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THE USEFULNESS OF TASK-BASED EXPOSURE DATA IN CHARACTERISING WORK TASKS THAT PRODUCE POTENTIALLY HIGH SHORT-TERM EXPOSURES.

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A research report submitted to the Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Master of Public Health (Occupational Hygiene).

Johannesburg, 2008

DECLARATION

I, Sean John Chester declare that that this research report is my own work. It is being submitted for the degree of Master of Public Health (Occupational Hygiene) at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at this or any other university.

…….

S.J. Chester

…….. day of ……., 2008.

ABSTRACT

Introduction: Single sample TWA samples collected over an 8-hour shift have the potential to mask elevated exposures, excursions or “peaks” that may have occurred thus permitting situations where workers are over-exposed or indeed over-dosed. The objectives of this study, undertaken in a small acrylic sheet manufacturing plant, are therefore to identify tasks that have the potential to exceed short-term occupational exposure levels and then simultaneously monitor employees undertaking these tasks for 8-hour TWA and Short-Term exposure concentrations. The results obtained from this sampling are then compared to their respective legal limits and then finally correlated to establish their statistical significance.

Materials and Methods: The study setting comprises a syrup room wherein two employees are assigned per shift. Employees in this setting manufacture an acrylic “syrup” which is achieved by dosing raw materials into any one of 13 mixing vessels. Whilst mixing, these vessels also heat the ingredients until the required viscosity is reached. This “syrup” comprising mostly of liquid methyl methacrylate, is then decanted into a pressure vessel from where it is pipe-fed into a casting chamber and finally poured between two glass sheets. When cured, the final product is stored and sold as a clear or tinted acrylic sheet. All operations with this area are therefore associated with facilitating the syrup manufacture. Personal 8-hour TWA and Task-Based measurements of methyl methacrylate vapour were simultaneously obtained from the breathing zones of six employees over five separate shifts. These employees routinely work within the setting and also undertake tasks that have the potential to exceed the Short-Term Occupational Exposure Limit (ST-OEL) for methyl methacrylate vapour. Tasks were studied and those selected for quantitative monitoring were captured using a qualitative risk assessment tool. These selections were based on studying each task to establish the employee’s exposure probability and severity i.e. whether performing the task could indeed lead to excessive Short-Term exposures. Eight-hour TWA monitoring was undertaken using activated carbon 3M 3500 passive monitoring badges which were attached to each of the subject’s breathing zone and left over 80 % of the shift. The task-based measurements were obtained by using a Drager PAC III electro-chemical monitoring instrument, which was also placed in each

subject's breathing zone, and provided real-time exposure data whilst the employees were undertaking the various tasks.

Results: All measurements (N = 116) were obtained over a series of 5 full-shift monitoring periods. When analysed, 8 of the 10 of the TWA samples returned results that were below the 8-hour TWA OEL. Of the 106 task-based measurements obtained for the nine identified tasks, when averaged, 89.1 % of results exceeded the ST-OEL. When the TWA and ST measurements were correlated, only one of the nine tasks were statistically significant in their correlation. This correlation coefficient was however highly statistically significant ($r = 0.339$, $p = 0.032$ and $r = 0.337$, $p = 0.022$ respectively). Both negative and positive correlations were obtained however these were statistically insignificant.

Discussion: A significantly higher proportion of the sample results were above the ST-OEL than the 8-hour TWA OEL concentrations contributing to the argument that ST exposure monitoring may add additional insight to employees' exposure profiles. A major limitation of the study is however the small sample size, which makes it difficult, due to inter-worker variability amongst other factors, to extrapolate the results and their corresponding interpretations to larger, more generalised occupational hygiene monitoring scenarios.

Conclusion: The results obtained therefore support the assertion that the inclusion of short-term monitoring is important in characterising employee exposures in situations where these tasks are themselves potential sources of significant chemical exposures.

Recommendations: As a basis for undertaking any form of monitoring and particularly in settings where short-term, task-based exposures may exist, the importance of undertaking a systematic approach to hazard identification and risk profiling via the use of a known risk assessment tool to compile a air sampling programme, has been demonstrated in the results of this research. Further research that specifically addresses the problem of characterising workplace exposures would be useful in larger study populations as well as occupational settings which expose employees to the various types of airborne contaminant e.g. fume, mists, particulates and gases.

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ABBREVIATIONS

- EPA - Environmental Protection Agency
- OEL - Occupational Exposure Limit
- OSHA – US Occupational Safety and Health Administration
- ppm - parts per million
- RHCS - Regulations for Hazardous Chemical Substances
- ST-OEL - Short-Term Occupational Exposure Limit
- TWA-OEL – Time-Weighted Average Occupational Exposure Limit
- TWA - Time Weighted Average
- VOC - Volatile Organic Compound

DEFINITIONS

Breathing Zone	A hemisphere forward of the shoulders with a radius of approximately 30 cm (i.e., an area as close as practicable to the nose and mouth of the employee being monitored for methyl methacrylate vapour exposure concentrations). Breathing zone samples provide the best representation of actual exposure.
OEL	Occupational Exposure Limit. A generic term used to represent: (1) the concentration or intensity of the agent that is legally allowable, (2) the time period over which workplace concentrations are averaged to compare with the allowable intensity. In South African legislation, methyl methacrylate has two OELs i.e. one for 8-hour exposures and one for Short-Term Exposures (usually 15 minutes).
Peak Exposure	In the context of this report, a peak exposure is defined as a period during which the exposure exceeded the Short-Term Occupational Exposure Limit for methyl methacrylate.
TWA OEL	The airborne concentration of methyl methacrylate that represents an acceptable exposure level and generally expressed as 8-hour Time-Weighted Average (TWA) concentrations.
ST-OEL	The airborne concentration of methyl methacrylate which workers can be exposed continuously for a short period of time without suffering from irritation, chronic or irreversible tissue damage, or narcosis of sufficient degree to increase the likelihood of accidental injury, impair self-rescue or materially reduce work efficiency.

Task	In this report, tasks are defined as those routine work practices that are excursive in nature and have the potential to expose a worker to elevated levels of airborne methyl methacrylate.

CHAPTER 1

1. INTRODUCTION:

The aim of this chapter is to provide background information on the integral components of this study.

The chapter begins by expounding on the rationale associated with excursions and their associated significance in the occupational setting. Excursions are then further defined and formally compared to 'peaks' and related directly to the study setting.

Exposure limits and the various definitions used in the United States, United Kingdom and European Community are also described. The Exposure Limits applied in South Africa and this study are then described in detail.

Once the exposure limits are discussed, the chapter progresses to broadly discussing the various risk assessment and air monitoring methodologies and their applications in relation to exposure. A general discussion of the sampling strategies applied in this study is included.

The next section of this chapter provides greater explanation on the health hazards, uses and physical properties associated with methyl methacrylate. This section ends with tabling the two South African Exposure Standards for airborne methyl methacrylate vapours.

The penultimate section of this chapter discusses the importance of the study.

The chapter ends with the aims and objectives of the study described in this research report.

1.1. Excursions and Their Significance:

Excessive peak or excursion exposures to airborne contaminants are of special concern since they produce an elevated dose rate at target tissues and organs, potentially altering metabolism, overloading protective and repair mechanisms and amplifying tissue responses [1].

Despite the above, in studies of chronic health-effects related to occupational exposure, it is common practice to use exposure sampling methodology that does not reflect these peak exposures (e.g. TWA exposure, Long-Term Mean exposure and Career Cumulative exposure measurements). In the previous decade, it was hypothesized that short-term high exposure levels play a role in the etiology of chronic occupational diseases traditionally associated with exposures accumulated over a long time period [2]. Such hypotheses have been suggested for the relationships between exposure to volatile organic compounds (VOC's) and chronic toxic encephalopathy [3,4,5] (CTE) as well as allergens/ irritants and asthma [6,7,8,9], and have been suggested, but not supported, for some chemical carcinogens [10].

1.2. Defining Excursion Exposures:

Since the basic premise of this study is the proposition that task-based monitoring would yield more information about exposure when compared to the relevant legal limit and simultaneously obtained full-shift TWA monitoring results, one of the fundamental difficulties with assessing excursion exposures lies in obtaining consensus on what constitutes a toxicologically significant or relevant peak exposure.

Wegman and Eisen (1992)[11], suggest that duration and magnitude, as well as frequency of peaks should be evaluated. Ott *et al*. (2002) [9] defined peak exposures to toluene di-isocyanate as a nine minute average concentration that exceeded 20 parts per billion. In another study of respiratory health effects amongst bakers, it was suggested that a peak exposure could be defined as the

highest level of exposure monitored during a specific task within a group of workers [12]. Blair and Stewart (1990) define peak exposures as the highest level of exposure monitored for job/work area/time combinations [13]. In their study of exposures to organic solvents and within-shift variability, Kumagai and Matsunaga (1995, 1999) used 7.5, 15, 30 and 60 minute averages of concentration [14 15]. Marrow *et al.* (1991), defined peak exposures in relation to CTE as an episode in which workers had been exposed to a larger than 'normal' amount of solvent(s) for a 'brief' time period that resulted in a visit to the emergency room or hospitalization[3].

In this study, the use of the term peak and excursion are interchangeable and can be further defined as a period during which the exposure exceeded the South African legislated Short-Term Occupational Exposure Limit for methyl methacrylate.

1.3. Exposure Limits Applied to Airborne Contaminants:

Most developed countries have occupational exposure limits (OEL) for airborne chemical contaminants in the workplace. The types and sources of standards applied in the USA, United Kingdom and Europe are discussed below:

In the United States, the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLV) and the Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL) standards are the most cited airborne contaminant standards.

In the United Kingdom, the Heath And Safety Executive, through their Control of Substances Hazardous to Health Regulations, 2002 (COSHH), list two types of occupational exposure limits. A Maximum Exposure Limit (MEL) is proposed for substances which may cause the most serious health effects, such as cancer and occupational asthma; these are substances for which no threshold level of exposure for the key health effect can be determined or for which exposure thresholds may be identified but at a concentration that is not yet

routinely achievable in the workplace. An Occupational Exposure Standard (OES) is proposed at a level at which, based on current scientific knowledge, there is no indication of risk to the health of workers who breathe it in day after day. If exposure to a substance that has an OES is reduced at least to that level, then adequate control has been achieved.

Indicative Occupational Exposure Limit Values (IOELVs) are European Community limit values, which are health based (earlier directives referred to them as ILVs). This means that they indicate levels of exposure to hazardous substances considered to provide protection from ill health caused by work. IOELVs are similar to the British OELs system under COSHH.

In South Africa, it is acceptable to utilize COSHH, OSHA and ACGIH standards only in the absence of local standards. Locally, the Regulations for Hazardous Chemical Substances (RHCS), 1995 as framed under the Occupational Health and Safety Act (85 of 1993), contain Occupational Exposure Limits for Time-Weighted Averages (TWA) and Short-Term Exposure Limits (ST-OEL) for many industrial chemicals. These sub-categories of the OEL standards are described in greater detail below.

1.4. Describing the Time-Weighted Average and Short-Term OEL:

In South Africa there are two categories for OELs. Firstly, "Occupational Exposure Limit Time-Weighted Average (TWA OEL) i.e. the "time weighted average concentration for a normal 8-hour workday and a 40 hour workweek, to which nearly all workers may be repeatedly exposed, day after day, without adverse effects" [16].

And secondly, Short-Term Occupational Exposure Limits (ST-OEL) i.e. "the concentration to which workers can be exposed continuously for a short period of time without suffering 1) irritation, 2) chronic or irreversible tissue damage, or 3) narcosis of sufficient degree to increase the likelihood of accidental injury" [16]. The ST-OEL is further defined as a 15 minute TWA exposure which should

not be exceeded at any time during a workday even if the 8 hour TWA is within the TWA OEL [16].

The definitions applied to standards in South Africa and abroad are generic and are widely understood to have the same or similar meaning.

