].
- Persons may also be exposed to trichloroethylene through the use of products containing the chemical (i.e. TY PLY 2033) and from evaporation and leaching from waste disposal sites[59].

2.3.3.4 Health Hazard Information

Acute Effects

- Central nervous system effects are the primary effects noted from acute inhalation exposure to trichloroethylene in humans, with symptoms including sleepiness, fatigue, headache, confusion, and feelings of euphoria. Effects on the liver, kidneys, gastrointestinal system, and skin have also been noted[59].
- Neurological, lung, kidney, and heart effects have been reported in animals acutely exposed to trichloroethylene[59].

- Tests involving acute exposure of rats and mice have shown trichloroethylene to have low toxicity from inhalation exposure and moderate toxicity from oral exposure[59, 62].

Chronic Effects (Noncancer)

- As with acute exposure, chronic exposure to trichloroethylene by inhalation also affects the human central nervous system. Case reports of intermediate and chronic occupational exposures included effects such as dizziness, headache, sleepiness, nausea, confusion, blurred vision, facial numbness, and weakness[59].
- Effects to the liver, kidneys, and immune and endocrine systems have also been seen in humans exposed to trichloroethylene occupationally or from contaminated drinking water[61].
- Studies have shown that simultaneous alcohol consumption and trichloroethylene inhalation increases the toxicity of trichloroethylene in humans[59].
- Neurological, liver, and kidney effects were reported in chronically-exposed animals[59].
- ATSDR has calculated an intermediate-duration inhalation minimal risk level (MRL) of 0.1 parts per million (ppm) which is equal to 0.5 milligrams per cubic meter, (mg/m^3) for trichloroethylene based on neurological effects in rats. The MRL is an estimate of the daily human exposure to a hazardous substance that is likely to be without appreciable risk of adverse noncancer health effects over a specified duration of exposure. Exposure to a level above the MRL does not mean that adverse health effects will occur. The MRL is intended to serve as a screening tool[59].
- The California Environmental Protection Agency (CalEPA) has calculated a chronic inhalation reference exposure level of 0.6 mg/m^3 based on neurological effects in humans. The CalEPA reference exposure level is a concentration at or below which adverse health effects are not likely to occur[63].

Reproductive/Developmental Effects

- A study of nurses occupationally exposed by inhalation to trichloroethylene along with other chemicals in operating rooms, and another epidemiological study of women exposed occupationally or nonoccupationally to trichloroethylene and other solvents, have reported increases in the incidence of miscarriages, no exposure concentrations has been highlighted. The presence of other chemicals, however, limits the ability to draw conclusions specific to trichloroethylene[59].

- An epidemiological study of 2,000 male and female workers exposed to trichloroethylene via inhalation found no increase in malformations in babies born following exposure[59].
- Several studies have evaluated and not found an association between adverse reproductive effects in humans and exposure to trichloroethylene in contaminated drinking water. An association was found between the occurrence of congenital heart disease in children and a drinking water supply contaminated with trichloroethylene and other similar chemicals; however, no causal relationship with trichloroethylene could be concluded[59].
- Animal studies have reported developmental effects from exposure to trichloroethylene and its metabolites (trichloroacetic acid [TCA] and dichloroacetic acid [DCA])[59,61,64].

Cancer Risk

- The cancer epidemiology for trichloroethylene has grown in recent years with several large, well-designed studies being published. A recent analysis of available epidemiological studies reports trichloroethylene exposure to be associated with several types of cancers in humans, especially kidney, liver, cervix, and lymphatic system. Consistency across epidemiological studies is strongest for an association between trichloroethylene exposure and kidney cancer. These results are supported by recent molecular epidemiology studies showing specific renal cell mutations found primarily in renal cell carcinoma patients exposed to trichloroethylene[61].
- Animal studies have reported increases in lung, liver, kidney, and testicular tumors and lymphoma from inhalation and oral exposures in rats and mice[59, 61,64].
- EPA does not currently have a consensus classification for the carcinogenicity of trichloroethylene. However, the Agency is currently reassessing its potential

carcinogenicity, and new data suggest that trichloroethylene is a likely human carcinogen[61, 65, and 66].

2.3.3.5 Exposure Concentrations in Animal and Human Studies

Animal studies

- Is a moderate to low acute toxicity with an acute oral LD_{50} of 6000 to 7000 mg/kg reported in rats, cats and rabbits [67,68].
- Death in laboratory animals from acute exposure to trichloroethylene vapor resulted from central respiratory failure or ventricular arrhythmias and subsequent cardiac arrest [69,70].
- Exposures to concentrations of 400 ppm without any effect for a 6 month period were observed in monkeys, a 200 ppm no effect for rats and rabbits and a 100 ppm no effect for guinea pigs of the same exposure period [71].
- A decreased fetal body weights have occurred in rats exposed to 100 ppm, 4 hours per day throughout the pregnancy [72].
- No significant effects on sperm count, motility, morphology, or behavior were detected in male rats given trichloroethylene at up to 1000 mg/kg/day, 5 days/week for 6 weeks [73].

Human studies

- The knowledge of acute human toxicity of trichloroethylene comes mainly from its use as an anesthetic [74].
- Tachypnea and ventricular arrhyhmias equate with inhaled concentrations greater than 15 000 ppm. Systemic toxicity has been low following anesthesia, but occasional hepatotoxicity has been reported [75,76].
- No abnormalities in either motor or sensory conduction velocities in workers exposed to 400 ppm for over a period of up to 36 years [77].

- It was found that a 2-our exposure of a volunteer at 1000 ppm concentrations resulted in adverse effects on visual perception and motor skill. However 2-hour exposures at 300 ppm and 100 ppm produced no significant effect [78].
- When urinary trichloroacetic acids were measured to estimate exposure to trichloroethylene, the chief symptoms were abnormal fatigue, irritability, headaches, gastric disturbances and ethanol intolerance [79].
- A 30 ppm TWA of vapor as a desirable limit for control of occupational exposures, based on urinary trichloroacetic acid levels has been suggested [80].
- Varies studies has reported a variety of nervous disturbances in a group of 50 workers exposed to vapors at concentrations ranging from 1 to 335 ppm. These disturbances increased with the length of exposure and were reported more frequent when average concentrations exceeded 40 ppm.
- It has further been reported that workers exposed at concentrations averaging about 10 ppm (12% of tests showed values about 40 ppm) complained of headaches, dizziness, and sleepiness [81].

2.3.4 Xylene

2.3.4.1 Physical Properties

- *m*-, *o*-, and *p*-Xylene are the three isomers of xylene. Commercial or mixed Xylene usually contains about 40-65% *m*-xylene and up to 20% each of *o*- and *p*-Xylene and Ethylbenzene[82].
- Mixed Xylenes are colorless liquids that are practically insoluble in water and have a sweet odor[82].
- The odor threshold for *m*-Xylene is 1.1 ppm[83].
- The chemical formula for mixed Xylenes is C_8H_{10}, and the molecular weight is 106.16 g/mol[82].
- The vapor pressure for mixed Xylenes is 6.72 mm Hg at 21 °C, and the log octanol/water partition coefficient (log K_{ow}) is 3.123.20[82].

2.3.4.2 Uses

- Mixed Xylenes are used in the production of ethyl benzene, as solvents in products such as paints and coatings, and are blended into gasoline[82].
- In this operation it is used during the full reline processes and is a major ingredient of the TY PLY UP and RC products (refer to table 1.1).

2.3.4.3 Sources and Potential Exposure

- Mixed Xylenes are distributed throughout the environment; they have been detected in air, rainwater, soils, surface water, sediments, drinking water, and aquatic organisms[82].
- Xylenes are released into the atmosphere as fugitive emissions from industrial sources, from auto exhaust, and through volatilization from their use as solvents[82].
- Ambient air concentrations of mixed Xylenes in urban areas of the United States range from 0.003 to 0.38 milligrams per cubic meter (mg/m^3) [82].
- Mixed Xylenes have also been detected at low levels in indoor air. Xylenes have been widely used in home use products such as paints. One study reported concentrations of *m*- and *p*-Xylene ranging from 0.010 to 0.047 mg/m^3 [82].
- Levels of mixed Xylenes in drinking water have been reported to range from 0.2 to 9.9 micrograms per liter (µg/L), with mean concentrations of less than 2 µg/L[82].
- Occupational exposure to mixed Xylenes may occur at workplaces where mixed Xylenes are produced and used as solvents[82].
- Xylene exposure may be to any of the three isomers or to mixtures of the isomers[82]. During this operation exposure was found to be a mixture of isomers.

2.3.4.4 Health Hazard Information

Acute Effects

- Human and animal data show that all xylene isomers or xylene mixtures produce similar effects, although specific isomers may not be equally potent in producing the effects[82].
- Acute inhalation exposure to mixed Xylenes in humans has been associated with dyspnea and irritation of the nose and throat; gastrointestinal effects such as nausea, vomiting, and gastric discomfort; mild transient eye irritation; and neurological effects such as impaired short-term memory, impaired reaction time, performance decrements in numerical ability, and alterations in equilibrium and body balance[82, 84].
- Acute dermal exposure in humans results in transient skin irritation and dryness and scaling of the skin[82, 84].
- Acute inhalation exposure to a mixture of toluene and xylenes resulted in more than additive respiratory and neurological toxicity in humans and animals[82].
- Acute animal studies have reported respiratory, cardiovascular, CNS, liver, and kidney effects from inhalation exposure to mixed Xylenes[82].
- Acute animal tests in rats and mice have shown mixed Xylenes to have low to moderate toxicity from inhalation exposure and moderate toxicity from oral exposure[83, 85].

Chronic Effects (Noncancer)

- Chronic exposure of humans to mixed Xylenes, as seen in occupational settings, has resulted primarily in neurological effects such as headache, dizziness, fatigue, tremors, incoordination, anxiety, impaired short-term memory, and inability to concentrate. Labored breathing, impaired pulmonary function, increased heart palpitation, severe chest pain, abnormal EKG, and possible effects on the kidneys have also been reported[82, 86].
- Mixed Xylenes have not been extensively tested for chronic effects, although animal studies show effects on the liver and CNS from inhalation and oral exposures and effects on the kidneys from oral exposure to mixed Xylenes[82].

- The Reference Dose (RfD) for mixed Xylenes is 2 milligrams per kilogram body weight per day (mg/kg/d) based on hyperactivity, decreased body weight, and increased mortality in rats, and the provisional RfD for *m*- and *o*-Xylenes is also 2 mg/kg/d. EPA has not established an RfD for *p*-Xylene. The RfD is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily oral exposure to the human population (including sensitive subgroups) that is likely to be without appreciable risk of deleterious noncancer effects during a lifetime. It is not a direct estimator of risk but rather a reference point to gauge the potential effects. At exposures increasingly greater than the RfD, the potential for adverse health effects increases. Lifetime exposure above the RfD does not imply that an adverse health effect would necessarily occur[87, 88].
- ATSDR's has calculated a chronic inhalation minimal risk level (MRL) of 0.4 mg/m^3 (0.1 parts per million [ppm]) for mixed Xylenes based on neurological effects in occupationally exposed workers. The MRL is an estimate of the daily human exposure to a hazardous substance that is likely to be without appreciable risk of adverse noncancer health effects over a specified duration of exposure[82].

Reproductive/Developmental Effects

- Several human studies examined exposure to organic solvents (including mixed Xylenes) and developmental effects. An increased potential for spontaneous abortions among the wives of occupationally exposed men was reported. However, no conclusions can be drawn from these studies because they all involved concurrent exposure to multiple chemicals[82].
- Mixed Xylenes have been shown to produce developmental effects, such as an increased incidence of skeletal variations in fetuses, delayed ossification, fetal resorptions, and decreased fetal body weight in animals via inhalation exposure. Some studies observed maternal toxicity as well[82, 84].

Cancer Risk

- No information is available on the carcinogenic effects of mixed Xylenes in humans[82].
- An increase in tumors was not reported in rats or mice exposed to mixed Xylenes via gavage (experimentally placing the chemical in the stomach). Other animal studies have reported equivocal results[82, 84,87].
- EPA has classified mixed Xylenes as a Group D, not classifiable as to human carcinogenicity[87].

2.3.4.5 Exposure Concentrations in Animal and Human Studies

Animal Studies

- The acute oral LD_{50} of mixed Xylenes in rats has been reported to range from 3523 mg/kg to 8600 mg/kg. Acute oral LD_{50} of *m*-Xylene is 6631 mg/kg [89].
- Mild to moderate skin irritation and transient erythema were noted in rabbits and guinea pigs after topical application of mixed Xylenes [89-91].
- Nine rats inhaled 690 ppm of mixed Xylenes, 8 hours per day, 6 days per week for 110 to 130 days. Furthermore, six inhaled 1200 ppm 8 hours per day and 6 days a week for 40-50 days. In some animals exposure resulted in paralysis of the hind legs, weight loss, a slight decrease in leukocytes, increases in blood urea, urinary blood, and albumin and hyperplasia of the bone marrow. There were also slight congestion of the kidney, liver, heart, adrenal, lung and spleen was observed [92].
- Fertility and pregnancy indices were no different among male and female rats inhaling 60,250 or 500 ppm for 6 hours per day and for 131 premating days, during 20 mating days and throughout gestation and lactation as compared with the concurrent control animals [93].

