School of Public Health

Exposure to Diesel Particulates and their Health Effects on Employees in a Metalliferous Mine in Western Australia

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DECLARATION

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

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Date: August 2015.

ABSTRACT

This study aimed to investigate workplace diesel particulates (DP) exposure of employees working in an underground mine in Western Australia and whether exposure to DP is potentially associated with irritant effects.

Data for DP exposure was collected through personal air monitoring on employees and fixed spot air monitoring in various areas underground with a range of exposure levels. Emission data from mining vehicle/equipment engines used during the underground mining on site was obtained as well as Contaminant Monitoring (CONTAM) data, which had been, collected from this mine every three months since 2003. CONTAM monitoring that was collected during this study was also obtained to provide a comparison against the research results.

An outcome of the research was the determination of the air quality underground, personal exposure levels of DP and any potential irritant effects related to diesel particulate exposure among underground workers. In addition, the study has contributed to the development of effective controls to minimize DP exposure among underground mine workers.

This study can form the foundation for further studies on DP exposure and health outcomes on a larger scale.

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ABREVIATIONS

DE: Diesel Exhaust

DP: Diesel Particulates

DPM: Diesel Particulate Matter

AIOH: Australian Institute of Occupational Hygienist

EC: Elemental Carbon

OC: Organic Carbon

TC: Total Carbon

CONTAM: Contaminant Monitoring

DPF: Diesel Particulate Filter

DMP: Department of Mining and Petroleum

CDC: Centres for Disease Control and Prevention

NOISH: National Institute for Occupational Safety and Health

MSHA: Mine Safety and Health Administration

TWA: Time Weighted Average

EXPOSURE TO DIESEL PARTICULATES AND THEIR HEALTH EFFECTS ON EMPLOYEES IN A METSALIFEROUS MINE IN WESTERN AUSTRALIA.

1. INTRODUCTION

1.1 Introduction

Diesel exhaust is a complex mixture of gases and particles emitted by a diesel-fuelled internal combustion. Diesel emissions have the potential to cause adverse health effects. However, the complex nature of diesel exhaust composition has meant that limited studies on the health effects of diesel exhaust are available.

This study aimed to investigate workplace diesel particulates (DP) exposure of employees working in an underground mine in Western Australia and whether exposure to DP is potentially associated with irritant effects. Data for DP exposure was collected through personal air monitoring on employees and fixed spot air monitoring in various areas underground with a range of exposure levels. Emission data from mining vehicle/equipment engines used during the underground mining on site was obtained as well as Contaminant Monitoring (CONTAM) data, which had been, collected from this mine every three months since 2003. CONTAM monitoring that was collected during this study was also obtained to provide a comparison against the research results. This study can form the foundation for further studies on DP exposure and health outcomes on a larger scale.

1.2 Research Background

Diesel exhaust is a complex mixture of gases and particles emitted by diesel-fuelled internal combustion engines (Lipsett and Campleman 1999; IARC 1989; Hesterberg et al. 2005). Many epidemiological studies have revealed an increase in morbidity and mortality from cardiovascular and respiratory diseases that have been associated with exposures to ambient air polluted with diesel exhaust (Hesterberg et al. 2009; Arlt 2005). Diesel exhaust has been found to be even more toxic than gasoline exhaust by approximately 100 times (Krivoshto et al. 2008). It has been estimated, by the National Institute for Occupational Safety and Health (NIOSH 2009) that millions of workers are exposed to diesel fuel and its combustion products in their workplace. Epidemiological studies have reported high rates of chronic respiratory diseases for those living near or working among diesel exhaust (Krivoshto et al. 2008; Hesterberg et al. 2006). Acute or short term exposure to diesel exhaust can cause acute irritation of the nose, eyes and throat and respiratory symptoms (U.S. Environmental Protection Agency 2002; Solomon et al. 1998).

However, the complex nature of diesel exhaust composition makes attempting to associate the exposure and the risk of disease burden inherently difficult. Even though employees working in underground mines are considered to be a group that are likely to be exposed to high level of DP exposure they are not usually targeted for epidemiological studies related to DP. This is generally due to their exposure to other contaminants causing confounding issues; therefore there is a lack of studies on exposure assessment and associated health effects on Western Australian (WA) miners, especially in underground mines.

The distribution and production of diesel fuel containing low sulphur content is widely available in Australia. Diesel particulate traps, filter and other after treatment devices are now being implemented, with studies showing that buses using particulate traps and clean diesel fuel are of a superior standard when it comes to reducing diesel emissions (Krivoshto et al 2008). However these control systems and after treatment devices may not always be completely effective in all situations as the particle sizes of DP are so small that they may be able to bypass some current filter systems (Krivoshto et al 2008).

While overseas DP management policies have been put in place to protect the employees from DP exposure, there is a lack of studies in WA mines for DP exposure assessment, as well as minimal to no policies and legal requirements developed in Australia for DP exposure management. The CONTAM Database maintained by Resource Safety in WA for the WA mining industry indicates that “one in four exposures to diesel particulate matter in underground mines exceeded the recommended exposure standard” of 0.1mg/m^3 elemental carbon (Department of Mines and Petroleum 2013, 33).

Currently there is no legislation in Western Australia on the limit of diesel particulates and any exposure standards set are only recommendations. The Australian Institute of Occupational Hygienists (AIOH) as well as the Department of Mines and Petroleum have adopted the value of 0.1mg/m3 measured as submicron elemental carbon as a guideline value. AIOH (2007, p. 5), states ‘Notwithstanding the lack of a defined dose relationship, experience has shown that when workplace exposures are maintained below 0.1mg/m^3 DP, irritant effect decreases markedly’. With no legislation there is also no standard for monitoring of DP in the workplace. The only current requirement for DP exposure is the analysis method, which is the NIOSH 5040 Method. Therefore closer examination of monitoring techniques needs to be addressed and a standardised method of monitoring should be established

This study focused on investigating employees’ DP exposure patterns among underground mine workers. The NIOSH 5040 method was used to measure personal DP exposure. This study looked at potential irritant effects caused by DP by surveying workers to obtain information on any irritant effects (such as stinging eyes, coughing, sore throat and tickling nose) that the workers might have experienced during their surveyed work period.

1.3 Research Aim and Objectives

This research aimed to determine possible short term health effects associated with exposure to diesel particulates in an underground mine in Western Australia.

The objectives of this study were to:

(1) Evaluate the air quality of an underground mine.

(2) Evaluate the personal diesel exhaust exposure of underground mine workers.

(3) Assess potential irritant effects among underground mine workers in relation to DP exposure.

(4) Evaluate monitoring practises and assess which of these is the most accurate.

1.4 Research Questions

To answer the research objectives the following research questions were addressed.

- What is the air quality of the underground mine?
- Which parts have the highest and lowest levels of DMP exposure and why?
- What are the personal DPM exposure levels for underground workers?
- Are there any links with job description and tasks that are being performed?
- What irritant conditions are affecting workers exposed to DPM?
- Are those exposed to higher levels of DPM for longer periods of time experiencing more acute ill health conditions than those less exposed?
- What monitoring method is giving the most accurate results FOR DPM exposure?
- Can a monitoring method for DPM exposure be applied throughout the metalliferous mining industry?

1.5 Research Significance

This is the first study at this mine to investigate DP exposure by using element carbon monitoring data while concomitantly reporting on potential irritant effects. The findings of this research can be used as a foundation for further studies on a larger scale. Since this company has access to many other mines run by different clients it may allow further studies to be considered. The research findings have added to knowledge of exposure level to diesel particulates of miners who work underground in a Metalliferous mine and the acute health effects experienced by these miners.

An outcome of the research was the determination of the air quality underground, personal exposure levels of DP and any potential irritant effects related to diesel particulate exposure among underground workers. In addition, the study has contributed to the development of effective controls to minimize DP exposure among underground mine workers.

The outcomes of the study provide evidence-based information for the management of DP exposure underground which are important as:

- Studies on underground metalliferous mines have been minimal and recommended standards used are based on findings, research and legislation from states outside Western Australia.
- Most previous Australian underground mining research related to diesel particulates has been based on studies done in coal mines.
- Most legislation and sampling techniques related to diesel particulates are based on American procedures that are quite out of date.
- There is no metalliferous form of monitoring for DP. This research has developed a metalliferous monitoring practice for diesel particulates.

1.6 Methodology

This study investigated workplace DP exposures and the associated potential irritant effects among current employees working in an underground mine. A questionnaire was used to identify any irritant effects that underground workers may experience during their work. Information on DP exhaust concentration was collected through air monitoring at different locations underground. These locations varied in environmental conditions as well as the work performed in this area and also had varying ventilation systems. Some of these areas were monitored more than once to compare results given at the exact same location but on different days. In some positional locations different types of cassettes were used for sampling at the same time in the same place to determine if there was any variation present when sampling using different techniques.

Historical DP monitoring data (CONTAM data) (Government of Western Australia Department of Mines and Petroleum, 2010) collected every three months from this mine from 2003 to the present were obtained and analysed by the researcher. Use of multiple methods to collect data has improved the reliability and validity of research findings (Perry, Wong & Bernhardt, 1995).

The study took place in an underground metalliferous mine located in Western Australia; with the participants performing underground mining operations as part of their daily work.

1.7 Limitations

While the methods listed under methodology are considered the best way to conduct this research (Rogers and Davies 2005; Hesterberg et al. 2009) there are always various confounders that may be present such as other large particles entering the filter. The SKC cassette has a special design that takes a cut at 1 μm thus ensuring that principally DP will be collected.

Other details that need to be considered that may affect the results are ventilation and environmental conditions on different days. To overcome this limitation, data on wind velocity, temperature and humidity at monitored workplace locations and days was recorded simultaneously over the air monitoring period. Variations in underground mine air quality is mainly affected by the type of work performed and the type of equipment used. Therefore, work performance and the type of equipment and machinery used every day during the study was collected by the researcher. In addition historical monitoring data (CONTAM data) which has been collected quarterly was included to overcome this limitation.

Other details that were considered that can affect the results were ventilation and environmental conditions on different days. To overcome this limitation, data on wind velocity, temperature and humidity were monitored at different workplace locations and days where diesel particulate monitoring was conducted. Variations in underground mine air quality is mainly affected by the type of work performed and the type of equipment used. Therefore, work performance and the type of equipment and machinery used during the study was collected as well as asking monitored employees what their job descriptions would be for that day.

Personal sampling monitoring relies mainly on the employee wearing the equipment. This can include whether the employee:

- wears the equipment correctly;
- has kinks in the hose;
- keeps the monitor running;
- wears the monitor at all times.

To help combat these issues a Power Point presentation was shown to the employees explaining them the correct way to wear the monitoring equipment and the importance of wearing it appropriately for the whole monitoring time.

1.8 What Was Known About The Researched Topic

While there has been an increase in research over the past few years with diesel particulates due to their growing concern, there are still many things that are unknown. However the main facts that are known is that diesel particulates have a complex structure, employees working in underground mining have the potential to be greatly exposed, many workers are currently exposed above the recommended levels and that diesel particulates have the potential to cause numerous health concerns. The following chapter, the literature review, discusses what was already known about the researched topic.

1.9 New Knowledge Generated From the Findings of This Research

This research provides further understanding in regards to the health effects of diesel particulate exposure in metaliferious mining. This finding explore the need for a standardised method of monitoring and report on acute health effects related to diesel particulate exposure using employees in current real work situations and add to the body of knowledge on the acute health effects experienced by underground miners. This research provides a platform for further future studies to be conduct, not only in this areas related to diesel particulates, but also to other areas of air quality research. The discussion, conclusions and recommendations chapters discuss more in depth the knowledge generated from the findings of this research.

1.10 Overview Of The Thesis

The outline of this thesis is as follows:

Chapter 1: Introduction: The introduction provides a background of the research topic and an overview about the study being performed. This includes the research aim and objectives of the study, what questions need to be answered, summary of the methods being used to collect research data and considerations that needed to be taken into account when conducting this research. This chapter outlines what is included in the rest of the research study.

Chapter 2: Literature Review: The literature review gives an overall background of the history of diesel, any possible health effects of diesel particulates, any current legislation related to the exposure of people to diesel particulates, how diesel particulates can be monitored and controlled to prevent the exposure of people to these particulates, what is known and what were the gaps in knowledge about diesel particulates.

Chapter 3: Methodology: The methodology section explains, describes and justifies the research study design, the methods used to collect data and how these methods were used to answer the research questions. It includes information on how research participants were selected, who was involved in the study, how the data was collected and analysed, how validity and reliability was achieved, statistical analysis procedures used and how ethical considerations were addressed.

Chapter 4: Results: The results chapter summarises the results of analysing the data that was collected.

Chapter 5: Discussion: The discussion chapter examines the results obtained from the study and answers the questions. In this chapter results are critically evaluated in comparison with past and present published literature.

Chapter 6: Recommendations and Conclusion: The recommendations and conclusions include recommendations that can be suggested in correlation with the analysis of the results and any future endeavours that may need to occur. This chapter concludes and summaries the findings in this research study.

The next chapter is a review of published information that includes the history of diesel particulates and issues related to this including health related matters, current findings, risk controls used and specific concerns with exposure of people who work in underground metalliferous mining.

2. LITERATURE REVIEW

2.1 Introduction To Chapter

This chapter reviews past and current literature relating to diesel particulates by looking at its history, what the latest studies have found in regards to diesel particulate exposure in underground mining, current information on possible health effects of diesel particulates, current legislation related to the exposure of people to diesel particulates, how diesel particulates can be monitored and controlled to prevent the exposure of people to these particulates, what is known and what are the gaps in knowledge about diesel particulates. The information in this chapter is used in later chapters to assist with determining the best practised methodology for risk control measures to prevent diesel particulate exposure to underground miners and it is referred to in the analysis and discussion of results. The literature review supports the recommendations that have been proposed in the conclusion.

2.2 Methodology For Literature Review

Published literature related to diesel particulate was reviewed using database searches from Proquest and Google and Goggle Scholar. The literature search was limited to English and the dates searched were between 2000 and present. The key words used for the searches were “diesel particulates”, “mining”, “Australia” and “health effects”.

An initial search in ProQuest with only peer reviewed publications and date range on 2000 till present with the keywords diesel particulates cited 12,238 results. A refined search with diesel particulates and health effects cited 5016 results. Other searches with diesel particulates and mining cited 636 results and diesel particulates and health effects and mining and Australia cited 110 results.

A search in Google Scholar with the keywords diesel particulates cited 108,000 results. A refined search with diesel particulates and health effects and mining and Australia cited 10,800 results.

A total of (to be filled) publications were used, this included (to be filled) are cited in this research report.

2.3 Background

Diesel exhaust is a complex mixture of gases and particles emitted by diesel-fuelled internal combustion engines. (IARC 1989, Lipsett and Campleman 1999, Hesterberg, Bunn et al. 2005). Due to diesel exhaust's complex nature much of the research done in this area has been inherently difficult to conduct and hence has been quite limited. With the use of diesel engines being only looked at in more recent times historical information on possible health effects are not greatly prevalent. That diesel exhaust is quite a complex gas means that identifying the health concerns and identifying ways to control it are sometimes quite difficult and costly.

Attfield et al. (2012) published the findings of a cohort mortality study of 12,315 miners working in 8 non-metal mines in the United States of America and identified that lung cancer rates were higher in underground miners with at least 5 years of exposure to diesel particulates (HR= 5.01,95% CI = 1.97 to 12.76). The International Agency for Research (2012) subsequently classified diesel particulates as a Group 1 Carcinogen, meaning that exposure to diesel particulates is a cause of cancer in humans.

Prior to 2012 a number of questions had been asked when discussing diesel particulates with the main, and most important issue, of whether exposure to diesel particulates cause any adverse health effects. In other words, was then any real health concerns associated with diesel particulates; therefore is there any real need for its risk management? Employees may feel that no proof is needed (Monforton 2005). Monforton (2005, p.1) recorded the following quote from an underground mine employee. "Some of the stresses you can feel - you don't need a gauge to measure this – your burning eyes, nose, throat, your chest irritation. The more you're exposed to, the higher this goes."

Due to the lack of large human occupational health studies prior to 2012 potential evidence of negative health effects related to D.P exposure in workplaces were neither very substantial nor reliable. This was a main factor as to why no set standards had been developed, however the Australian Institute of Occupational Hygienist (AIOH) (2007, p.1) states “In the absence of any other definitive data, the AIOH supports the use of an exposure standards of 0.1 mg/m3.” The AIOH (2007, p.9) further recommends that “based on the available information, the AIOH believes that worker exposure to DP levels should be controlled to below 0.1 mg/m3 measured as submicron elemental carbon. At this level irritation should decrease significantly and other adverse health effects may be controlled”. The Department of Minerals and Petroleum (DMP) of Western Australia (2013, p.10) documents that “the currently accepted TWA exposure limit for mine workers in Western Australian mines is 0.1 mg/m3 of elemental carbon. While there is no national standard, the accepted limit for Western Australia is based on AIOH guidance”.

There is, to some extent, quite a great deal of information on DP that has been found in a public setting, such as areas with high levels of vehicle activity, but there was limited research based on underground workplace employee exposure and health effects identified. (Lightfoot et al 2010) noted that studies are hindered by insufficient data in regards to occupational hygiene and an absence of attention to potential confounders.

HEI, (2002) discusses how the power of diesel engines as well as their efficiency and durability has meant that diesel fuel is extensively used in the transport industry especially in heavy-duty applications. The use of diesel engines has extended to not only on road equipment but also off road equipment with its used being applied to a wide range of industries including railroad, construction and mining. The increased use of diesel engines in a widespread of industries occurred between 1930s and 1950s and has continued to present day (Pronk et al 2009).

Not only is diesel exhaust complex but the particles with in diesel exhaust are also complex: the characteristics depend on different factors including the emission-control technologies, diesel fuel formulation and conditions in both engine combustion and ambient environment into which the exhaust is emitted. When approaching exposure assessment there is a need for diesel particulates to be identified and separated from any other sources of particles in the air. Approaches currently used are rather nonspecific such as using measurements of mass and of markers, such as compounds like elemental carbon. The issue with this is that sources other than diesel emissions have this compound (HEI, 2002). The complex nature of diesel particulates and the presences of other confounders, especially in the underground mining industry, make control and monitoring inherently difficult.