Similar to COSHH, in their definition and application of MEL and OES, the RHCS further divides the standards into regulatory categories i.e. Table 1 and Table 2 substances where Table 1 Substances have control limits (OEL-CL) and Table 2 substances are assigned recommended limits (OEL-RL). The key difference between the two types of limits is that one OEL-RL is set at a level at which there is no indication of a risk to health; for an OEL-CL, a residual health risk may exist at the exposure level. Both the OEL-RL and OEL-CL exposure limits prescribe TWA OELs and ST-OELs for the listed airborne contaminants.

1.5. Selecting Air Monitoring Methodologies:

Various methods of exposure assessment exist [17]. In order to utilise the most appropriate standard it is essential to assess and apply the correct sampling methodology.

In South Africa, the prescriptive nature of the Regulations for Hazardous Chemical Substances (RHCS), 1995, directs the assessor, in choosing a sampling strategy, to the U.S. National Institute for Occupational Safety and Health (NIOSH), Occupational Exposure Sampling Strategy Manual (OESSM), 1977.

The various methodologies laid out in OESSM are presented as follows:

1.5.1 Full Period Single Sample Measurement:

One sample is taken over the *entire exposure duration*. This would be 8-hours for the TWA standard and 15 minutes for the ST-OEL standard.

This method of sampling is appropriate for the use in reasonably uniform exposure over a work shift and is cost effective. Conversely, if used in situations of varied exposure levels, the averaging of these measurements would negatively skew (or hide) peak exposures.

1.5.2 Full-Period Consecutive Samples Measurement:

Several samples, of equal or unequal duration, are obtained during the *entire period* appropriate to the legislated standard (OEL). The total time covered by the samples must be 8 hours for an 8-hour TWA standard and 15 minutes for a ST-OEL standard.

In terms of South African legislation, and from a pure Occupational Hygiene perspective, this sampling methodology is preferable to the full-period single sample measurements, in that it more accurately defines the exposure profile of the worker over a work shift. However, it is labour intensive and costly to implement. As such, it is not considered practical in most industries.

1.5.3 Partial Period Consecutive Samples Measurement:

One or several samples (equal or unequal duration) are obtained for only a *portion of the period* appropriate to the legislated standard. For an 8-hour TWA standard, this would mean that the sample or samples cover between 4 and 8 hours.

Although this method of sampling is both cost effective and convenient, it also has the capacity to exclude significant, non-routine (excursion) exposures.

1.5.4 Grab Samples Measurement:

Grab samples are samples that are taken over short periods of time less than 1 hour each (generally only over minutes or seconds). Grab samples are taken at

random intervals over the period of time for which the legislated standard is defined.

This methodology accounts for peak exposures, however it cannot determine full-shift exposure.

In addition to the above advantages and disadvantages, the various sampling methodologies are also prone to errors in measurement and analysis. Since the various methods of exposure assessment are each prone to some type of error - no single method can be considered a 'gold standard' [18].

If a 'gold standard' did indeed exist then exposure assessments of airborne contaminants in occupational environments should ideally be based on repeated measurements on randomly selected days of a randomly selected number of workers from *a proiri* defined occupational groups [19, 20, 21, 22, 23]. However, this method of exposure assessment is extremely labour intensive and would be prohibitively costly for most South African companies. Therefore, despite being ideal, it lacks practical applicability.

Critical to establishing the most appropriate sampling methodology, the assessor must consider that exposure varies between workers in a given exposure group [20, 24, 25, 26]. This is also known as inter-worker variance and includes many factors – the most notable of which being worker height; task approach and environmental conditions. These variance components should be taken into account in an exposure assessment and for more effective hazard control, as well as in legal compliance testing and evaluation of exposure response relationships [25, 26, 27, 28].

Understanding and accounting for the factors that affect air-borne chemical concentrations and subsequent air monitoring results, enables the assessor to utilise the most appropriate sampling method in order to best identify and quantify unhealthy exposures which ultimately protects the employee.

1.6. Discussing the Qualitative and Quantitative Methods Used in the Study Setting:

1.6.1 Background to the Strategies Applied:

The monitoring methods adopted by a Kwa-Zulu Natal based acrylic sheet manufacturing company to determine airborne vapour exposure concentrations, have historically been via full-shift 8-hour single sample measurements, which by their nature preclude consideration of short-term or 'excursion' exposures.

To elaborate, full shift exposure monitoring entails sampling a worker for a full-shift duration. The result is therefore depicted as a TWA exposure, in that the sample analysis returns a single result that, when adjusted for time and sample volume, yields an average over time.

Exposure peaks and troughs (which relate directly to the various tasks performed by the worker) are therefore not reflected. This TWA sample result is then compared to an Occupational Exposure Limit (TWA OEL) which if exceeded, represents a situation of legal non-compliance for the exposed worker.

Similarly, if the sample returns a result that falls below the TWA OEL the worker's exposure is said to represent a compliant exposure. Single sample 8-hour TWA sampling (as conducted in the workplace focus of this study) therefore assumes relatively uniform exposures over an entire work shift.

Problems with this type of sampling arise when the worker performs tasks within a work shift that have the potential to exceed the Short-Term OEL (ST-OEL). However important, these excursion exposure levels are masked by TWA sampling methodology and therefore go undetected during the sampling period and indeed within an exposed worker population (see Figure 1).

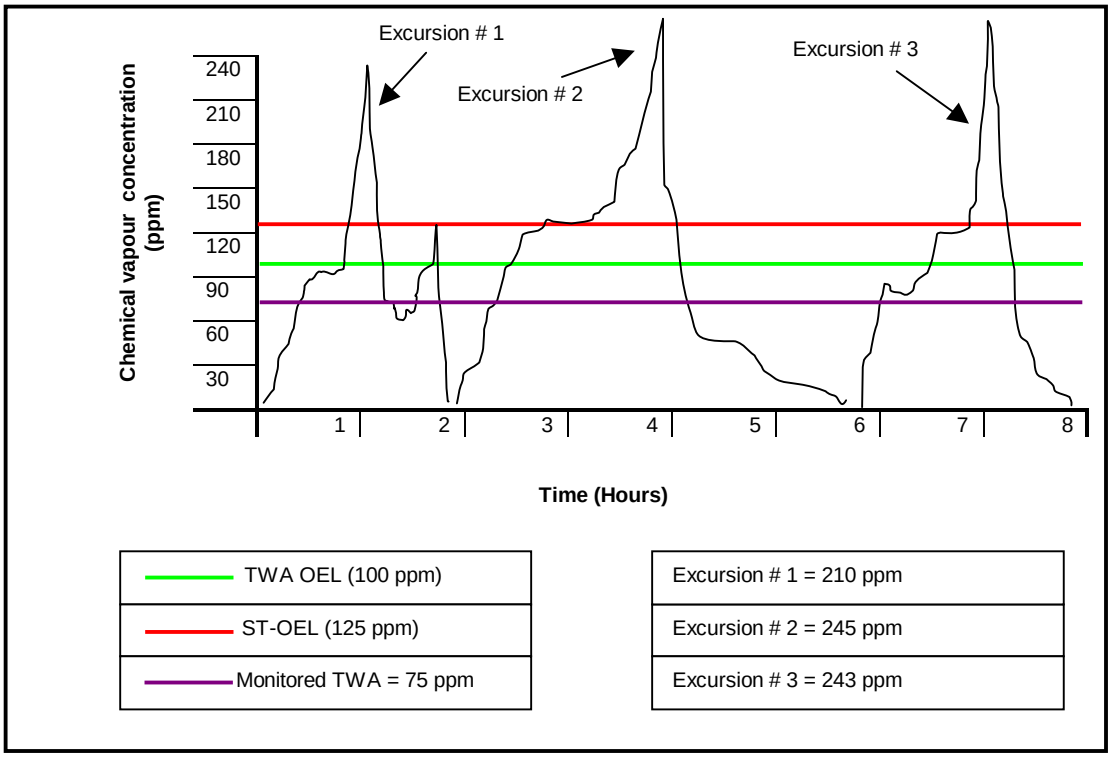


Figure 1: Features of peaks using real-time instrumentation, illustrating the potential of certain work tasks (excursions) to exceed the TWA OEL and ST-OEL

Note: ppm – parts per million

In summary, exposure may occur continuously or at regular intervals or in irregular spurts or excursions. As a result of exposure to a chemical, and depending on the magnitude of the exposure, some harmful effect may occur [27].

The aforementioned company uses methyl methacrylate as a base ingredient in its' manufacturing process.

1.6.2. Qualitative Risk Assessment:

Employees within the study setting are involved in a multitude of tasks that are associated with methyl methacrylate. Many of these tasks have, to varying degrees, the potential to expose employees to significant concentrations of methyl methacrylate vapour. However, the order of exposure magnitude is likely to vary significantly between tasks and it is anticipated that not all tasks are

sources of significant exposure. In order to eliminate unnecessary monitoring, it was decided that the utilisation of a risk assessment tool would serve to identify, describe and ultimately rank these tasks according to their perceived exposure potential. Tasks that were identified as having a Risk Ranking lower than a High Risk Ranking i.e. Moderate, Low and Very Low priority, were omitted from this report.

Risk assessment tools are widely used by occupational hygiene, health and safety practitioners as a means of qualitatively assigning Risk Rankings to workplace practices, situations or scenarios. These tools are largely subjective and require the expertise of a professional to utilise.

The ultimate aim of these assessments is therefore generally to compile a risk profile, based on Risk Rankings, in order to add structure and prioritise intervention strategies.

Occupational hygienists broadly utilise exposure ***Probability*** and ***Severity*** scales which assess exposure according to various criteria contained in their sub-structure. These criteria further combine to obtain a score and these scores are finally plotted on the ***x*** and ***y-axis*** of a risk ranking graph thus finally producing a risk ranking.

In this study, the tasks that have the potential to fit the criteria of 1) being excursive in nature and; 2) possibly exceed the ST-OEL for methyl methacrylate vapours, were evaluated using a risk assessment tool that was marginally adapted from the American Industrial Hygiene Association's "Strategy for Occupational Exposure Assessment" to suit the researchers application [29].

This strategy is principally concerned with evaluating task / risk relationships (***see Table 3***), and finds its basis in the principals of Exposure Probability Ratings and Health Effect Ratings which are explained as follows:

i. Exposure Probability Rating

Can be explained as a scientific estimate of the probable extent of a worker's exposure to hazards or hazardous chemical substances derived from the product of the following independent variables:

(a) Duration of exposure. (i.e. the amount of time to which a person is exposed to a substance calculated over an eight hour work shift);

(b) Frequency of exposure. (i.e. the number of exposures occurring over a weekly, monthly, quarterly or annual period depending on the type of process);

(c) Existing control measures. (i.e. the efficacy, usage, appropriateness, reliability and maintenance of existing control measures).

ii. Health Effect Rating

Is the rating given to a specific hazardous chemical substance, which indicates the degree of harm the substance is capable of imposing on a biological system. The above rating is derived from the scientific incorporation of the following independent variables:

i. The nature of the process. (i.e. production rates, the quantities of hazardous chemical substances being used and the method of application or use of these substances);

ii. Health effects (i.e. chronic and/or acute) Health impairments considered include those that shorten life expectancy, compromise physiological function, impair the capability for resisting other toxic or disease processes, or adversely affect reproductive function or developmental processes.

The Risk Analysis Procedure consisted of the systematic gathering of all relevant task-relevant information about processes, exposures (frequency, duration and potential intensity of exposure), control measures and work practices.

The final outcome of the Risk Assessment procedure is the qualitative ranking of the risk into various levels of priority as indicated in Figure 2.

In this study, the progression to the next phase i.e. quantitative assessment of identified excursion tasks, was qualified by obtaining a High or Very High Risk Ranking. Tasks that were assigned lower Risk Rankings are not included in this research report.