Human studies

- The most frequent symptoms listed among workers exposed to xylene were headaches, fatigue, lassitude, irritability and gastrointestinal disturbances (nausea, anorexia and flatulence) [94].
- A further study recorded reports of injury to heart liver, kidneys and nervous system among workers with xylene exposure [95].
- At levels of 200 ppm for 3 to 5 minutes was found to irritate eyes, nose and throats of experimental human subjects [96].
- Gross overexposure to xylene, estimated concentrations of 10 000 ppm, has reported renal impairment, temporary confusion, transient memory loss and some evidence of disturbance of liver function [97].
- Corneal changes in furniture polishers exposed to xylene has also been reported [98].
- Exposure of volunteers to 100 ppm of xylene vapour for 5 to 6 hours found changes in manual coordination, reaction time and slight ataxia [99,100].
- It was found that there no concentration-response relationship between eyes closed: eyes open ratio for volunteers exposed at 64 to 400 ppm xylene [99].

2.3.5 Toluene

2.3.5.1 Physical Properties

- The chemical formula for toluene is $C_6H_5CH_3$, and its molecular weight is 92.15 g/mol[101, 102].
- Toluene occurs as a colorless, flammable, refractive liquid, that is slightly soluble in water[101, 103].
- Toluene has a sweet, pungent odor, with an odor threshold of 2.9 parts per million (ppm) [101,104].
- The vapor pressure for toluene is 28.4 mm Hg at 25 °C, and its log octanol/water partition coefficient (log K_{ow}) is 2.69[101].

2.3.5.2 Uses

- The major use of toluene is as a mixture added to gasoline to improve octane ratings. Toluene is also used to produce benzene and as a solvent in paints, coatings, adhesives, inks, and cleaning agents[101].
- Toluene is also used in the production of polymers used to make nylon, plastic soda bottles, and polyurethanes and for pharmaceuticals, dyes, cosmetic nail products, and the synthesis of organic chemicals[101].
- In this operation it is used in patch, dome and full reline work processes as a major ingredient of CHEMLOCK 286, TY PLY 2033 and WD 473 & 472 products (refer to table 1.1).

2.3.5.3 Sources of Potential Exposure

- The highest concentrations of toluene usually occur in indoor air from the use of common household products (paints, paint thinners, adhesives, and nail polish) and cigarette smoke. The deliberate inhalation of paint or glue may result in high levels of exposure to toluene, as well as to other chemicals, in solvent abusers[101].
- Toluene exposure may also occur in the workplace, especially in occupations such as printing or painting, where toluene is frequently used as a solvent[101].
- Automobile emissions are the principal source of toluene to the ambient air. Toluene may also be released to the ambient air during the production, use, and disposal of industrial and consumer products that contain toluene[101].
- Levels of toluene measured in rural, urban, and indoor air averaged 1.3, 10.8, and 31.5 micrograms per cubic meter ($\mu g/m^3$), respectively[101].

2.3.5.4 Health Hazard Information

Acute Effects

- The CNS is the primary target organ for toluene toxicity in both humans and animals for acute and chronic exposures. CNS dysfunction (which is often reversible) and narcosis have been frequently observed in humans acutely exposed to low or moderate levels of toluene by inhalation; symptoms include fatigue, sleepiness, headaches, and nausea. CNS depression and death have occurred at higher levels of exposure[101].

- Cardiac arrhythmia has also been reported in humans acutely exposed to toluene[101].
- Following the ingestion of toluene a person died from a severe depression of the CNS. Constriction and necrosis of myocardial fibers, swollen liver, congestion and hemorrhage of the lungs, and tubular kidney necrosis were also reported[101].
- Acute exposure of animals to toluene has been reported to affect the CNS as well as to decrease resistance to respiratory infection[101].
- Acute animal tests in rats and mice have demonstrated toluene to have low acute toxicity by inhalation or oral exposure[101].

Chronic Effects (Noncancer)

- CNS depression has been reported to occur in chronic abusers exposed to high levels of toluene. Symptoms include drowsiness, ataxia, tremors, cerebral atrophy, nystagmus (involuntary eye movements), and impaired speech, hearing, and vision. Neurobehavioral effects have been observed in occupationally exposed workers[101, 105].
- Effects on the CNS have also been observed in studies of animals chronically exposed by inhalation[101, 105].
- Chronic inhalation exposure of humans to toluene causes irritation of the upper respiratory tract and eyes, sore throat, dizziness, headache, and difficulty with sleep[101, 105].
- Inflammation and degeneration of the nasal and respiratory epithelium and pulmonary lesions have been observed in rats and mice chronically exposed to high levels of toluene by inhalation[101].
- Mild effects on the kidneys and liver have been reported in solvent abusers chronically exposed to toluene vapor. However, these studies are confounded by probable exposure to multiple solvents[101, 105].
- Slight adverse effects on the liver, kidneys, and lung and high-frequency hearing loss have been reported in some chronic inhalation studies of rodents[101].

- The Reference Concentration (RfC) for toluene is 0.4 milligrams per cubic meter (mg/m^3) based on neurological effects in humans and degeneration of the nasal epithelium in rats. The RfC is an estimate (with uncertainty spanning perhaps an order of magnitude) of a continuous inhalation exposure to the human population (including sensitive subgroups) that is likely to be without appreciable risk of deleterious noncancer effects during a lifetime. It is not a direct estimator of risk but rather a reference point to gauge the potential effects. At exposures increasingly greater than the RfC, the potential for adverse health effects increases. Lifetime exposure above the RfC does not imply that an adverse health effect would necessarily occur[105].
- The Reference Dose (RfD) for toluene is 0.2 milligrams per kilogram body weight per day (mg/kg/d) based on changes in liver and kidney weights in rats[105].

Reproductive/Developmental Effects

- CNS dysfunction, attention deficits, minor craniofacial and limb anomalies, and developmental delay were observed in the children of pregnant women exposed to toluene or to mixed solvents during solvent abuse. Growth retardation and dysmorphism were reported in infants of another study. However, these studies were confounded by exposure to multiple chemicals[101, 105].
- Children born to toluene abusers have exhibited temporary renal tubular acidosis[101].
- Paternal exposure (in which the mothers had no occupational exposure to toluene but the fathers did) increased the odds ratio for spontaneous abortions; however, these observations cannot be clearly ascribed to toluene because of the small number of cases evaluated and the large number of confounding variables. An increased incidence of spontaneous abortions was also reported among occupationally exposed women[101].
- Several inhalation studies have shown toluene to be a developmental toxicant, but not a reproductive toxicant, in rodents[101].

Cancer Risk

- Two epidemiological studies did not detect a statistically significant increased risk of cancer due to inhalation exposure to toluene. However, these studies were limited due to the size of the study population and lack of historical monitoring data[101].
- Chronic inhalation exposure of rats did not produce an increased incidence of treatment-related neoplastic lesions[101, 105].
- EPA has classified toluene as a Group D, not classifiable as to human carcinogenicity[105].

2.3.5.5 Exposure Concentrations in Animal and Human Studies

Animal Studies

- The oral LD_{50} values in rats range from 2600 mg/kg to 7530 mg/kg [106,107].
- Inhalation of 1400 to 2000 ppm toluene by F344 male rats for 8 hours per day for a little as 3 days resulted in reversible high-frequency hearing loss [108,109].
- The exposure of 27 to 30 male and female CFY rats at 1000 mg/m^3 toluene for 6 hours per day, 5 days per week for 6 months recorded the following observations, reduced body weight gain, increased liver weights, increased liver Cytochrome P-450 and increased bromosulfophthalein retention times [110].
- A group of 60 male and female B6C3F1 mice inhaled 0,120,600 or 1200 ppm toluene, 6.5 hours per day, 5 days per week over a two year period, showed no biological relevant increases for any non-neoplastic or neoplastic tissue changes [111].
- Pregnant mice who inhaled 500 mg/m^3 toluene, 24 hours per day on days 6 to 13 of gestation, had a reduced mean fetal body weight compared with the offspring of controls [112].
- Toluene inhalation was said to cause a shift in the fetal rib profile at 400 ppm but toluene inhalation was not considered fetotoxic [113].

Human Studies

- Intentional solvent abuse or occupational exposure at high ambient toluene concentrations (≥200 ppm) are clearly associated with CNS encephalopathy, headaches, depression, lassitude, impaired coordination, transient memory loss and impaired reaction time.
- 16 volunteers who inhaled 100 ppm toluene for 6 hours, eight reported headaches, dizziness and CNS disturbances [114].
- Fatigue, sleepiness, discomfort and CNS depression were found in 43 printers inhaling 100 ppm toluene for 6.5 hours [115].
- Delays in hand – eye reaction times in volunteers inhaling 200 ppm for a total of 7 hours [116].
- Reaction times were increased in volunteers inhaling ≥300 ppm toluene in four 20-minute exposures [117].
- Perceptual speed was impaired after the inhalation of concentrations at 700 ppm. It was further reported that within the first 2 hours of inhaling 100 ppm toluene for 4 hours, visual vigilance task performance was significantly impaired in 30 volunteers [117,118].
- No eye irritation has been reported at up to 1100 ppm of toluene in the air, but mild throat irritations have occurred. Extremely high ambient levels, between 10 000 – 30 000 ppm has appeared to be without marked irritant properties for the eyes [119].
- Dose response information compiled among workers inhaling 50 to 1500 ppm toluene for 1 to 3 weeks, yielded the following [120]:
  - Headache, lassitude and loss of appetite were frequent among 60 % of those inhaling 50 –200 ppm;
  - Those inhaling 200 to 500 ppm, some 30 % experienced impaired coordination, increased reaction time and transient memory loss
  - About 10% inhaling ≥ 500 ppm experienced weakness, palpitations, incoordination, increased reaction time, headaches and momentary memory lapse.

- After 5 years of exposures to unspecified concentrations of toluene and other chemicals at a print shop, one young adult male experienced hallucinations and developed incoordination, headaches, nausea and vomiting and was diagnosed as a paranoid schizophrenic [121].
- When 42 healthy volunteers inhaled 150-ppm toluene, 7 hours per day for 3 days, headaches, thirst, sleep and eye and mucous membrane irritation were increased [122].

2.3.6 Petroleum Solvent

This product is a major ingredient of the TY PLY RC solvent product that is used during the full reline work process (refer to table 1.1).

As detailed information on the exact solvent composition was not available from the manufactures, it was not possible to review literature outlining a detailed description of this solvent. However, a general overview has been compiled with regards to the solvent in question.

2.3.6.1 General Overview

- Petroleum products consist of complex mixtures of hydrocarbon compounds which share similar chemical and physical properties. Petroleum solvents are often distinguished on the basis of the boiling range of the mixture, while the actual composition of the product is determined by the crude feed stock from which the product is derived and the subsequent processing and blending[123].
- Refined petroleum solvents are usually mixtures of straight and branched-chain alkanes (paraffins), cyclic alkanes (naphthenes), alkenes (olefins) and the aromatics (for example, benzene and its homologues). Due to different manufacturing processes, and the complexity of the mixtures, detailed information on the exact solvent composition may not be available from the manufacturers nor may it be necessary for assessment of occupational exposure[123].
- While the components of these petroleum products share some similar physical and chemical characteristics, the toxicological properties of these components can be

quite different. For this reason, where generic standards are not available or when toxic components are known to be present, it is usually necessary to determine the atmospheric concentration of each of the major or toxic components and compare these with the appropriate individual exposure standard[123].

2.3.7 Assessing of Personal Exposures

Atmospheric concentrations which includes, personal and environmental / area samples, can be determined for all chemicals listed below, with the exception of Petroluem Solvent (2.3.7.6) as the componetns of this solvent is not known. A more detailed discussion, with regards to the determination of atmospheric concentrations (personal and environmental / area), will follow in the preceding chapter. Biological monitoring of urine samples and analysis will be undertaken accordingly.

2.3.7.1 Methyl Ethyl Ketone (MEK)

- Levels of MEK in the urine can be measured to determine exposure to the chemical[23].

2.3.7.2 Methylene Chloride

- Several tests exist for determining exposure to methylene chloride. These tests include measurement of methylene chloride in the breath, blood, and urine. It is noted that smoking and exposure to other chemicals may affect the results of these tests[42].

2.3.7.3 Trichloroethylene

- Trichloroethylene can be measured in the breath, and breakdown products of trichloroethylene can be measured in urine or blood[59].

2.3.7.4 Xylene

- Exposure to mixed Xylenes may be determined by measuring the breakdown products of mixed Xylenes in the urine or by measuring levels of xylene in blood or exhaled breath[82].

2.3.7.5 Toluene

- Toluene and its breakdown products can be detected in the blood or urine to determine whether or not exposure has occurred. Metabolites measured in the urine are not specific to toluene, and testing must occur within 12 hours of exposure[101].

2.3.7.6 Petroleum Solvent

- As the toxic components of the product used, are not known, information on determining the exposure is therefore not known either.

CHAPTER 3

METHODS

3.1 SAMPLING EQUIPMENT USED

3.1.1 Sampling Pumps

Air sampling device mainly consists of five components: an inlet orifice, a collection device an airflow meter, a flow-rate control valve and a suction source. Suction causes movement of air through the sampling train. Most sampling pumps are lightweight and quiet, use nickel/cadmium rechargeable batteries and can easily be attached to the worker's belt. Pumps may be equipped with flow control valve and some are programmable. Air-sampling pumps are generally available in: low-flow (0.5-500ml/min), high-flow (0.5-5l/min), and dual range (high-and –low) [124].