Diesel being such a complex mixture, and as for some time being classified as a 2b probable carcinogenic, has meant there has been no real push for standards to be developed, however the change of classification to a 1a carcinogenic in 2012 may mean that a standard will be developed for how diesel particulates are measured, monitored and risk control measures required.

For more than 50 years the diesel engine has been the most selected engine for heavy-duty functions in industries such as transport, construction, agriculture and for industrial machinery. The capacity, fuel efficiency and durability of diesel are what has been attributed to its high demand over the years (Knothe et al 2005). Appropriate monitoring and control is vital as the use of diesel in all industries and countries increases (Attfield et al., 2012).

The National Institute of Occupational Safety and Health (NIOSH) estimated that between the years of 1981 to 1983 approximately 1.4 million workers in the United States were occupationally exposed to diesel exhaust (DE) (NIOSH, 1983). This figure was more than doubled in a study by Pronk et al (2009) which estimated that between 1990 and 1993, three million workers were exposed to diesel exhaust in over 15 countries in the European Union. These figures show that the use of diesel particulates is increasing and it is expected that the use of diesel engines will continue to increase due to their superior performance (EPA, 2002; Friesen, et al., 2013).

With mining so prevalent in Australia the use of diesel engines and diesel fuels are excessive and in high volumes, however the research Australia has related to diesel engine pollution are well below that compared to other countries with only a real focus occurring the last few years. The negative health effects associated with the gaseous portion of diesel exhaust emissions have been acknowledged for many years however it is only in recent decades that research has found that the particulate fraction of diesel emissions, which is diesel particulates, also has the likelihood of stimulate negative health effects (Rogers & Davies, 2005). Growing research and mounting evidence is continuing to reveal a link between both diesel exhaust and diesel particulate matter to various health effects (Monforton 2005; Wierzbicka, 2014).

2.4 The History And Nature Of Diesel

The design of the diesel engine was first noted when the creator Rudolf Diesel completed a patent in Berlins Imperial Patent Office on February 27th 1892 for a ‘new rational heat engine’. The patent ‘DRP 67207’ for the ‘Working Method and Design for Combustion Engines’ was then granted On February 23, 1893, (Mollenhauer and Schreiner 2010). Diesel engines are internal combustion engines that convert fuel, which is chemical energy, to mechanical energy. (U.S. Department of Energy, 2003).

In western society the two most common internal combustion engines are the Otto (also known as gasoline) engine and the diesel engine (Neeft et al., 1995). The diesel engine was based on the design of the Otto engine, with the goal of improving its efficiency. While for both gas and diesel engines energy is released through combustion as fuel reacts with air, gas engines require spark plugs to spark the combustion whereas diesel engines ignite on their own fuel (U.S. Department of Energy 2003).

It is believed that diesel engines are now more efficient then gasoline engines leading to the use of diesel engines being more prevalent (HE1, 2002). This is especially the case in larger transport vehicles such as trucks and vans and also sport utility vehicles, that means places such as the United States have reduced reliance on foreign petroleum products (HEI, 2002). However the concern of NOx and PM emissions is still present and while diesel is growingly efficient it does not necessarily mean these emissions go away.

With the creation of the diesel engine came the production of its fuel counterpart. Diesel fuel is a mixture of compounds and substances, therefore the components in diesel can vary as to the amount in it (Henderson & Willwerth, 2003). This means that the individual components of chemicals have the potential to vary greatly in different batches of diesel fuel. Therefore the characteristics that are, or at least should be, consistent in different batches is their performance, and this is what is used to define whether they can be sold as diesel. In other words any fuel that burns inside the requirements and can run a diesel engine is able to be sold and classified as diesel (Henderson and Willwerth 2003).

Even though it has been known for some time about the potential issues associated with DP it is only recently that a further look into standards has occurred. Thirty years of research has established diesel exhaust as a human carcinogen (Monench, 2011).Per horse power generated, traditional diesel engines produced 100 times more pollution than gasoline engines, but increasingly stringent EPA emissions standards (1988-2010) for diesel exhaust have stimulated major technological advances in diesel engine technology and diesel fuel/lubricant composition, resulting in the emergence of what has been termed New Technology Diesel Exhaust (NTDE). This exhaust exhibits marked improvements in emissions compared to pre-1988 diesel engines, with far less human toxicity. The technology developed to achieve more strict diesel emissions standards - electronic controls, ultra-low-sulphur diesel fuel, oxidation catalysts, and wall-flow diesel particulate filters -generated new American jobs, exportable technology and the economic boost of improving health for millions of people worldwide (Monench, 2011). However in developing diesel particulate exposure standards there are many issues that have made it difficult such as, within diesel fuel, is diesel particulate matter. Specific diesel exhaust composition, and the particulate portion, differs and is reliant on type of fuel and engine, maintenance of engine and treatment devices on exhaust (Monforton 2005).

HEI (2002) discusses the efficiency of diesel engines over gasoline engines and the advantages it has in addressing global warming due to the fact that it is believed to emit less of the greenhouse gas carbon dioxide per work unit. This factor is an issue of growing importance due to the fact that the number of kilometres travelled by vehicles is increasing quickly worldwide (HEI, 2002). However despite the many worthy qualities of diesel engines, there are still two emissions of diesel that cause concern these are nitrogen oxides as it adds to ozone creation, and also particulate matter, as it is linked to both acute and chronic adverse health effects (HEI, 2002).

With many health effects being associated with diesel particulates it has become growingly import to understand the nature of diesel and its particulate matter, how it operates and to develop developing appropriate exposure standards.

2.5 What Is Diesel Particulate Matter (DPM)?

Diesel Particulate Matter (DPM) has been defined as “the particle-phase compounds emitted in DE” (EPA 2002, page. 15). The composition of DPM depends on many factors such as the level of dilution and its subsequent atmospheric processing after being emitted from the tailpipe, the engine operating conditions and presence of after-treatment devices (Ristovski et al, 2012). The relevant masses and sizes of DP are of particular significance as it can define the chemical, deposition, optical toxic and transport properties of diesel particulates; however it is believed that particle mass is not always the best way to determine the presence of diesel particulates (Chandler, Teng & Koylu, 2007).

Due to their small size, DPM aerosols behave similarly to the surrounding gases. They have much longer residence times in a mine atmosphere than larger mechanically generated particles, which are removed from the atmosphere quite quickly by gravitational settling. In addition, a large portion of diesel particles are deposited in the human respiratory tract in comparison to larger aerosols. These small diesel aerosols penetrate deeply into regions of the human lung where gas exchange occurs, potentially increasing the health risks associated with long-term exposure to diesel aerosols (Pietikäinen et al. 2009; Morawska et al. 2005). For these reasons, control of exposure to DPM particles is both an important and challenging task (CDC, 2012).

Diesel particulate matter (DPM) has a centre core that is made of organic and elemental carbon compounds, it also consists of small amounts of metals, nitrate, sulphate and other trace elements. DPM also contains fine particles and ultra-fine particles. Fine particles have a diameter that is less than 2.5um whereas ultra-fine particles have a diameter of less than 0.1um. DPM have a large number of ultrafine particles, their large surface area makes them an exceptional channel for capturing organics. Their ultrafine size also means they are very respirable and that they can reach deep into the lungs to penetrate into the alveolar spaces (Wierzbicka, et al., 2014). Numerous organic compounds that are possibly toxic can be found on these particles (EPA, 2002).

Diesel particulate matter (DPM) is a significant component of airborne particulate matter, as diesel engines are widely used in modern industry and transportation, but DPM contains substances that can pose a risk to human health (Bai & Eeden, 2013). DPM is widely used as an experimental model for particulate air pollution for several reasons: they are a common real-life pollutant; they are chemically and physically well-characterized; standardized material is available; and the existing literature on DPM exposure (in cultures, animal models, and humans) gives us a broad knowledge base from which to base our protocols and expectations (Schroeter 2013). However, the complex nature of diesel exhaust composition makes attempting to associate the exposure and the risk of disease burden inherently difficult.

2.6 Health Effects

With diesel and its particulates being so complex, and with research on its effects on health being only quite recent, there is still a lot of questions towards its magnitude on health effects. However diesel particulate matter is still considered an occupational hazard, especially among those who operate and work with diesel-powered equipment (Papapostolou, et al., 2013). This is due to the fact the diesel particulate matter are fine carbon particles and have the potential to travel deep into the lungs therefore posing serious risks to health (Office of Environmental Health Hazards Assessment, 2007).

In the past diesel particulates were constantly referred to as a probably cancer causing agent, due to great belief and evidence and also a lack of substantial proof. However this has changed in recent years with diesel particulates now referred to a definite cancer causing agent (International Agency for Research on Cancer, 2012). Health effects associated with diesel emissions have in the past only been focused on the gaseous portion as their adverse health effects have been acknowledged for some time, but there is now extensive focus on the particulate fraction as research has shown the potential ill health effects associated with diesel particulates exposure. There are also non-health effects associated with diesel emissions such as nuisance, malodour and visual pollution. (AIOH, 2007)

A major change in the classification of diesel exhaust occurred on the June 12, 2012, where, a meeting lasting a week and involving experts from the International Agency for Research on Cancer (IARC), also associated with the World Health Organisation (WHO), found that there was significant evidence that associated exposure to diesel engine exhaust with an added risk of developing lung cancer. It was at this meeting that diesel particulates were classified by the World Health Organisation as a Group 1 carcinogenic to humans.

Prior to this diesel exhaust was classified by IARC as a Group 2A probable carcinogenic to humans in 1988. Furthermore in 1998 it was recommended, by an Advisory Group, that IARC review and re-evaluate diesel exhaust as a high priority. Between these years concerns related to the potential diesel exhaust has on causing cancer was increased due to finding in epidemiological studies at various workplace with workers exposure to diesel exhaust (IARC, 2012). A publication in March 2012 further highlighted this concern with results from a large occupational exposure study set in an underground mine, conducted by the US National Cancer Institute/ National Institute for

Occupational Safety and Health which identified an increased risk of lung cancer mortality in workers exposed to diesel emissions (Attfield, et al., 2012).

A thorough review of all scientific evidence was conducted by the IARC Working Group concluded that overall there was adequate evidence to show that diesel exhaust is carcinogenic to Humans. Specifically, the Working Group establish that there was sufficient evidence that diesel exhaust exposure caused lung cancer and also there was evidence that it was associated with an increased risk of bladder cancer (IARC, 2012).

An important issue that has occurred when determining any health issues related to diesel particulates is that, due to the number of other possible confounders in an underground mine site, it is difficult to determine whether the negative health affect is specifically caused by exposure to diesel, or whether it is caused by another air contaminant or agent.

Many epidemiological studies, (Arlt 2005; Hesterberg, Long et al. 2009; Parnia, et al., 2014), have revealed an increase in morbidity and mortality from cardiovascular and respiratory diseases that have been associated with exposures to ambient air polluted with diesel exhaust. It has been estimated by the National Institute for Occupational Safety and Health (NIOSH 2009) that millions of workers are exposed to diesel fuel and its combustion products in their workplace. Epidemiological studies have reported high rates of chronic respiratory diseases for those living near or working among diesel exhaust (Hesterberg, Bunn et al. 2006, Krivoshto, Richards et al. 2008).

Another issue with diesel exhaust is that all components that are vapours, gases and solids find a way to interact with human systems, whether it be tissues or the bloodstream (Grenier, 2000). In 2005 an environmental group found that at least half a million school and work absences, and more than 1,100 premature deaths, were due to breathing emissions from diesel equipment such as bulldozers and tractors. This lead to an estimated $9.1 billion public health cost (Wilson, 2006).

In 2012 the WHO released a report with an estimation that air pollution can be associated with causing more than 1 million deaths worldwide. The level of air pollution consequences and its negative health effects have been recognised for quite some time (Miller, Shaw & Langrish, 2012). Medical science has proven that the Clean Air Act has saved hundreds of thousands of lives a year, has lengthened life expectancy five months in the last 20 years and has provided economic benefits that average about 30 times the cost to industry of implementing pollution controls (EPA, 2010). These findings have revealed even more urgency to cleaning up air pollution (Miller, Shaw & Langrish, 2012).

Just like smoking, pollution impairs every critical organ system: the heart, lungs, brain and placenta. Particulate pollution can penetrate every cell in the body, even invading the nucleus of the cell causing chromosomal damage where, especially in children and the developing human embryo, it can predispose a person to multiple chronic diseases decades later (Moench, 2011). Diseases now known to be caused and/or exacerbated by air pollution include sudden death from aberrant heart rhythms, heart attacks, strokes, asthma, bronchitis, permanent loss of lung function, Alzheimer's, intellectual impairment, autism, pre-mature births, birth defects, diabetes, obesity, immune diseases and several types of cancer (Moench, 2011; Bai & Eeden, 2013). New science compels people to think about pollution completely differently than was thought about even a few years ago (Moench, 2011). In the same way there is no safe number of cigarettes a person can smoke, there is no safe level of air pollution a person can breathe. Even concentrations well below the EPA's standards can provoke all the diseases mentioned above. The Clean Air Act requires the EPA to continually reassess the adequacy of existing standards and match them with new research (Moench, 2011).

Acute or short term exposure to diesel exhaust can cause acute irritation of the nose, eyes and throat and respiratory symptoms (U.S. Environmental Protection Agency 2002; Wierzbicka, et al., 2014). Various regulatory agencies, including Resources Safety, have adopted the Australian Institute of Occupational Hygienists (AIOH 2007) recommendation for an exposure standard of 0.1 mg/m^3 (measured as submicron elemental carbon). The standard was developed in view of the irritant health effects from exposure to diesel emissions. Miners exposed to diesel exhaust, especially at high levels, have complained about acute health effects, which included flulike symptoms and headaches (Monforton 2005).

Further acute effects that have been associated with diesel exhaust exposure include eyes and nose irritation, changes to respiration and lung function, nausea, headache, and fatigue. Chronic exposures are connected to production of phlegm, lung function decrements and coughing. Studies on exposure in healthy humans have identified that inflammatory changes in the airways can be detected before pulmonary function changes can be noted (Sydbom et al 2001). This may be even more so in subjects with pulmonary function issues such as asthmatics and it highlights the need for a focus on acute health effects (Sydbom et al 2001).

Pollution is considered to have a higher risk of causing human ill health than any other environmental hazard and pollution in ambient air has been acknowledged as the eighth highest reason for deaths worldwide (Lim et al., 2012; Hawley et al 2014). It is still not fully known how, or even if, nanoparticles are dangerous to the environment or human health however, many claim that nanoparticles have the potential to cause ill health effects in humans (Getto et al, 2009).

The OEHHA list of specific risk factors assigns a greater specific cancer inhalation risk (increased risk per $\mu g/m^3$) to diesel exhaust than it does to the 'classical' cancer causing VOC's benzene and 1.3 butadiene.

Table 1 Components and risk

Component	Risk Factor	Increased deaths per million over 70 years
Benzene	$(2.9 \times 10^{-5}\ \mu g/m^3)^{-1}$	29
1.3 butadiene	$(1.7 \times 10^{-4}\ \mu g/m^3)^{-1}$	170
Diesel exhaust particulate	$(3.0 \times 10^{-4}\ \mu g/m^3)^{-1}$	300

The EPA (2002) concluded in its assessment that long-term exposure to the inhalation of diesel emissions can pose a hazard to humans and cause chronic health effects including lung cancer and other lung damage that varied according to the level of exposure. Short-term human exposure to diesel particulates can pose acute health issues such as inflammatory and irritation symptoms which are usually brief acute symptoms. These symptoms vary across groups of exposed people and may depend on the level of exposure and the health of the people exposed (EPA, 2002). Further evidence showed a presence of higher asthma and allergy symptoms occurring in people exposed to diesel particulates (EPA, 2002).

A vast amount of studies completed on the health effects related to diesel exhaust exposure have occurred in animals. The main concern with this type of research is if the finding and exposure levels used can be generalised into humans. Further assessment of diesel emission health effects, both acute and chronic, need careful consideration of their effects in comparison to the exposure levels on humans. Therefore it is important that, whenever feasible, research be conducted in human studies; but this can only occur when it is ethically acceptable (Sydbom, 2001). Studies including controlled human exposure, epidemiological and toxicological have revealed a range of health effects associated with exposure to diesel particulate matter and several of these studies identified that specific population features can be differently affected (Stanek, Sacks et al 2011).

Every year air pollution can be related to more deaths worldwide than to motor accidence (WHO, 2012). The European Commission conducted a study in 2005 that calculated the average life expectancy of the European Union population was reduced on average by nearly nine months due to air pollution. Respiratory allergies, emphysema, aggravated asthma and heart and lung disease are among the causes of death. The Environmental Protection Authority (EPA) in the US believes that a number of changes proposed for diesel engine initiatives potentially could leave to 12,000 less premature deaths, 15,000 less heart attacks, 6,000 less children visiting the emergency room due to asthma, and 8,900 less hospital admissions due to respiratory – related issue each year (Sharma et al 2013).

A study conducted by the World Health Organisation (WHO) in 2012 established that every year 3.5 million people died prematurely due to indoor air pollution and outdoor air pollution caused an additional 3.3 million deaths prematurely (Rom et al, 2013). Among one of the greatest workplace and public air pollution contaminants is diesel particulates. The increasing concern of environmental and occupational particulate matter exposure and the related health effects has generated the necessity of improved physical and chemical measuring of particulate matter both in the atmosphere and from their sources. (Schauer, 2003).

Research focus in identifying health effects

As this research was a cross sectional study conducted over a short period of time, the health effects that were focused on were short term acute respiratory health issues that could be identified during a work shift. Longer developing chronic health issues were not focused on as the study did not have the time span, however the questionnaire analysis results from this study can be used for further studies in relation to identifying other health effects linked to diesel particulate exposure.

With much research pointing to diesel particulates being detrimental to health and with the IARC changing it from a 2b to 1a carcinogenic, it can be assumed that current management guidelines will be assessed and possibly changed in the near future.

2.7 Diesel Guidelines Management

With diesel particulates its exposure can be greatly affected by other factors, therefore its management has to be adapted for different worksites, environments and job descriptions. Mounting medical and scientific research has discovered that particulate matter exposure, both fine and ultra-fine, may possess significantly higher health consequences than larger particle matter exposure or other air contaminants (WHO, 2012). However, there is currently insufficient information proving a definitive exposure-response relationship of fine and ultra-fine particulate matter to develop guidelines that would appropriately safeguard the population or even to groups that are most susceptible (WHO, 2012).