Table 1: A Qualitative Risk Ranking Scheme Incorporating Exposure and Health Effect (Severity) Ratings for Chemical Inhalation Exposure Scenarios

EXPOSURE RATING		**HEALTH EFFECT RATING**	
0	No Exposure Low Priority	**0**	Reversible effects of little concern or no known health effects
1	Low exposure (Low Priority - concentrations expected to be below 50% of the ST-OEL)	**1**	Reversible health effects of known concern
2	Moderate exposure (concentrations expected to be at or just higher than 50% of the ST-OEL)	**2**	Severe reversible health effects of concern
3	High exposure (concentration estimated to be within 20 – 30% of the ST-OEL)	**3**	Irreversible health effects of concern
4	Very high exposure (concentration anticipated to exceed the ST-OEL)	**4**	Life threatening or disabling injury or illness of concern

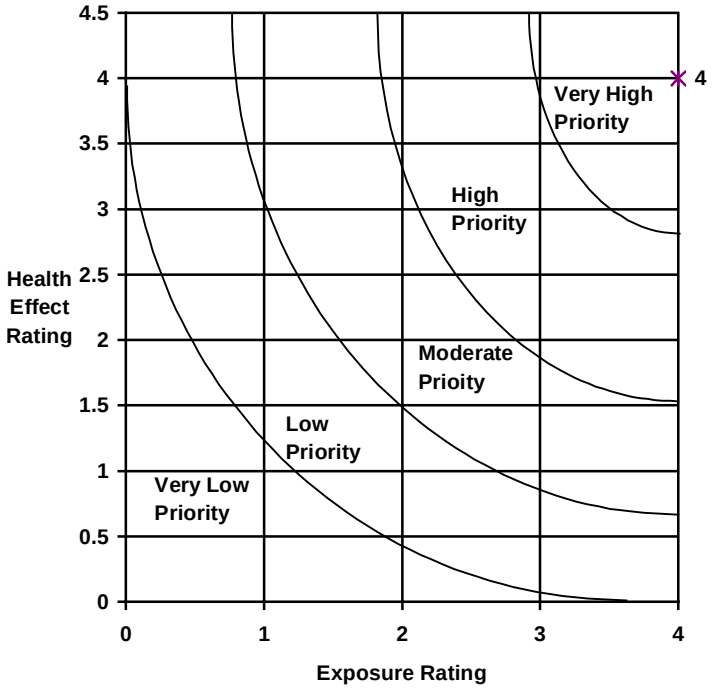


Figure 2: Risk Rating Chart which combines a Health Effect Rating and an Exposure Rating to produce an Overall Risk Rating

1.6.3. Quantitative Assessment (Air Monitoring):

i. Supplementary Data

A total of 36 eight-hour TWA observations obtained monthly over a three year period are included in this report as additional background information on the historical TWA concentrations to which employees were exposed in the study setting.

These data offer some additional support to the TWA exposure concentrations to which employees in the study setting are routinely exposed. Although they were collected in a similar manner to the primary TWA data, they cannot be statistically correlated in any way to the ST and TWA monitoring data presented in this report since these TWA and ST data were obtained simultaneously. They therefore offer only limited depth and validity to the primary TWA dataset.

ii. Simultaneous Time-Weighted Average Monitoring:

Eight-hour TWA and real-time ST monitoring was conducted simultaneously in order to reveal the significance of either and both monitoring methods utilised in the context of this research report.

The TWA data set consisted of 10 observations, comprising of full shift, single sample TWA monitoring results which were obtained in accordance with the requirements of the Regulations for Hazardous Chemical Substances, 1995, Regulation 6, Air Monitoring.

iii. Sample Media:

The monitoring methods applied for obtaining TWA data consisted of the use of 3M 3500 organic vapour diffusion monitoring devices (***see Figure 4***). The validity of using these devices to obtain meaningful and reproducible data is provided as follows:

(a) These devices show a high level of recovery (desorption efficiency or desorption coefficient) when containing methyl methacrylate [30].

(b) The recovery or desorption coefficient is a measure of the ability of a solvent to elute the compound (methyl methacrylate) from the sorbent material for analysis [30]. For many compounds, this coefficient differs from the ideal value of 1.0.

(c) The NIOSH validation protocols recommend that it be greater than 0.75 [31].

(d) The amount recovered may be affected by factors such as humidity during sampling, length of storage after sampling, and temperature during storage [30].

(e) The details of this recovery coefficient when obtained from a device loaded with methyl methacrylate are provided in Table 2.

Table 2: The Recovery Rate of Methyl Methacrylate Vapour from a 3M 3500 Passive Monitoring Badge using Two Parameters of Time and Temperature

AMOUNT SPIKED (mg)	INITIAL RECOVERY	2 WEEKS (ROOM TEMP.)	2 WEEKS (COLD)	3 WEEKS (ROOM TEMP.)	3 WEEKS (COLD)
3.28	0.93	0.99	0.99	1.00	1.00

Note: While the ideal desorption coefficient is 1.0, the NIOSH recommended desorption coefficient is > 0.75.

mg – milligrams.



Figure 3: Photo depicting a 3M 3500 Organic Vapour Monitor

iv. TWA Monitoring Sampling Strategy:

Sampling has been performed according to the requirements of the South African Regulations for Hazardous Chemical Substances (R1179 of

1995) (RHCS). The regulations prescribe an adherence to the Occupational Exposure Sampling Strategy Manual (OESSM) for the sample selection and sampling strategy to be applied for obtaining of 'representative' results [32].

Identified workers wore 3M 3500 Organic Vapour Monitors through 80 % of their work shift as recommended in OESSM [32].

The monitors were placed in the workers breathing zone (*see Figure 4*) and operated over fixed periods in order to calculate the TWA OEL exposure concentrations [33].

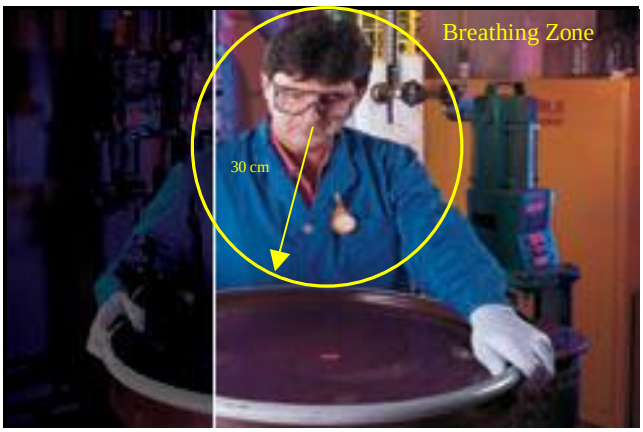


Figure 4: Typical placement of a Sample in a Worker's Breathing Zone

iv. TWA Sample Analysis:

All methyl methacrylate samples were be taken, stored, transported and analysed according to requirements of 3M [30]. This method is recognised as appropriate for accurate sample collection and analysis by the South African Regulations for Hazardous Chemical Substances.

All sample results were adjusted to reflect 8-hour TWA exposures, by the 3M analytical laboratory.

v. Short-Term (Task) Monitoring:

The use of a real-time, direct reading, digital display instrument was considered the most appropriate for gathering data on task exposure concentrations as they occurred. A Dräger PAC III direct reading instrument, fitted with an organic electro-chemical sensor was chosen as the most appropriate device (*see Figure 5*). With a standard deviation of 0.5 %, the use of this instrument exceeds the precision and accuracy requirements stipulated in OESSM. This instrument was calibrated prior to use (*see Appendix 1*).



Figure 5: Dräger PAC III Direct Reading Instrument

1.7. Hazard Summary of Methyl Methacrylate:

1.7.1. Physical Properties of Methyl Methacrylate:

The chemical formula for methyl methacrylate is $C_5H_8O_2$, and it has a molecular weight of 100.1 g/mol (*see Figure 6*). Methyl methacrylate is furthermore a colourless, volatile, flammable, organic liquid that is soluble in warm water. It also has an acrid, repulsive odour with an odour threshold of 0.08 parts per

million (ppm) (0.3 mg/m^3). Finally, the vapour pressure for methyl methacrylate is 29.3 mm Hg at 20 °C [30].

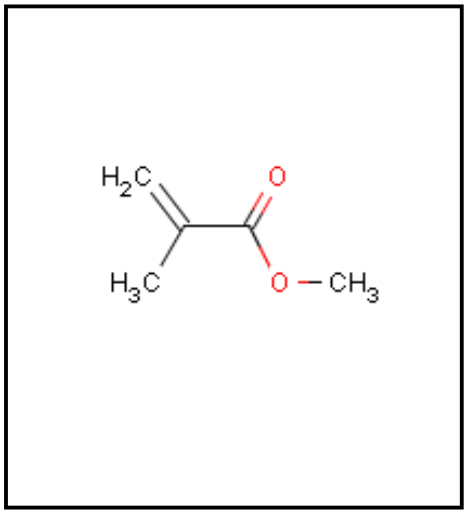


Figure 6: Molecular Structure of Methyl Methacrylate

1.7.2. Uses of Methyl Methacrylate:

Methyl methacrylate is used in the manufacture of methacrylate resins and plastics (e.g., Plexiglas). With the principal uses of methyl methacrylate being acrylics cast sheets like advertising signs and displays, lighting fixtures, glazing and skylights, building panels and sidings, and plumbing and bathroom fixtures. Also used in moulding and extrusion powder, and coatings (latex paints, lacquer, and enamel resins) [34].

Methyl methacrylate is also used in the impregnation of concrete to make it water-repellent, and also has uses in the fields of medicine and dentistry to make prosthetic devices and as a ceramic filler or cement [35].

1.7.3. Sources and Potential Exposure:

Exposure to methyl methacrylate is primarily occupational, through dermal and inhalation routes. Potential for exposure exists for employees of manufacturers of methyl methacrylate and its polymers, as well as doctors, nurses, dentists, and dental technicians. Individuals may also be exposed to methyl methacrylate via consumption of contaminated water [35].

1.7.4. Health hazard Information of Methyl Methacrylate:

i. Acute Effects:

Methyl methacrylate is irritating to the skin, eyes, and mucous membranes in humans. An allergic response to dermal exposure may develop. Respiratory symptoms reported in humans include chest tightness, dyspnea, coughing, wheezing, and reduced peak flow. Neurological symptoms, including headache, lethargy, light-headedness, and sensation of heaviness in arms and legs, have occurred in humans following acute exposure to methyl methacrylate [36].

In mice and rats acutely exposed to high concentrations of methyl methacrylate by inhalation, degenerative olfactory changes in the nasal passages and lung damage have been observed. High doses of methyl methacrylate may cause pulmonary oedema. Acute oral exposure of animals to methyl methacrylate has caused damage to the liver [34].

Tests involving acute exposure of rats, mice, rabbits, and guinea pigs have demonstrated methyl methacrylate to have low to moderate acute toxicity by inhalation or oral exposure [34].

ii. Chronic Effects (Non-cancer):

Respiratory and nasal symptoms and reduced lung function have been reported in chronically exposed workers [34]. In one study, occupational

exposure to high doses of methyl methacrylate was associated with cardiovascular disorders in humans [37].

Chronic inhalation of methyl methacrylate by rats has resulted in respiratory effects (e.g., inflammation of the nasal cavity, degeneration/loss of olfactory epithelium in nasal turbinates, and lung congestion). Chronic inhalation of high levels of methyl methacrylate has resulted in degenerative and necrotic changes in the liver, kidney, brain, spleen, and bone marrow, decreased body weight gain, listlessness, prostration, and ocular and nasal discharge in animals [38].

iii. Reproductive / Developmental Effects:

No adequate reproductive or developmental studies in humans are available. Inhalation exposure of rats to maternally-toxic levels of methyl methacrylate resulted in foetal abnormalities (haematomas and skeletal anomalies) and decreased foetal weight and crown-rump length [34].

iv. Cancer Risk:

From a retrospective epidemiology study, a causal relationship between occupational exposure and increased incidences of colon and rectal cancers has been suggested; however, the causal relationship could not be established when accumulated total exposures and latency were considered. No carcinogenic effects were observed in several inhalation and oral animal studies. The Environmental Protection Agency (EPA) considers methyl methacrylate not likely to be carcinogenic to humans [37].