In the selection of the appropriate suction pump, one should consider: ease of use, the sampling flow rate, constant flow and the pumps suitability for use in a potentially hazardous or flammable environment[124].

The BUCK - GENIE and GILAIR sampling pumps used in this study met all of the above criteria and considerations and this ensured that a constant low-airflow for the duration of the measurements were maintained.

3.1.2 Sampling Media

In this study airborne gases and vapours needed to be sampled. Since gases and vapours exist in the molecular state (i.e. size range 0.0001 – 0.001 μm) and will easily penetrate filtration systems that are used to collect other airborne matter (i.e. solid particles), they are collected by absorption in or adsorption on to suitable media. In this study adsorption on solid substrate was followed. NIOSH approved / recommended sampling tubes for organic vapours was used.

Air sampling for insoluble or non-reactive gaseous is commonly conducted using tubes filled with granular sorbent such as activated charcoal or silica gel. The gas or vapours are retained or adsorbed, physically or chemically unchanged, onto the surface of the granules for subsequent laboratory extraction and analysis[124, 125]. For the purpose of this study and as per the prescribed sampling method, standard activated charcoal tubes where used as the sampling media.

Activated charcoal is the most widely used solid sorbent for adsorbing organic vapours. The charcoal most commonly used is from coconut shells. Coconut shell charcoal provides a large adsorptive surface area and is electrically non-polar and therefore it preferentially adsorbs organic vapours rather than polar molecules such as water vapours[124].

A standard charcoal tube is 7 cm long and 4 mm wide, and is divided into two sections. The first section contains 100 mg of charcoal and a fiberglass, glass wool, urethane foam plug. The second or backup section contains 50 mg charcoal. Although these tubes have a large adsorptive capacity, some contaminants invariably pass through the first section. The backup section increases collection efficiency by adsorbing some of the material that was initially missed. Due to its high adsorptive capacity, it can be used for a large range of organic vapours. It can furthermore be used to sample several kinds of vapours at once, but analysing laboratories should be consulted on whether there are limited numbers of organic vapours that can be extracted from one sample[124, 125,126].

3.1.3 Air Velocity Meter

A Velocicalc multi parameter ventilation meter, which was recently calibrated and serviced, was used to determine the air current of mechanical ventilation used during the processes. Readings from the meter is registered by the positioning the probe at the location where measurements are needed to be made. As air blows over the heated head (end of the probe), cooling takes place. The cooling ability rate of the air (air velocity), over the heated element / head, is registered through an electric current that is passed to maintain it (the heated head) at a constant temperature. This reading is then displayed in either ft/min or m/s.

3.1.4 Temperature and Pressure Gauge

Air temperature and pressure were monitored during every sampling session. These readings were taken from the sampling pumps used, as it was equipped with both temperature and pressure sensors. As the sampling pumps were newly purchased, it met all calibration requirements as required by the manufactures.

3.2 PROCEDURES

3.2.1 Calibration of Sampling Pumps

A soap bubble meter was used for the calibration of all sampling pumps. The calibration entailed that activated charcoal tubes were placed inline (sampling train) with the sampling pumps, while air was drawn, at variable adjusted airflow rates, through the soap bubble meter, in order to reach the desired flow rate as outlined by the prescribed method for sampling[124, 125].

This calibration procedure was conducted before the commencement and after the completion of all measurements, which ensured that prescribed flow rates were maintained throughout the entire process of sampling.

3.2.2 Sampling Strategy

All samples were taken as outlined by the NIOSH document, the Occupational Exposure Sampling Strategy Manual (OESSM) [127,128].

The exposure measurement sampling strategy adopted for this study, as per OESSM, was to sample all employees that were exposed. This "exposed group" entailed all employees who were required to work with the solvents, during the various work processes. All sampling were conducted for the duration of each work process, which therefore, represents the time it took the workers to complete a particular work process.

The following table highlights the individual solvent component and its corresponding, prescribed NIOSH sampling method:

Table 3.2.2: Individual component solvent and its corresponding prescribed NIOSH method and date of issue

INDIVIDUAL COMPONENT SOLVENT	PRESCRIBED NIOSH METHOD	DATE OF ISSUE
Methyl Ethyl Ketone	2500	15 August 1994
Methylene Chloride	1005	15 January 1998
Trichloroethylene	1022	15 August 1994
Xylene	1501	15 August 1994
Toluene	1501	15 August 1994

3.2.3 Urine Sampling and Analysis

All urine samples were collected before the commencement and after the completion of each work processes. Urine analysis was conducted by making use of both high performance liquid and gas chromatography laboratory techniques.

3.2.4 Verification of Procedures

Both calibration and sampling procedures, outlined above, were verified by an Approved Inspection Authority.

All analytical results were conducted at the National Institute for Occupational Health's (NIOH), Analytical Services Department. This department is well equipped and employs high caliber scientists and medical technologists. In maintaining total quality management, all of the departments' activities, although not formally accredited as yet, are in-line with the South African National Accreditation Scheme (SANAS) requirements, as is outlined by the International Standards Organisation Guide, ISO 17025. The laboratory also participates in a quality programme run by NEQAS, Birmingham, UK and in the National Quality Control Scheme. It also participates for aluminum in the World Wide Interlaboratory Aluminum Quality Control Scheme. Furthermore the Analytical Services Department is also responsible for the National Quality Control Programme for lead and cadmium, to which a number of laboratories subscribe.

3.3 WORK PROCESS BREAKDOWN

Refurbishing of chemical rail tankers consists of three different types of work processes. These processes include:

- Full reline, which is required when the rubber lining the inside of tanker has deteriorated, due to age and frequency of usage, to the extend where patching the areas would not be an viable and cost effective option;
- Dome Work, is normally conducted in conjunction with a full reline work process, which is required when the rubber lining the middle top area of tanker has deteriorated, due to age and frequency of usage;
- Patch Work, this work process is required when the rubber lining the inside of the tanker has deteriorated, due to age and frequency of usage, in certain areas within the tanker. This option is also chosen as a cost effective measure, as it is a cheaper option to conduct patch work as appose to a full reline.

The following section will provide a detailed procedure breakdown, of all the main processes involved during the refurbishment of chemical rail tankers.

3.3.1 Full Reline

This process entails the application of three different solvents at various time intervals.

3.3.1.1 TY-PLY UP

This product is referred to as a metal to rubber-bonding agent. It is used to prevent the formation of rust on the inside of the tanker[13]. For the application of this product, the tanker is divided into three application areas, namely: a front, middle and back section. Following this, the application of the solvent entails that two workers per application area, enters the tanker from the bottom and smears it with the solution. At any given time, for this application process, only two workers are present inside the tanker. The process of application takes between 20 and 35 minutes.

3.3.1.2 TY-PLY RC

This is the second application that is applied to the tanker and is also referred to as a rubber to metal bonding agent[14]. The same procedure as outlined above is followed during the application of this product. The process of application similarly takes between 20 and 35 minutes.

3.3.1.3 CHEMLOCK 286

This is the third application that is applied to the tanker and it is referred to as tacky tie cement[15]. This application is applied both to the tanker as well as the rubber panels before they are affixed to the tanker.

A total of between 7 to 10 employees are required to perform this task and the employee distribution were the following:

- A maximum of four (4) employees enters the tank at once in order to smear the tank and affix the rubber panels to the inside of the tanker;
- On the outside of the tanker, another one (1) to two (2) employees are further responsible for cutting rubber panels to their required sizes,
- Another 1 to 2 employees are responsible for smearing the rubber panels with the solvent solution;
- The last set of employees has a further responsibility to "pass on" the smeared rubber panels to those employees that are on the inside of the tanker.

The final process entails the affixing rubber panels to the tanker. This process is also commonly referred to as stitching. This process entails the use of a hand tool that is rolled across the entire surface of rubber panels in order to ensure that it is affixed to the metal surface of the tanker.

3.3.2 Patch and Dome Area Work

This process entails the application of two different solvents at variable time intervals. Furthermore, during the study it was found that two different products are being used interchangeable, as second applicators. The reason for this interchange was based on which product was available at site when it was required.

3.3.2.1 TY-PLY UP

This product is referred to as a metal to rubber-bonding agent. It is used to prevent the formation of rust on the inside of the tanker[13]. For the application of this product:

a) the patched areas, inside the tanker, is smeared with this solution, and
b) the dome area, outside middle top area of tanker, is smeared as well.

The above sub-work processes (a, b) are performed by 1 to 2 employees and take between 10 to 35 minutes, depending on the area to be patched.

3.3.2.2 WD 472, 473 and TY-PLY 2033

In this application WD 472, 473 and TY-PLY 2033, which are referred to as synthetic rubber based adhesives[16, 17], are used as the second applicators.

During the Patch Work process, 1 to 2 workers enter the tank, at the bottom, and are responsible for smearing and stitching of the rubber patches to the tank surface.

During Dome Work, 1 to 2 workers access the dome area of the tank, either by a temporary erected suspended platform, placed next to the tanker, or by means of the fixed ladders on the side of the tanker. They are then responsible for smearing and stitching of rubber panels to the outside dome area of the tanker.

In addition to the above, both work processes further require the following:

- 1 to 2 workers for the cutting of rubber panels and patches to their required sizes;
- another 1 to 2 employees are responsible for smearing the rubber panels and patches with the solvent solution;
- the last set of employees has a further responsibility to "pass on" the smeared rubber panels and patches to those employees that are either working inside or on the dome area of the tanker.

3.4 DESCRIPTION OF THE SAMPLING AREA

The following section will list the main work processes and the work environments in which they are conducted.

Work processes that entail, full reline and patch work, are conducted on the inside of the chemical rail tankers and exposure to work stresses of chemical, physical and ergonomical type are common. These work processes are regulated by the Occupational Health and Safety Act, 1993 (Act no. 85 of 1993) [11], under the General Safety Regulations, Government Notice R.1031 of 30 May 1986. In specifically regulation 5, of the above regulation, which entails the conducting of work in confined spaces.

Furthermore, it was observed that the use of personal protective equipment was not encouraged, enforced or in some instances not provided for, by employers. This therefore led to workers, for the majority of their working time, to conduct work processes without being adequately protected against chemical exposures.

3.4.1 Full Reline and Patchwork

These work processes are conducted on the inside of the tanker. The size of the tankers ranges from 63-83m^3 or 34 860 liter capacity. The tanker has two openings, one at the top and the other at the bottom. During the study workers entered the tankers through both these openings in order to gain access and exit from the tankers.

The work area covered during the full relining process entails 63-83 m^3 of rubber panels that are affixed to the inside of the tanker. During patchwork the work area covered varies and depends largely on the area damaged. During the study the areas covered ranged from 1-40 m^2 of rubber patches that were affixed to the inside of the tanker.

Lighting within the tanker is made possible with a moveable lead light that has its power supply from outside the tanker. Ventilation, in most cases, was provided for by mechanical means in the form of an extraction fan, which is either mounted at the top or bottom of the tanker. Temperature within the tanker varied from low early morning temperatures to high midday temperatures and was further influenced by the amount of workers on the inside of the tanker at any given time, and the time span for the usage of the lead light.

3.4.2 Dome Area

This work process is conducted on the outside of the rail tanker. The middle top area of the tanker is commonly referred to as the dome or the apron. The rubber panels that are affixed to this area, is also referred to as the saddle.

The work area covered by the saddle during the study was 17 m^2. During the affixing of the saddle the workers are required to work for extended periods of time at an elevated position at the top of the tanker. Access to the top of the tanker is provided by two means:

- side step ladders that are affixed to the sides of the tanker, and
- a temporary erected suspended platform, next to the tanker.

The following photographic panels highlights:

- the rail tankers (Figure 3.5 and 3.6);
- the workspace (patch, full reline and dome work processes) (Figure 3.7, 3.8, 3.9);
- general working environment (Figure 3.10), and
- light source and ventilation used (Figure 3.11 and Figure 3.12, 3.13).