The CONTAM Database maintained by Resource Safety in WA for the WA mining industry indicates that "one in four exposures to diesel particulate matter in underground mines exceeded the recommended exposure standard" of 0.1mg/m^3 elemental carbon (Department of Mines and Petroleum 2013, p. 33). This is supported by the AIOH who stated that until more conclusive data can be presented the exposure standards of 0.1 mg/m^3 DP (measured as submicron elemental carbon) should be used (AI0H, 2007).

The Mine Safety and Inspection Regulations, 1995 of Western Australia Part 9 – Ventilation and control of dust and atmospheric contaminants, Division 4 – Diesel units, set out specific requirements for diesel units in underground mines. These requirements are included in Appendix 5. It is also stated that in determining the minimum ventilation quality it is necessary to consider the total power and number of operating diesel engines running at any same time in the same ventilation area. Good practice for a developing new mine is to provide 0.13/skW of diesel engine power to overcome diesel emissions such as particulates and gases and also to overcome heat stress. In the past it has been shown that workplaces that control the exposure of DP below 0.1 have a noticeably decrease of irritant effects. (AIOH 2007)

At present there is no specific standard for monitoring of diesel particulates and current exposure limits are only recommendations with only guidelines presents thus far and the previous standards and regulations mentioned we're given when diesel exhaust was still rated as a 2b carcinogenic, since the finding of IARC and this rating going to Class 1 carcinogenic, it would be assumed that further regulations and standards will follow in the not too distant future. This may then lead to standards in monitoring being developed.

Diesel emission toxicity varies greatly on its dose, physical form, and route of exposure (Henderson and Willwerth 2003). As the toxicity is very much dependant of the amount and size an accurate monitoring of diesel exposure needs to occur.

2.8 Diesel Monitoring

Diesel Particulate monitoring and sampling is essential for the assessment of risk related exposure (DEEP, 2001). In many circumstances sampling in conducted for compliance commitments, that is, to demonstrate worker exposure is under the acceptable threshold standards. Sampling also assists in determining the maintenance condition of a diesel engine, measuring the effectiveness of control methods such as exhaust treatment strategies and particulate filter designs or in monitoring how well the ventilation system works. The most commonly used form of monitoring is personal exposure sampling (Deep, 2001).

Previously the mass of DPM was utilised as the substitute measurement of overall DE exposure. Even though there is still some doubt that DPM is the most suitable factor to associate with health effects in humans, it is believed to be an acceptable alternative until further conclusive data about toxicity and systems of DE are presented (EPA, 2002).

Current monitoring methods are not mindful as to whether the employees are wearing the equipment properly and as to the given instructions. Personal monitoring requires reliance on individuals therefore it may not always be as accurate as real time positional monitoring. However the NIOSH recommended thermal optical method (5040) used to measure EC to indicate personal exposure to DP is considered the most accurate and the only validated method to measure organic carbon and elemental carbon and total carbon, with elemental carbon being considered as probably the best indicator or marker for DP exposure (Rogers and Davies 2005, Hesterberg, Long et al. 2009). NIOSH Method 5040 was specially created for assessing EC in DPM in an occupational environment (Wallen, Liden et al. 2010).

Studies of diesel particulate matter (DPM) in air have used elemental carbon (EC) as an appropriate indicator of DPM presence in occupational exposure, this is due to the fact it forms a substantial part of DPM and is able to be measured at lower concentrations (Wallen, Liden et al. 2010). Underground mines also currently use Elemental carbon (EC) as an indicator for diesel particulate matter (DPM) due to its measure accuracy at low levels and also that diesel is usually the main source of EC in an underground mine setting (Bugarski et al. 2012).

The amount of EC measures from DPM is challenging to custom as a quantitative indicator of exposure to diesel exhaust, this is because the quantity of EC in DPM changed depending on a number of factors, including engine load, maintenance and type as well as fuel composition (Wallen, Liden et al. 2010).

Ramachandran and Watts (2003) conducted a study comparing four different methods to sample and analyse the DPM in underground mining, these were: Respirable combustible dust sampling (RCD), size selective sampling with gravimetric analysis (SSG), respirable dust sampling with Elemental Carbon (EC) analysis, respirable dust sampling with Total Carbon (TC) analysis. The researchers found EC to be the most sensitive measure where diesel exhaust is concerned. Current regulations for DPM are assisting in the reduction of allowable levels of DPM in mines. As allowable levels decrease, the use of EC as a marker for dpm exposure rises as currently no other method has the adequate sensitivity tin determining exposure.

A main issue with using EC is that many workplaces have other particles that are airborne and contain EC meaning that this approach cannot be used in all worksites (Scheepers, Micka et al. 2003). Therefore elemental carbon can only be used as an accurate indicator for occupational diesel exhaust exposure in settings where diesel particulates are the only dominant source of EC. Thus, other markers for DP should be investigated as elemental carbon for a marker as the specificity and sensitivity necessary is insufficient. (HEI, 2002).

An exposure study conducted on workers from seven underground non-metalliferous mine to examine the accuracy of the Mine Safety and Health Administration (MSHA) accepted monitoring approach (NIOSH) 5040 analytical sampling method for diesel exhaust. Around 1000 cyclonic air samples were administered both in positional areas and on workers throughout the mine. (Cohen et al, 2002). While this is the accepted

method, noteworthy issues concerning its accuracy have been presented, these include:
(1) Disparities in methods of analysis for measuring of EC;
(2) an absence of consideration of other EC sources; and
(3) the allocation of EC in relation to particulate mass in diesel particulate matter (Schauer, 2003).

In regards to mass, ultrafine particles, that is particles with a diameter of less than 0.1 are only a minor part, that is 1% of the atmospheric aerosol weight, however in regards to number they are a key component with an 86% count. (Abraham, Siwinski, Hunt 2002). These figures bring the question about whether monitoring for diesel particulate mass instead of number is very accurate. Improvements to monitoring are essential as they can lead to better control methods and solutions being developed.

2.9 Control Methods Possible Solutions

As with any control methods being developed for occupational risk the hierarchy of controls need to be looked at, this are:

- Elimination
- Substitution
- Isolation
- Engineering
- Administrative
- PPE

In controlling workplace exposure to diesel emissions it is first and foremost important to recognise that a combined strategy is required and that all departments and specialists may need to be involved and made responsible. Diesel operations in an underground system is both interactive and complex, therefore all areas that are involved with diesel exhaust contaminant need to work collectively. This approach is sometimes considered unique and may mean that the departments in many of these mines have to develop a change in focus and culture. It is also important to recognise that there may be a great deal of effort required in making these changes but it is essential if an effective and efficient control of diesel emissions is to occur. (Schnakenberg, 2006).

The distribution and production of diesel fuel containing low sulphur content is widely available in Australia. Diesel particulate traps, filter and other after treatment devices are now being implemented, with studies showing that buses using particulate traps and clean diesel fuel are of a superior standard when it comes to diesel emissions (Krivoshto et al 2008). The AIOH, 2007 notes that in the absences of a definitive dose response association, practise has proven that workplace where DP is controlled to below 0.1 mg/m^3 EC exposure have reported noticeable decreases in irritant effects of employees (AIOH, 2007)

The NSW Mine Safety (2008) provided the following as recommendations for managing diesel particulates.

- Using electrically powered vehicles
- Selecting equipment which minimizes exhaust output
- Use of ventilation systems appropriate to the demands of the emissions as this is a higher order control that should be considered
- Optimising the use of diesel powered equipment through proper maintenance of engines
- The correct selection of fuels which can have a significant impact upon the amount of diesel particulate generated
- Proper and regulate maintenance of the haul roads in and around the mine which can impact heavily on the minimisation of harmful exposures through reduced emissions.

A critical part of any underground mine is an economical and safe ventilation system. The safe process and design of ventilations systems in mine sites have been researched and explored by engineers and scientists over the years (Hartman, et al., 2012). These studies main purpose was to help recognize and improve primary ventilation system procedures in mine sites to reduce the costs of powering fans while still working at the required performance level. The primary job the ventilation officer is to distinguish the duty, location and number of fans and structure mechanisms included in the defined ventilation system to determine the necessary fresh airflow at the lowest cost. Implementing these strategies successfully may generate a calculated design instrument to help ventilation engineers and mine planning. (Acuña and Lowndes, 2014)

Some factors that can contribute to the level of driver exposure to diesel exhaust include state of vehicle windows such as whether they are closed or open as higher exposure occurs when windows are open, varying climates with warmer weather creating higher levels of exposure than cooler weather, and time of exposure with daytime exposure being higher than evening and even rural, suburban and long – haul driving. Truck age also influences exposure level of humans due to fuel exhaust being more probably to be leaking through the rubber seals of older trucks surrounding the driver compartment. (Pamphlett & Rikard – Bell, 2013).

For most hazards prevention of exposure is better than treatment. Pharmacological interventions have many fundamental costs, therefore a more suitable intervention is to decrease PM air pollution exposure to groups believed to be most at risk. There is little indication that wearing personal protective equipment (PPE) such as face- masks helps decrease exposure to PM and associated negative effects, it is also unsure if the use of such respiratory PPE can decrease the frequency of acute cardiovascular incidence. Although these types of intervention are cheap and easily attainable in the short term, they should never be used as a permanent intervention, rather a temporary control until further resilient controls can be applied (Miller, Shaw & Langrish, 2012).

The most effective approach in decreasing air pollution exposure and reducing ill health effects for humans is to minimize emissions in the vehicle design stage. Adverse health effects related to air pollution are strongly associate with fine and ultra-fine particles that are generated from overall traffic and the process of industrial burning fossil fuels (Miller, Shaw & Langrish, 2012; Papapotolou, et al., 2013). Evidence is already available showing that a reduction in diesel engine PM emissions by using risk control measures, such as particle traps, can help eliminate negative vascular effects occur through exposure of diesel exhaust. Another risk control measure is the use of alternative engine and fuel technology as this can help in creating a more complete combustion and reduce PM emissions (Miller, Shaw & Langrish, 2012).

The replacement of on- road older engines for newer clean emission engines have been occurring since 2007 and will be required to occur by law from 2014 (Traviss et al, 2010). The durability of diesel engines indicated that the complete replacement of current engines for cleaner engines may take many years. A further issue is that even though associations with diesel exhaust exposure and health hazards have been greatly researched, the outcomes of diesel emissions in air, different fuel formulations and the effect of diesel on health effects not related to cancer are presently not well known. Therefore the introduction of biodiesel provides a control method that is immediate and can be used while further research continues to identify the health risks related to diesel exposure (Traviss et al, 2010).

In creating risk controls to prevent human exposure to diesel particulates it may be essential to first focus on groups that have a high risk of diesel emission exposure. A setting that has a high level of diesel operation is underground mine sites. Therefore underground mine employees are a group that has a high exposure level and which are important to conduct research with.

2.10 Diesel In Underground Mines

Workers in underground mines are among a group that are highly exposed to diesel particulates. However due to their work conditions and other confounding factors research on the effects of diesel particulates in this work group have been somewhat limited. Another issue is that much of the research that has been done in underground mines tends to mainly been conducted in coal mining rather than metalliferous underground mines.

Underground mine sites are a confined environment that, even with ventilation. In a confined space higher concentrations of atmospheric particulates from diesel powered mining equipment may be present than if this equipment was used for surface mining. Therefore underground mine workers are exposed to greater levels of DPM than many other work groups. The DPM rule was established for Metal and None Metal (MNM) underground miners of a permissible exposure limit (PEL) of total carbon, which is also used as a substitute for measuring a DPM exposure. Included in this rule are numerous other requirements to protect the health of miners (MSHA, 2001).

"For miners who work in this confined underground world exposure to diesel exhaust and particulate matter is just part of the job" (Monforton 2005, p.1). Another issue facing vehicle operators is that diesel exhaust, especially in large amounts is the affect it can have in visibility, this is an extra concern in underground mining environments as worker vision is already compromised by the amount of darkness and the size of equipment used. (Deep, 2001.) There is also the significant risk of operating diesel equipment in this confined space. Elemental carbon (EC) levels measured in underground coal mines in Australia have included ranges of 0.01 to 0.37 mg/m^3 (Joint Coal Board, 1999), although levels of up to 2.2mg/m^3 have been recorded, varying on mine operation and different job types (Pratt et al., 1997). EC levels in underground metalliferous mines in Australian have been measured with a range of 0.01 to 0.42 mg/m^3 identified (Rogers & Davies, 2001) (AIOH May 2007).

The New South Wales coal mining industry has completed a considerable amount of work in this area. Even with the use of ventilation system requirements, the confined space of underground mine settings meant that a significant accumulation of both gases and particulates does occur. These gases and particulates are produced by the mine settings themselves such as methane gas and respirable dusts and also produced by the equipment used such as diesel particulates. Respirable particles are widely recognised as causing adverse health effects. Even with the use of ventilation, the confined work environment of an underground mine also play a significant part in the high concentration of particles created by mine equipment. This means that exposure of DPM are at higher concentrations for underground miners compared to most other occupational types and so underground mine workers are exposed to a significantly higher risk of developing health issues such as allergic responses, heart failure, lung cancer, and other problems related to cardiopulmonary disease.

Various mines have used ventilation designs aimed to meet the replaced 1964 Mines Regulation Act required rates of 0.04 m3/s/kW. The Mining and Quarrying Safety and Health Regulations Queensland 2001 uses risk based requirements. As stated in other states including NSW and also in most states in Canada, the minimum required ventilation rate is 0.06 m3/s/kW. This ventilation rate however will differ in design and practice subject to the type of diesel engines used and the current controls in place. (Hedges et al, 2007)

Even though employees working in underground mines are considered to be a group that are likely to be exposed to high level of DP exposure they are not usually targeted for epidemiological studies related to DP. This is generally due to their exposure to other contaminants causing confounding issues; therefore there is a lack of studies on exposure assessment and associated health effects on Western Australian (WA) miners, especially in underground mines. Exposure of diesel particulates due to diesel-powered engine use may be anywhere from 3 to 10 times higher for mine workers in an underground mining environment compared to those in surface mining. (Scheepers, Micka et al. 2003).

Diesel fuel is used for heavy duty equipment in the mining industry because diesel fuel provides more kilometres per litre than petrol, larger quantities can be stored on site (diesel 100,000 litres; petrol 2,500 litres) and because mining can require the lifting of heavy loads that are unsafe for humans to lift and the transport of these heavy loads in narrow spaces (Workplace Health & Safety, Queensland, 2012). Diesel is less of a fire hazard than petrol as petrol has a flash point where a spark will ignite it at -43^{D} C so is classed as a category 2 flammable liquid. Diesel’s flash point is above 62^{D} C so if there is an ignition source this is a safer fuel to use in underground mining vehicles (Workplace Health & Safety, Queensland, 2012). However the use of diesel fuel produces air quality conditions that provide unfavourable air quality conditions to miners working in or around the area that these vehicles are used in. (Scheepers, Micka et al. 2003). Diesel has now been recognised as frequently being the largest stress factor in terms of ventilation for modern underground mining. (Grenier, 2000).

The IARC (2012) reports that studies have shown that carcinogens (for example, Radon) that show an association to occupational groups who are highly exposed and risk of adverse health effects have also lead to similar finding in the general public population. For this reason diesel exposure actions and controls that are used to reduce occupational exposure should also be generated to the public population. (IARC, 2012)

Modern mines extensively use trucks, load-haul-dump (LHD) machines and other diesel powered vehicles, This mobile equipment not only expels diesel particulate matters and exhaust gases but also radiates increased levels of heat. With increasingly more stringent regulations regarding diesel engine use and overall air quality in mine environments have led to higher ventilation costs. (Paraszczak et al 2014).

There is a large amount of evidence related to the harmful effects of diesel particulate exposure on a person's the cardiovascular system (Fang et al 2010). It is important to consider these effects as occupational exposure can be quite different to general exposures, not only in particle type and composition, but also in frequency of exposure as environmental exposure tends to me more constant whereas occupational exposure is more likely to vary (Fang et al 2010).

Duration of exposure is another differing factor, (e.g. comparing work shits to overall day) as well as concentration and intensity with exposure in occupational setting usually being of a higher level. These variables in composition, frequency, duration, and concentration may affect how occupational exposure to DPM impacts the cardiovascular system and also how these variables are studied. All over the world workers are exposed to occupational particulate matter, with a greater chance of prolonged, frequent and regular exposure increasing the risk of workers being exposed to unfavourable health effects. (Fang et al 2010)

2.11 National And Worldwide Management

Growing concern of diesel particulates and its health effects have led to greater efforts to manage public exposure, this is occurring nationally and worldwide. However there are still many hurdles that are being presented.

A challenge that still remains for occupational hygienists is assessing diesel particulate exposure in an occupation setting (Hebisch et al 2003). The main reason for this is that the diesel emission complexity and ever-changing composition of particulates makes it difficult to accurately assess the exposure, therefore compromise has to occur through the use of a representative index selection. Another factor is that the index currently selected, which is elemental carbon, is not a clearly defined chemical type. It is more method-dependent as elemental carbon's composition is not entirely known but it is identified as not being pure carbon. At present occupational exposure levels to diesel and the control of potential related health risks have been founded on elemental carbon in most countries, but the assessment methods used are not the same world-wide (Cram, 1998). Hence, it is essential to find a sampling method and analysis method that produces precise and reliable results. (Hebisch et al 2003).

Different exposure limits for compliance in different countries have been developed depending on how diesel is measured; this is usually either elemental carbon or total carbon (Deep, 2001). Over the past two decades environmental concerns in Europe, North America and other parts of the world have lead to regulatory action resulting in continually firmer standards for not only gasoline but diesel engine emissions. Standard and technology have a strong relationship; standards motivate the introduction of new technology and this new technology allows for further rigorous standards. Where diesel emissions are concerned this means modifications in fuel used such as those with a lower sulphur content, alterations in the design of the engine so the fuel is burned more effectively and decrease in emissions by using controls in exhaust technology. Even though these changes can reduce the amount of chemicals and particulates, it is still unclear on how these qualitative and quantitative controls can alter associated health effects, therefore further research into this area is required.