1.7.5. South African Standards for Methyl Methacrylate:

Table 3 presents the South African standards for exposure to airborne concentrations of methyl methacrylate vapour.

Table 3: The South African OELs Applied to Methyl Methacrylate Vapour

SOURCE	TWA OEL (PPM)	ST-OEL (PPM)
Regulations for Hazardous Chemical Substances - Table 2, 1995.	100	125

ppm – parts per million.

1.8. The Importance of the Study:

South African legislation contains two standards against which airborne concentrations, derived from sampling, are compared. These two standards include Time Weighted Average and Short-Term Exposure Limits. The selection of the appropriate standard is dependent on the nature of the tasks that the worker engages in. As such, sampling methodology that accounts for TWA (such as full-shift single sample measurement) would be an ideal when assessing fairly uniform exposures or when interested in total inhalable concentrations over a full shift. However, when assessing tasks that are excursive in nature, the use of TWAs could mask peak exposures. In this scenario using sample methodology that correctly accounts for Short-Term or excursion exposures (such as a grab sample measurement) would be more appropriate.

1.9. The Aim of the Study:

The major aim of this study is to establish whether the inclusion of Short-Term monitoring would provide a more comprehensive picture of the worker's exposure profiles than the current exclusive use of the 8-hour TWA, single sample sampling methodology.

1.10. The Research Objectives:

1.10.1. The First Objective

To qualitatively describe, by way of a risk assessment, the types of exposures occurring within the Syrup Room of a small acrylic sheet mixing facility in order to identify potential excursions.

1.10.2. The Second Objective:

To quantitatively measure excursion methyl methacrylate vapour concentrations in the Syrup Room and compare them to the South African Short-Term Occupational Exposure Limit.

1.10.3. The Third Objective:

To quantitatively measure 8-hour equivalent methyl methacrylate vapour concentrations in the Syrup Room and compare them to the South African TWA OEL.

1.10.4. The Fourth Objective:

To correlate monitored excursion methyl methacrylate vapour concentrations with 8-hour equivalent methyl methacrylate vapour.

CHAPTER 2

2. MATERIALS AND METHODS:

This study adopts a tiered approach to gathering the appropriate data against which the study objectives are examined. Firstly, by using a risk assessment and ranking tool, tasks within the workplace were identified, qualitatively characterised and assigned a risk ranking.

Next, those tasks assigned a High or Very High Risk Ranking were quantitatively monitored using short-term (real time) sampling methodology.

Workers responsible for undertaking the high and very high ranked tasks were also simultaneously monitored for their full-shift exposure.

Finally, statistical analysis was conducted on the basis of firstly describing the short-term exposures against the short term exposure limit for methyl methacrylate, and secondly, describing the full shift TWA monitoring results against the TWA exposure limit. The two data sets were then correlated to establish the significance of applying short-term monitoring methodologies in the study setting.

The chapter ends by devoting a section to quality assurance and then finally describing the ethical considerations of the study.

2.1. The Study Setting:

The workplace under investigation is known locally as the Syrup Room and comprises a dedicated acrylic “syrup” mixing facility with 13 mixing vessels and numerous pressure vessels.

Using stirrers, thirteen stainless steel mixing vessels in the area function to agitate and mix the various ingredients added to them and then using heat, to cure the mix to the correct viscosity before piping it into a pressure vessel.

From the pressure vessels, the mix is finally piped into the casting chamber, which is situated below the syrup room, where the acrylic monomer is poured between two glass sheets, cooled and thereby moulded into acrylic sheet.

A multitude of tasks are undertaken in the study area, some of which have an inherent and oftentimes direct association with methyl methacrylate and as such are of interest in this study. These tasks and their corresponding exposure issues are described in Table 4 below.

Table 4: Characteristics of tasks and operations performed by operators and assistants in the Syrup Room of a small acrylic mixing facility

TASK DESCRIPTION	EXPOSURE ISSUES
Pressure Vessel (PV) Cleaning - employee opens the vessel hatch and uses a mop and monomer to clean the PV. A major clean is required for grade changes and minor cleaning is done between batches of the same grade.	1) The task requires close proximity of employee's breathing zone to the monomer 2) Large volumes of monomer are used. 3) Vessel is closed on one end thus all vapour release occurs past the employee. 3) Splashes onto respiratory protective equipment are likely (thus potentially overloading the device and shortening the life-span / effectiveness) 4) Some air displacement into the employee's breathing zone occurs as a result of the aggressive nature and technique applied during cleaning as well as the addition on monomer to the vessel 5) Exposure frequency is low however duration is high (see adjacent columns).
Methyl methacrylate Check Pour – draining 50 kg syrup from PV before commencing with the batch pour into the mixers.	1) Air is displaced as the monomer is poured into the container 2) Process is non-aggressive and vapour release is not expected to be forced into the employee's breathing zone 3) Associated exposures are however expected to be close to or exceed the ST-OEL 4) Exposure frequency and duration is relatively low.

Table 4: (Continued)

TASK DESCRIPTION	EXPOSURE ISSUES
Adjusting mixer speed – this is done at various stages of the batch and at different temperatures.	1) Often requires the dosing hatch to be open to observe the mixer speed 2) The employee's close proximity (breathing zone) to the task is a potential issue 3) Higher vapour release is expected when the mixer blades are agitating the mix at higher velocities 4) As the batch is heated to 80^{o} C, a higher vapour release is also expected 5) Although exposure duration is low, exposure frequency is considered high as mixer adjustments occur routinely throughout the shift.
De-pressurising PVs – after emptying / pouring the batch into the casting chamber below.	1) Employee opens the pressure release valve and monomer-contaminated air is released into the employee's immediate vicinity 2) Exposure duration and frequency is low.
Dumping waste syrup into waste container – employee takes waste syrup from various cleaning operations and pours it into a waste hopper.	1) The waste hopper is located in an area outside the syrup room and is well ventilated 2) Although exposures are brief, exposure concentrations could be high 3) Exposure duration and frequency is low.
Adding raw materials and master batch mix – raw materials consist of several ingredients which are added to an active mixer.	1) Employees must open the dosing hatch to add various ingredients to the raw monomer which is heated to various temperatures (up to 80^{o} C) 2) The employee's close proximity (breathing zone) to the task is a potential issue 3) Higher vapour release is expected when the mixer blades are simultaneously agitating the mix 4) As the batch is heated to 80^{o} C, a higher vapour release is also expected 5) Task frequency is considered moderate and the task duration is low.
Viscosity test – once the correct viscosity is reached, the batch can be poured. This task also requires the any one of the 13 mixer's dosing hatches to be opened and a sample removed, checked and replaced.	1) As with most mixer-related processes, the employee's close proximity (breathing zone) to the task is a potential issue 2) Higher exposures are expected as the mix is heated to 80^{o} C 3) Any agitation of the mix during the check would increase exposures 4) Although task duration is low, the frequency with which the task is carried out is considered significant.

2.2. The Study Population:

The study population was taken as employees who were routinely associated with operational aspects of the syrup room. Of particular interest were those employees directly involved in the handling of, or working in close proximity to, methyl methacrylate.

Two workers per eight-hour shift operate this plant over a three-shift system. Although job titles differ i.e. operator and assistant, work tasks are interchangeable with both workers undertaking similar tasks as the need arises.

2.3. Data Collection:

This section describes the two broad methodologies applied to collection of the necessary data utilised in the study.

The first method was an extensive risk assessment with a view to obtaining the qualitative data necessary to fulfil objective one and hence proceed to the next research objectives of undertaking occupational hygiene monitoring on selected workers and tasks.

2.3.1. Qualitative Analysis (Risk Assessment):

A walk-through inspection of the study setting was undertaken and using professional judgement, tasks were reviewed according to their potential to over-expose the employees. Processes were described and specific observations relating to exposure frequencies, durations and intensities were captured. Using professional judgment and the Risk Rating tool described in section 1.6.2 above, the tasks were then assigned an individual Exposure Probability Rating and a general Health Effect Rating.

For the purposes of this study, a Health Effect Rating of 3 to 4 was given to methyl methacrylate vapour and related processes, which best supports the

toxicological data provided by the National Institute for Occupational Safety and Health (NIOSH): Pocket Guide to Chemical Hazards, 2000.

The combining of the parameters for exposure rating and health effect rating were then transposed onto a risk ranking chart to obtain an overall Risk Rating.

2.3.2. Quantitative Assessment (Air Monitoring):

i. Time-Weighted Average Monitoring:

The monitoring methodology described in this section was used for all TWA sampling including the three year historical supplementary monitoring.

Formal instructions detailing the use of the monitor were enclosed in the sample package; these instructions were followed to the letter. Prior to sample deployment, the 3M 3500 passive diffusion monitors were removed from the package and the necessary sampling information was recorded as follows: monitor number (each monitor has a unique number), date of exposure, employee identification, temperature and relative humidity as well as start and stop times.

Each monitor was attached to the respective worker's breathing and exposed to the workplace air for at least 80 % of the shift.

After sampling, the retaining ring and white barrier film was removed and discarded. The clear elution cap was snapped into place. The ports were securely sealed with the cap plugs.

Humidity and atmospheric pressure were taken into consideration during sampling to ensure that sample and equipment parameters were not exceeded.

ii. Time-Weighted Average Sample Analysis

The analytical methodology described in this section pertains to the samples obtained from the simultaneous TWA / ST monitoring episodes as well as the supplementary three year historical TWA sampling.

The 3M South Africa (Pty) Ltd: Occupational Health and Environmental Safety Division analytical laboratory was used for sample analysis. The analysis technique was developed by 3M USA and is traceable to national standards [30].

In the laboratory, 1.5 milliliters of the desorption reagent was added to each monitor through the center port. The port was immediately resealed. After standing for 30 minutes with occasional gentle agitation, the eluent was decanted into a marked 2 millilitre vial, sealed and a 1 to 5 microlitre sized sample was automatically introduced into the gas chromatograph. The area of the peak of interest was recorded and the amount in milligrams or micrograms was determined from the standard curve.

If the weight collected for a single contaminant was greater than the defined capacity listed in the 3M Organic Vapor Monitor Technical Data Bulletin [39], then the validity of the sample would be questioned.

iii. TWA Monitoring Sampling Calculations

The time-weighted-average concentrations in parts per million of methyl methacrylate, were calculated using the following calculation:

$$\mathbf{C\ (ppm) =} \frac{\boldsymbol{W \times B}}{\boldsymbol{r \times t}}$$

Where:

C (ppm) = concentration in parts per million
W = weight (ug) found (corrected for blank and sample elution volume)

r = recovery coefficient (calculation constant provided by 3M)

t = length of sampling period (minutes)

v. Short-Term (Task) Monitoring:

A Dräger PAC III direct reading instrument, fitted with an organic vapour electro-chemical sensor, was used to undertake short-term monitoring.

This instrument was placed in the breathing zone of the employees whilst undertaking selected tasks. Vapour concentrations were recorded intermittently throughout the excursion and averaged over the task duration to reflect a single sample result, which in essence, represents the workers exposure to methyl methacrylate during that task.

2.4. Quality Assurance:

All workers identified as undertaking short-term tasks that may give rise to significant excursion exposures have been monitored. The confidence interval related to monitoring the 'maximum-risk worker' should thereby exceed 90 % as recognised by OESSM.

The Dräger PAC III direct reading instrument was calibrated by Industrial Safety, an independent laboratory to 14 ppm of Ethylene prior to use. The monitoring range of the Organic Vapour sensor is 0 – 300 ppm with a resolution of 1 ppm. This range is ideal for measuring the exposure ranges required in this study as it includes the ST-OEL of 125 ppm.

The 3M 3500 Organic Vapour Monitoring devices were used before their sample expiry date.

For deployment onto and subsequent removal from the subjects, the 3M 3500 Organic Vapour Monitoring devices were opened directly prior to deployment

and then capped and refrigerated within 1 hour of removing the device from the employee.

All methyl methacrylate samples taken on the 3M 3500 organic vapour monitoring badge were stored, transported and analysed in accordance with the requirements of the 3M Technical Data Bulletin [30].