Figure 3.5: A front side view of a chemical rail tanker

Figure 3.6: A back side view of a chemical rail tanker

Figure 3.7: Inside view of the workspace for patch and full reline work processes

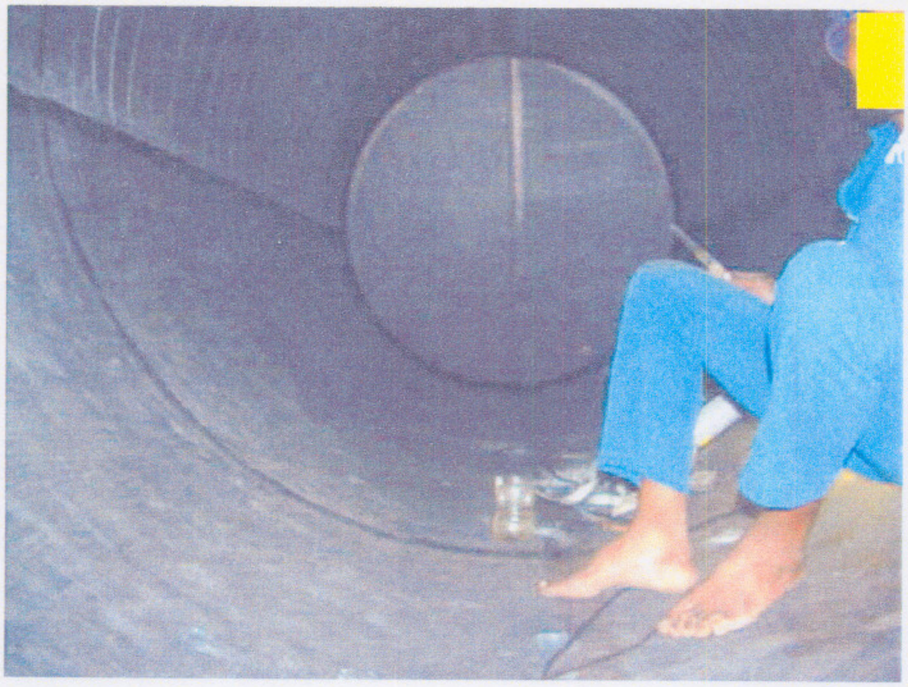


Figure 3.8: A view of the workspace (grey area) for the dome area work process

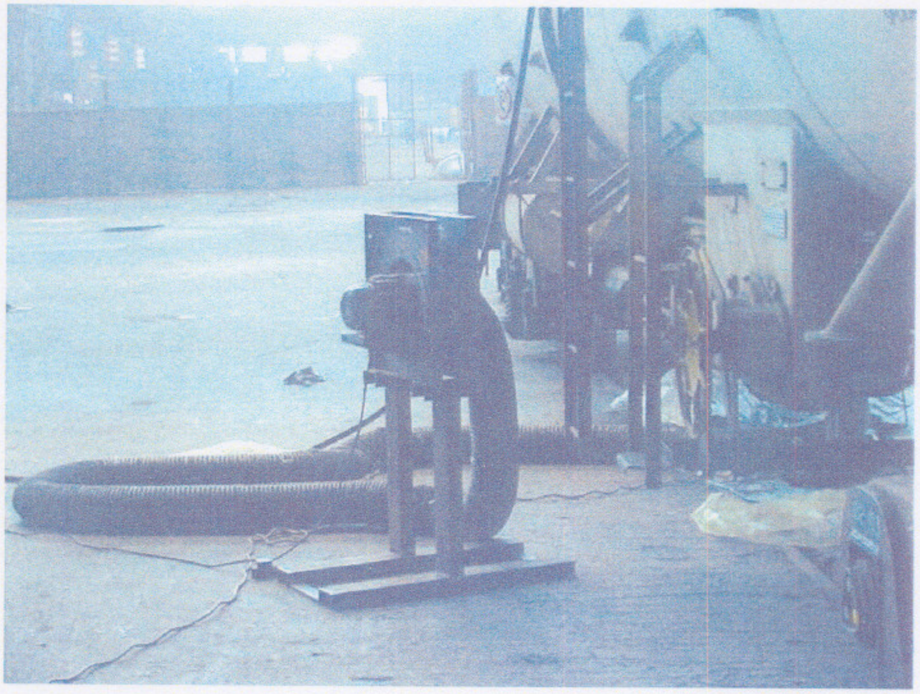
Figure 3.9: A close-up view of the grey area, which indicates the workspace for the dome area work process

Figure 3.10: General working environment outside tanker

Figure 3.11: Light source used within tanker.

Figure 3.12: Ventilation fitting (extraction fan), which is mounted at the top opening of the tanker

Figure 3.13: Ventilation fitting (extraction fan), which is placed at the bottom opening of the tanker



CHAPTER 4

RESULTS AND DISCUSSION

The following were highlighted as the main research questions that needed to be answered by this study:

- what are the airborne organic concentration levels workers are being exposed to while performing their tasks;

- are work processes compliant to the requirements as prescribed by the Regulations for Hazardous Chemical Substances. Government Notice R.1179: 25 August 1995;

- can any health deficiency correlation be concluded from the results obtained from the air and biological samples as well as those from the self-administrated questionnaires.

In order to answer the above questions both personal and area sampling for chemical stresses were completed. In support of this, the following will be reported on:

- both personal and environmental / area sampling results of the occupational exposure measurements, as was recorded on the various days;

- temperature and pressure readings as was taken on the various sampling days;

- ventilation readings, taken from the extraction fans being used;

- analyses results from biological samples, and

- results from the self administrated health questionnaire.

4.1.1.1 DISCUSSION

As a rule of thumb, as it relates to the OEL's for mixtures, when two or more hazardous substances which act upon the same organ system are present, their combined effect, rather than that of either individually, should be given primary consideration[123, 124].

When the above is taken into consideration the sampling results recorded during the application of TY-PLY UP was found to be in violation of the OEL, for all personal samples, as it has exceeded the unity of 1. Therefore, the threshold limit of the mixture can be considered as being exceeded for the application of this solvent.

During the sampling time the smell of MEK and Xylene was a strong acetone like-sweet odor as concentrations exceeded the odor thresholds of 5.4 and 1.1 ppm respectively.

During this operation airborne MEK concentrations ranged from 0.42 to 66.52 ppm. Results for personal monitoring ranged from 31.26 to 66.52 ppm and environmental / area monitoring results ranged from 0.42 to 1.25. All MEK results were below the Short Term OEL-RL. The Reference Concentration (RfC) of 1 mg/m^3 has been exceeded. It has been documented that exposures increasingly greater than the RfC, the potential for adverse health effects increases [22].

Airborne concentrations for Xylene ranged from 137.73 to 394.63 ppm and the geometric mean was between 174 and 230. It has been documented that mixed Xylene usually contains about 40-50% of *m*-Xylene[82]. Furthermore, human and animal data show that all Xylene isomers or Xylene mixtures produce similar effects, although specific isomers may not be equally potent in producing the effects[82]. Results for this isomer, m-Xylene, ranged between 286.75 to 394.63 ppm. Personal monitoring results were 394.63 and 295.09 ppm and environmental / area monitoring results were 305.95 and 286.75 ppm. All *m*-Xylene results were above the Short Term OEL-RL. The chronic inhalation minimal risk level (MRL) of 0.4 mg/m^3 for mixed Xylene[82] has been exceeded.

The high environmental / area monitoring results provides an indication of the extend of work area contamination, as this area is a confined space.

The employees and myself experienced a burning sensation over exposed skin areas as well as an uncontrolled tearing of our eyes, during the use of the solvent. These symptoms validate previous research findings associated with acute inhalation and dermal exposures[23, 24, 82, 84, 96].

4.1.2 TY-PLY RC

This mixture is used as a rubber to metal bonding agent. It contains xylene and petroleum solvent.

As detailed information on the exact solvent composition of the petroleum solvent was not available from the manufactures, concentration levels could therefore not be determined, and it is therefore not reflected in the accompanying result table.

The preceding result table reflects both the personal and environmental / area sampling results as was recorded for xylene. The Short Term OEL-RL for **xylene is 150 ppm or 650 mg/m^3.**

Table 4.1.2: Results recorded during the application of the solvent product TY-PLY RC

SAMPLING TYPE	SUB -WORK PROCESS	SAMPLE	TIME (min)	CHEMICAL	RESULTS	
					mg/m^3	ppm
Personal	Smearing tank	• 1	• 34	• p-Xylene • m-Xylene • o-Xylene	• 354.41 • 708.82 • 210.3	• 81.63 • 163.25 • 48.43
Personal	Smearing tank	• 2	• 21	• p-Xylene • m-Xylene • o-Xylene	• 376.2 • 752.4 • 219.05	• 86.64 • 173.29 • 50.45
Environmental	Smearing tank	• 1	• 30	• p-Xylene • m-Xylene • o-Xylene	• 280 • 570 • 165	• 64.49 • 131.28 • 38
Environmental	Smearing tank	• 2	• 30	• p-Xylene • m-Xylene • o-Xylene	• 553.33 • 1105 • 330	• 127.44 • 254.5 • 76

4.1.2.1 DISCUSSION

Overall sampling results for xylene ranged from 38 to 254.5 ppm. Personal monitoring results ranged from 48.43 to 173.29 ppm and environmental monitoring results ranged from 38 to 254.5 ppm. The geometric mean for xylene ranged between 69 and 135.

As m-Xylene is one of the major isomer components, between 40-65%, of commercial or mixed Xylene[82], results for this isomer, m-Xylene, ranged from 131.28 to 254.5 ppm. Personal monitoring results were 163.25 and 173.29 ppm and environmental / area monitoring results were 131.28 and 254.5 ppm.

When comparing the results found for m-Xylene to its corresponding Short Term OEL for xylene, it was found that the results for all personal samples exceeded the statuary limit. As the application of this solvent product preceded the previous application after a twenty to thirty-minute drying period, the rule of thumb, as it relates to the OEL's for mixtures can still be considered as being relevant, as not all preceding chemical fumes has been allowed to evaporate. Therefore, these results too were found to be in violation of the OEL, for all personal samples, as it has exceeded the unity of 1. The chronic inhalation minimal risk level (MRL) of 0.4 mg/m^3 for mixed Xylene[82] has been exceeded.

During the sampling time the smell of xylene was a sweet odor as concentrations exceeded the odor threshold of 1.1 ppm.

The high environmental / area monitoring results provides an indication of the extend of work area contamination, as this area is a confined space.

4.1.3 CHEMLOCK 286

This product is referred to as tacky tie cement[15], and it contains toluene as it major chemical component. This product is applied both to the tanker as well as the rubber panels, before it is affixed. The Short Term OEL-RL for **toluene is 150 ppm or 560 mg/m^3.**

Table 4.1.3: Results recorded during the application of solvent product Chemlock 286.

SAMPLE TYPE	SUB -WORK PROCESS	SAMPLE	TIME (min)	CHEMICAL	RESULTS	
					mg/m^3	ppm
Personal	Smearing tank	o 1 o 2	o 23 o 31	Toluene	o 8647.8 o 6324.2	o 2294.5 o 1677.9
Personal	Smearing rubber panels	o 1	o 20	Toluene	o 321.5	o 85.3
Personal	Stitching rubber panels	o 1 o 2 o 3	o 142 o 45 o 141	Toluene	o 1016.8 o 993.9 o 1142.1	o 269.7 o 263.7 o 303.04
Environmental	Smearing tank and stitching rubber panels	o 1 o 2 o 3 o 4	o 195 o 195 o 100 o 100	Toluene	o 1135.9 o 48.72 o 1190 o 906.5	o 301.39 o 12.93 o 315.74 o 240.52

4.1.3.1 DISCUSSION

Overall results for toluene ranged from 12.93 to 2294.51 ppm. Results for personal monitoring ranged from 85.3 to 2294.51 ppm and environmental / area monitoring ranged from 12.93 to 315.74. The majority of personal and environmental / area monitoring results exceeded the prescribed Short Term OEL-RL for toluene.

During the sampling time the smell of toluene was a strong sweet pungent odor as concentrations exceeded the odor threshold of 2.9 ppm.

As the application of this solvent product preceded the previous application after a twenty to thirty-minute drying period, the rule of thumb, as it relates to the OEL's for mixtures can still be considered as being relevant, as not all preceding chemical fumes has been allowed to evaporate. Therefore, these results too were found to be in violation of the OEL, for all personal samples, as it has exceeded the unity of 1. The Reference Concentration (RfC) of 0.4 mg/m^3 has been exceeded. It has been documented that exposures increasingly greater than the RfC, the potential for adverse health effects increases [105]. The high environmental / area monitoring results provides an indication of the extend of work area contamination, as this area is a confined space.

4.2 Patch Work

During this operation airborne organic vapours were monitored. Personal and area monitoring were performed simultaneously at varies sampling times. Results recorded for personal samples were taken during peak exposures and sampling times are a reflection of the duration / time span of the varies sub-work processes.

The tables reflected under this section will highlight the results that were recorded for both personal and environmental / area samples respectively, during the patch work process.

4.2.1 TY PLY 2033

This product is also referred to as a synthetic rubber based adhesive[16, 17], and is a mixture of three solvents namely trichloroethylene, methylene chloride and toluene. The Short Term OEL-CL for **trichloroethylene is 150 ppm or 802 mg/m^3** and the Short Term OEL **RL for methylene chloride is 250 ppm or 780 mg/m^3** and **toluene is 150 ppm or 560 mg/m^3.**

Table 4.2.1: Results recorded during the application of the solvent product TY-PLY 2033,

SAMPLE TYPE	SUB -WORK PROCESS	SAMPLE	TIME (min)	CHEMICAL	RESULTS	
					mg/m^3	ppm
Personal	Smearing tank	• 1	• 10	• Trichloroethylene • Toluene • Methylene Chloride	• 606 • 807.5 • 30	• 112.67 • 214.25 • 8.64
		• 2	• 30	• Trichloroethylene • Toluene • Methylene Chloride	• 796.67 • 2615 • 9.5	• 148.24 • 693.83 • 2.73
Personal	Smearing rubber panels	• 1	• 87	• Trichloroethylene • Toluene • Methylene Chloride	• 128.12 • 165.06 • 3.4	• 23.84 • 43.8 • 0.98

Personal	Stitching rubber panels	• 1	• 104	• Trichloroethylene • Toluene • Methylene Chloride	• 486.86 • 881.14 • 2.4	• 90.59 • 233.79 • 0.69
		• 2	• 75	• Trichloroethylene • Toluene • Methylene Chloride	• 14.07 • 55.07 • 3.3	• 2.62 • 14.61 • 0.95
Environmental	Smearing tank and stitching rubber panels	• 1	• 115	• Trichloroethylene • Toluene • Methylene Chloride	• 517.83 • 1150 • 1.3	• 96.35 • 305.13 • 0.37
		• 2	• 115	• Trichloroethylene • Toluene • Methylene Chloride	• 55.69 • 1217.3 • 1.8	• 10.36 • 323 • 0.52
		• 3	• 81	• Trichloroethylene • Toluene • Methylene Chloride	• 503.70 • 715.62 • 2.4	• 93.73 • 189.87 • 0.69
		• 4	• 43	• Trichloroethylene • Toluene • Methylene Chloride	• 534.07 • 1358.8 • 6.9	• 99.38 • 360.54 • 1.99
Personal	Smearing tank, rubber panels and stitching panels	• 1	• 141	• Trichloroethylene • Toluene • Methylene Chloride	• 1059.6 • 778.25 • 0.8	• 197.17 • 206.49 • 0.23
Environmental	Smearing tank, rubber panels and stitching rubber panel	• 1	• 135	• Trichloroethylene • Toluene • Methylene Chloride	• 869.33 • 791.29 • 0.7	• 161.76 • 209.95 • 0.2
		• 2	• 235	• Trichloroethylene • Toluene • Methylene Chloride	• 82.23 • 417.47 • 0.5	• 15.3 • 110.77 • 0.14

4.2.1.1 DISCUSSION

The OEL as it relates to mixtures would be applicable for determining whether the legal limit has been exceeded or not.