Current vehicles and fuels that do not yet have these modifications may take several years to be substituted, especially in countries that are less developed and where regulatory standards are less strict. Many parts of the world that are classified as developing lack enforced regulatory standards and it is also important to not tat data on the exposure and effects of diesel exhaust are very limited in these areas. (IARC, 2012)

At present, the use of diesel equipment in worldwide mine environments is becoming more problematic with increased health effects, progressively challenging mine regulations, extreme temperature, etc., this factors may be due to mine deposits being extracted from increasing mine depths. (Paraszczak et al 2014)

In an effort to decrease the negative effects associated with diesel emissions on both the environment and human health worldwide many policies have been developed (Resitoglu, 2014). Approved standards for diesel emission have been put forward by government bodies to help combat the effects diesel emissions has on the environment, and public health. Standards have been developed in Europe which have the allowable exposure levels continuously decreasing since 1993 from the introduction of Euro I to currently Euro VI. (Resitoglu, 2014)

While overseas DP management policies have been developed and enforced to protect the employees from DP exposure, there is a lack of studies in WA mines for DP exposure assessment, as well as minimal to no policies and legal requirements developed in Australia for DP exposure management. Over the last few years many regulatory governments have implemented recommendations or requirements that enforce control strategies and exposure limits in occupational workplaces and environmental settings. The QLD Department of Mines and Energy, Simtars Unit, conducted a DPM survey in early 2005 and recommended further monitoring to better define exposure profiles across different mining site work groups. In WA the Department of Consumer and Employment Protection the Resources Safety Division added DPM to the CONTAM atmospheric contaminants list and has included sampling in underground mine

CONTAM quotas since late 2005-06. The NSW Department of Primary Industries released a draft guideline for underground environments towards the end of 2006.

An exposure standard of 0.1 mg/m3 measured as elemental carbon using the NIOSH 5040 analytical method in now generally accepted.

For many years the MDG29 guidelines were those mainly used and only accepted guidelines in Australia, but these guidelines only really focused on underground coal mining. However this research has helping in developing a Western Australian guideline for the management of diesel exhaust in underground metalliferous mining. While there are many steps forward there are gaps in current knowledge that are still present

2.12 Gaps In Current Knowledge.

The findings of this review of published literature have identified gaps in current knowledge related to the health effects of exposure to diesel particulates, particularly for underground metalliferous miners. Most studies and references related to DP in underground mines focuses on coal mines as most of the research has occurred there so there are gaps in knowledge about exposure of people working in other types of mines.

Currently used methods for monitoring DP levels reflect greatly on mass and also are time weighted averages rather than real time monitoring, which means that it is not certain where peaks and drops are occurring, therefore gives values not reasons.

Epidemiologic studies of populations exposed to diesel can only deliver the required precision of risk assessments needed if (a) the exposed populations studied are applicable to the general population, (b) an accurate estimate of exposures has occurred, (c) data on possible confounding factors is available, and (d) adequate information is provided in the research follow up (HEI, 2002). This can be difficult to achieve leaving gaps in current knowledge about the health effects on employees exposed to diesel particulates in workplaces (HEI, 2002).

For this reason real time human studies are essential in understanding the health effects related to air pollution. Although chamber studies have ethically acceptable exposures models that have pollutant levels that are either above or the same as set standards of air quality and adverse health effects are measured these studies do not take into account all of the factors that people in workplaces may be exposed to the way that real life situations and the monitoring of people in these situations do (Rom et al 2013). In previous studies there have generally been a number of methodological restrictions which include methods of exposure assessment, design and the type of statistical analysis applied (Olsson et al 2011). A main issue in understanding the epidemiological data is the absence of unbiased exposure information. (Sun et al 2014). As most studies have limited sufficient controls for possible confounders the evaluation of epidemiological data is inadequate therefore very few studies report exposure-response relationships. (Olsson et al 2011)

Diesel engines are the most industry-preferred engines particularly in vehicles that are heavy-duty. This is due to their durability, low-operating costs, high efficiency, together with their reliability. While the diesel engines widespread use has numerous advantages it also plays a significant part in worldwide environmental pollution. Exhaust emissions caused by diesel engines are regards as one of the main causes of environmental air pollution and can adversely affect human health (Resitoglu et al 2014). Research is required to study the remaining gaps in data and to assist with understanding the potential of health effects related to New Technology Diesel Exhaust, or NTDE, however for the time being there is adequate evidence that shows health effects studies of diesel exhaust prior to 2007 will probable have minimal significance in evaluating the health risks associated to potential NTDE exposure (Hesterberg et al 2011).

There has been substantial evidence that demonstrates a relationship between health problems and occupational exposure to diesel exhaust but there is minimal studies that investigate exposures to biodiesel (Traviss et al 2010). Even though research in diesel exhaust has been quite extensive over the last 20 years, the factors that are the most harmful to the health of the population and the levels in which they have the potential to cause harm are not yet completely known. (Traviss, et al 2010)

In 2012 Attfield et al .published the results of a cohort study that included 12,315 miners working in non-metal mines. The findings of this research identified work related exposure to diesel particulates resulted in a higher incidence of lung cancer in the exposed population, particularly if they had been exposed to diesel particulates for 5 or more years. Subsequently diesel particulates were classified as a Group 1 Carcinogen. This issue, along with other health concerns, face employees exposed to DPM during their work. The use of diesel fuel has increased over time and the varieties of diesel fuels used have also changed, with added effective filters also being used by vehicles that are diesel – powered. (Pamphlett and Rikard – Bell, 2013). As the latest models of diesel engines may have cleaner exhaust emissions there is a need to re-evaluate employee exposure levels to diesel particulate emission exposures and to increase knowledge of the health effects related to diesel particulate exposure (EPA, 2002). A gap identified in current knowledge is that there is very little published information on the short term health effects of exposure to diesel particulates. This research was designed to add information to assist with filling this gap in in knowledge about the short term health effects related to exposure to diesel particulates.

2.13 Conclusions

There is a need for ongoing research related to the health effects of human exposure to diesel particulate matter and the requirement to develop a consistent method of proper monitoring and management. It appears there are still many gaps in knowledge where diesel particulates are concerned, and as more questions are answered in turn more questions need to be asked. It is also important to note that the review of published literature has identified that there is no ‘magic silver bullet’ when dealing with diesel particulate matter exposure and that it requires a range of methods and risk control solutions to be dealt with most effectively.

3. METHODOLOGY

3.1 Introduction To Chapter

Chapter three discusses the research methods chosen for this study and the methodology behind it. This chapter includes what type and reasons for the chosen study design, research setting, participants, data collection methods, statistical analysis and method of data presentation. This chapter also discusses validity and reliability of the study and also the study's limitations and how these limitations were overcome.

3.2 Study Design

This study was designed to investigate workplace DPM exposures consisting of both air quality sampling and personal exposure sampling and with this information taking a look at the associated potential irritant effects among current employees working in a metalliferous underground mine.

The study was an observational, cross-sectional study that looked at exposure to diesel particulates as well as possible irritant effects among employees in a metalliferous mine site. This study design was used to assess the prevalence of acute conditions for a population highly exposed to diesel particulates.

Some of the advantages of choosing a cross sectional design for this study included:

- the availability of looking at data from a number of subjects at the same time in an overall snapshot. (Shuttleworth 2010)
- data gained was able to look at multiple health variables as well as exposure (Ho et al. 2008).
- this type of study design assisted with answering questions related to who, what, when and where as this type of study allows for questionnaire use. (Olsen and St. George, 2004)
- the data collected here may be useful for future research (Woodward, 2014).

Another significant reason that a cross sectional study design was chosen for this study was that it provided a snap shot (Apel, 2014.) which is what was well matched for the short period of time this study took place, it was also more straightforward, efficient and affordable to conduct a cross sectional study. Furthermore as this research was focusing on acute symptoms and not a disease that produces disability a cross sectional study was best suited. (Levin, 2006)

A number of methods for collecting data were used in this cross sectional study. A questionnaire was used to identify any irritant effects that underground workers may experience. Information on DP exhaust concentrations was collected through air monitoring at different locations underground. In addition historical DP monitoring data (CONTAM data) (Government of Western Australia Department of Mines and Petroleum, 2010) collected every three months from this mine from 2003 to the present, along with vehicle emission data collected from this mine was retrieved and then analysed.

Using different methods (personal monitoring, environmental monitoring and answers from an employee questionnaire) helped to gain answers to the questions and provided not only straight forward data and observation, but also information related to attitudes and behaviours of the employees monitored which helped to eliminate some confounders. Some possible confounders included area employees living in (eg close to a main road or factors), hereditary and prior health conditions and lifestyle factors.

The use of multiple methods to collect data has improved the reliability and validity of the research findings (Perry, Wong & Bernhardt, 1995).

3.3 Research Setting

The setting for this research study was an underground gold mine located in Western Australia. This setting was chosen for a number of reasons.

1. A metalliferous mine was wanted rather than a coal mine, as coal mines have many other confounding factors that need to be addressed when looking at diesel

particulate levels and monitoring, a key aspect of this is the fact that coal dusts have to be made accountable when looking at elemental carbon as a benchmark. Another reason a metalliferous mine was of interest is that a majority of current studies had focused on coal mining, as a result there is a lack of studies in metalliferous mining and most of the current recommended levels are based on coal mining rather than metalliferous mining, therefore a certain level of focus is currently needed for DP issues in underground metalliferous mining.

2. The manager of the mine where the study was conducted was very interested in DP and their possible ill-health effects on employees. Due to this management had already begun examining ways to reduce employees’ exposure to diesel particulates from both an engineering and environmental health and safety perspective and they were interested in lowering the level of DP emissions and also finding the best way to reduce employees’ exposure to diesel particulates. Therefore determining actual levels of DP, related health effects and possible risk control measures were of definite interest and a major priority of the mine. The active cooperation from the mine managers and other employees was very important and was the base for the success of this research.
3. The mine used was experiencing issues with higher levels of diesel particulates exposure than the recommended $0.1mg/m^3$. As a result their monitoring was done at a more frequent level then most mines. The monitoring was done by a contracted occupational hygienist who monitored in a different way than other metalliferous mines; therefore it was essential that current monitoring results were compared with the monitoring to be performed in this study to see if this was affecting the levels being recorded.
4. Another reason that this setting was ideal is that the mining company was a contracting company which worked at many different mine sites with different clients; therefore they used different methods and had different approaches to dealing with DP on their sites.

3.4 Research participants

The participants were all underground employees at this mine site. For monitoring a purpose only employees that spent a majority of their work day underground were sampled. However for the completion of the questionnaire, all employees were invited to complete the questionnaire. Monitoring was offered to both male and female employees with both genders also presented with information about diesel and all miners were asked to complete the questionnaire however typical to this type of workplace the majority of participants were male.

3.5 Data Collection

Data collection was conducted by air monitoring underground and also by a questionnaire survey.

3.5.1 Air Quality

Air Quality underground was monitored in a number of locations with different levels of exposure. The locations were determined by data previously collected by an occupational hygienist and suggestions given by the ventilation officer and other employees. Exposure to respirable particles and particular matters with sizes of 2.5um, 10um and 1.0 um was assessed using TSI DustTrak's using both single channel DustTrak's and a multi channel DRX DustTrak. Ultrafine particles number concentrations were measured by TSI P-Trak and TSI P-Trak 3007. SKC pumps will be used to collect DP followed by the measurement of elemental carbon (EC) by NIOSH 5040 method and used as a reference method. Concentrations of Nitrogen Oxide (NOx), Carbon Monoxide (CO), Carbon Dioxide (CO_2) and Sulfur Oxide (SOx) will also be measured using a multiple gas monitor. Physical parameters that are likely to affect DP concentrations such as temperature, humidity and wind speed will also be measured. Measurements will be carried out for 12 hours a day during the working shift. At the same time some observations related to the ventilation system and the diesel powered equipment running during the monitoring periods will be recorded and taken into account during the analysis.

3.5.2 Personal Exposure Monitoring

The sample size for the personal monitoring was based on the 15% of prevalence of hay fever in Australia (ABS 2009) which determines a sample size of 32 in each group, (YES and NO) (64 in total) This sample size will give a 80% power to detect a difference of 0.35 between the two groups using a two-sided Chi-square test with continuity correction and with a significance level of 0.05. The sample size calculation was obtained based on NCSS Statistical & Power Analysis Software (http://www.ncss.com) for power and sample size estimation.

The monitoring for DP exposure amongst employees underground were conducted using the following methods

- NIOSH recommended thermal optical method (5040) was used to measure personal exposure to DP. This method is considered the most accurate and the only validated method to measure organic carbon and elemental carbon and total carbon, with elemental carbon being considered as probably the best indicator or marker for DP exposure (Rogers and Davies 2005; Hesterberg et al. 2009; Grenier et al. 2001).
- Employees' daily activities were recorded to identify if the airborne levels of DP change depending on what activities are being undertaken by employees each day. Observations of activities will be matched with environmental concentrations, personal exposure data and emission data from diesel powered machines.
- A presentation was communicated to the employees that we're going to be monitored, this presentation included some general facts about DP, why testing was being done and the proper way for employees to wear the monitors.
- CONTAM data on DP monitoring from Resource Safety which was collected each three months for this mine since 2003 to the present will be analysed and used as historical monitoring data.

3.5.3 CONTAM Data

"Under the *Mines Safety and Inspection Act 1994* (WA), mine managers are required to inform the District Inspector, for the region in which the mine is situated, of any occurrence at the mine which had the potential to cause serious injury or harm to health - even when no injury or harm has in fact happened.

The Mine Safety and Inspection Regulations 1995 (WA) require the mining industry to regularly sample for atmospheric contaminants and report results to Resources Safety.
Since 1995 sample results submitted to Resources Safety have been recorded on a computerised system, now known as CONTAM. ‘CONTAM is a database that stores the results of all atmospheric contaminate monitoring reported to Resource Safety. A representative subset of total mine site data is sent to CONTAM. This representative subset is a ‘quota’. (Department of Mines and Petroleum, 2013) The quota is a site’s minimum sampling requirements which are set by resources safety regional occupational health inspector, with consultation with site Surface Ventilation Officers. (Department of Mines and Petroleum, 2013)

3.5.4 Vehicle Emissions

- Records of the type of fuel, the date all underground diesel machines were manufactured and purchased, their maintenance history and when they were last serviced was obtained from the Mine Maintenance Manager’s records.
- Records of monitoring of nitrogen oxides, sulfur oxides, DP and total volatile organic compounds emitted from all diesel machines in the area was obtained from the Mine Maintenance Manager’s records.

3.5.5 Questionnaire

The method used to identify the prevalence of potential irritant health effects was a questionnaire. This questionnaire was administered to all employees (120 totals). The questionnaire includes questions about the tasks employees perform, their employment history, general background questions and whether they experience certain acute irritant or other related symptoms. The questionnaire used in this study is a structured standardised questionnaire modified from Occupational Respiratory Questionnaire developed by Professor David Christiani at Harvard School of Public Health for occupational diesel fume exposure and with some minor modifications adopted from the American Thoracic Society Questionnaire (NIOSH 2009); (2) “OccIDEAS”, a web-based application tool (Fritschi 2009) to assess hazards related to occupational exposure and managed by Professor Lin Fritschi, a senior occupational cancer epidemiologist at The Western Australia Institute for Medical Research; (3) the "Health assessment form" created by the Department of Mines and Petroleum (Government of Western Australia Department of Mines and Petroleum 2013). The questionnaire has been used and validated in DP surveys in a crane and a transport company in WA (Meyerkort 2009). Questions on smoking are included in the current Mine Health Surveillance system "Health assessment form" that is a legal requirement for employees working in WA mines to complete with their pre-employment medical examination and then every 5 years. Confounding factors such as smoking and alcohol consumption have been included in the questionnaire. These have been included as they may have synergistic effects with DP.

A pilot study was conducted to determine any issues with the questionnaire or to point out any missing links, while the study took place the questionnaire that was presented to employees was changed slightly. Thirty mine workers were given a copy of the draft questionnaire to answer the questions. Any identified opportunities for improvements to the questionnaire were made before the sampled research subjects are provided with this questionnaire.

3.5.6 Comparison Of Different Monitoring Methods

This mine site had a contracted hygienist company that did their contaminant monitoring, it was discovered that they performed monitoring different from the way that this study monitored for equipment. Therefore it was decided that some comparative monitoring of these different methods would occur so that it could be determined if different methods of monitoring provide different results.

3.6 Validity and Reliability Assessment

Air monitoring with a lab analysis using NIOSH method 5040 is the standard way of measuring DP concentration in the air with much research showing it is a reliable and widely accepted validated method (Rogers and Davies 2005; Hesterberg et al. 2009; Birch 1998). This provides consensual validity.

The reliability of the monitoring equipment was censured by calibrating all environmental monitoring equipment before and after each use to ensure that the measurements are accurate. When calibrating before it was made sure that calibration occurred just before monitoring was scheduled and that all calibration was as close to each other as possible.

The majority of questions in the questionnaire have been validated by the American Thoracic Society and by other studies and were also re-tested for the reliability of the irritant effects with the pilot study and the formal study.

3.7 Statistical Analysis

All research data was collected, entered and analysed by SPSS for windows (Statistical Package for the Social Sciences, version 17.0). A p value <0.05 is considered statistically significant.

The reliability of the measuring in questionnaire for the pilot study and formal study (test-retest) will be analysed by Kappa and Intra-classification Correlation. Descriptive statistics, such as mean, median, standard deviation, inter-quartile range, Pearson correlation coefficient and cross tabulation will be used to determine DP exposure levels from environmental, personal and vehicle monitoring at this mine and symptoms of irritant effects. The results are presented in the form of tables and graphs, using excel and SPSS programs.

3.8 Ethical Issues

An information sheet on the project was distributed to participants and consent forms were obtained from employees before the start of this project. Ethics approval to conduct this research was sought from the University's Human Research Ethics Committee and was obtained. Collected data was de-identified and reported as group data. All information is confidential and no names of the company and employees were made available except to the researcher. Participation was voluntary and participants were free to withdraw at any time.

The next chapter presents and explains the results obtained while this study was carried out.