Variation in exposure has been accounted for by using exposure data collected with a strategy that uses worst-case assumptions to evaluate the highest foreseeable employee exposure levels [40].

2.5. Ethical Considerations:

The Risk Manager, Line Manager and Risk Officer overseeing the sampled workplace were fully informed of the aims of the study and the procedures that were to be carried out (*see Appendix 2*). Once written consent from the Risk Manager was obtained, voluntary informed written consent from subjects was also obtained. The subjects were handed a subject information sheet which explained the research objectives and procedures (*see Appendix 3*). All subjects were conversant in written English and the contents of the subject information sheet were also verbally disseminated. Confidentiality and anonymity was guaranteed. Subjects involved in the study were routinely updated whilst ST monitoring results were being obtained and then formally via email correspondence with the Risk Manager, who was sent both the TWA and ST monitoring results. Upon final acceptance of this paper, these participants will receive an electronic copy of the research report, also via email correspondence with the Risk Manager.

Ethical approval was obtained from the Wits Human Ethics Committee (M03-02-06) (*see Appendix 4*).

2.6. Data Handling:

Quantitative monitoring data were analysed using SPSS version 15.0 (SPSS Inc., Chicago, Illinois, USA).

Descriptive analysis entailed frequency counts and percentage tabulation, and graphical representation by means of bar charts and box and whisker plots.

Due to the skewness of the distributions of the concentration data, non parametric statistics were used to describe and compare groups.

Spearman's rank order correlation coefficients were used to examine relationships between concentrations. Wilcoxon signed ranks test was used to compare the excursion measurement and the time weighted concentration in paired samples.

CHAPTER 3

3. RESULTS:

In this chapter the data are presented according to the research objectives in the following order:

i. Results from the qualitative risk assessment, which assign a Risk Ranking to nine observed tasks. This risk ranking forms the basis for task-based sample selection.
ii. Supplementary data monitoring results obtained at a rate of one measurement per month over a 36 month period (n = 36).
iii. Objective 2 monitoring results, which compare the task-based monitoring results to the ST-OEL of 125 ppm (n = 106).
iv. Objective 3 monitoring results, which compare the full-shift TWA monitoring results to the TWA OEL of 100 ppm (n = 10).
v. Objective 4 results, which correlate excursion monitoring results with TWA monitoring results.

The chapter ends with a brief summary describing the data and their statistical significance.

3.1. Qualitative Risk Assessment Results:

The results below depict Risk Rankings derived from utilising the methodologies contained in Chapter 2, section 2.1.

Table 5: Final Analysis of Work Tasks Undertaken Within the Research Area Risks and their Corresponding High and Very High Risk Ranking

TASK NO.	TASK DESCRIPTION	± NO. OF TASKS / SHIFT	± DURATION OF TASK (MINS)	RISK RATING		OVERALL RISK RATING
				EXPOSURE	HEALTH	
1	Pressure Vessel (PV) Cleaning	1 – 3	**Major Clean:** 60 **Minor Clean:** 35	4	3	Very High Priority
2	Mixer Cleaning (Grade Change)	3	30	4	3	Very High Priority
3	Floor Cleaning using methyl methacrylate.	10	5	3	3	High Priority
4	Methyl methacrylate Check Pour	10	5	3	3	High Priority
5	Adjusting mixer speed	20	2	4	3	Very High Priority
6	De-pressurising PVs	3	1	2	3	High Priority
7	Dumping waste syrup into waste container	3	1	2	3	High Priority
8	Adding raw materials and master batch mix to mixers.	10	2	4	3	Very High Priority
9	Viscosity test	52	1	4	3	Very High Priority

Note: Although only nine tasks are reflected in the table above, 14 tasks were initially identified as fitting the criteria for exposure to methyl methacrylate vapour. Further qualitative assessment of the six tasks not listed however revealed either a **Low** or **Very Low** Risk Ranking; these tasks were hence withdrawn from representation in Table 5. The table above therefore only contains those tasks that were identified as having the potential to incur non-compliant ST exposures.

3.2. Quantitative Monitoring Results:

3.2.1. Supplementary Data Results:

Inter Quartile Range statistical analysis of samples obtained on a monthly basis over a 3-year period (One sample per month; n = 36) is represented in Table 6 and shows that the median TWA value was 36.66 ppm (IQR 25.42 to 89.99). The exposure limit of 100 ppm corresponded with the 79th percentile, indicating that 21% of the values exceeded the TWA-OEL of 100 ppm.

Table 6: Descriptive Statistics for Monthly Monitored TWA Concentrations over Three Years (n= 36)

PERCENTILES	25	25.5
	50 (median)	36.7
	75	90.0
	79	99.7

Note: The distribution of the above data is shown graphically in Figure 7.

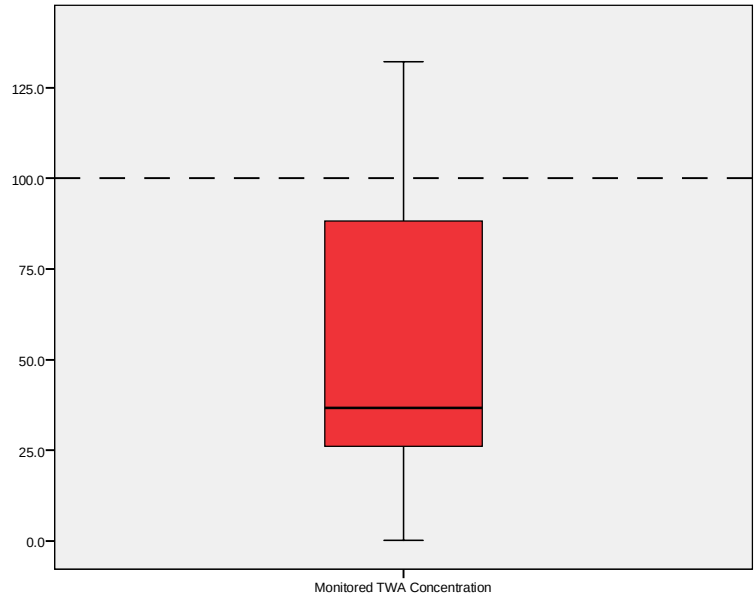


Figure 7: Boxplot of the Distribution of Monitored TWA Concentrations Obtained Monthly Over all Three Years (n = 36)

3.2.2. Analytical Objective 2:

To measure excursion methyl methacrylate vapour concentrations and compare them to the Short-Term Occupational Exposure Limit.

Table 7 shows that with the exception of tasks 3 and 4, the majority of samples exceeded the exposure limit of 125 ppm. When the values were averaged for each task, 89.1% of samples exceeded the ST-OEL. This is also shown graphically in Figure 8.

Since some of the participants were measured more than once for any particular task and some were not measured, a new variable called "mean of the 9 tasks" was created which averages out the measurements for each of the tasks, for 46 measurements (rows of data).

Table 7: Frequency and Percentage of Compliant and Non-Compliant Samples in the Nine Tasks and Overall (n = 106)

	<=125PPM		>125PPM	
	NO. OF MEASUREMENTS	%	NO. OF MEASUREMENTS	%
TASK 1	0	0%	20	100.0%
TASK 2	6	42.9%	8	57.1%
TASK 3	2	66.7%	1	33.3%
TASK 4	5	83.3%	1	16.7%
TASK 5	0	0%	8	100.0%
TASK 6	2	50.0%	2	50.0%
TASK 7	1	33.3%	2	66.7%
TASK 8	1	12.5%	7	87.5%
TASK 9	7	17.5%	33	82.5%
MEAN OF THE 9 TASKS	5	10.9%	41	89.1%

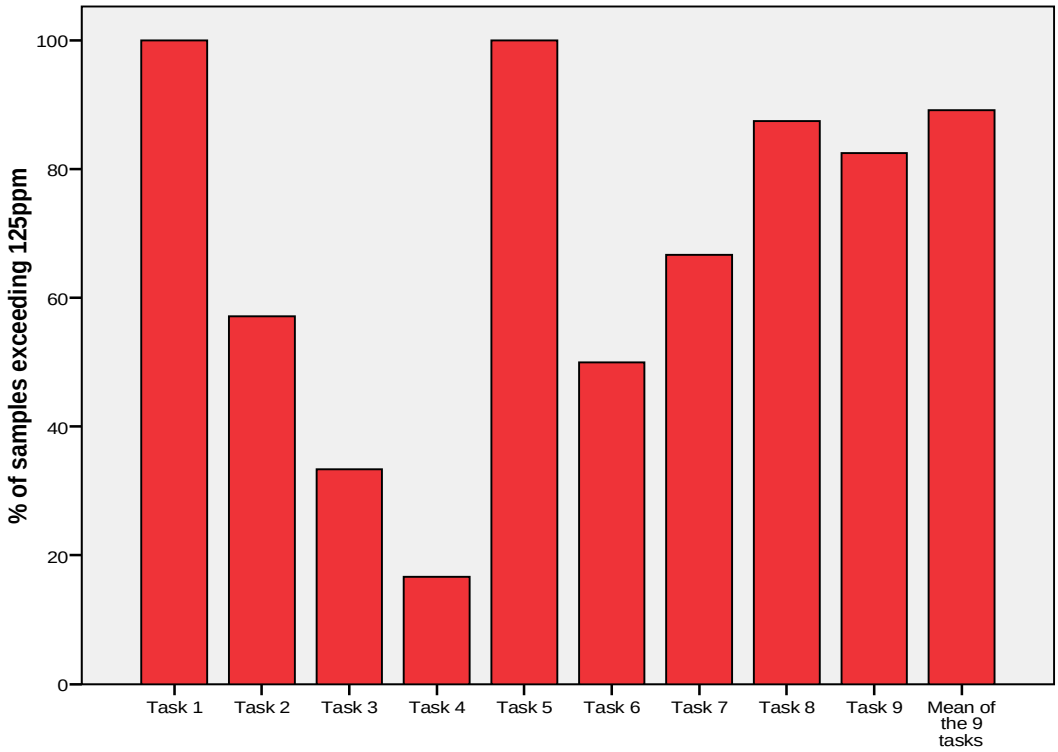


Figure 8: Bar chart of Percentage of Samples Exceeding the Exposure Limit by Task and Overall

Figure 9 shows the distribution of the measured values in each of the tasks and overall. The majority of values were above the reference line showing the exposure limit of 125 ppm.