When the above is taken into consideration the sampling results recorded during the application of TY-PLY 2033 was found to be in violation of the OEL, in both environmental / area and personal samples, as it has exceeded the unity of 1. Therefore, the threshold limit of this mixture can be considered as being exceeded.

During the sampling time the smell of trichloroethylene and toluene was a strong sweet pungent odor as concentrations exceeded the odor threshold of 28 and 2.9 ppm respectively.

During this operation airborne trichloroethylene concentrations ranged from 2.62 to 197.17 ppm. Results for personal monitoring ranged from 2.62 to 197.17 ppm and environmental / area monitoring ranged from 10.36 to 161.76 ppm. One personal sample result i.e. 197.17 ppm, and one environmental / area sample result i.e. 161.76 ppm, were found to be above the Short Term OEL CL for trichloroethylene. The inhalation minimal risk level (MRL) of 0.1 ppm[59] has also been exceeded. The chronic inhalation reference exposure level of 0.6 mg/m^3 as calculated by the California Environmental Protection Agency (CalEPA) [63], has been exceeded. It has been reported that at concentrations below this exposure level that adverse health effects are not likely to occur [63]. It was found that this concentration was only established for trichloroethylene.

During this operation airborne toluene concentrations ranged from 14.61 to 693.83 ppm. Results for personal monitoring ranged from 14.61 to 693.83 and environmental / area monitoring ranged from 110.77 to 360.54 ppm. The majority of personal and environmental / area monitoring results exceeded the prescribed Short Term OEL-RL for toluene. The Reference Concentration (RfC) of 0.4 mg/m^3 has been exceeded. It has been documented that exposures increasingly greater than the RfC, the potential for adverse health effects increases [105].

During this operation airborne methylene chloride concentrations detected ranged from 0.14 to 8.64 ppm. Results for personal monitoring ranged from 0.23 to 8.64 and environmental / area monitoring ranged from 0.14 to 1.99 ppm. All methylene chloride results were well below the prescribed statutory Short Term OEL-RL. The Reference Concentration (RfC) of 3 mg/m^3 has been exceeded for the majority of results. It has been documented that exposures increasingly greater than the RfC, the potential for adverse health effects increases [48].

The environmental / area monitoring results provides an indication of the extend of work area contamination, as this area is a confined space.

4.2.2 WD 472,473

This product is also referred to as a synthetic rubber based adhesive[16, 17], and is a mixture of two solvents namely MEK and toluene. It is further used interchangeable as the second applicator during the patch work process. The Short Term OEL-RL for **MEK is 300 ppm or 885 mg/m^3** and for **toluene is 150 ppm or 560 mg/m^3.**

Table 4.2.2: Results recorded during the application of the solvent product WD 472,473 during patch work.

SAMPLE TYPE	SUB -WORK PROCESS	SAMPLE	TIME (min)	CHEMICAL	RESULTS (mg/m^3)	RESULTS ppm
Personal	Smearing tank, rubber panels and stitching rubber panels	• 1	• 206	• MEK • Toluene	• 54.46 • 975.22	• 18.47 • 258.75
Area	Smearing tank, rubber panels and stitching rubber panel	• 1	• 240	• MEK • Toluene	• 51.98 • 878.96	• 17.63 • 233.21
		• 2	• 240	• MEK • Toluene	• 39.25 • 820.92	• 13.31 • 217.81
Personal	Stitching rubber panels	• 1	• 120	• MEK • Toluene	• 67.54 • 1626.67	• 22.9 • 431.6
		• 2	• 130	• MEK • Toluene	• 168.19 • 1527.46	• 57.04 • 57.04

Personal	Smearing rubber panels	• 1	• 55	• MEK • Toluene	• 286.82 • 584.73	• 97.26 • 155.15

4.2.2.1 DISCUSSION

The OEL as it relates to mixtures would be applicable for determining whether the legal limit has been exceeded or not.

When the above is taken into consideration the sampling results recorded during the application of WD 472,473 was found to be in violation of the OEL, in both environmental and personal samples, as it has exceeded the unity of 1. Therefore, the threshold limit of this mixture can be considered as being exceeded.

During the sampling time the smell of MEK and toluene was a strong acetone like sweet odor as concentrations exceeded the odor threshold of 5.4 and 2.9 ppm respectively.

During this operation airborne MEK concentrations ranged from 13.31 to 97.26 ppm. Results for personal monitoring ranged from 18.47 to 97.26 ppm and environmental / area monitoring ranged from 13.31 to 17.63 ppm. All MEK results were found to be well below the Short Term OEL RL. The Reference Concentration (RfC) of 1 mg/m^3 has been exceeded. It has been documented that exposures increasingly greater than the RfC, the potential for adverse health effects increases [22].

During this operation airborne toluene concentrations ranged from 57.04 to 431.6 ppm. Results for personal monitoring ranged from 57.04 to 431.6 ppm and environmental / area monitoring ranged from 217.81 to 233.21 ppm. The majority of personal and all environmental / area monitoring results exceeded the prescribed Short Term OEL-RL for Toluene. The Reference Concentration (RfC) of 0.4 mg/m^3 has been exceeded. It has been documented that exposures increasingly greater than the RfC, the potential for adverse health effects increases [105].

The environmental / area monitoring results provides an indication of the extend of work area contamination, as this area is a confined space.

4.3 Dome Work

During this operation airborne organic vapours were monitored. Personal and area monitoring were performed simultaneously at varies sampling times. Results recorded for personal samples were taken during peak exposures and sampling times are a reflection of the duration / time span of the varies sub-work processes.

The tables reflected under this section will highlight the results that were recorded for both personal and environmental / area samples respectively, during the dome work process.

4.3.1 TY-PLY 2033

This product is also referred to as a synthetic rubber based adhesive[16, 17], and is a mixture of three solvents namely trichloroethylene, methylene chloride and toluene. The Short Term OEL-CL for **trichloroethylene is 150 ppm or 802 mg/m³** and the Short Term OEL **RL for methylene chloride is 250 ppm or 780 mg/m³** and **toluene is 150 ppm or 560 mg/m³.**

Table 4.3.1: Results recorded during the application of the solvent product TY-PLY 2033, during dome work.

SAMPLE TYPE	SUB-WORK PROCESS	SAMPLE	TIME (min)	CHEMICAL	RESULTS mg/m³	RESULTS ppm
Personal	Smearing tank	• 1	• 32	• Trichloroethylene	• 162 .19	• 30.18
				• Toluene	• 69.22	• 18.37
				• Methylene Chloride	• 6.4	• 1.84
Personal	Smearing rubber panels	• 1	• 22	• Trichloroethylene	• 128.12	• 23.84
				• Toluene	• 165.06	• 43.8
				• Methylene Chloride	• 10.5	• 3.02
		• 32	• 32	• Trichloroethylene	• 144.17	• 26.83
				• Toluene	• 101.67	• 26.98
				• Methylene Chloride	• 6.7	• 1.93

Personal	Smearing rubber panels	• 3	• 35	• Trichloroethylene • Toluene • Methylene Chloride	• 90.43 • 70.71 • 8.3	• 16.83 • 18.76 • 2.39
Personal	Stitching rubber panels	• 1	• 73	• Trichloroethylene • Toluene • Methylene Chloride	• 36 • 30.93 • 1.9	• 6.7 • 8.21 • 0.55
		• 2	• 67	• Trichloroethylene • Toluene • Methylene Chloride	• 33.23 • 40.31 • 2.4	• 6.18 • 10.7 • 0.69
Personal (continue)	Stitching rubber panels (continue)	• 3	• 76	• Trichloroethylene • Toluene • Methylene Chloride	• 21.73 • 46.07 • 3.3	• 4.04 • 12.22 • 0.95

4.3.1.1 DISCUSSION

The OEL as it relates to mixtures would be applicable for determining whether the legal limit has been exceeded or not.

When the above is taken into consideration the sampling results recorded during the application of TY-PLY 2033 was found to be in violation of the OEL, in both environmental / area and personal samples, as it has exceeded the unity of 1. Therefore, the threshold limit of this mixture can be considered as being exceeded.

During the sampling time the smell of trichloroethylene and toluene was a strong sweet pungent odor as concentrations exceeded the odor threshold of 28 and 2.9 ppm respectively.

No environmental / area monitoring was conducted, as this particular work process was conducted outside the tanker.

During this operation airborne trichloroethylene concentrations ranged from 6.18 to 30.18 ppm and this range was similar for personal monitoring results as no environmental / area monitoring was conducted. All results for trichloroethylene was found to be well below its Short Term OEL CL. The inhalation minimal risk level (MRL) of 0.1 ppm[59] has been exceeded. The chronic inhalation reference exposure level of 0.6 mg/m^3 as calculated by the California Environmental Protection Agency (CalEPA) [63], has been exceeded. It has been reported that at concentrations below this exposure level that adverse health effects are not likely to occur [63].

During this operation airborne toluene concentrations ranged from 8.21 to 43.8 ppm and this range was similar for personal monitoring results as no environmental / area monitoring was conducted. All results for toluene were found to be well below its prescribed Short Term OEL-RL. The Reference Concentration (RfC) of 0.4 mg/m^3 has been exceeded. It has been documented that exposures increasingly greater than the RfC, the potential for adverse health effects increases [105].

During this operation airborne methylene chloride concentrations detected ranged from 0.55 to 3.02 ppm and this range was similar for personal monitoring results as no environmental / area monitoring was conducted. All results for methylene chloride were found to be well below its prescribed statutory Short Term OEL-RL. The Reference Concentration (RfC) of 3 mg/m^3 has been exceeded for the majority of results. It has been documented that exposures increasingly greater than the RfC, the potential for adverse health effects increases [48].

4.3.2 WD 472,473

This product is also referred to as a synthetic rubber based adhesive[16, 17], and is a mixture of two solvents namely MEK and toluene.

As mentioned previously, under the work process breakdown, this product mixture is used interchangeable as the second applicator during the dome work process. The Short Term OEL-RL for **MEK is 300 ppm or 885 mg/m^3** and for **toluene is 150 ppm or 560 mg/m^3.**

Table 4.3.2: Results recorded during the application of the solvent product WD 472,473, during dome work.

SAMPLE TYPE	SUB -WORK PROCESS	SAMPLE	TIME	CHEMICAL	RESULTS	
					mg/m^3	ppm
Personal	Smearing tank	• 1	• 25	• MEK • Toluene	• 380.6 • 169.2	• 129.07 • 44.89
Personal	Smearing rubber panels	• 1	• 49	• MEK • Toluene	• 142.44 • 128.78	• 48.03 • 34.17
Personal	Stitching rubber panels	• 1	• 39	• MEK • Toluene	• 6.38 • 11.13	• 2.16 • 2.95
		• 2	• 56	• MEK • Toluene	• 2 • 9.45	• 0.68 • 2.51

4.3.2.1 DISCUSSON

The OEL as it relates to mixtures would be applicable for determining whether the legal limit has been exceeded or not.

When the above is taken into consideration the sampling results recorded during the application of WD 472,473 was found to be in violation of the OEL, in both environmental / area and personal samples, as it has exceeded the unity of 1. Therefore, the threshold limit of this mixture can be considered as being exceeded.

During the sampling time the smell of MEK and toluene was a strong acetone like sweet odor as concentrations exceeded the odor threshold of 5.4 and 2.9 ppm respectively.

No environmental / area monitoring was conducted, as this particular work process was conducted outside the tanker.

During this operation airborne MEK concentrations ranged from 0.68 to 129.07 ppm and this range was similar for personal monitoring results as no environmental / area monitoring was conducted. All MEK results were found to be well below its Short Term

OEL RL. The Reference Concentration (RfC) of 1 mg/m^3 has been exceeded. It has been documented that exposures increasingly greater than the RfC, the potential for adverse health effects increases [22].

During this operation airborne toluene concentrations ranged from 2.51 to 44.89 ppm and this range was similar for personal monitoring results as no environmental / area monitoring was conducted. All results for toluene was found to be well below its Short Term OEL RL. The Reference Concentration (RfC) of 0.4 mg/m^3 has been exceeded. It has been documented that exposures increasingly greater than the RfC, the potential for adverse health effects increases [105].