4. RESULTS

4.1 Introduction To Chapter

Chapter four presents the results that were revealed in this study. This chapter includes a description on the study setting, historical survey outcome, and positional DPM levels at different underground locations, personal exposure levels and from vehicle emissions. Results related to health effects in relation to DP exposure and also a comparison of monitoring methods. These results help to build the discussion and further recommendations

4.2 Exposure Assessment

Exposure assessment involves all areas of contaminant exposure. This is related to personal and positional monitoring and assessment of diesel particulate exposure. Both positional and personal monitoring needed to be addressed to determine not only what areas of an underground mine were monitored as being high or low level areas but to also investigate which job descriptions were exposed to certain levels. The exposure assessment was then used to determine if there were any co-relations with the answers provided in the questionnaire in regards to exposure levels and health effects.

4.3 Environment Monitoring Description

The mine where sampling was conducted is an underground mine that has one entry and exit portal. Travelling down the portal the mine has one main pathway, which is then divided into two declines the Exhibition decline (EXH) and the North decline (NTH). Along both declines are access ways, these access ways are numbered and as the decline goes further down the number decrease, this number represent meters above sea level. Diagram 1 is a representation of the mine layout, depicting where positional monitors were places. Photo 1 and 2 are photos leading towards the entrance of the mine and the portal in which all vehicles pass to enter and exit the mine.

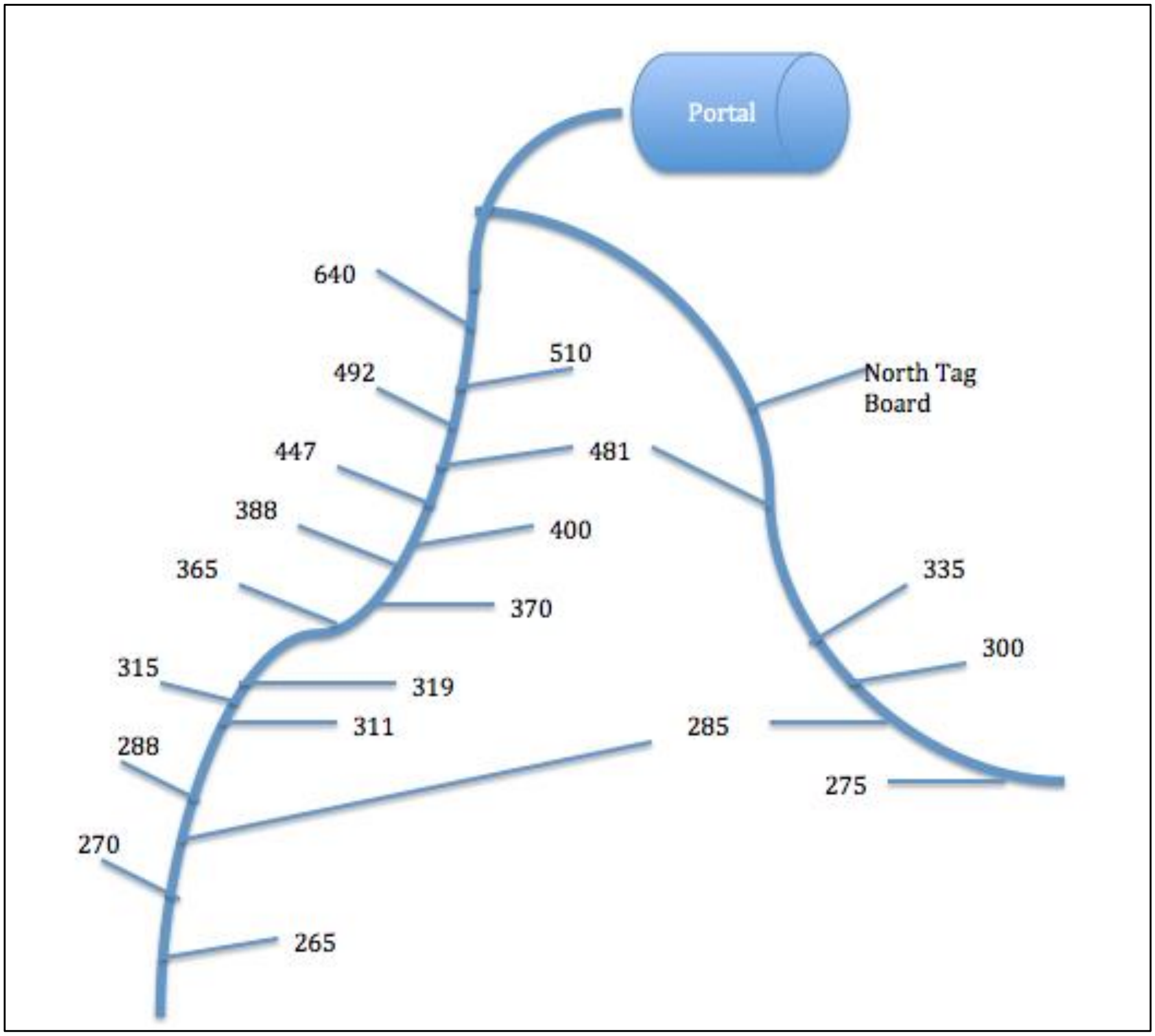

Figure 1. Representation of underground mine site

Figure 2 – Portal (mine entrance) photo. Figure 3 – Road leading to portal

4.4 DPM Concentrations In Various Locations

In the past no structured positional monitoring had been performed in collecting these results monitoring was done using a personal monitor which was placed at around breathing level for most heights and was running for an average of 6-10 hours spread on both day and night shifts. Locations varied from low to high diesel exposure and activity.

Table 2. All Positional monitoring results

Date	Position	EC mg/m$_3$	OC mg/m$_3$	TC mg/m$_3$
22.02.11	EXH 288	0.31	0.08	0.39
22.02.11	EXH 319	0.29	0.07	0.36
22.02.11	EXH 388	0.21	0.06	0.27
22.02.11	EXH 311	0.23	0.07	0.3
24.02.11	EXH 492	0.057	0.02	0.08
24.02.11	EXH 370	0.35	0.08	0.42
24.02.11	EXH 285	0.28	0.08	0.36
01.03.11	EXH 311	0.16	0.06	0.21
01.03.11	NTH 285	0.46	0.11	0.57
01.03.11	NTH 335	0.49	0.1	0.6
01.03.11	EXH 365	0.14	0.05	0.19
02.03.11	North Tag Board	0.033	0.03	0.06
03.03.14 n	EXH 492	0.066	0.04	0.1
03.03.11 n	EXH 510	0.12	0.04	0.16
08.03.11	EXH 285	0.36	0.11	0.46
08.03.11	EXH 447	0.13	0.04	0.17
09.03.11	NTH 275	0.32	0.08	0.4
09.03.11	EXH 481	0.19	0.06	0.25
09.03.11	EXH 315	0.14	0.05	0.2
13.04.11 n	NTH 300	0.55	0.3	0.86
13.04.11 n	NTH 481	0.081	0.05	0.13
13.04.11 n	NTH 285	0.38	0.14	0.53
13.04.11 n	EXH 400	0.16	0.05	0.21
14.06.11 n	EXH 365	0.22	0.06	0.28
14.06.11 n	EXH 319	0.19	0.08	0.26
15.06.11	NTH 335	0.12	0.06	0.18
15.06.11 n	EXH 270	0.18	0.07	0.25
15.06.11 n	NTH 275	0.09	0.04	0.13
15.06.11 n	EXH 400	0.53	0.24	0.77
16.06.11	NTH 275	0.11	0.05	0.16
16.06.11	EXH 400	0.082	0.07	0.15
16.02.12	All over	0.15	0.06	0.22
16.02.12	EXH 640	0.34	0.11	0.45
16.02.12	EXH 265	0.1	0.07	0.17
	Mean	0.224088235	0.078823529	0.302941
	Median	0.185	0.065	0.25

Table 2 shows all the positional monitoring that was done during this study. Sample that we're taken during night shift are recorded with an "n" next to the date. The mean from all the samples was 0.224 mg/m3 and the median was 0.185 mg/m3.

Table 3. Positional monitoring averages by month

		Mean (mg/m³)			Median (mg/m³)			Range		
Date	**No**	**EC**	**OC**	**TC**	**EC**	**OC**	**TC**	**EC**	**OC**	**TC**
Feb-11	7	0.25	0.07	0.31	0.28	0.07	0.36	0.06-0.35	0.02-0.08	0.08-0.42
Mar-11	12	0.22	0.06	0.28	0.15	0.06	0.21	0.03-0.49	0.03-0.11	0.06-0.60
Apr-11	4	0.29	0.14	0.43	0.27	0.10	0.37	0.08-0.55	0.05-0.30	0.13-0.86
Jun-11	8	0.19	0.08	0.27	0.15	0.07	0.22	0.08-0.53	0.04-0.24	0.13-0.77
Feb-12	3	0.20	0.08	0.28	0.15	0.07	0.22	0.10-0.15	0.06-0.11	0.17-0.45

Table 3 shows the averages for positional monitoring divided into months. From the results February and April recorded the highest mean averages of 0.25 and 0.29 respectfully and with median averages of 0.28 and 0.27 respectfully. March and June of 2011 and February of 2012 all recording a similar lower level of mean with values of 0.217, 0.190 and 0.197 respectfully and all three having a median of 0.15 mg/m3. April 2011 recorded the greatest range it a minimum of 0.08 and a maximum of 0.55, whereas February 2012 recorded the smallest range with a minimum of 0.10 and a maximum 0f 0.15 mg/m3.

Table 4. Positional monitoring averages by month in Exhibition Decline

		Mean (mg/m^3)			Median (m			Range (mg/m^3)		
Date	**No**	**EC**	**OC**	**TC**	**EC**	**OC**	**TC**	**EC**	**OC**	**TC**
Feb-11	7	0.25	0.07	0.31	0.28	0.07	0.36	0.06-0.35	0.02-0.08	0.08-0.42
Mar-11	8	0.16	0.06	0.22	0.14	0.05	0.20	0.07-0.36	0.04-0.11	0.10-0.46
Apr-11	1	0.16	0.05	0.21	0.16	0.05	0.21	0.16	0.05	0.21
Jun-11	5	0.24	0.10	0.34	0.19	0.07	0.26	0.08-0.53	0.06-0.24	0.15-0.77
Feb-12	3* 2	0.20 0.22	0.08 0.09	0.28 0.31	0.15 0.22	0.07 0.09	0.22 0.31	0.10-0.34	0.06-0.11	0.17-0.45

* Average including monitor that travelled all over mine site.

Table 4 shows the averages for positional monitoring in the Exhibition Decline divided into months. From the results February and June of 2011 recorded the highest mean averages of 0.31 and 0.34 respectfully and with median averages of 0.36 and 0.26 respectfully.

Table 5. Positional monitoring averages by month in North Decline

		Mean (mg/m^3)			Median (mg/m^3)			Range (mg/m^3)		
Date	**No**	**EC**	**OC**	**TC**	**EC**	**OC**	**TC**	**EC**	**OC**	**TC**
Feb-11	0	No monitoring done in north in this month on in exhibition								
Mar-11	4** 3	0.33 0.42	0.08 0.10	0.41 0.52	0.39 0.46	0.09 (0.1)	0.485 (0.57)	0.03-0.49	0.03-0.11	0.06-0.60
Apr-11	3	0.34	0.16	0.51	0.38	0.14	0.53	0.08-0.55	0.05-0.30	0.13-0.86
Jun-11	3	0.11	0.05	0.16	0.11	0.05	0.16	0.09-0.53	0.04-0.24	0.13-0.77
Feb-12	1*	0.15	0.06	0.22	0.15	0.06	0.22	0.15	0.06	0.22

* Average including monitor that travelled all over mine site.

****** Average including tag board

Table 5 shows the averages for positional monitoring in the North Decline divided into months. From the results March and April of 2011 recorded the highest mean averages of 0.41 and 0.51 respectfully and with median averages of 0.49 and 0.53 respectfully.

Table 6. Positional monitoring averages by location

Averages		Mean (mg/m^3)			Median (mg/m^3)			Range		
Location	**No**	**EC**	**OC**	**TC**	**EC**	**OC**	**TC**	**EC**	**OC**	**TC**
All Over	1	0.15	0.06	0.22	0.15	0.06	0.22	0.15	0.06	0.22
EXH 200s	5	0.25	0.08	0.33	0.28	0.08	0.36	0.10-0.36	0.07-0.11	0.17-0.46
EXH 300s	9	0.21	0.06	0.28	0.21	0.06	0.27	0.14-0.35	0.05-0.08	0.19-0.42
EXH 400s	7	0.17	0.07	0.25	0.13	0.05	0.17	0.06-0.53	0.02-0.24	0.08-0.77
EXH 500+	2	0.23	0.08	0.31	0.23	0.08	0.31	0.12-0.34	0.04-0.11	0.16-0.45
NTH<300	6	0.23	0.08	0.31	0.22	0.07	0.28	0.03-0.46	0.03-0.11	0.06-0.57
NTH 300+	4	0.31	0.13	0.44	0.31	0.08	0.39	0.08-0.55	0.05-0.30	0.13-0.86

Table 6 shows the averages for positional monitoring divided into grouped locations. The highest average area was in the North Decline 300+ and the lowest average area was going all around the mine site and in the Exhibition Decline 400's.

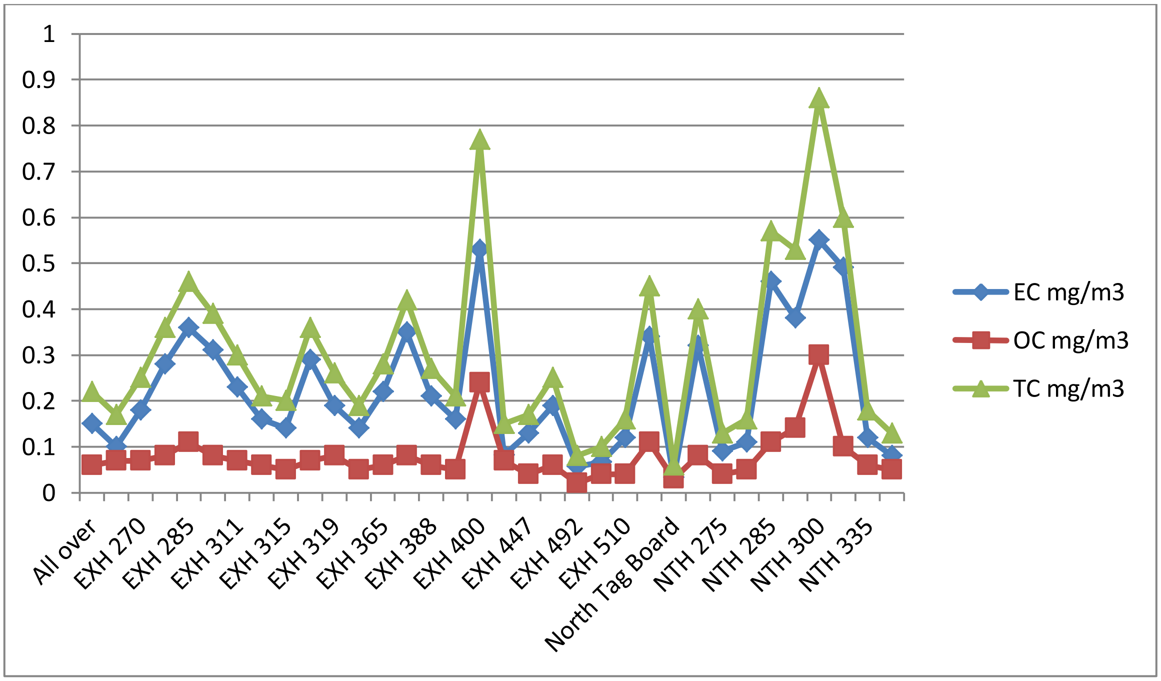

Figure 4 Positional averages by location

Figure 4 shows the areas of peak exposure with DP. It shows that most of the peaks are between 0.4 and 0.5 mg/m3. It also shows that there is no obvious relationship between location and D~~.~~P exposure.

4.5 Vehicle Exposure

All trucks that belonged to the company were monitored for diesel particulate output regularly by the Engineering Department. All vehicles had monitoring of diesel particulate output conducted by the same external occupational hygiene company that conducted the CONTAM monitoring. Table 7 shows the vehicle exhaust output from a vehicle that was used on site with and without a filter.

Table 7. Vehicle output at free acceleration

Free acceleration	Standard Exhaust (mg/m3)	Mammoth DPF Filter (mg/m3)
Average	41.2	1.2
Average Idle	53.4	1.5
Average Power	23	0.7
Min	3.6	0
Max	319	9.2
Free acceleration Test % Reduction		97%

Table 8. Vehicle output at brake stall

Brake Stall Test	Standard Exhaust (mg/m3)	Mammoth DPF Filter (mg/m3)
Average	28.2	0.6
Average Idle	13.5	0.3
Average Power	57.5	0.8
Min	8	0
Max	222	1.6
Brake Stall Test % Reduction		98%

Table 7 shows that exhaust output of a vehicle cat free acceleration it is apparent that the use of a filter can greatly reduce the output of vehicle exhaust. As these vehicles are diesel operated a majority of the vehicle output would be diesel particulates, therefore the use of filters will most probably reduce diesel particulate matter. Table 8 shows the vehicle output at break stall, which also shows a great reduction in exhaust when a filter is added. It is important to note in both these results that exhaust output was tested just before and just after a filter was added, therefore the filter was very new and would therefore give optimum results, this however will likely change over time.