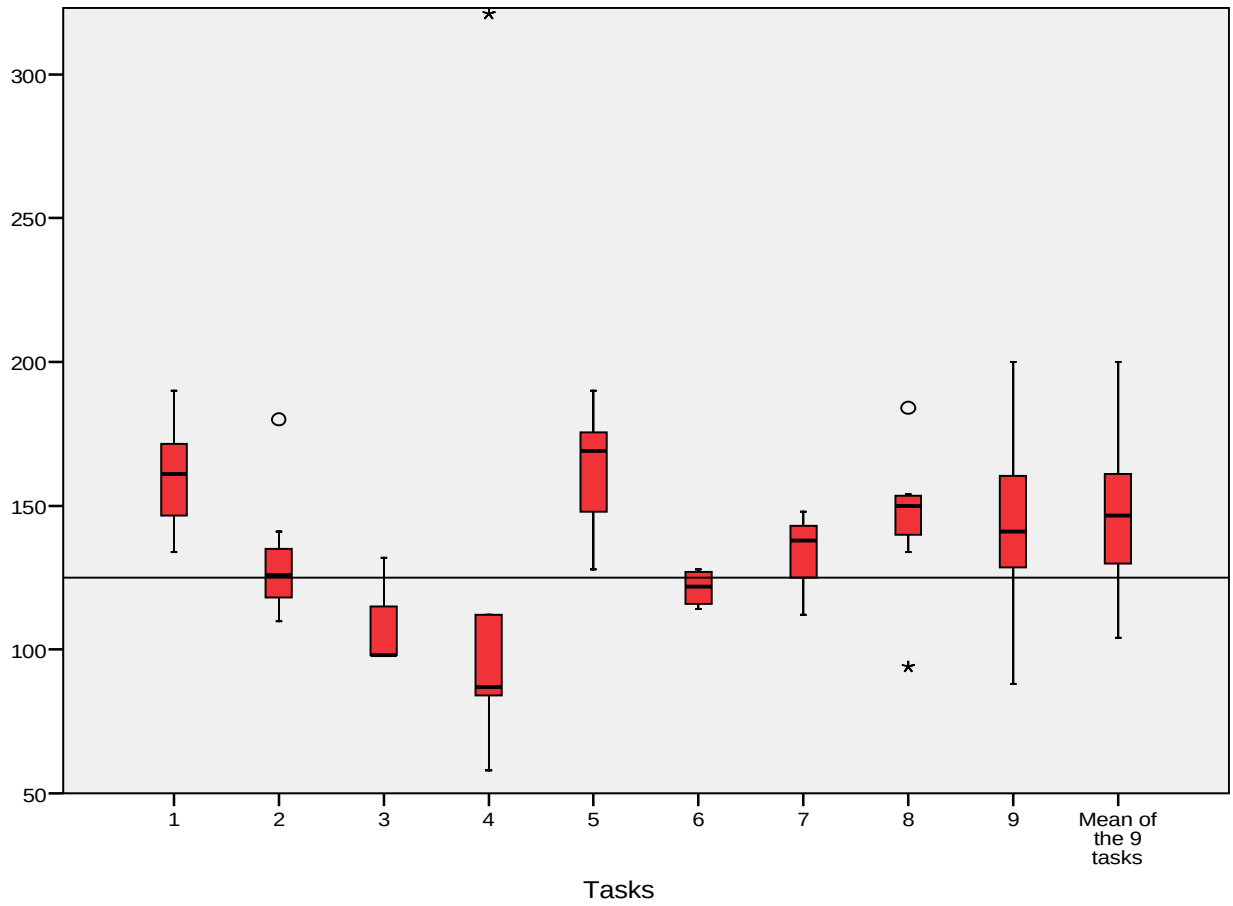


Figure 9: Boxplot of the Distribution of Monitored Exposure Concentrations by Task and Overall

3.2.3. Analytical Objective 3:

To measure 8-hour TWA methyl methacrylate vapour concentrations and compare them to the TWA-OEL.

Inter Quartile Range statistical analysis of TWA samples obtained from each of the subject's breathing zones is represented in Table 8 and shows that the median TWA value was 70.02 ppm (IQR 56.14 to 94.1). The exposure limit of

100 ppm corresponded with the 90th percentile, indicating that only 10 % of the values exceeded the TWA-OEL of 100 ppm.

Table 8: Descriptive Statistics for Monitored TWA Concentrations obtained in conjunction with the ST measurements (n=10)

N	Valid	10
Median		70.02
Minimum		42.98
Maximum		116.51
Percentiles	25	56.15
	50	70.02
	75	94.09
	90	99.99

Table 8 shows that 90% of the samples were compliant. Only one sample (116.51 ppm) was non-compliant. The distribution of values is shown in Figure 10.

Table 9: Frequency Table of Compliance in 8-hour TWA Equivalent Methyl Methacrylate Vapour Concentrations

	FREQUENCY	VALID PERCENT
COMPLIANT (<100 PPM)	9	90.0
NON COMPLIANT (>=100 PPM)	1	10.0
TOTAL	10	100.0

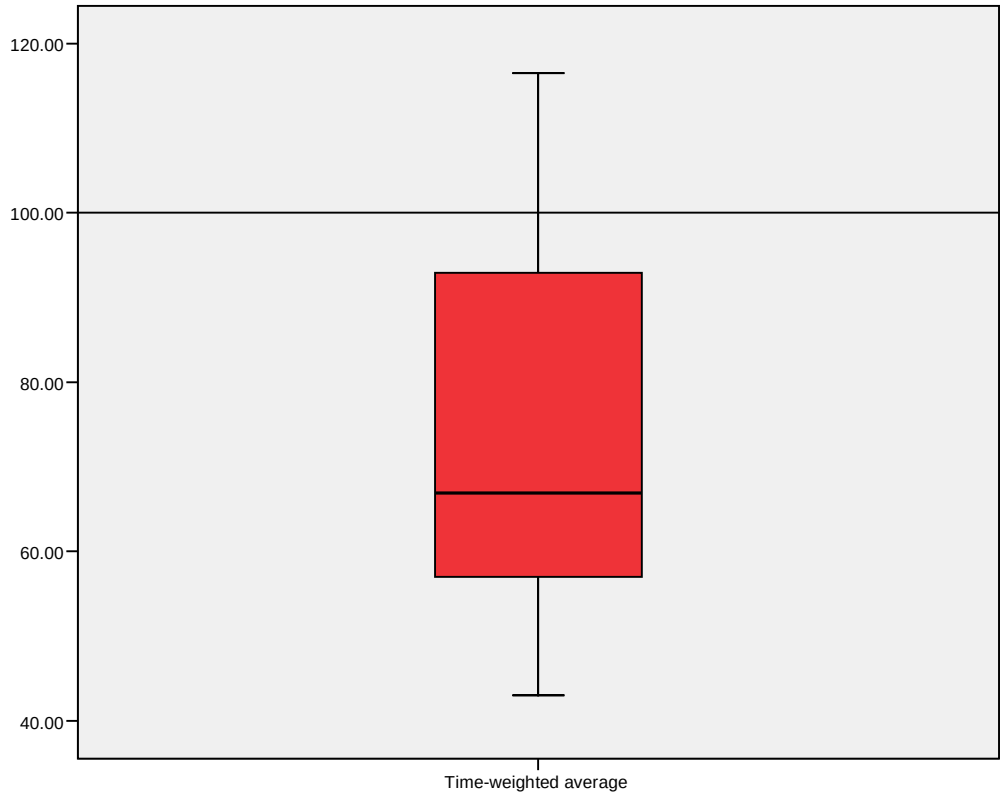


Figure 10: Boxplot of the Distribution of TWA Methyl Methacrylate Vapour Concentrations (n = 10)

3.2.4. Analytical Objective 4:

To correlate excursion methyl methacrylate vapour concentrations with 8-hour equivalent methyl methacrylate vapour concentrations.

The null hypothesis is that excursion exposures do not alter the interpretation of the TWA measurements.

Table 10 below presents the two-tailed significance and correlation coefficient between the measurements obtained for each task and the collective TWA concentrations.

Only task 9 and the mean of the 9 tasks (average of task measurements) showed a statistically significant correlation between the two concentrations. However,

this correlation coefficient was not significant and very low (r = 0.339, p=0.032 and r =0.337, p=0.022 respectively). In general as one measurement increased, so did the other, but not all the measurement pairs conformed to this relationship. Some of the individual tasks showed negative correlations between the two concentrations, which were not statistically significant, while others showed positive correlations which were also not significant. These are shown in Table 10.

Table 10: Spearman's Rank Order Correlation between Excursion Concentrations and 8-hour TWA Concentrations

TASK	STATISTICAL ANALYSIS	TIME-WEIGHTED AVERAGE
1	Correlation Coefficient	0.160
	Sig. (2-tailed)	0.501
	N	20
2	Correlation Coefficient	-0.031
	Sig. (2-tailed)	0.917
	N	14
3	Correlation Coefficient	0.866
	Sig. (2-tailed)	0.333
	N	3
4	Correlation Coefficient	-0.174
	Sig. (2-tailed)	0.742
	N	6
5	Correlation Coefficient	-0.272
	Sig. (2-tailed)	0.515
	N	8
6	Correlation Coefficient	-0.400
	Sig. (2-tailed)	0.600
	N	4
7	Correlation Coefficient	-0.500
	Sig. (2-tailed)	0.667
	N	3
8	Correlation Coefficient	0.374
	Sig. (2-tailed)	0.362
	N	8
9	Correlation Coefficient	0.339(*)
	Sig. (2-tailed)	0.032
	N	40

Mean of the 9 tasks	Correlation Coefficient	0.337(*)
	Sig. (2-tailed)	0.022
	N	46

Note: * Correlation is significant at the 0.05 level (2-tailed).

Figure 11 is a scatterplot of the participants TWA values on the Y axis and their mean of the 9 task values on the X axis. Since this is the only variable (along with task 9) which shows a significant correlation with TWA, it was plotted in this manner. This scatterplot demonstrates the lack of a clear relationship between the 2 readings, and it also shows how the TWA reading is consistently lower than the excursion reading.

Figure 11 further shows that this relationship between TWA and ST concentrations was weak as there was a very large scatter of points. The exposure limits of both measurement types are shown on the Figure, dividing it into four quadrants. The majority of the points fell into the 4^{th} quadrant, indicating that they were over the excursion exposure limit but under the time weighted concentration exposure limit. Therefore, the TWA measurement tended to under estimate the concentration compared with the excursion measurements.

The difference between the excursion levels and the time weighted concentrations was highly statistically significant ($p<0.001$). The excursion levels were higher than the time weighted concentrations in all pairs of samples.

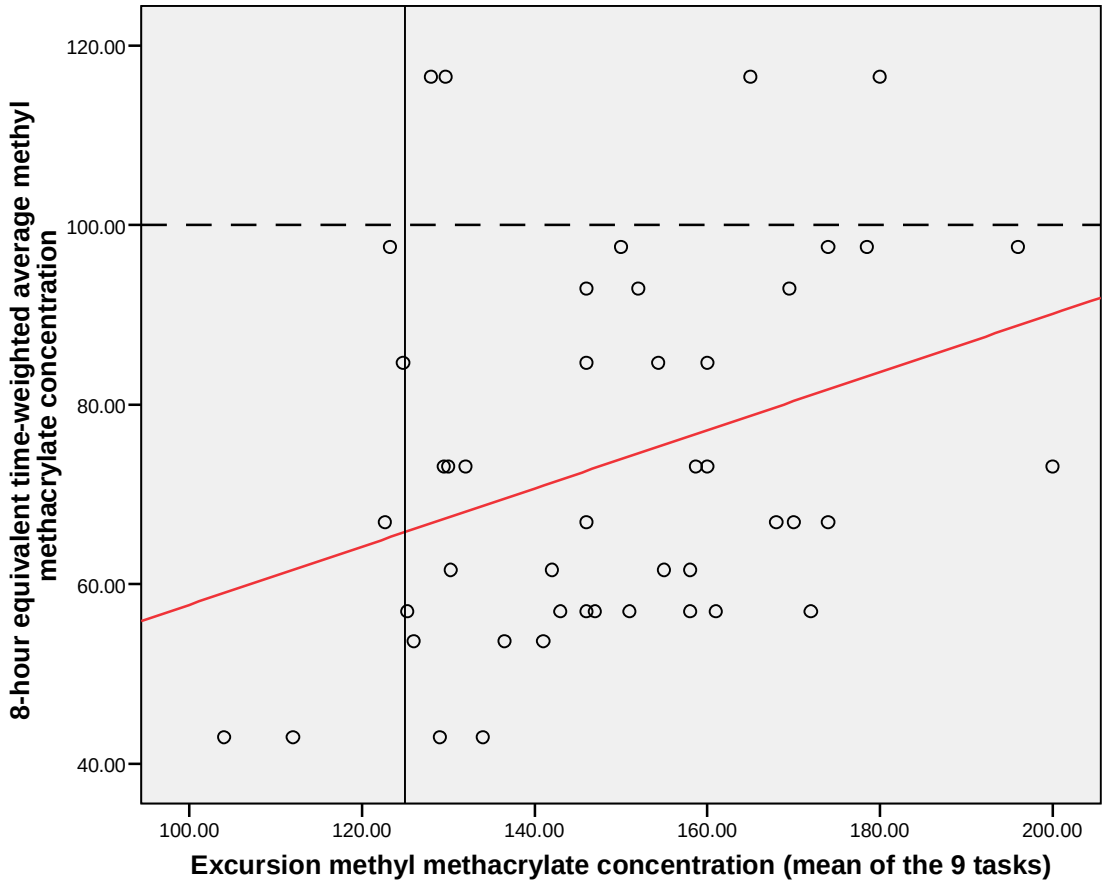


Figure 11: Scatter Plot of the Relationship between Excursion Concentrations and Time-Weighted Average Concentrations

3.3. Summary:

There was no relationship between the Short-Term excursion levels and the TWA levels of methyl methacrylate. The excursion levels were significantly higher than the time weighted concentrations. A higher proportion of the samples were above the exposure limit for excursion values than the 8-hour equivalent TWA concentration.