4.4 Temperature and Atmospheric Pressure readings

4.4.1 Temperature Readings

Temperature readings, which were taken inside the tanker as well as within the working environment on various sampling days, ranged between 10-15°C for early morning temperatures and between 20- 35°C for midday afternoon temperatures.

4.4.2 Atmospheric Pressures

Atmospheric pressure readings, which were taken inside the tanker as well as within the working environment on various sampling days, were within ranges of between 627 and 628 mm HG.

4.5 Ventilation Readings

An extraction fan was switched on during the refurbishing process, which created a negative pressure to prevail during the full reline and patch work processes.

Air velocity measurements taken from both extraction fans, used during the refurbishing process, yielded the following results:

4.5.1 Extraction fan mounted on the top opening of tanker

Air velocity readings measured from this extraction fan recorded a result of 45 m/s^{-1}. This extraction fan was securely mounted at the top opening of the tanker, before the commencement of any work operation within the tanker. This particular mounting and usage of the extraction fan was found to yield sufficient extraction of fumes, generated from within the tanker, during work processes. The calculated air changes per hour for this particular extraction fan were 175.5 m^3/h.

4.5.2 Extraction fan placed at the bottom opening of the tanker

Air velocity readings measured from this extraction fan recorded a result of 35.60 m/s^{-1}. This particular extraction fan was placed at the bottom opening of the tanker and the following was found:

- it was not securely mounted to the bottom opening;
- was not in frequent use, and
- when it was in use, it was not placed securely in position before the commencement of any work operation within the tanker.

These conditions linked with the usage of this extraction fan were found to yield the insufficient extraction of fumes, generated from within the tanker, during work processes. The calculated air changes per hour for this particular extraction fan were 106.8 m^3/h.

4.6 Urine test analyses results

Urine samples were collected before the commencement and after the completion of every working shift, during the various sampling days and those samples yielded the following results:

4.6.1 Toluene

Of the forty-nine samples analysed, sixteen samples were above the legal limit.

Table 4.6.1: Urine analysis test results recorded for toluene

BIOLOGICAL EXPOSURE INDEX (BEI)	LEGAL LIMIT mg/g Creatinine	LOWEST VALUE mg/g Creatinine	HIGHEST VALUE mg/g Creatinine
O-Cresol in Urine	1	<0.01	7.18

4.6.2 Trichloroethylene

Of the thirty-eight samples analysed, none were found to be above the legal limit. The highest value recorded of 31.00 mg/m Creatinine, was however the highest recorded for the laboratory at any given time

Table 4.6.2: Urine analysis test results recorded for trichloroethylene

BIOLOGICAL EXPOSURE INDEX (BEI)	LEGAL LIMIT mg/g Creatinine	LOWEST VALUE mg/g Creatinine	HIGHEST VALUE mg/g Creatinine
Trichloroacetic Acid in Urine	100	1.29	31.00

4.6.3 Methyl Ethyl Ketone

Of the twelve samples analysed, one sample were found to be above the legal limit.

Table 4.6.3: Urine analysis test results recorded for MEK

BIOLOGICAL EXPOSURE INDEX (BEI)	LEGAL LIMIT mg/l	LOWEST VALUE mg/l	HIGHEST VALUE mg/l
MEK in Urine	2	0.03	2.41

4.7 Results from self-administrated health questionnaire

Self-administrated health questionnaires were used during this study to determine the occupational and medical histories of employees currently involved in the work processes for the refurbishment of chemical rail tankers. The following are the results obtained from the questionnaires:

4.7.1 Age of employees, Years of service and Hours of contact

It was found that the age group of employees interviewed, and who were directly involved in the process of refurbishing of rail tankers, ranged between 24 and 63 years and the average mean was 37.5 years.

The years of services, which included the total amount of years working in environments that involves the coming in contact with solvents, ranged between 2 and 39 years and the average mean was 9.9 years of service.

All employees interviewed indicated that they spend more than 6 hours per day in contact with solvents as part of their working conditions.

4.7.2 Personal Protective Equipment (PPE) Used

The majority of employees interviewed indicated that they make use of PPE in the form of gloves and respiratory protection.

4.7.2.1 Respiratory Protection

Employees indicated that they make use of both respirators, for protection against organic vapours, and the dusk mask type of protection. A total of 86% of employees interviewed indicated that the type of respiratory protection frequently used were the disposal dust mask type. The remaining 14% either made use of a dust mask or respirator, and some only used respirators.

4.7.2.2 Gloves

A total of 73% of employees interviewed indicated that they make use of gloves that are suitable for protection against solvent exposure, when engaged in work processes. The remaining 27% either did not have gloves or just did not use it when in contact with solvents.

4.7.3 Hazard Awareness

Of the employees interviewed, 53% indicated that they have been told about the hazards linked to working with solvents. The remaining 47% has never been told about these dangers and normally just follow what other employees were doing or read about the dangers of the solvents on the labels of the containers.

4.7.4 Smoking History

A total of 40% of employees interviewed indicated that they are currently smoking. The amount of cigarettes smoked per day, ranged between 2 to 10 per day. The total amount of years smoking ranged between 12 to 33 years. The remaining 60% of employees has either never smoked before or has quite smoking 10 or more years ago.

4.7.5 Symptoms Experienced

This section will reflect the results of the symptoms employees were experiencing while being engaged in their daily work processes. These symptoms and the percentage of employees experiencing it, included the following:

- A total of 66% of employees were experiencing headaches;
- 73% of employees experiences dizzy spells;
- 80% of employees constantly felt fatigued;
- 13% of employees felt like vomiting;
- 86% of employees experienced a feeling of being drunk;
- 40% of employees frequently felt a sense of irritability;
- 66% of employees experiences eye irritations;
- 40% of employees have breathing problems.

4.8 Health Deficiency Correlation

Although the health effects of single contaminants may be apparent under circumstances of high exposure, the great majority of people are exposed to chemical mixtures of organics and inorganics at lower concentrations. Contaminants individually may increase the risk of certain diseases; the question of how contaminants interact remains a relatively unexplored subject [129].

The study of chemical mixtures is limited for a number of reasons. It is much easier to study a single compound in an animal study to obtain traditional dose response information. An almost infinite number of combinations of contaminants are possible, and often it is not do not known which is the most important, or which dose ranges should be investigated or which end points should be studied. Although relatively few studies have investigated the interactions of even two chemicals, in real life there are exposures to multiple substances, and the biological effects of 20 different chemicals may be very different from those of just two. Even statistics relating to how one deals with complex mixtures is a newly developing science [129].

From numerous studies conducted to ascertain the cumulative effect of exposure to mixtures, it was found that the majority of these studies were based on concluding what the neurobehavioral effects was of such exposures. Summaries of these results includes:

- A cross-sectional study of 113 male car painters and printers and 81 controls found that those exposed to mixtures had poorer performance of the Benton visual retention for visual perception and memory, than their controls [130];
- A neurobehavioral evaluation, by means of the Neurobehavioral Core Test Battery (NCTB) of Venezuelan workers, exposed to organic solvents found that those exposed groups showed poorer results in simple motor function, short term memory, eye-hand coordination, affective behaviuor and psychomotor perception and speed [131];
- A neurological and neurophysical examinations of workers occupationally exposed to organic solvent mixtures used in paint and varnish productions, revealed that the most frequent complaints, among those exposed were headaches, vertigo, concentration difficulties, sleep disorders during the day, increased emotional irritability, mood swings with a tendency to anxiety [132];
- In a study, to assess the neurobehavioral effects of occupational exposures to low-level organic solvents among Taiwanese workers in paint factories, it was found that the one exposed group (blue-collar group) had significant prolonged response latencies in tests of continues performance, pattern comparison and pattern memory. The other exposed group (white-collar group) had significant impairment which was observed in the continuous performance test [133];
- A study assessing the neurobehavioral effects of chronic occupational exposure to mixtures of solvents used in furniture varnishing, has found that the exposed workers had a slow down of perceptive and motor activities that intensified with the duration of exposure. Furthermore, workers employed for periods longer than 15 years more often reported symptoms of psychic function disturbances and deterioration of their health condition[134].

Taking cognisance of the preceding studies and results found, it is not possible for this study to draw a conclusive health deficiency correlation due to the limitations presented by the study. These limitations, amongst others, in summary included the following:

- the sample size of the employees were small;
- no medical results of the workers were available;
- workers did not agree to give blood, therefore no blood samples were analysed nor could any liver function test be conducted
- results from urine samples for xylene, has not been received back from the laboratory it has been sent to for analyses. It has been indicated by a laboratory representatives that the results would be available in early January 2004, as they are dealing with a backlog of samples, which requires analyses;
- the turnover of tankers to be relined, patched or those that required dome work, were slow, and
- there were delays in the delivery of solvents, required to conduct work processes.

Concerns, based on the study results generated, can however form the platform for further exposure assessment studies within typical work environment settings. The following highlights those concerns:

- the majority of the results recorded, were above the OEL as prescribed for mixtures;
- individual chemical components also reflected similar findings which were above their prescribed OEL;
- full re-line and patch work processes were conducted in a confined space;
- working hours, under these conditions (confined space), for the majority of times exceeded six hours per day;
- no proper use and availability of sufficient and ideal (correct) personal protective equipment;
- ventilation in the work space is provided in the form of an extraction fan, which is either mounted at the top or placed at the bottom opening of the tanker;
- health hazard awareness, as it related to the health effects of solvents, were not evident in the study;

- majority of workers are suffering from acute effects of solvent exposure;
- the above finding was supported by the urine analyses test results. The majority of these results indicated traces of the solvent as a urinary marker, and this was found to be above the prescribed allowable limit for its correspondent marker, and
- a laboratory representative from the National Institute for Occupational Health (NIOH), who was responsible for the analyses of the majority results, indicated that the findings, both air and urine samples, were the highest recorded for the laboratory.

CHAPTER 5

RECOMMENDATIONS

This chapter will highlight the overall recommendations as it pertains to the entire work processes of chemical rail-tanker refurbishment. Management from the various areas sampled, are advised to seriously consider these recommendations as it will ensure:

- compliance to relevant legislation, and
- promoting and maintaining a healthy worker and work environment.

These recommendations has been compiled from the requirements as is outlined under the Regulations for Hazardous Chemical Substances. Government Notice R.1179: 25 August 1995, General Safety Regulations. Government Notice R.1031: 30 May 1986, and the Environmental Regulations for Workplaces. Government Notice R.2281: 16 October 1987.

These regulations has been adjusted to meet the specific requirements of all work processes involved during the refurbishing of chemical rail tankers

5.1 Information and Training

Information and training session should, as a minimum, include the following:

- the potential sources of exposures;
- potential risks to health caused by exposures;
- potential detrimental effect of exposure on the reproductive ability;
- precautions to take to protect against the health risks associated with exposure;
- necessity, correct use and maintenance of personal protective equipment provided;
- importance of good housekeeping;
- importance of conducing personal air sampling and medical surveillance;
- safe working procedures regarding the use, handling and storage of solvents, and
- procedures to be followed in the event of an emergency situation.

5.2 Assessment of potential exposures

- An immediate assessment to be conducted, and thereafter at intervals not exceeding two years, to determine if any employee may be exposed by any route of intake;
- The following information should be documented during the assessment:
  - the solvents to which the workers are being exposed to;
  - the effects the solvents can have on the employees;
  - where the solvent may be present and the physical form it is in;
  - identifying the route of intake and the extent to which the workers can be exposed;
  - the nature of the work processes and control measures applied;
- Air monitoring and medical surveillance programmes are to be designed, implemented and administered, and
- Assessments should be reviewed if previous assessment is no longer valid or there is a change in a process involving the solvents.

5.3 Respirator Zone

The entire working environment is to be declared a respirator zone, and no-one should be allowed to enter the area, without the wearing of the correct respiratory protective equipment. The area declared as a respirator zone, should be demarcated and identified accordingly.

5.4 Control of Exposures

- Exposures should be controlled by limiting the amount of solvents used;
- Limiting the amount of workers who will or maybe exposed;
- Limiting the period of exposure;
- Investigate the use of substitutes to the current solvents used;
- Introducing the following engineering controls:
  - process separation;

  - instillation of an adequate local extraction ventilation systems to the processes for the control of emissions of the airborne solvents;
- develop and introduce appropriate work procedures which workers must follow. These work procedures should, for the minimum, cover the following:
  - safe handling, use and disposal of solvents;
  - local extraction and general ventilation systems are safely used and maintained;
  - machinery and work areas are kept clean, and
  - early corrective action to be readily identified and addressed.

5.5 Personal Protective Equipment and facilities

- All workers to be provided with suitable respiratory protective equipment and non-solvent permeable protective clothing;
- Issued protective equipment and clothing should ensure that:
  - exposures are controlled below the OEL's for the solvents, and
  - solvents are not absorbed through the skin.
- Adequate storage facilities are to be provided for all protective equipment and clothing, and
- Workers to be adequately trained in the proper usage, storage and maintenance of all issued protective equipment and clothing

5.6 Maintenance of Control Measures

- All control equipment and facilities provided should be maintained in good working order, and
- Examinations and test of all engineering control measures are to be carried out immediately, and thereafter at intervals not exceeding 24 months by an Approved Inspection Authority.

5.7 Prohibitions

- No-one should be allowed to use compressed air to remove particles of a solvent from any surface or person, and
- No person should be allowed to smoke, eat, drink or keep food or beverages within the declared respirator zone.