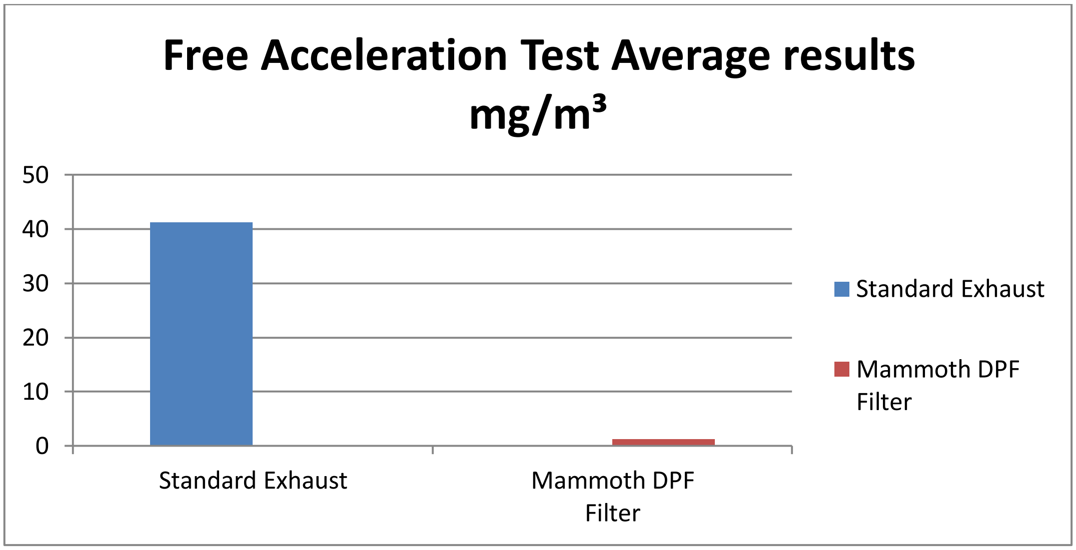

Figure 5 Comparison of a standard exhaust versus an exhaust with a mammoth filter in free acceleration.

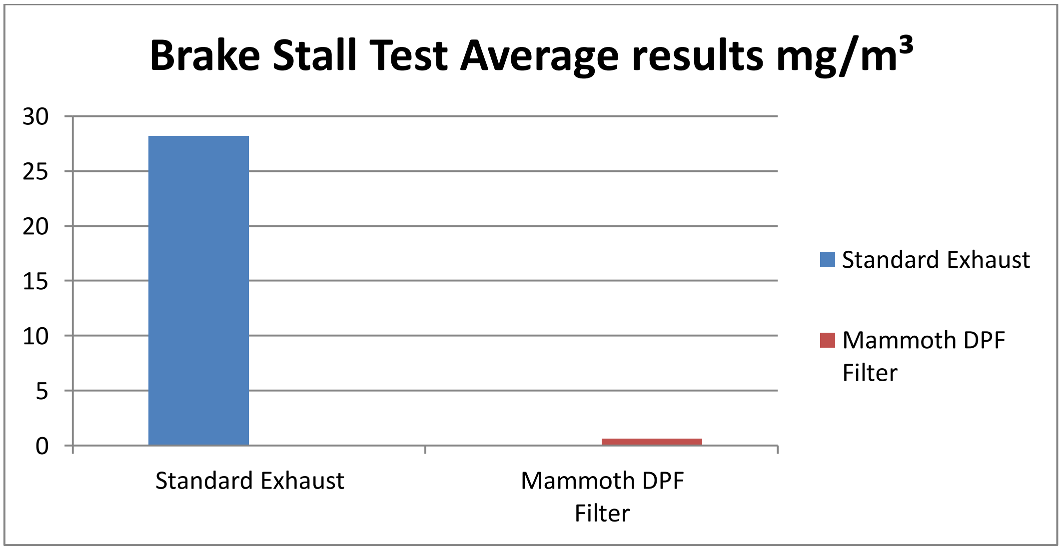

Figure 6 Comparison of a standard exhaust versus an exhaust with a mammoth filter in brake stall.

Figure 5 and Figure 6 show filter testing that was done on a vehicle with a standard exhaust compared to the vehicle installed with a mammoth filter, the figures show that the use of a filter recorded a lower dp reading of that with a standard exhaust. These results do not compare other confounders and further testing would need to occur to determine if effectiveness continues over time.

4.6 Job Descriptions

In this study all employees working in an underground environment for a majority of their shift were used as the study group for monitoring purposes however some employees that worked for other contractors or that had roles which meant they spent a majority of their day on the surface were used for the questionnaire part of this study. This was due to a number of reasons such as they were in the same room while questionnaires we're being conducted and it also provided a control group for this study these employees were given the job title as other.

Table 9. Description of job titles

Job Title	No.	Roster	Job Description	Frequent work area
Truck Driver	42	14 days on 7 days off	Drive up and down decline moving ore body to other parts of the mine	Enclosed vehicle
Charge Up Crew	9	7 days on 7 days off	Complete tasks needed for charge up such as delivering and setting up explosives	Open vehicle
Jumbo Operator	10	7 days on 7 days off	Jumbo Operators are responsible for operating jumbo drilling rig for underground development mining with the installation of ground support.	Enclosed vehicle
Shift Boss	8	7 days on 7 days off	Responsible for supervising all underground operations. Will go around the mine looking at an issues that need to be addressed	Enclosed vehicle
Long Hole Operator	7	7 days on 7 days off	Operation of long hole drill rig	Enclosed vehicle
Bogger Operator	17	7 days on 7 days off	Bogger Operators are responsible for transporting or bogging, waste rock and soil or ore onto trucks or to different parts of a mining operation.	Enclosed vehicle
Service Crew	16	7 days on 7 days off	Complete tasks needed for all around the mine and support underground operations	Open vehicle
Nipper	1	7 days on 7 days off	Supply materials and give assistance to underground crews	Open vehicle
Grader Operator	3	7 days on 7 days off	Grader operators are responsible for the safe and efficient operation of graders to spread and level materials on site.	Enclosed vehicle
Shotcreter	4	7 days on 7 days off	Shotcreters or Nozzleman spray cement on to underground walls to provide extra support in the underground environment	Open vehicle
Other	34	varies	Jobs completed by another contractor or was a job not spent underground for a majority of the shift (these employees only completed questionnaires	Other

Table 9 lists the job titles that are found in an underground working environment and that we're used in this study. The number represents the number of people in this job title that were involved in the study includes those who filling out the questionnaire, or wearing a monitor, or both. As the table shows that the normal roster is 7 days on 7 days off, however truck drivers work 14 days on 7 days of, in some occasions some people my work a different roster to their job title, this can occur if they want a longer roster to therefore earn more money or they have a number of different positions therefore their roster can vary. All vehicles operated use diesel fuel.

4.7 Personal Monitoring

In the past personal monitoring on DP exposure was done by a contracted hygiene company whose results were submitted to Resource Safety, Department of Mine and Petroleum as part of CONTAM data, with the contracted hygienist visiting site at least every quarter. However, due to high DP results the contract hygienist visited more often. Appendix 3 shows the CONTAM monitoring results.

4.8 Historical Exposure (CONTAM) To DPM

Historical data was collected from this site by a contracted hygiene company. This company performed all air contaminant and vehicle testing, which was then reported to site and this was sent to the Resource Safety for inclusion in the CONTAM data. Historical data contained both personal and positional monitoring results with personal monitoring conducted on a range of different job descriptions with the use of a personal monitor and positional monitoring was done on a number of locations also using a personal monitor. ~~C~~ontracted hygienists are used by a number of mines in the same area and have qualified hygienists with at least a Certificate Three ventilation technician certificate.

Appendix 3 shows all the results that were received by CONTAM from this mine site. CONTAM has special codes that represent different occupations and different work locations. The concentration is given as Elemental Carbon (EC) in mg/m3 and the date entered is the date that the sample was taken. It is quite likely that more samples were taken over this period but these were the only samples submitted to the Department of Mines and Petroleum (DMP).

Table 10. CONTAM codes

Occupation Code	**Job Title**
211000	Contract miner
223000	Shotfirer
224000	Shotfirer's assistant (charging)
231000	Diamond drill operator
232000	Diamond drill assistant
241000	Diesel loader operator
242000	Mechanical bogger driver
245000	Truck driver
248000	Conveyor attendant or operator
260000	Services occupations (underground)
265000	Nipper, salvage man or utility man
269000	Underground services occupations NOC
361000	Haulage truck driver
362000	Water truck driver
Location Code	**Location Title**
190	Underground
210	Face loading Area

Table 10 lists the codes CONTAM has assigned to specific job roles and locations (for results recorded in Appendix 3).

Table 11. DPM (EC) concentrations (median range) recorded in CONTAM dataset from November 2004 to November 2011.

Date	Number	Mean EC	Median EC
Nov-04	8	0.1075	0.095
Jan-05	3	0.2	0.24
Apr-05	2	0.04	0.04
Jul-05	1	0.06	0.06
Feb-06	2	0.05	0.05
Feb-07	2	0.06	0.06
Nov-07	7	0.058571	0.04
Mar-09	4	0.09025	0.091
Apr-09	5	0.1036	0.076
May-09	2	0.066	0.066
Jun-09	7	0.081143	0.091
Sep-09	4	0.12675	0.125
Sep-10	9	0.099	0.081
Jul-11	8	0.08525	0.0645
Sep-11	1	0.01	0.01
Nov-11	10	0.0931	0.0755

Table 11 presents the average concentrations of DP for each month and year. The table shows that there was a gap in results presented in 2008 and that there is no consistence in the number of results being recorded in CONTAM.

Table 12. DPM (EC) concentrations by occupation

Occupation	Number	Mean EC	Median EC
211000	10	0.122	0.11
223000	2	0.15	0.15
224000	2	0.04	0.04
231000	3	0.046667	0.04
232000	3	0.096667	0.08
241000	7	0.041571	0.039
242000	8	0.1095	0.099
245000	22	0.094318	0.088
248000	1	0.23	0.23
260000	2	0.102	0.102
265000	2	0.0365	0.0365
269000	7	0.097714	0.097
361000	3	0.044333	0.054
362000	3	0.078	0.064

Table 12 presents the average diesel particulate levels by occupation code as given by CONTAM. The occupation codes with the highest average exposure are 211000 (with a mean of 0.122 and a median of 0.11) 223000 (with a mean and a median of 0.15), 248000 (with a mean and a median of 0.23) and 260000 (with a mean and a median of 0.102). These codes belong to occupations of contract miners, shotfirers , conveyor attendant and service occupations underground, respectively. The occupation code with the lowest average exposure was 265000 with a mean and median of 0.0365 and this code belonged to nippers and other similar type occupations.

4.9 Personal Exposure

A total of eighty-two personal monitoring results were captured by the researcher. The table in Appendix 4 is a record of all the personal results taken during this study listing the date the sample was taken the job role for that employee on the day of monitoring and the elemental carbon, organic carbon and total carbon found in analysis. This table documents the average results of specific mine workers' exposure level to DPM [using element carbon, (EC)] from a range of job positions. This table shows that the highest personal result was captured in March 2011 by a bogger operator with an EC of 0.35.

The lowest personal exposure of 0.006 occurred 3 times by a service crewman, a truck driver and also another bogger operator.

Table 13. Personal DPM exposure in different job positions

Job Title	Exposure from highest to lowest	Total Monitored	Precent over TWA	EC* (Mean, mg/m^3)	EC (Median, mg/m^3)	EC (Range, mg /m^3)
Bogger	1	13	84.62%	0.178	0.180	0.006 – 0.35
Charge Up	4	6	66.67%	0.099	0.098	0.006 – 0.19
Grader	9	1	n/a	0.022	0.022	n/a
Jumbo	2	10	70%	0.105	0.120	0.028 – 0.17
Long Hole	8	3	33.33%	0.053	0.045	0.02 – 0.093
Shotcreter	5	2	n/a	0.096	0.096	n/a
Service Crew	3	10	70%	0.093	0.101	0.021 – 0.14
Shift Boss	6	6	50%	0.090	0.084	0.009 – 0.17
Truck	7	31	22.58%	0.055	0.054	0.006 – 0.14
Total		82	51.22%	0.092	0.080	0.006 – 0.35

* Element carbon

From the results it is apparent that truck drivers, long-hole operators and grader operators were among the lowest average exposure groups and bogger operators had the highest average exposure. Bogger operators, charge up, jumbo operators, service crew and shift bosses all had more than half of the employees in each of these employment positions whose recorded results over the recommended Time Weighted Average (TWA). These same roles also had an average exposure that was over the recommended TWA. Nearly 50% of all employees monitored were above the recommended TWA. A majority of those monitored were truck drivers. When the truck drivers were removed, the percentage over the TWA exposure limit was then 28/34. This equals 82.4% of the miners monitored and provides an average exposure of 0.116 mg/cm^3. The average exposure, when all groups were included, was 0.09 mg/cm^3, which was still above the recommended TWA of 0.07 mg/cm^3 assigned to those working a 12 hour shift with 7 days on and 7 days off. This is the most common roster for each job titled in the above table.

4.10 Health Assessment

There were total 124 questionnaires collected. The following table documents the employees who responded to questions on acute health effects and the frequencies of the effects distributed in different job positions.

Table 14. Irratant health effects in different job positions

Job Title	**Eye Sting**					**Runny Nose**					**Sore Throat**				
	No	Yes	Occ*	Often	Now	No	Yes	Occ	Often	Now	No	Yes	Occ	Often	Now
Bogger	3	9	9	0	0	5	6	6	0	0	5	7	7	0	0
Charge Up	4	5	5	0	0	5	4	3	1	0	5	4	3	1	0
Grader	1	2	2	0	0	1	2	2	0	0	1	2	2	0	0
Jumbo	2	7	5	2	0	2	6	6	0	0	2	7	5	2	0
Long Hole	2	2	2	0	0	2	2	2	0	0	2	2	2	0	0
Shotcreter	0	4	2	2	0	2	2	1	1	0	2	2	0	2	0
Service Crew	8	6	5	1	0	9	5	4	1	0	8	6	6	0	0
Shift Boss	1	4	4	0	0	2	2	2	0	0	2	2	2	0	0
Truck	19	7	6	0	1	18	8	7	0	1	17	9	6	2	1
Other	17	12	11	1	0	17	13	11	1	1	16	12	9	2	1
Total	57	58	51	6	1	63	50	44	4	2	60	53	42	9	2
With vs. without Chi-Square (p-value)	18.701 (0.028)					6.650 (0.673)					6.465 (0.6931)				
Frequency Chi – Square (p-value)	44.607 (0.018)					20.026 (0.830)					26.025 (0.517)				

* Occ: occasional

From these results it is apparent that truck drivers were among the group that recorded the least frequency of irritant effects whereas bogger operators, jumbo operators, shotcreters and shift bosses were among the groups that recorded the highest level of frequency for irritant effects. The Chi-square tests showed that there was a statistical significant correlation between job title and eye sting ($p<0.05$), however there were no such correlations between job title and runny nose or sore throat ($p>0.05$).

4.11 Comparison Of Two Sampling Monitoring Methods

Two methods of monitoring DPM were used. Table one shows the similarities and difference. Method 1 was the method administered by the company contracted to do the monitoring at this mine site. This method included a cassette that was prepared by the laboratory where analysis occurred. The sampling train was calibrated before and after the monitoring period by an employee of the contracted occupational hygiene company who was a qualified ventilation technician. Method 2 was the method administered by a Curtin University research student who was completing a study on DP exposure in this mine site. Method 2 included a preloaded specialised SKC DPM cassette. The sampling train was calibrated before and after the monitoring period by the Curtin student who was also a qualified ventilation technician and qualified ventilation officer.

Table 15 Comparisons of two types of DPM monitoring methods

Sampling Train	**Method 1**	**Method 2**
Sampling Pumps	AirChek 2000	AirChek XR5000
Cassette	Three Piece Styrene	Precision-jeweled impactor
Filter Paper	Heat – treated quartz	2 heat – treated quartz
Cyclone	Plastic cyclone	DPM Cyclone
Flow Rate (l/min)	2.2	2.0

Both monitoring trains were placed in the same area, side by side, positioned exactly the same way and were started and stopped at the same time. This was done to reduce the measuring bias. Sampling was conducted over a work shift, with monitors being placed in positions just after shift had commended and collected just before the completion of the same shift. Monitoring was conducted both during the day shift and night shift with most monitoring being carried out over on 8-hour period.

Elemental carbon (EC) is considered as probably the best indicator or marker for DP exposure (Rogers and Davies 2005; Hesterberg, Long et al. 2009) and National Institute of Occupational Safety and Health (NIOSH) recommended to use thermal optical method (5040) to measure EC. This method is considered the most accurate and the only validated method to measure EC, organic carbon (OC) and total carbon (TC) thus was used in both monitoring procedures. To eliminate measurement bias, samples collected by both monitoring methods were sent to the same lab for analysis of elemental carbon. This lab is accredited to use the NIOSH method 5040.

The results of DP concentrations by using two sampling methods are displayed in Table 16. The numbers next to each of the declines represent meters above sea level and the results with "n" represent the data collected during night shifts. Among 11 pairs of sample collected, one result was not included in the table as for unknown reasons the pump for method 1 stopped working half way through monitoring.

Table 16 Comparisons of DPM monitoring results by using the two sampling methods

Date	Position	Method 1	Method 2	Difference
22.02.14	EXH 288 **	0.41	0.31	0.1
22.02.14	EXH 388	0.29	0.21	0.08
22.02.14	EXH 311	0.28	0.23	0.05
13.04.14 n *	NTH 300 ***	0.58	0.55	0.03
13.04.14 n	NTH 481	0.2	0.081	0.119
13.04.14 n	NTH 285	0.27	0.38	0.11-
13.04.14 n	EXH 400	0.4	0.16	0.24
15.06.14 n	EXH 270	0.23	0.18	0.05
15.06.14 n	NTH 275	0.12	0.09	0.03
15.06.14 n	EXH 400	0.36	0.53	0.17-
Mean (mg/m^3)	Mean (mg/m^3)	0.314	0.274	0.040
Median (mg/m^3)	Median (mg/m^3)	0.285	0.23	0.055
Range (mg/m^3)	Range (mg/m^3)	0.12 – 0.58	0.081 – 0.55	0.039 – 0.03

* n=nightshift
** EXH = exhibition decline, the numbers represent meters above sea level
*** NTH = north decline

The paired *t* test showed that the monitoring results from the two sampling methods had relatively good correlation (r=0.731, *p*=0.016) and there was no statistical significant difference between the two methods (t=0.155 and *p*=0.278). While there seems to be no statistical difference in comparing the two sampling methods, there does seem to be a different trend in the results, with some difference being up to 0.119 (mg/m^3) which is above the recommended level for DP. Overall the readings recorded in Method 2 were lower than those in Method 1. However in 2 occasions Method 2 recorded higher readings. Another interesting point is that one of the areas where Method 2 recorded a higher reading had monitoring done in the same location just 2 months prior and those results showed that Method 2 having lower readings. Figure 7 shows a plotted graph format comparing the two sampling methods.