CHAPTER 4

4. DISCUSSION:

This chapter begins by re-stating the aim of the study. A brief summary of the major findings are then presented which is followed by a presentation of the limitations of the study.

The existing control measures and their effectiveness in protecting the workforce against the monitored concentrations are also discussed briefly.

The major findings are then discussed in greater detail.

4.1. The Aim of the Study:

The major aim of this study was to establish whether the inclusion of task-based monitoring provides a more comprehensive picture of the workers' exposure profile than the current exclusive use of the TWA, single sample methodology.

4.2. Summary of Major Findings:

Results obtained from Short-Term monitoring were consistently above the ST-OEL indicating that workers engaged in the identified tasks would most likely be consistently and repeatedly exposed to non-compliant and potentially unhealthy concentrations of methyl methacrylate vapours.

Conversely, the results obtained from the TWA monitoring, for the most part, showed that workers engaged in operations over a full-shift, were unlikely to be exposed to non-compliant or indeed unhealthy concentrations of methyl methacrylate vapours.

Further data analysis correlating the results from simultaneous monitoring of both the TWA and Short-Term suggests a weak relationship between the two data sets.

The findings of this study are therefore successful in illuminating the need to identify, characterise and independently monitor tasks that have the potential to exceed Short-Term Occupational Limits or indeed cause, by their higher dose, negative health impacts in workers.

4.3. Limitations of the Study:

In considering the findings of this study it is important to bear in mind the following limitations.

The sample size for both the TWA (n=10) and ST (n=106) measurements was small. These data therefore cannot be viewed as epidemiologic in that they are not representative for all workplace situations where excursive tasks and corresponding chemical exposures occur.

Due to large variations in the number and types of tasks undertaken as well as the potential variations in vapour concentrations between day and night shift work practises, measured concentrations could vary somewhat if more measurements were obtained and night shifts were monitored.

Direct-reading instrumentation is prone to false readings due to interferences, or cross-reactivity with similarly structured chemical agents. In addition, direct-reading instrumentation can be affected by temperature, humidity, and moisture presence, which are likely factors in an incident site. Temperature and relative humidity readings were obtained during the measuring period and found, in all cases, to be within acceptable limits for the PAC III Direct Reading instrument. Interferences and cross-sensitivities were insignificant since methyl methacrylate is a pure substance and the only organic chemical used within the Syrup Room.

A minimum face velocity on the surface of the 3M 3500 passive monitor is crucial in obtaining a constant and reliable sampling rate [41]. High air velocity accelerates the diffusion rate. Since all TWA data were collected on personal samplers, and general mechanical ventilation was provided to the syrup room, the required minimum air velocity (usually 0.2 – 0.4 m/s) [41] was easily reached. In addition, workers' movement would also aid in provide ideal conditions for vapour diffusion onto the passive sampler.

4.4. Major Findings:

4.4.1. Research Objective 1:

The use of the Risk Ranking tool to identify, describe and ultimately rank the various tasks in preparation for quantitative monitoring proved useful. The adapted risk assessment method allowed the author to comprehensively describe key elements of the various tasks and judge those elements against key exposure criteria of probability and severity (health effects).

Although the use of a Risk Assessment tool is not specifically indicated in the RHCS, the relevance and usefulness in undertaking a Risk Assessment prior to conducting any air monitoring is prescribed in regulation 5. In addition to listing some specific requirements and considerations, regulation 5 further prescribes the conducting a risk assessment prior to any airborne monitoring (regulation 6). Indeed, one of the primary outcomes of a risk assessment is the formulation of an air monitoring strategy.

The study setting presented in this report has never been subjected to any form of chemical risk assessment as prescribed by the RHCS thus explaining the indiscriminate adoption of TWA monitoring methodologies in the past.

Based on the subsequent monitoring results, this oversight has resulted in poor workplace exposure characterisation and also, most likely, numerous hidden non-compliant exposures.

4.4.2. Research Objective 2 and 3:

The high percentage (89.1 %) of tasks that exceeded the ST-OEL, demonstrate that excursive, short-term exposure factors play a significant role in worker exposures within the study setting.

Conversely, the majority (90%) of TWA samples taken in conjunction with the Short-Term samples returned compliant results. In addition, supplementary TWA monitoring data obtained monthly and concurrently over three years also returned a high percentage of compliance (79%). These results concur with those reported by Thomenson *et al* in their study of the exposures of 1526 subjects at the Darwen plant who were engaged from 1949 onwards. In this study, the mean duration of exposure was 7.6 years at 13.2 ppm (8-hour TWA), although Thomenson *et a*l also noted that exposures in some work groups were as high as 100 ppm [42]. This study was about mortality rates and did not focus on any specific area of a typical acrylic sheeting manufacturing plant, one could expect the exposures in the Syrup Rooms to be higher than in other areas.

The TWA measuring data, if viewed in isolation, therefore presents a high degree of error if used to describe and account for the task-based exposures occurring during the average work shift.

The true impacts of the excursive and previously masked exposures in the context of the study setting, would best described by their role in the potential development of health effects. Many researchers, at least in the field of occupational asthma, believe that excursive or peak exposures may be important in the development of occupational asthma [43]. To further support this statement, Malo and Cartier (1996) speculated that although TWA exposures may be more important than short-term or peak exposures once symptoms appear, excursive

or peak levels are probably more important in causing 'sensitisation' to an agent [44].

4.4.3. Research Objective 4:

The use of Spearman's correlation to statistically interpret the data obtained for the Short Term and TWA monitoring results proved interesting and, by estimating weak correlations between the data sets, reinforces the argument that task-based exposure monitoring is important for characterising work scenarios that include excursive exposures.

Low statistical power limits the extent to which the findings of this study can be generalised. For some excursive measurements, the number of observations measured was small. This is especially true for the task numbers three to eight, with three of these tasks having four or three measurements. This may lead to an unstable estimation of the metrics and, hence, more uncertainty in the factor analysis. However, these measurements still conform to the minimum criteria required for factor analysis i.e. at least three to five observations for each variable [9 x (3–40) = 27–360 in this case], this research produced 106 Short-Term and 10 Time-Weighted Average observations.

A study of dust exposure in bakeries, which used full-shift and task-based exposure measurements, produced results that suggested a strong correlation between peak exposure intensities and full-shift average exposures [45]. This finding is contrary to the findings presented in this report.

In another study, results presented for organic solvent exposure in the micro-electronics industry, the correlation between the logarithms of TWA exposure and maximum peak exposure during 17 tasks was estimated to be 0.82, again presenting opposing findings to those depicted in this study [46].

Among workers producing or using formaldehyde, it was however reported that there was no correlation between average and peak formaldehyde exposures [47].

Any comparison of the results obtained in this study should therefore be viewed with caution since it appears that there is still some debate between studies about

the true definition of peaks as well as large variations in study circumstances. It may be difficult to estimate whether these differences lead to true differences in actual correlations between measurements.

According to Preller *et al* (2004), studies that only deal with the quantification of inhalation exposure and ignore skin absorption, as with this study where dermal exposure was highly likely during some tasks, neglect an important aspect of peak exposure. Many of the organic solvents, including methyl methacrylate are known to penetrate skin, but little is known about the contribution of this exposure pathway to internal dose or its correlation with inhalation exposure [48]. Consequently, dermal exposure must be considered in any future characterization of peak exposure in the studied industries.

The weak correlation between the TWA and Short-Term data sets illuminates the problems associated with relying on single sample TWA monitoring to describe overall workplace exposures and subsequent protective / preventative measures that might be adopted in workplaces where task variations exist.

In the study setting for example, a general dilution ventilation system is used as the primary engineering control device to limit exposures. By definition, these systems are effective in reducing background or ambient chemical concentrations as well as preventing chemical build-up within the work area. A general dilution ventilation system is however not appropriate for controlling chemical concentrations which are emitted close to the worker, especially if those concentrations must first travel past the worker's breathing zone before being diluted by the ventilation system. Examples of these types of sources are in fact intimately associated with many of the tasks described in this research report.

CHAPTER 5

5. CONCLUSION AND RECOMMENDATIONS:

5.1. Although the importance of 8-hour TWA sampling cannot be ignored, a combination of the two strategies, especially in situations where excursive tasks exist, may be advantageous with task based exposure measurements being used to characterise and quantify exposure conditions likely to be missed in TWA monitoring strategies.

5.2. An increasing awareness that differences in exposure profiles may have different health effects with a similar daily dose and the improving ability to measure exposure on a real-time basis should stimulate research into differences in exposure profiles and their biological relevance. Until such research has yielded conclusive results, arguments, which date back about half a century, about the value of assessment of peak exposures in epidemiology and occupational hygiene will persist [49].

5.3. Had the foundation for the monitoring programme initially been described and contextualised in a comprehensive risk assessment of the workplace and subsequent task-based and TWA monitoring, the methods used to control exposures may be somewhat different. For example, in addition to the existing general dilution ventilation system, it may be possible to easily reduce exposures associated with two of the key tasks identified viz:

i. Pressure Vessel Cleaning, a significant exposure source due to:

(a) the high probability that exposures will exceed the ST-OEL (100 % of monitored tasks exceeded the ST-OEL);
(b) the aggressive nature of the cleaning task;

(c) the poor ventilation of the pressure vessel and subsequent orientation of the hatch to the worker i.e. only open on one side through which cleaning is done;

(d) The close proximity of the worker to the task;

(e) The liberal use of liquid methyl methacrylate in the cleaning process; and

(f) The relatively prolonged duration of the task (minor clean = 35 minutes; major clean = 60 minutes).

ii. Viscosity testing at the Mixers - is also a key area due to the high concentrations monitored and although exposure durations are short (1 minute), the frequency of these tasks is significant (52 tests / shift).

Exposure reduction could be achieved by the installation of Local Extraction Ventilation systems as follows:

(a) PV Cleaning occurs with a dedicated PV Cleaning bay. The installation of a flexible extraction duct within this bay that can be coupled to any pressure vessel would eliminate much of the exposures related to this task. In effect, the worker would couple the duct to the dorsally situated syrup feeder valve, prior to the commencement of cleaning. When engaged and operational, this system would effectively convert the vessel into a ventilation hood with its intake being the open work hatch thus creating a negative air pressure gradient at the hatch (capture face) and preventing vapours from being released into the worker's breathing zone as well as the general work environment.

(b) Each of the 13 Mixers could be fitted with similar local exhaust ducts thus also creating negative pressure gradients at the lid openings. Although in this scenario, process impacts like product loss though increased evaporation as a result of increased extraction, should be considered. These extraction systems could be linked to automatic switches which activate used whenever the

hatches are opened. This measure would thereby reduce exposures associated with all mixer related exposures some of which include: Viscosity Checks, Mixer Cleaning, Grade Changes and Adjusting Mixer Speeds.

The two control measures described above should also have positive impacts on the ambient concentrations of methyl methacrylate. For the remaining tasks, it would be prudent to provide organic cartridge respirators to the employees. These devices, if properly worn, stored and maintained, should provide adequate protection against the measured concentration of methyl methacrylate vapours.