5.8 Labelling, Packaging, Transportation and Storage

- Solvents to be stored are to be properly identified, classified and handled in accordance with South African Bureau of Standards (SABS) 072 and 0228, and
- All containers used for decanting of solvents should be clearly labeled with regards to the contents.

5.9 Disposal of Solvents

Appropriate waste disposal methods should be developed which will ensure that all waste generated during the use of the solvents are handled in a manner that will not negatively impact the environment or those involved in its disposal.

5.10 Working in Confined Spaces

A confined space is defined as an enclosed, restricted or limited space in which a hazardous substance may accumulate or an oxygen-deficient atmosphere may occur or in which a dangerous liquid or a dangerous concentration of gas, vapour, dust or fumes may be present.

The following has specific application to work processes (full reline and patch work) being conducted on the inside of the tanker:

- No person should be allowed to enter the tanker prior to it been tested and evaluated by a competent person, who has pronounced the safety thereof;

- The tanker is to be purged and ventilated to provide and maintain a safe atmosphere for the conduction of all work processes;
- Appropriate and approved breathing apparatus is to be supplied to all persons who are required to enter the tanker;
- One person trained in resuscitation, is required to remain in attendance immediately outside the tanker;
- Approved and effective apparatus for breathing and resuscitation should be available at all times, on the outside of the tanker;
- Measures should be put in place to ensure that all persons has safely vacated the tanker, at the end of each shift, and
- The concentration of all solvents used should not exceed twenty five percent (25%) of the lower explosive limit for any of the solvent products.

5.11 Ventilation requirements

Ventilation requirements to be provided, either mechanically or naturally, should meet the following requirements:

- Air breathed by all persons, on the inside of the tanker, should not endanger their safety;
- The time weighted average concentration of carbon dioxide within the tanker, taken over an eight hour period, should not exceed one half per cent by volume of air. Furthermore, the carbon dioxide content should not at any time exceed three percent by volume of air;
- The prescribed exposure limits for airborne substances inside the tanker should not be exceeded, and
- Air concentration of solvent vapours, inside the tanker, should not exceed the lower explosive limit of the particular solvent being used.

If the above ventilation requirements cannot be met, all person entering the tanker is to be provided with respiratory protective equipment of a type that would reduce exposure to a safe level.

6. Conclusion

Management from both work areas sampled, are advised to ensure adherence to all listed recommendations as it will ensure that all work processes comply to legislative requirements and also contribute to protecting the health and safety of all persons involved in the process of refurbishing.

No statistical analyses were performed due to the following:

- the sample size was too small to draw a meaningful statistical conclusion within the larger population from which the data sample was derived,
- the study design was that of a cross sectional design and therefore the study focused, amongst others, on the workers health status, measurement of workplace exposures and providing an overview of prevalent health conditions within the work environment,
- the study forms part of a preliminary study that evaluated the health hazards prevalent during the refurbishing of chemical rail-tankers, and
- there are currently limited research published with regards to the associated health effects stemming from the exposure to a mixture of solvents during a single exposure.

It is suggested that a longitudinal follow-up study, which should ensure that all study limitations highlighted are addressed as well as all other health hazards inherent to the processes of tanker refurbishment, be conducted as results thereof would be conclusive as to the health effects of workers during the process of chemical rail tanker refurbishment.

I want to finally thank the management of both companies, for allowing this study to be conducted, as well as for their commitment shown during the study to address work environment health hazards confronted by their employees.

7. REFERENCES

1. Brautbar, N. 1999. Solvents and kidney disease, scientific methodology for causation. http://www.expertlaw.com/library/exparticles/solvents_kidney.html

2. American Mutual Insurance Alliance. 1980. Technical Guide No.6, Handbook of organic industrial solvents.

3. NIOSH (National Institute for Occupational Safety and Health). 1987. Current Intelligence Bulletin 48 – Organic solvent neurotoxicity. Publication No. 87-104.

4. OSHA (Occupational Safety and Health Administration). 2002. Solvents. http://www.osha.gov/oshinfo/priorities/solvents.html

5. RSRC (Railroad Safety Research Council). 1996. Hazardous exposure to industrial solvents. http://www.bzqlaw.com/1-10.htm

6. OSHA (Occupational Safety and Health Administration). 1989. Rulemaking docket for OSHA Air Contaminants Standard (29 CFR 1910.1000).

7. NIOSH (National Institute for Occupational Safety and Health). 1994. NIOSH Pocket guide to chemical hazards. Publication No. 94-116.

8. CCOHS (Canadian Centre for Occupational Health and Safety). 1992. The neurotoxicity of organic solvents. http://www3.sympatico.ca/cnin/ccohs.html

9. NIOSH (National Institute for Occupational Safety and Health). 1977. Criteria for a recommended standard: Occupational exposure to refined petroleum solvents. Publication No. 77-192.

10. ACGIH (American Conference of Governmental Industrial Hygienists). 1994/1995. Threshold limit values for chemical substances, physical agents and biological exposure indices.

11. (a) South Africa. 1993. Occupational Health and Safety Act, No. 85 of 1993. Pretoria Government Printer.

11. (b) South Africa. 1995. Regulations for Hazardous Chemical Substances. Pretoria Government Printer.

12. South Africa. 1973. Hazardous Substances Act, No. 15 of 1973. Pretoria Government Printer.

13. Anchor Chemicals (Pty) Ltd. 2000. Material Safety Data Sheet - TY – PLY UP. MSDS0021.

14. Anchor Chemicals (Pty) Ltd. 2000. Material Safety Data Sheet - TY – PLY RC. MSDS0020.

15. Anchor Chemicals (Pty) Ltd. 2000. Material Safety Data Sheet - CHEMLOCK 286. MSDS0011.

16. Pekay Chemicals (Pty) Ltd. 2003. Material Safety Data Sheet- WD 472 & 473.

17. Anchor Chemicals (Pty) Ltd. 2001. Material Safety Data Sheet - TY – PLY 2033. MSDS0025.

18. U.S. Environmental Protection Agency. 1987. Health advisory for methyl ethyl ketone. Office of Drinking Water, Washington, DC.

19. Amoore, J.E. & Hautala, E. 1983. Odor as an aid to chemical safety: Odor thresholds compared with threshold limit values and volatilities for 214 industrial chemicals in air and water dilution. Journal of Applied Toxicology, 3(6): 272-290.

20. CalEPA (California Environmental Protection Agency). 1999. Air toxics hot spots program risk assessment guidelines: Part III. Technical support document for the determination of noncancer chronic reference exposure levels. Office of Environmental Health Hazard Assessment, Berkeley, CA.

21. U.S. Environmental Protection Agency. 1993. Assessment tools for the evaluation of risk (ASTER, online database). Environmental Research Laboratory, Duluth, MN.

22. U.S. Environmental Protection Agency. 1999. Integrated Risk Information System (IRIS) on methyl ethyl ketone. National Center for Environmental Assessment, Office of Research and Development, Washington, DC.

23. U.S. Environmental Protection Agency. 1990. Updated health effects assessment for methyl ethyl ketone. EPA/600/8-89/093. Environmental Criteria and Assessment Office, Office of Health and Environmental Assessment, Office of Research and Development, Cincinnati, OH.

24. U.S. Department of Health and Human Services. 1993. Hazardous Substances Data Bank (HSDB, online database). National Toxicology Information Program, National Library of Medicine, Bethesda, MD.

25. U.S. Department of Health and Human Services. 1993. Registry of Toxic Effects of Chemical Substances (RTECS, online database). National Toxicology Information Program, National Library of Medicine, Bethesda, MD.

26. Smyth, Jr. H.F., Carpenter, C.P., Weil, C.S., et al. 1962. Range-finding toxicity data: List VI. Am.Ind. Hyg. Assoc. J. 23:95-107.

27. Krasavage, W.J., O'Donoghue, J.L. & Divincenzo, G.D. 1982. Ketones. In: Patty's Industrial Hygiene and Toxicology, 3rd Rev. ed., Vol. 2C, Toxicology, pp. 4728-4733. G.D. Clayton and F.E. Clayton, Eds. John Wiley & Sons, New York.

28. Patty, F. A., Schrenk, H.H. & Yant, W.P. 1935. Acute response of guinea pigs to vapors of some new commercial organic compounds – VIII. Butanone.U.S. Public Health Rep. 50:1217-1228.

29. Altenkirch, H., Stoltenburg, G. & Wagner, H.M. 1978. Experimental studies on hydrocarbon neuropathies induced by methyl ethyl ketone (MEK). J. Neurol. 219:159-170

30. Deacon, M.M., Pliny, M.D., John, J.A., et al. 1981. Embryo and fetotoxicity of inhaled methyl ethyl ketone in rats. Toxicol. Appl. Pharmacol. 59: 620-622.

31. Schwetz, B.A., Leong, B.K.J. & Gehring, P.J. 1974. Embryo and fetotoxicity of inhaled carbon tetrachloride, 1,1-dichloroethane and methyl ethyl ketone in rats. Toxicol. Appl. Pharmacol. 28:452-464.

32. Nelson, K.W., Ege, Jr. J.F., Ross, M., et al. 1943. Sensory response to certain industrial solvent vapors. J. Ind. Hyg. Toxicol. 25:282-285.

33. Smith, A.R., Mayers, M.R. 1944. Study of poisoning and fire Hazards of butanone and acetone. N.Y. State Ind. Bull. 23:174-176.

34. Manufacturing Chemists Association. 1968. Research on chemical odors, Part 1, odor thresholds for 53 commercial chemicals. MCA, Washington, DC.

35. Murphy, D.C. 1984. Acute illness among workers connected to solvent exposure. Occup. Health Safety 53:36-38.

36. Binashi, S., Gassangia, G. & Crovato, E. 1976. Behavioral toxicology in the evaluation of the effects of solvent mixtures. Adverse Effects Environ. Chem. Psychotroic Drugs 2:91-98.

37. Fagius, J. & Gronqvist, B. 1978. Function of peripheral nerves and signs of polyneuropathy in solvent-exposed workers at a Swedish steelworks. Acta. Neurol. Scand. 57:305-316.

38. Baker, E.L. & Feldman, R.G. 1982. Paraoccupational exposure to mixed solvents. J. Toxicol. Clin. Toxicol. 19:27-34.

39. Billmaler, D., Yee, H.T., Allen, N., et al. 1974. Peripheral neuropathy in a coated fabrics plant. J. Occup. Med. 16:665-671.

40. Dyro, F.M. 1978. Methyl ethyl ketone polyneuropathy in shoe factory workers. Clin. Toxicol. 13:371-376.

41. Alderson, M.R. & Rattan, N.S. 1980. Mortality of workers in an isopropyl alcohol plant and two MEK dewaxing plants. Br. J. Ind. Med. 37:85-89.

42. Agency for Toxic Substances and Disease Registry (ATSDR). 1998. Toxicological profile for methylene chloride. Public Health Service, U.S. Department of Health and Human Services, Atlanta, GA.

43. U.S. Environmental Protection Agency. 1999. Integrated Risk Information System (IRIS) on methylene chloride. National Center for Environmental Assessment, Office of Research and Development, Washington, DC.

44. The Merck Index. 1989. An encyclopedia of chemicals, drugs, and biologicals. 11th ed. Ed. S. Budavari. Merck and Co. Inc., Rahway, NJ.

45. Amoore, J.E. & Hautala, E. 1983. Odor as an aid to chemical safety: Odor thresholds compared with threshold limit values and volatilities for 214 industrial chemicals in air and water dilution. Journal of Applied Toxicology, 3(6):272-290.

46. U.S. Department of Health and Human Services. 1993. Hazardous Substances Data Bank (HSDB, online database). National Toxicology Information Program, National Library of Medicine, Bethesda, MD.

47. U.S. Department of Health and Human Services. 1993. Registry of Toxic Effects of Chemical Substances (RTECS, online database). National Toxicology Information Program, National Library of Medicine, Bethesda, MD.

48. U.S. Environmental Protection Agency. 1997. Health Effects Assessment Summary Tables. FY 1997 Update. Solid Waste and Emergency Response, Office of Emergency and Remedial Response, Cincinnati, OH. EPA/540/R-97-036.

49. Lehmann, K.B. & Flury, F. 1943. Toxicology and hygiene of industrial Solvents, pp. 13-138. Williams & Wilkins, Baltimore.

60. Amoore, J.E. & Hautala, E. 1983. Odor as an aid to chemical safety: Odor thresholds compared with threshold limit values and volatilities for 214 industrial chemicals in air and water dilution. Journal of Applied Toxicology, 3(6): 272-290.

61. U.S. Environmental Protection Agency. 2001. Trichloroethylene health risk assessment: Synthesis and characterisation. Office of Research and Development, Washington, DC.

62. U.S. Department of Health and Human Services. 1993. Registry of Toxic Effects of Chemical Substances (RTECS, online database). National Toxicology Information Program, National Library of Medicine, Bethesda, MD.

63. CalEPA (California Environmental Protection Agency). 1997. Technical support document for the determination of noncancer chronic reference exposure levels. Office of Environmental Health Hazard Assessment, Berkeley, CA.

64. U.S. Environmental Protection Agency. 1985. Health assessment document for trichloroethylene. Environmental Criteria and Assessment Office, Office of Health and Environmental Assessment, Office of Research and Development.

65. U.S. Environmental Protection Agency. 1998. National Emission Standards for Hazardous Air Pollutants: Wood Furniture Manufacturing Operations. Federal Register 63 FR 34336-346.