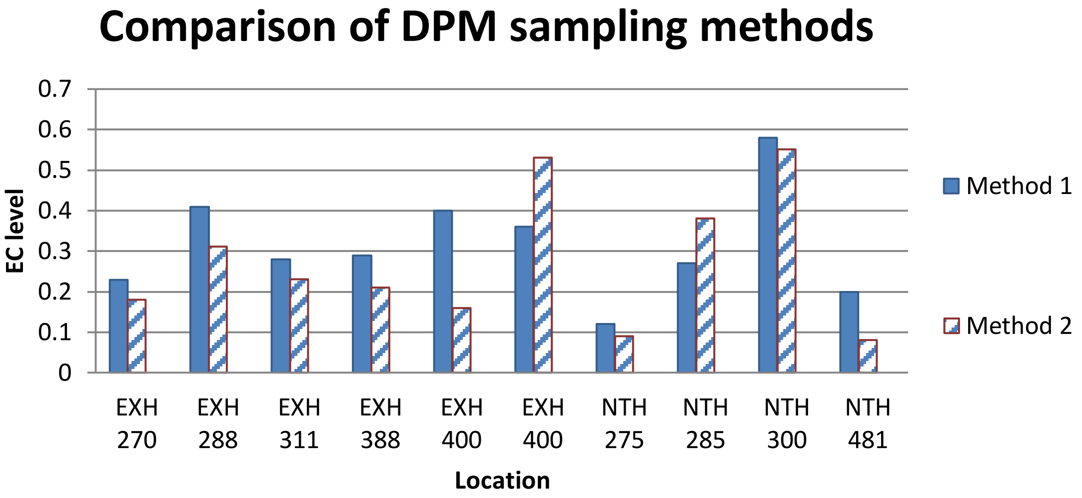

Figure 7 Comparisons of DPM monitoring results by using the two sampling methods

The meaning and the significance of the results provided in this chapter are discussed in the following chapter of the report.

5 DISCUSSION

5.1 Introduction To Chapter

Chapter five examines and discusses the results found in this study in comparison to literature, other published information provides a comparisons between the results of this study and the results from other studies. This it reviews the research results in line with the research objectives and questions. From this discussion an overall conclusion and recommendations are provided in the final research chapter.

Based on the results of this study it was identified that diesel particulate exposure at this mine site had been showing levels higher than the recommended level. Therefore monitoring was done on a more regular basis than many other mines. However no existing analysis was identified as to which areas and job descriptions were experience the most exposure. Therefore this study was very relevant for this mine site

The main purpose of this study was to investigate any links between exposure of diesel particulates and acute health effects through identify the exposure levels of diesel particulate in this mine site. This was achieved from assessing personal exposure levels in different work groups and comparing them with answers given in a questionnaire addressing irritant health effects.

As the study continued different areas were focused on that were not originally planned to be monitored. For example, while conducting this study another purpose was created, as it was found that the current method of monitoring this mine site was different to the method incorporated in this study. Therefore the current method was used alongside the study methods and results were then compared.

The research results could have been interpreted in other ways by having different focuses; the interpretation used was chosen to answer the initial questions. For the research questions to be answered, this study focused on mine air quality, personal exposure amongst different jobs descriptions, possible irritant effects and different monitoring methods and controls. The information in 5.1 to 5.5 provides the answers to the five research questions based on the findings of this research. The question answers are then discussed to compare with the findings of previously published literature. .

5.2 Air Quality Of Underground Mine.

What is the air quality of the underground mine. Which parts have the highest levels, which parts have the lowest levels and why?

In protecting the health of miners it has been recognised that improving the air quality in underground mines by various techniques plays a significant part in providing employees with a healthier work environment.

The mine site only had one portal, which was the only entry and exit route for all vehicles therefore this was the only real entry for fresh air. With underground mine sites being a confined environment particles produced by underground equipment can remain deep within the mine in great concentrations. Therefore primary and secondary ventilation was required to create a greater amount of cool fresh air circulating through the mine. Ventilation in underground mines is used to provide adequate quantities of air to travel ways and work areas to dilute contaminates to an acceptable level (Howes, 2011). However ventilation can come at a great expense to mine sites. Consequently leading to air flow requirements not always being sufficient to eliminate the amount of air pollutants being produced.

In this study the overall mean level of elemental carbon is shown to be 0.224088235 mg/m3, this is more then triple the standard twa for a mine worker that is on a 2 week on 1 week off roster, whose t.w.a recommendation is 0.07. However it is found that most mines percentage of samples exceed limits (Hedges et all 2007), therefore this mine site having an average that exceeds the twa was expected.

The area in this study with the highest level of DPM is NTH 300 with a reading of 0.55 while the lowest reading was recorded at the North Tag Board with a reading of 0.033.

The North Tag Board is an area that contains a board where personnel put their name tags on if they are planning to enter then north decline of the mine, this is to see who is present and that they evacuate before any blasting occurs. The North Tag Board is an area that is considered to have low exposure as vehicles do not stay here long at there is always a high level of air flow in this area. Therefore it was expected that the lowest levels would be found in The North Tag Board.

The highest averages were in the North Decline and the lowest levels of the exhibition. The North decline was known to have what was considered worse air quality then the Exhibition decline, this was due to the fact that there was less air flow going through this area and at the time of monitoring work had increased in this decline.

The lowest levels of the exhibition having high readings can be explained by the fact that the deepest levels of an underground mine site tend to accumulate the highest concentrations of particles this is due to the fact that there can be great activity with limited ventilation.

These results correspond Scheepers et al 2003 research which found that concentrations are higher underground than on the surface, this may explain why average levels exceed current recommendations and also why levels are higher the further away locations are from the surface.

In future studies for evaluating air quality it may be worthwhile to also determine gaseous exposures as well as other air quality conditions such as velocity, humidity and other such qualities. It may also be essential to determine work activity that is happening in the mine at the time of monitoring to help explain some of the rises and lows in exposure. An attempt was made to monitor gases and air quality conditions however it became difficult as equipment underground would need to be continuously monitored and with resources and underground regulations being as they were it was near impossible to gain accurate results.

To keep dust levels to a minimum water suppression in this underground mine took place regularly and while this helped with dust suppression it is unclear as to the effect it would have had on diesel particulates and whether particulates are more likely to stay within mine walls then other particulates. As diesel particulates are very complex a greater understanding of how airborne particulates are affected by the use of water to suppress dust is needed.

Answers to this question achieve the first research objective which was to' evaluate the air quality of an underground mine.' The second research objective was to 'evaluate the personal diesel exhaust exposure of underground mine workers.' The achievement of this objective is discussed in the answers to the following research question.

5.3 Personal Diesel Exhaust Exposure Of Underground Mine Workers.

What are the personal diesel particulate levels for underground workers? Are there any links with job description and exposure levels?

The job title that had the highest exposure was Bogger operator. A Bogger operator is usually in an enclosed cab however the areas that they constantly work in is usually areas of high activity with many diesel equipment being on, as well as the fact that most bogger operators will not stay enclosed in their cab for the whole of their shift. This corresponds with (Irving 2006) that also found operators to be among the higher level DPM exposure groups.

The job title with the lowest exposure are truck drivers. A truck driver is also usually in an enclosed cab and while they do go to areas that diesel equipment is being operated they spend most of their shift traveling along the decline and also outside to unload, therefore a majority of their work shift is spent in low exposure areas where open air or primary ventilation is flowing. This is also identified in (Pronk et al 2009) as this study reported that the lowest levels were found in enclosed areas as they provided a separation from the source this group included truck drivers.

From the results it is apparent that Truck Drivers were among the lowest average exposure group and bogger operators had the highest average exposure. Bogger operators, charge up, jumbo operators, service crew and shift bosses all had more than half of the employees in each of these employment positions who record results over the recommended TWA. These same roles also had an average exposure that was over the recommended TWA. Nearly 50% of all employees monitored were above the recommended TWA. A majority of those monitored were truck drivers. When the Truck drivers were removed the percentage over the TWA exposure limit was then 28/34. This equals 82.4% of the miners monitored and provides an average exposure of 0.116 mg/cm^3. The average exposure, when all groups are included, was 0.09 mg/cm^3, which is still above the recommended TWA of 0.07 mg/cm^3 that is assigned to those working a 12 hour shift with 7 days on and 7 days off. This is the most common roster on this mine site.

The data indicates that certain job descriptions have higher DP exposure then other job descriptions. It is determined that this may be for a number of reasons, such as time spent in an enclosed cab and where the main areas of work activity occur. In conducting these studies it may be necessary to note what areas and activities employees were doing on the day of monitoring, This is where the questionnaire was important, however it realise a lot on the accuracy of the employee in providing the appropriate information. For example in one instance a truck has a broken window therefore the truck driver was not in an enclosed cab, this meant that their reading was higher that normal truck driver results.

Another important limitation that may occur in this part of access exposure is that a lot of reliance is placed on employees wearing the monitors properly. Unfortunately employees to not always use the monitors correctly. Employees in the past had been noted as leaving the monitors in their vehicles or putting the monitors near exhaust pipes to accumulate higher readings. Sometimes the monitors have stopped working and employees have not realised, or the work they have had to do has meant that some of the tubing has been detached therefore readings have not always been accurate. This is an issue that can be difficult to solve as employees cannot always be supervised while wearing the monitors. However in this study participants were shown a power point where they were presented with information on diesel particulates that included why monitoring was occurring and the importance of data being accurate. This meant that employees had a better outlook to the study and what was being done and therefore were willing to provide more reliable data.

5.4 Level Of Diesel Exhaust Emissions From Vehicle/Equipment Engines Working Underground.

What is the level of emissions being generated from vehicle exhaust? Which vehicles are generating the most particulates and why?

Any mine site should have a record of the diesel exhaust emissions generated from vehicle/equipment engines. At this mine site diesel exhaust emissions were monitored by an external hygienist and kept in engineering department records.

The engineering department of this company performed some extra testing on their vehicle equipment to see the difference a use of a filter had on their vehicles. The results showed that the use of the filter in fact significantly decrease the exhaust output, therefore it can be assumed that diesel output was reduced, however an issue with these filters is that while they may reduce overall exhaust output they may not be able to capture smaller nano particles. Therefore further testing will need to continually occur.

A common concept that is followed in most engineering departments is that eighty twenty rule which in this case is that eighty per cent of the emissions are caused but twenty percent of the engines on site. Determining risk control measures for vehicle emissions is a key area that would need to be analysed and assessed in future studies. This is also mentioned in (Konstandopoulos et al 2000) that for future compliance with diesel vehicle emission standards to occur it will most probably involve the used of control strategies including particulate filters.

5.5 Potential Irritant Effects Among Underground Mine Worker In Relation To DPM Exposure.

What irritant conditions are affecting workers exposed to diesel particulates? Are those exposed to higher levels for longer periods of time experiencing more acute ill health conditions than those less exposed?

In researching diesel particulates and health effects there seemed to be more of a focus on chronic health effects with most of the literature available petaining to this and therefore little published research was identified in relation to the acute health effects of diesel particulates. The 2 groups that recorded the highest DP exposure were bogger operators and jumbo operators. These jobs also recorded some of the higher frequencies of acute health effects compared to truck drivers with average lower DP exposure and lower frequency of acute health effects.

In some cases, such as long hole and grader operators, there was a recorded lower DPM exposure but a high frequency of accute health effects, however this job group had a lower number of participants so this may contributed to a higher average of acute health effects. One hundred and twenty four questionnaires were completed but not all participants answered all questions related to irrantant effects. There were only 115 responses to eye sting and 113 responses to runny nose and sore throat. Therefore the response rates were between 91.1% and 92.7%.

A study conducted on labratory mice showed that pathelogical details of acute pulmonary inflammation and tissue injury induces by intratracheal instillation of various low doses of DP. Dose-response pulmonary effect of DP was also revealed (Inoue, Shimada et al. 2009). Another experimental study also performed on mice and results showed that low doses of diesel particules can acutely elicit pulmonary toxicity in mice (Laks, Carvalho de Oliveira et al. 2008).

As reported in Hesterberg's recent review paper (Hesterberg, Long et al. 2009) that as there has been a limited amount of data collected on potential acute health effects of diesel exhaust exposure in humans so laboratory animal studies have been used to identify acute health effects. This highlights the relevance of this study as it demonstrates the needs to conduct research in humans to investigate the exposure and acute health effects in real-life work situations.

Some studies have used human volunteers in settings that have been developed by the researchers. One such study found that in 15 healthy volunteers, 24 hours after inhalation of 300 mu g/m^3 diesel exhaust for 1 hour, mild systemic inflammation and an impairment of vascular endothelial function were observed (Tornqvist, Mills et al. 2007).

This research used real-life and real time work situations which makes it even more unique as usually, “human exposure studies often use relatively high DE concentrations, compared with real-world exposure levels. For ethical reasons, DE exposures to volunteers must remain below those that are suspected to increase the risk of long-term or irreversible health effects” (Hesterberg, Long et al. 2009, p.198).

In many studies there has been a focus on measurable health effects. However, Monforton quoted that one miner as stating “Some of the stresses you can feel – you don’t need a gauge to measure this – your burning eyes, nose, throat, your chest irritation. The more you’re exposed to the higher this goes” (Monforton 2006). Therefore it is important to also look at health effects that are not only measurable but effect employees on an irritable level (symptom). Irritable effects were the focus in this study as they can be assessed in the short term, whereas other health effects may take years to develop.

The questionnaire also had another benefit in that it helped employees look at their own health, especially irritant effected. This was apparent with one of the questions asking if employees experienced the same irritant effects at home as they did at work and one employee made the comment that he had never realised it but these irritant affects only occurred or were a lot worse when are work.

Follow up questionnaires with this group may be beneficial to see if conditions had changed for those still in the industry or if they had become more aware of issues. It is hoped that this study also educated employees as this type of culture can also mean that monitoring practises are done more accurately.

This section has discussed the achievement of the third research objective which was to 'assess potential irritant effects among underground mine workers in relation to DP exposure.' The following section disses the achievement of the last research objective which was to 'evaluate monitoring practises and assess which of these is the most accurate.'

5.6 Monitoring Practises.

What monitoring method is giving the most accurate results? Can this be adopted into a standardised method for use throughout the mining industry?

Currently there is no standard method of monitoring DP in Australia with the only requirement being that an analysis is done using the NOISH Method 5040. This method has been specifically developed to measure elemental carbon from DP. Studies on occupational exposure to DP have determined that EC forms a considerable portion of DP therefore it is a suitable marker for DP exposure as it can also be measured at low concentration (Wallen, Liden et al. 2010) .

Ramachandran et al (Ramachandran and Watts 2003) conducted a study comparing four different methods to sample and analyse DP in underground mining. These methods were: 1) respirable combustible dust sampling (RCD), 2) size selective sampling with gravimetric analysis (SSG), 3) respirable dust sampling with EC analysis, and 4) respirable dust sampling with TC analysis. The researchers discovered that as levels of DP decrease, the necessity to use EC as a marker for exposure of DP increases as it is more sensitive than other methods. However, in many workplaces this approach cannot be used because there are other airborne particles that contain EC (Scheepers, Micka et al. 2003).

(Noll, Timko et al. 2005) investigated how DP samples were collected on a quartz filter to measure carbon content using the NIOSH 5040 Method and explained the importance of using size-selective samplers to collect DP. Noll et al also mentioned that an impactor can be used to separate larger dusts from DP dusts. However data on the efficiency of using SKC DPM cassettes is limited. This exemplifies that not only the method chosen currently is more acceptable but also there is a need for further research using this method.

SKC, a company that produces air monitoring equipment claimed that while "Other cassettes may meet NIOSH Method 5040 specifications for the collection of diesel particulate, but only the SKC DPM Cassette separates diesel particulate matter (DPM) from other respirable dust (such as coal dust) based on particle size. The precision-jeweled impactor and impaction substrate, loaded into a streamlined, single-use cassette, screens out and retains respirable particles ≥ 1.0 µm aerodynamic diameter. Particles less than 1.0 µm are collected on a heat-treated low carbon quartz filter." (SKC Inc.) Another advantage is these cassettes are pre loaded and therefore do not need any weighing before or after or any other type of preparation by the lab, therefore less errors have the potential of occurring with Method 2.

The variations showed in Table 2 may be due to a number of reasons such as one of the monitoring trains was not working properly due to environmental issues such as a high level of dust causing overflow or larger particles being present in the environment that may affect one sampling method more then another. It may also be that a sampling train may have moved slightly by an employee not realising what it was there or some other external movements occurring, therefore causing it to be in a different position at some point during the monitoring period. There are many different possibilities that are hard to determine unless the sampling trains are observed throughout the whole monitoring process and this is not very practical.

From the information gathered both from past studies and this study it would seem that Method 2 is more specific to diesel particulates and that Method 1 may collect larger particles as it does not contain the Impactor that is present in Method 2. However more analysis of all methods for monitoring DP needs to occur. As such it is recommended that for better controls for diesel particulates to occur first an understanding of their effects needs to be established and better monitoring practises must be developed by having a standardised method of monitoring.

There are limitations in both of these currently used methods. The first limitation is that both methods have a wait time for the results to come back, meaning the high exposure had already occurred and may have continued for the weeks between monitoring was conducted and results from the laboratory were returned. Another limitation is that these methods only show a t.w.a over the shift, there is no reference to when higher exposures occurred, and this then limits accurate controls occurring. With more studies being conducted on DP it may be assumed that more methods of monitoring will be looked into. A push for real time monitoring would be key as wait time would be limited and a better idea of where peaks in exposure occur mean that employees would be required to wear monitors appropriately and more specific controls can be administered.

5.7 Discussion Summary

The results of this study show that overall average of diesel particulate exposure in this working location in both positional and personal exposures have higher levels than the current recommendation of 0.1 E.C (AIOH, 2007). This study shows that acute effects are more prevalent in high exposure groups and follow up research may be required to see how conditions develop in those who stayed exposed. This study shows that different monitoring methods give different results identifying that a standardised method needs to be developed so that the same valid, reliable, consistent monitoring method is used across all work sites.