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Appendix 1: PAC III Calibration Certificate

Dräger safety

WCC NO: WCC4354

CALIBRATION CERTIFICATE
PAC III

CUSTOMER: I.S.S

EQUIPMENT	SERIAL NUMBERS	FUNCTION TEST	TYPE OF SUPPLY	KIT ACCESSORIES
PAC III	ERNM-0112	PASSED	RECARGABLE	COMPLETE

TEST CERTIFICATE
SENSORS

SENSOR	CALIBRATED TO	ALARM LEVELS	
CV	15 PPM C_2H_4	A1= 10 PPM	A2= 20 PPM

INSPECTION SUMMARY

CALIBRATION VERIFIED	√
FUNCTIONAL INSPECTION	√
VISUAL CHECKED	√

CALIBRATED & CHECKED BY: Lizelle Janse van Vuuren

SIGNATURE:

DATE: 31/08/2006

Dräger S.A. (Pty) Ltd.
P.O. Box 6660
Bryanston 2021
Tel.: (011) 466-9556 Fax: 466-8953
Company registration No: 1959/003553/07
VAT No. 4710111577

THIS CERTIFICATE IS INVALID UNLESS OVERSTAMPED WITH COMPANY STAMP

The issue of this certificate does not imply any warranty in respect of any instrument as to its fitness for use once the instrument has left the Company's premises save that at the time of calibration it conformed to manufacturer's standard operating specifications under a standard test conditions, using the test gases above. This instrument is required to be periodically re-calibrated in accordance with these standard manufacturer specifications.

Appendix 2: Letter of Informed Consent

19 June 2003

Mr S.J.Chester
6 Peace Avenue
Morningside
4001

Re: Consent from host organisation granting the researcher access and expressing support for the study.

Dear Mr. Chester

We would like to inform you that your request to undertake a research study entitled ***"The usefulness of task-based exposure data in characterising work tasks that produce potentially high short-term exposures"*** at our Umbogintwini Factory is hereby granted.

We further acknowledge that you have explained the concept and benefits of this research to us and it is in this light that we offer complete support for the study.

We also grant you permission to use previous air monitoring results obtained since January 2000.

Finally, we would like to request that you keep our company name and the name of any participating employees anonymous as per the requirements of the company clearance certificate.

Yours sincerely,

P.S. Anonymity clause accepted by researcher:
S.J. Chester

Appendix 3: Subject Information Sheet

SUBJECT INFORMATION SHEET

My name is **Sean Chester**, I'm a 3rd Year MPH Occupational Hygiene Student at the University of Witwatersrand and I'm conducting a study to determine the concentrations of Methyl Methacrylate vapour (monomer) you are exposed to while you undertake your routine work tasks.

The purpose of the study is to establish how much monomer you are exposed to on average over an entire work shift as well as how much monomer you are exposed to when undertaking monomer syrup cleaning tasks like PV and floor cleaning (when vapour concentrations are much higher than normal).

The methods used are similar to the way I've been doing the monitoring every month for the last 2 years except that in this study I will be monitoring certain cleaning tasks in addition to the sample I normally place on you for most of the work shift. These tests may be repeated more than once over several work shifts, in which case you'll simply be asked to again undertake your routine activities while wearing a sampling pump.

Cast Plant 1 Syrup Room has been selected because cleaning tasks within this area are performed manually and as such require operators and assistants to physically clean PV's and floors using mops and concentrated monomer. Exposures are thus expected to increase, if only briefly, when cleaning and using concentrated monomer. In addition, you have been selected on the basis that you are the employee that will be undertaking the cleaning tasks in Syrup Room and thus potentially "**the most exposed employee**".

Participation in this study is entirely voluntary and if you chose not to participate, there will be no negative consequences. If you do participate, you may decline to answer any questions and you may also withdraw from the study at any time.

You will be anonymous in this study with no mention of your name or clock-card number.

The benefits this project provides you is a greater knowledge of your daily exposures to monomer vapour and potential improvement in protection from your company.

I would hereby like to invite you to participate in my research project and as such humbly request that you agree by signing below.

Should you have any queries or concerns, please feel free to contact me **anytime** at:
Home - 031 312 8523 Work - 031 914 1004 Cell - 082 772 2938

Signed consent:

.....
Date: 20/1/2006

Appendix 4: Ethics Clearance Certificate

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

Division of the Deputy Registrar (Research)

COMMITTEE FOR RESEARCH ON HUMAN SUBJECTS (MEDICAL)
Ref: R14/49 Chester

CLEARANCE CERTIFICATE **PROTOCOL NUMBER** M03-02-06

PROJECT The Usefulness of Task-Based Exposure Data in Characterising Work Tasks that Produce Potentially High Short Term Exposures

INVESTIGATORS Mr SJ Chester

DEPARTMENT School of Public Health, Wits Medical School

DATE CONSIDERED 03-02-28

DECISION OF THE COMMITTEE Approved unconditionally

Unless otherwise specified the ethical clearance is valid for 5 years but may be renewed upon application
This ethical clearance will expire on 1 January 2008.

DATE 03-07-08 CHAIRMAN ..... (Professor P E Cleaton-Jones)

* Guidelines for written "informed consent" attached where applicable.

c c Supervisor: Prof D Rees
Dept of School of Public Health, Wits Medical School
Works2\lain0015\HumEth97.wdb\M 03-02-06

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DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and ONE COPY returned to the Secretary at Room 10001, 10th Floor, Senate House, University.

I/we fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee. I agree to a completion of a yearly progress form. I/we agree to inform the Committee once the study is completed.

DATE 05/05/2003 SIGNATURE .....

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

Appendix 5: TWA and Short-Term Monitoring Results

The tasks listed below were monitored according to the methodology described in chapter 2 which committed the researcher to monitor all tasks that were assigned a Risk Ranking of high or very high in the Qualitative Risk Assessment.

Observations 1 and 2: TWA and Short-Term (Task-Based) Monitoring Results

Observation 1	Task Number								
	1	2	3	4	5	6	7	8	9
Individual excursion results (ppm) / excursion duration (mins)	143/60[#] 164/60[#]	NM	98/5	NM	NM	118/1	138/1[#]	154/2[#] 184/2[#]	126/1[#] 128/1[#] 130/1[#] 132/1[#] 160/1[#] 200/1[#]
No. of excursions monitored (n = 13)	2	NM	1	NM	NM	1	1	2	6
Total exposure duration (mins)	120	NM	5	NM	NM	1	1	4	6
Corresponding Full Shift (TWA) Monitoring concentration (ppm)	73.14								
Observation 2	Task Number								
	1	2	3	4	5	6	7	8	9
Individual excursion results (ppm) / excursion duration (mins)	134/30[#] 160/30[#]	NM	NM	90/5	NM	126/1[#]	112/1	134/2[#] 148/2[#]	130/1[#] 140/1[#] 168/1[#] 170/1[#] 174/1[#]
No. of excursions monitored (n = 12)	2	NM	NM	1	NM	1	1	2	5
Total exposure duration (mins)	60	NM	NM	5	NM	1	1	4	5
Corresponding Full Shift (TWA) Monitoring concentration (ppm)	66.92								

# Denotes task / excursion monitoring results that exceeded the ST-OEL exposure limit of 125 ppm

NM – Not Monitored due to logistical reasons on behalf of the researcher or the task was not undertaken by the operator during the work shift. ppm – parts per million; **mins** - minutes

Observations 3, 4 and 5 - TWA and Short-Term (Task-Based) Monitoring Results.

Observation 3	Task Number								
	1	2	3	4	5	6	7	8	9
Individual excursion results (ppm) / excursion duration (mins)	150/30[#] 160/60[#] 170/30[#]		132/1[#]	58/1	180/1[#]	NM	NM	146/5[#]	88/1[#] 132/1[#] 134/1[#]
No. of excursions monitored (n = 9)	3	NM	1	1	1	NM	NM	1	3
Total exposure duration (mins)	120	NM	5	5	5	NM	NM	5	3
Corresponding Full Shift (TWA) Monitoring concentration (ppm)	92.93								
Observation 4	Task Number								
	1	2	3	4	5	6	7	8	9
Individual excursion results (ppm) / excursion duration (mins)	142/35[#] 186/60[#]	110/30[#] 120/30[#] 128/30[#] 180/30[#]	NM	84/1	132/5 170/5	NM	NM	152/5[#]	158/1[#] 184/1[#]
No. of excursions monitored (n = 12)	2	4	NM	1	2	NM	NM	1	2
Total exposure duration (mins)	95	120	NM	1	10	NM	NM	5	2
Corresponding Full Shift (TWA) Monitoring concentration (ppm)	116.51[##]								
Observation 5	Task Number								
	1	2	3	4	5	6	7	8	9
Individual excursion results (ppm) / excursion duration (mins)	161/40[#] 170/35[#]	122/30[#]	NM	NM	NM	114/1	NM	NM	124/1[#] 140/1[#] 142/1[#] 158/2[#]
No. of excursions monitored (n = 7)	1	1	NM	NM	NM	1	NM	NM	4
Total exposure duration (mins)	75	30	NM	NM	NM	1	NM	NM	5
Corresponding Full Shift (TWA) Monitoring concentration (ppm)	61.6								

Observations 6, 7 and 8 - TWA and Short-Term (Task-Based) Monitoring Results

Observation 6	Task Number								
	1	2	3	4	5	6	7	8	9
Individual excursion results (ppm) / excursion duration (mins)	NM	NM	98/10	112/5	NM	NM	NM	94/2	112/1[#] 112/1[#] 129/1[#] 134/1[#]
No. of excursions monitored (n = 7)	NM	NM	1	1	NM	NM	NM	1	4
Total exposure duration (mins)	NM	NM	10	5	NM	NM	NM	2	4
Corresponding Full Shift (TWA) Monitoring concentration (ppm)	42.98								
Observation 7	Task Number								
	1	2	3	4	5	6	7	8	9
Individual excursion results (ppm) / excursion duration (mins)	141/30[#] 156/30[#] 173/35[#] 180/30[#]	112/30[#] 126/30[#] 130/30[#] 140/5[#]	NM	NM	128/2[#] 168/2[#]	NM	NM	130/5 #	118/1[#] 134/1[#] 160/1[#]
No. of excursions monitored (n = 13)	4	3	NM	NM	2	NM	NM	1	3
Total exposure duration (mins)	125	95	NM	NM	4	NM	NM	1	3
Corresponding Full Shift (TWA) Monitoring concentration (ppm)	84.68								
Observation 8	Task Number								
	1	2	3	4	5	6	7	8	9
Individual excursion results (ppm) / excursion duration (mins)	161/35[#]	NM	NM	58/10	164/1[#] 171/2[#] 190/2[#]	NM	NM	NM	118/1[#] 123/1[#] 126/1[#] 143/1[#] 146/1[#] 151/1[#] 161/1[#] 172/1[#]
No. of excursions monitored (n = 12)	1	NM	NM	1	3	NM	NM	NM	8
Total exposure duration (mins)	35	NM	NM	10	5	NM	NM	NM	8
Corresponding Full Shift (TWA) Monitoring concentration (ppm)	56.97								

Observations 9 and 10 - TWA and Short-Term (Task-Based) Monitoring Results

Observation 9	Task Number								
	1	2	3	4	5	6	7	8	9
Individual excursion results (ppm) / excursion duration (mins)	NM	117/25[#] 126/30[#] 141/5[#]	NM	NM	NM	128/1[#]	148/5[#]	153/10[#]	NM
No. of excursions monitored (n = 6)	NM	3	NM	NM	NM	1	1	1	NM
Total exposure duration (mins)	NM	60	NM	NM	NM	1	5	10	NM
Full Shift (TWA) Monitoring concentration (ppm)	53.67								
Observation 10	Task Number								
	1	2	3	4	5	6	7	8	9
Individual excursion results (ppm) / excursion duration (mins)	140/35[#] 161/30[#] 185/30[#] 190/5[#]	118/30[#] 135/30[#]	NM	84/1	NM	NM	NM	NM	151/1[#] 154/1[#] 163/1[#] 167/1[#] 196/1[#]
No. of excursions monitored	4	2	NM	1	NM	NM	NM	NM	5
Total exposure duration (mins)	95	60	NM	1	NM	NM	NM	NM	5
Full Shift (TWA) Monitoring concentration (ppm)	97.58								