66. U.S. Environmental Protection Agency. 1998. Risk assessment issue paper for carcinogenicity information for trichloroethylene (TCE). Superfund Technical Support Center, National Center for Environmental Assessment, Cincinnati, OH.

67. Smyth, Jr. H.F., Carpenter, C.P., Weil, C.S., et al. 1969. Range-finding toxicity data: List VII. Am. Ind. Hyg. Assoc. J. 30:470-476.

68. Spector, W.S. (Ed.). 1959. Handbook of toxicology, Vol. V., p. 76. W.B. Saunders Co., Philadelphia.

69. Torkelson, T.R. & Rowe, V.K. 1981. Halogenated aliphatic hydrocarbons containing chloride, bromine, and iodine. In: Patty's Industrial Hygiene and Toxicology, 3rd ed., Vol. 2B, Toxicology, pp. 3553-3560. G.D.Clayton and F.E. Clayton, Eds. John Wiley & Sons, New York.

70. Mikiskova, H. & Mikiska, A. 1968. Some electrophysiological methods for studying the action of narcotic agents in animals, with special reference to industrial solvents. Br. J. Ind. Med. 25:81-105.

71. Adams, E.M., Spencer, H.C., Rowe, V.K., et al. 1951. Vapor toxicity of trichloroethylene determined by experiments on laboratory animals. Arch. Ind. Hyg. Occp. Med. 4:469-481.

72. Healy, T.E.J., Poole, T.R. & Hooper, A. 1982. Rat fetal development and maternal exposure to trichloroethylene at 100 ppm. Br. J. Anaesth. 54:337-341.

73. Zenick, H., Blackburn, K., Hope, E., et al. 1984. Effects of trichloroethylene exposure on male reproductive function in rats. Toxicology 31:237-250.

74. Dobkin, A.B. & Byles, P.H. 1963. Clinical anesthesia halogenated anesthetics, pp.43-65. J.F Artusio, Ed. F.A. Davis Co., Philadelphia.

75. Ayre, P. 1945. Acute yellow fever after trilene anesthesia. Br. Med. J. 2:784

76. Secchi, G.C., Chiappino, G., Lotto, A., et al. 1968. Actual chemical composition of commercial trilene and their hepatotoxic effects: Clinical enzymologic study. Med. Lav. 59:486-487.

77. Triebig, G., Trautner, P., Weltle, D., et al. 1982. Untersuchungen zur neurotoxizitat von arbeitsstoffen. Int. Arch. Occup. Environ. Health 51:25-34.

78. Vernon, R.J. & Ferguson, R.K. 1969. Effects of trichloroethylene on visual-motor performance. Arch. Environ. Health 18:894-900.

79. Ahlmark, A. & Forssman, S. 1951. Evaluating trichloroethylene exposures by urinalyses for trichloroacetic acid. Arch. Ind. Hyg. Occup. Med. 3:389-398.

80. Ahlmark, A. & Friberg, L. 1955. Should the maximum allowable concerntration of trichloroethylene and similar substances be reduced? Nordisk. Hyg. Tidskrift 36:165.

81. Lilis, R., Stanescu, D., Mucia, N. & Roventa, A. 1969. Chronic effects of trichloroethylene exposure. Med. Lav. 60:595-601.

82. Agency for Toxic Substances and Disease Registry (ATSDR). 1995. Toxicological Profile for Xylenes. Public Health Service, U.S. Department of Health and Human Services, Altanta, GA.

83. Amoore, J.E. & Hautala, E. 1983. Odor as an aid to chemical safety: Odor thresholds compared with threshold limit values and volatilities for 214 industrial chemicals in air and water dilution. Journal of Applied Toxicology, 3(6): 272-290.

84. U.S. Department of Health and Human Services. 1993. Hazardous Substances Data Bank (HSDB, online database). National Toxicology Information Program, National Library of Medicine, Bethesda, MD.

85. U.S. Department of Health and Human Services. 1993. Registry of Toxic Effects of Chemical Substances (RTECS, online database). National Toxicology Information Program, National Library of Medicine, Bethesda, MD.

86. Calabrese, E.J. & Kenyon, E.M. 1991. Air toxics and risk assessment. Lewis Publishers, Chelsea, MI.

87. U.S. Environmental Protection Agency. 1999. Integrated Risk Information System (IRIS) on Xylenes. National Center for Environmental Assessment, Office of Research and Development, Washington, DC.

88. U.S. Environmental Protection Agency. 1997. Health effects assessment summary tables. Office of Research and Development, Office of Emergency and Remedial Response, Washington, DC.

89. Smyth, H.J., Carpenter, C.P., Weil, C. S., et al. 1962. Range-finding toxicity data: List VI. Am. Ind. Hyg. Assoc. J.23:95-107.

90. Hine, C.H. & Guideman, H.H. 1970. The toxicological properties of hydrocarbon solvents. Ind. Med.39 (5): 215.

91. Anderson, C., Sundberg, K. & Groth, O. 1986. Animal model for assessment of skin irritancy. Contact Dermatitis 15:143-151.

92. Fabre, R., Truhaut, R. & Laham, S. 1960. Toxicological research on replacement solvents for benzene: Study of xylenes. Arch. Mal. Prof. 21:301-313.

93. American Petroleum Institute. 1983. Parental and fetal reproduction inhalation toxicity study in rats with mixed Xylenes. API Medical Research Pub. Washington, DC.

94. Gerade, H.W. 1960. Prevention, detection and treatment of exposure to aromatic hydrocarbons. In: Toxicology and Biochemistry of Aromatic Hydrocarbons, pp. 171-180. Elsevier Publishing Co., New York.

95. Browning, E. 1965. Toxicity and metabolism of organic solvents, pp. 77-89. Elsevier Publishing Co., New York.

96. Nelson, K.W., Ege, J.F., Ross, M., et al. 1943. Sensory response to certain industrial solvent vapors. J. Ind. Hyg. Toxicol. 25:282-285.

97. Morley, R., Eccleston, D.W., Douglas C.P., et al. 1970. Xylene poisoning: A report on one fatal case and two cases of recovery after prolonged unconsciousness. Br. Med.J. 3:442-443.

98. Matthaus, W. 1946. Corneal lesions in workers dealing with surface varnishing in the furniture industry. Klin Monatsbl. Augenheilk. 144:713-717.

99. Savolainen, K. & Riihimaki, V. 1981. An early sign of xylene effect on human equilibrium. Acta Pharmacol, Toxicol. 48:279-283.

100. Savolainen, H., Riihimaki, V., Seppalainen, A.M. & Linnoila, M. 1980. Effects of short-term m-Xylene exposure and physical exercise on the central nervous system. Int. Arch. Occup. Environ. Health 45: 105-121.

101. Agency for Toxic Substances and Disease Registry (ATSDR). 1994. Toxicological Profile for Toluene. U.S. Public Health Service, U.S. Department of Health and Human Services, Atlanta, GA.

102. U.S. Environmental Protection Agency. 1986. Health effects assessment for toluene. Environmental Criteria and Assessment Office, Office of Health and Environmental Assessment, Office of Research and Development, Cincinnati, OH.

103. The Merck Index. 1989. An encyclopedia of chemicals, drugs, and biologicals. 11th ed. Ed. S. Budavari. Merck and Co. Inc., Rahway, NJ.

104. Amoore, J.E. & Hautala, E. 1983. Odor as an aid to chemical safety: Odor thresholds compared with threshold limit values and volatilities for 214 industrial chemicals in air and water dilution. Journal of Applied Toxicology, 3(6): 272-290.

105. U.S. Environmental Protection Agency. 1999. Integrated Risk Information System (IRIS) on toluene. National Center for Environmental Assessment, Office of Research and Development, Washington, DC.

106. Kimura, E.T., Ebert, D.M. & Dodge, P.W. 1971. Acute toxicity and limits of solvent residue for sixteen organic solvents. Toxicol. Appl. Pharmacol. 19:699-704.

107. Smyth, H.F., Carpenter, C.D., Weil, C.S., et al. 1969. Range-finding toxicity data: List VII. Am. Ind. Hyg. Assoc. J. 30:470-476.

108. Pryor, G.T., Dickson, J., Howd, R.A. & Rebert, C.S. 1983. Transient cognitive deficits and high frequency hearing loss in weanling rats exposed to toluene. Neurobehav. Toxicol. Teratol. 5:53-57.

109. Rebert, C.S., Sorensen, S.S., Howd, R.A. & Pryor, G.T. 1983. Toluene-induced hearing loss in rats evidenced by the brainstem auditory-evoked response. Neurobehav. Toxicol. Teratol. 5:59-62.

110. Ungvary, G., Manya, S., Tatrai, E., et al. 1980. Effect of toluene inhalation on the liver of rats. Dependence on sex, dose, and exposure time. J. Hyg. Epidemiol. Microbiol. Immunol. 24:243-252.

111. National Toxicology Program. 1990. Toxicology and carcinogenesis studies of toluene in F344/N rats and B6C3F1 mice (inhalation studies). Pub. No. 90-2826. NTP, Research Triangle Park, NC.

112. Hudak, A. & Ungvary, G. 1978. Embryotoxic effects of benzene and its methyl derivatives toluene, xylene. Toxicology 11:55-63.

113. Courtney, K.D., Andrews, J.E., Springer, J., et al. 1986. A perinatal study of toluene in the mouse. Fund. Appl. Toxicol. 6:145-154.

114. Andersen, I., Lundquist, G.R., Molhave, L., et al. 1983. Human response to controlled levels of toluene in six-hour exposures. Scand. J. Work Environ. Health 9:405-418.

115. Baelum, J., Andersen, I., Lundquist, G.R., et al. 1985. Response of solvent-exposed printers and unexposed controls in six-hour toluene exposure. Scand. J. Work Environ. Health 11:271-280.

116. Ogata, M., Tomokuni, K. & Takatsuka, Y. 1970. Urinary excretion of hippuric acid and m- or p-Methylhippuric acid in the urine of persons exposed to vapours of toluene and m- or p-Xylene as a test of exposure. Br.J. Ind. Med. 27: 43-50.

117. Gamberale, F. & Hultengren, M. 1972. Toluene exposure: Psychophysiological functions. Work Environ. Health 9:131-139.

118. Dick, R.B., Setzer, J.V., Wait, R., et al. 1984. Effects of acute exposure of toluene and methyl ethyl ketone on psychomotor performance. Int. Arch. Occup. Environ. Health 54:91-109.

119. Low, L.K., Meeks, J.R. & Mackerer, C.R. 1988. Health effects of alkyl benzenes. Toxicol. Ind. Health 4: 49-75.

120. Wilson, R.H. 1943. Toluene poisoning. JAMA 123:1106-1108.

121. Goldbloom, D. & Chouinard, G. 1985. Schizophreniform psychosis associated with chronic industrial toluene exposure: Case Report. J. Clin. Psychiatry 46:350-351.

122. Echeverria, D., Fine, L., Langolf G., et al. 1989. Acute neurobehavioral effects of toluene. Br. J. Ind. Med.46: 483-495.

123. NOHSC (National Occupational Health and Safety Commission). 2003. Refined Petroleum Solvent Mixtures. http://www.nohsca.gov.au/OHSInformation/NOHSCPubliation/599.htm

124. Plog, B. 1998. Fundamentals of Industrial Hygiene. 3rd edition. National Safety Council: Chicago.

125. Harmse, L. (ed). 1997. Course Notes: Occupational Hygiene Basic Measuring Techniques. Faculty of Environmental Sciences, Department: Environmental Health;

126. Rogers, G. 1994. A step by step guide to air sampling. An introduction to the basics. SKC Ltd, UK.

127. NIOSH (National Institute for Occupational Safety and Health). 2000. NIOSH Pocket Guide to Chemical Hazards. NIOSH Manual of Analytical Methods, Publication No. 2000-130.

128. Leidel, N.A., Busch, K.A. & Lynch, J.R. 1977. Occupational exposure sampling strategy manual. US Department of Health, Education and Welfare Public health service, Centre for disease control, National Institute for Occupational Safety and Health, Cincinnati, Ohio 45226.

129. Carpenter, D. O., Arcaro, K. & Spink, D.C. 2002. Understanding the Human health effects of chemical mixtures. Environmental Health Perspectives 110(1): 25-42.

130. Lee, S.H. & Lee, S.H. 1993. A study on the neurobehavioral effects of occupational exposure to organic solvents in Korean workers. Environ. Res. 60(2): 227-32.

131. Escalona, E., Yanes, L., Feo, O. & Maizlish, N. 1995. Neurobehavioral evaluation of Venezuelan workers exposed to organic solvent mixtures. Am. J. Ind. Med. 27(1): 15-27.

132. Indulski, J.A., Sinczuk-Walczak, H., Szymczak, M. & Wesołowski, W. 1996. Neurological and neurophysiological examinations of workers occupationally exposed to organic solvent mixtures used in the paint and varnish production. Int J Occup Med Environ Health 9(3): 235-44.

133. Tsai, S.Y., Chen, J.D., Chao, W.Y. & Wang, J.D. 1997. Neurobehavioral effects of occupational exposure to low-level organic solvents among Taiwanese workers in paint factories. Environ Res 73(1/2): 146-55.

134. Bazylewicz-Walczak, B., Walenczak, J., Wesolowski, W. & Jakubowski M. 1992. Neurobehavioral effects of chronic occupational exposure to mixtures of solvents used in furniture varnishing. Part I – Psychological examination. Med Pr 43(5): 363-70.