While this research discusses a number of issues related do diesel particulate matter, it is clear that further ongoing research is required. The next chapter give recommendations associated with this research and an overall study conclusion.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction To Chapter

Chapter six provides the study conclusions and recommendations. Recommendations are specific to this study but can be used in other situations involving DPM.

6.2 Conclusions

The Aim of this research was' to determine possible short term health effects associated with exposure to diesel particulates in an underground mine in Western Australia.' This was achieved by examining exposure and irritant health effects experienced by underground mine workers. It was found overall that increased exposure to diesel particulates lead to an increase in acute health issues including sore throat and runny nose, with a further statistically significant relationship between diesel particulate exposure and eye sting. This research can be used to determine further health effects associated with exposure to diesel particulates by further studies conducted using employees working in the underground mining industry.

The objectives of this study were to:

(1) Evaluate the air quality of an underground mine.

(2) Evaluate the personal diesel exhaust exposure of underground mine workers.

(3) Assess potential irritant effects among underground mine workers in relation to DP exposure.

(4) Evaluate monitoring practises and assess which of these is the most accurate.

In addressing these this study found that the air quality underground can vary greatly depending on a number of factors such as what activity is occurring at any given time, what ventilation is available, where monitoring is occurring and what equipment is in operation. This study showed that the air quality can change dramatically depending on the above factors and that there seems to be no real pattern as to what areas of a mine will have high or low concentrations. Therefore further monitoring needs to occur in all areas of an underground mine to determine if levels can be predicted.

Just as areas of an underground mine differ in diesel particulate levels so do different occupations. The study showed that truck drivers were among the occupation group that were exposed to lesser levels of diesel particulate matter. It was assumed that this was because they work in enclosed vehicles and spending a majority of their work shift in areas with good ventilation. Other occupations, especially those where employees do not always remain in an enclosed vehicle and work a majority of their shift in high activity areas, had a higher exposure level.

The study also identified that there was a correlation between some irritant conditions and job descriptions, with those in less exposed occupations recording less irritant conditions compared to those with higher exposure levels. Therefore it could be assumed that those exposed to higher levels for longer periods of time experience more acute ill health conditions than those less exposed. However with many other confounders and contaminants involved in underground mining it will always be a challenge to determine if there is a direct link between diesel particulate exposure and any health effects. This study had the opportunity to compare the changes in health conditions within this workforce as it after the exposure to diesel particulate matter monitoring it included a follow up questionnaire with the employees who had been monitored to see if any changes have occurred in workers responses to irritant conditions.

This study showed that there are monitoring methods that have the potential to give more accurate results, and therefore it would be a benefit to have a standardised method of monitoring for diesel particulates used in the mining industry.

In conclusion the main points discovered from a review of published literature and from analysing the research data include:

- Diesel is very complex therefore its analysis can be difficult
- DPM and its health effects is a growing issue
- Those working in underground mine potential face more prolonged exposure then those in other industries

- For effective risk control to occur a standardised monitoring method should be adopted throughout the industry

To make underground mining safe and minimize the occurrence of ill-health effects related to exposure to diesel particulate matter the following recommendations are made.

6.3 Recommendations

The following recommendations are suggested as an outcome from the research conducted.

6.3.1 Risk Control

Firstly a crucial point to the success of any risk control measure is that there is an understanding by all levels of an organisation, of the importance of the effect that diesel emissions have on the health of workers. Unfortunately it is not adequate to simply determine health implications related to diesel exposure; more effort needs to take place to guarantee the correct procedures occur to manage diesel particulates with the best possible approach. In accomplishing this it may be required to identify possible organisational issues involved that can be affected such as legal, corporate, financial and productivity.

To enable a well-managed control and containment strategy to work an evidence based Diesel Emissions Management Plan should be developed based on quantitative measurement data from the work site. A process for development of a risk management plan for minimising diesel emission exposure is as follows:

1. Review and audit current practice including vehicle performance, maintenance, fuel supply chain, lubricants, monitoring programs, systems and existing risk treatments.
2. Establish baselines that include monitoring, performance, quantitative and qualitative measurements.
3. Create a Due Diligence and Risk Analysis program.
4. Develop a ‘Whole of Mine’ Management Plan with a balanced score card,

integrated directly into the workplace safety and operational plans.

5. Conduct training related to the use of risk control measures.
6. Implement monthly vehicle maintenance audits.
7. Undertake continuous automated monitoring of the effectiveness of the risk control program. Treat any risks identified and implement any opportunities for improvements.

The risks of diesel emissions can be controlled and there are other operational benefits in doing so. It needs to be recognised that simply using ventilation or filtration, or fuel additives is not enough. Diesel emissions, particularly by DPM, must be managed with an integrated process including automated monitoring, effective treatment, training, maintenance, etc. The benefit is that Good Diesel Emissions Management is also Great Asset Management.

While the main benefit in controlling diesel emission is good employee health there are also many operational benefits that can occur from managing the risk posed by diesel emissions. Some of these added benefits can include a reduced cost in both maintenance and fuel and even potentially a reduce cost in emission management. This can occur as vehicles that record especially high emissions most often also have other problems associated. These include requiring an increased use of fuel as well as an increasing cost of maintenance needed, and in many cases these vehicles are inefficient in producing the adequate power desired for mine operations. Therefore in reducing the risk presented by diesel emissions organisations are not only preventing their workers from developing health issues, but also potentially decreasing associated operational costs therefore increase profitability. Consequently the use of effective control measures are recommended as they cannot only reduce the risk presented by emissions but also the risk associated to vehicles efficiency.

It is very important to acknowledge that most, if not all, systems that currently are used to treat diesel emissions have their own limitations. In other words no treatment solution alone can resolve all the issues associated with diesel emissions. If this is not understood and organisations only use a single solution more money and time is spent on a risk control measure that does not provide an effective solution. Examples of these include the fact that bio fuels can only reduce DPM mass and in turn increase the number of diesel particles. Another is that diesel catalysts may either reduce DPM but increase NOX, or will reduce NOX and increase DPM. Therefore it is recommended that a range of risk control measures be used as an incorporated system in managing diesel emissions.

It is recommended that in developing effective risk control measures to not only focus on the current regulated risks but to also keep in mind expected additional risks as more research is conducted on nanoparticles. Currently there is a focus on measuring Diesel Particulate levels using mass however there is a strong possibility that sometime in the very near future there will be a focus on Diesel particulate number to identify emissions. Therefore it is recommended to use combined risk control measures for vehicles and environmental management to control the variety of risks associated with diesel emissions to deliver not only operational benefits, but also the best outcomes for business success.

It is recommended when developing a risk control systems that not only the source of emissions is identified but also the destination point is identified. While it would be ideal to treat the source of emissions it must be recognised that treatment of the source can not always occur, therefore it may be more suitable to identify the area that most requires treatment. In mining operations this would involve controlling the areas where workers are most exposed to DPM instead of trying to control emissions of all vehicle fleet or the entire mine site. This is also required in industries not related to mining, for example, for office workers it would be more practical to treat diesel emissions within an air condition unit rather than attempting to control all the vehicles outside of the office. Therefore it is recommended to determine where diesel emissions cause the greatest problems and health risks to employees. This includes determining points of concentration, areas with increased toxicity, vortex points, areas missing ventilation and position of destination. In a mine setting this can usually be at the end of a decline as all emissions from all other levels of the mine can accumulate here. This is another reason as to why source is not always appropriate to control, as emissions monitored may be show low levels of emissions when monitored but when concentrated in an area can increase to a much higher levels in a very short time frame. A useful control method is using mapping or modelling to determine potentially high concentration areas. This can be achieved in grid based management formats. This control method will need to be combined with other risk controls to accomplish both corporate and health benefits.

Monitoring is similar to that of risk controls in that no matter how accurate the methodology used is, or how precise the monitoring unit is, the more data you can obtain the more accurate the results. Therefore it is recommended where possible to capture data from various sources over an entire working shift because it is rarely possible for a solitary point of monitoring to provide an accurate indicator of diesel emission exposure and risk This includes not only monitoring areas but also vehicles and employees. Ideally monitoring DPM should be remote and automated. Generally it has been shown that 10% of diesel run fleet can be held responsible for sometime over 50% of emissions created. Therefore by identifying these 10% of vehicles quickly and repairing this fleet an reduction of 50% in atmospheric DPM pollution can occur. The best way of identifying these vehicles is by using a combination of automated monitoring, self-vehicle monitoring and real time monitoring. This means that not only are emissions tracked faster but also it is much easier to make continuous improvements.

The operational efficiency in diesel engines can reduce quickly, which can lead to an increase in diesel emissions. In controlling the risk of diesel emissions it is recommended that the maintenance features of an engine that increase and produce emissions are understood, identified and measured where and when possible. Therefore systemic vehicle engine reporting is an important part of the solution. Improved maintenance has the potential to not only improve health outcomes in employees but also flow on to various operational benefits.

If the fuel supplied is dirty, high in sulphur or poorly stored not only will vehicle emissions be high be working efficiency of the vehicle will be low. Therefore it is recommended that the chosen supplier for all company vehicles delivers clean diesel fuel.

Effective risk control treatment for DPM pollution depends on the vehicle, the fuel, the use and the location of the pollution. Mining vehicles have a number of safety requirements, are used in harsh environments and they spend a lot of time idling. For this reason Particulate Management Platforms are recommended to be used that treat the full range of DPM from nanoparticles through to all particle sizes without presenting any risk of back pressure increases. This system has been developed collaboratively between Peak3 and Australia’s CSIRO with the objective to treat known and expected risks. The highest potential risk from DPM in mining is caused by nanoparticles but the corporate risk is caused by regulation on DPM mass.

6.3.2 Monitoring Recommendations

In monitoring air quality it is recommended that gaseous exposures also be monitored as well as other air quality conditions such as velocity, humidity and other such qualities. It is recommended to determine work activity that is happening in the mine at the time of monitoring to help explain some of the rises and lows in exposure.

From the information gathered both from past studies and this study it has been identified that Method 2, which used cassettes specific to diesel particulates, is more accurate then Method 1 which collect larger particles as it does not contain the Impactor that is present in Method 2. However further analysis of all methods for monitoring DP is recommended to conducted. It is recommended that a standardised method of monitoring is used so that when risk control measures are working effectively it is because they are genuinely reducing diesel particulate levels and not because different monitoring practises are being used.

With further developments in diesel particulates occurring it is recommended that more advanced monitoring procedures be developed as with continual changes in underground environment a push towards real time monitoring is recommended.

6.3.3 Recommendations For Future Research

It is anticipated that this study will be used as a start for future research in regards to exposure of diesel particulates in metalliferous settings and that a standardised method of monitoring nationally and across the industry will be developed.

Further research on acute health effects on a larger sample size need to be conducted to provide a more accurate relationship between exposure groups and acute health effects.

Greater analysis of confounding factors is recommended to be researched to determine if the acute health effects are directly associated with diesel particulate exposure. Monitoring of a control group may be beneficial to compare their exposure. It is not a requirement to monitor people working in areas of non-exposure as there is no benefit in doing this and many companies would not want to invest in unnecessary monitoring.

Further studies on dpm need to occur to determine their real effect. Any future monitoring done needs to also recognise control developments as filters developed may decrease the mass of diesel particulates but they may let nano particles through, therefore number of particles may need to be looked at. The methods used in this study can also be applied to other settings as well as other air contaminants.

A follow up questionnaires with this group is recommended to be provided to see if any of the answers recorded in relation to the acute ill health effects experienced when exposed to environmental DP previously have changed due to continual exposure to diesel particulates. It may also be worth while to assess if the study has educated these employees on the importance of monitoring practises and if they now engage in these practises truthfully.

As this research is the first research study at this mine to investigate DP exposure by using elemental carbon monitoring data while concomitantly reporting on potential irritant effects, it can be used as a foundation for further studies on a larger scale. Parts of this study, such as the questionnaire can also be used in other studies that are not necessarily related to diesel particulates as a number of the questions asked also gain information on general health factors and outcomes of work in the mining industry.

6.4 Research Summary

This report has described research conducted in a Western Australian underground mine to identify an environmental health problem related to exposure to DPM. It contains recommendations for innovative equipment and management improvements in risk control for employees who work in underground mines and for companies who use machines that are powered by diesel fuel. The risk control measures to reduced DPM pollution and ill health due to exposure to DPM are applicable internationally.

The benefits of this study have already begun with workers already saying that they were more aware of the issues related to diesel particulates now and more responsive to wearing personal monitors. Therefore it is hoped that more accurate monitoring can now occur in this industry and that these employees lead by example at future work sites they go to.

This research has had the ability to provide not only data but recommendations that can be applied not only to the underground mining industry, but also to other industries and occupations where employees may be exposed to diesel particulates

While it is hoped that this research has answered many questions related to diesel particulate matter, it is still obvious that there are many other questions to be answered in regard to this topic. Therefore it is essential that further studies be done to work towards controlling diesel particulates in underground metalliferous mines and improving the health of employee. It is hoped that this research can provided the basis for further research.

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8. APPENDIXES

APPENDIX 1.

Participant Information Letter And Consent Form.

Curtin University. School of Public Health
Participant Information Sheet

My name is Sara Fernandez I am currently completing research for my Masters of Philosophy of Public Health at Curtin University of Technology. This research study is titled *Exposure to diesel particulates on employees in an underground mine in Western Australia.*

I would like to take this opportunity to kindly invite you to participate in this study. If you agree you will be asked to complete a questionnaire (no more than 10 minutes) and tell us your work history, health condition and other related information. Your participation is very important and will assist us to achieve the objectives of this study. Some of you will be invited to wear an air monitoring device to record the dust you are exposed to during your work. There are no invasive procedures in this study.

Consent to Participate
Your involvement in the research is entirely voluntary. You have the right to withdraw at any stage without any negative effects on you.

Confidentiality
The confidentiality of all information obtained will be ensured. Only de-identified data will be used for analysis and publication.

Further Information
This research has been reviewed and given approval by Curtin University of Technology Human Research Ethics Committee (Approval number xxxxx). If you would like further information about the study, please feel free to contact me on 0437499412 or by email: sara.fernandez@student.curtin.edu.au Alternatively you can contact my supervisor Dr Janis Jansz on 0404917063 or 92663006 or Dr Le Jian on 92664250. Should you wish to discuss the study with someone not directly involved, in particular, any matters concerning the conduct of the study or your rights as a participant, or you wish to make a confidential complaint, you may contact the Ethics Officer on (08) 9266 9223 or the Manager, Research Integrity on (08) 9266 7093 or email hrec@curtin.edu.au.

CONSENT FORM

I have read the information on the information sheet. Any questions I have asked have been answered to my satisfaction. I agree to participate in this research and understand that I can change my mind or stop at any time. I understand that all information provided by me is treated as confidential. I agree that the research information gathered for this study may be published provided names or any other information that may identify me is not used.

- I understand the purpose and procedures of this study.
- I have been provided with the participant information sheet.
- I understand that my involvement is voluntary and that I can withdraw at any time without any problem.
- I understand that answering the questions asked by the researcher may not benefit me.
- I understand that no personal identifying information, like my name and address, will be used in the research report and that all information will be securely stored for 5 years before being destroyed.
- I have been given the opportunity to ask questions and to make any comments which is relevant for this research.
- I agree to participate in the study outlined to me.

Participant Name	
Participant Signature	
Date	

Declaration by researcher: I have supplied an Information Letter and Consent Form to the participant who has signed above, and believe that they understand the purpose, extent and possible risks of their involvement in this project.

Researcher Name	
Researcher Signature	
Date	

APPENDIX 2.

QUESTIONNAIRE

EMPLOYEES QUESTIONS

I agree to the independent researcher contacting me in the event that there is missing information ☐

Contact details:
Phone/Mobile:____

OCCUPATIONAL HISTORY & WORK EXPOSURE

1. Please state your current job title
____

2. On average, I work ____hours a day and ____days a week in my current job.

3. Where do you consider as your most frequent workplace?

Enclosed vehicle ☐ Office ☐ Open vehicle ☐ Other (please state)_____________________

4. Your work tasks are:
____

5. If you drive/operate a vehicle / equipment **at work** what type of fuel do you use?

Diesel ☐ Other (please state) ☐ ___________ N/A ☐

HEALTH CONDITION

1. When at work have you ever experienced

Acute Effect	No	Occasional	Often	Now
Eyes Sting				
Runny Nose				
Sore Throat				

Thank you for answering the questions.

APPENDIX 3.

(Explanation of what each code refers to is in Table 10)

Table 17. CONTAM results on DP.

Date	Occupation Code	Location Code	Conc. (ec mg/m3)
18/11/2004	242000	190	0.14
20/11/2004	362000	190	0.12
22/11/2004	242000	190	0.08
22/11/2004	245000	190	0.06
23/11/2004	242000	190	0.07
23/11/2004	245000	190	0.07
23/11/2004	362000	190	0.11
23/11/2004	362000	190	0.21
19/01/2005	361000	210	0.11
19/01/2005	361000	210	0.25
19/01/2005	361000	210	0.24
18/04/2005	242000	190	0.06
19/04/2005	245000	190	0.02
18/07/2005	242000	190	0.06
14/02/2006	245000	190	0.06
16/02/2006	245000	190	0.04
05/02/2007	245000	190	0.04
05/02/2007	248000	190	0.08
12/11/2007	245000	190	0.14
13/11/2007	242000	190	0.07
13/11/2007	269000	190	0.03
15/11/2007	242000	190	0.04
15/11/2007	242000	190	0.03
15/11/2007	245000	190	0.03
15/11/2007	245000	190	0.07
10/03/2009	211000	190	0.052
10/03/2009	231000	190	0.039
10/03/2009	241000	190	0.13
10/03/2009	245000	190	0.14
02/04/2009	211000	190	0.25
02/04/2009	231000	190	0.11
02/04/2009	245000	190	0.066

02/04/2009	245000	190	0.016
02/04/2009	269000	190	0.076
26/05/2009	224000	190	0.088
26/05/2009	265000	190	0.044
22/06/2009	211000	190	0.15
22/06/2009	211000	190	0.02
22/06/2009	224000	190	0.035
22/06/2009	241000	190	0.14
22/06/2009	245000	190	0.091
22/06/2009	245000	190	0.032
22/06/2009	265000	190	0.1
29/09/2009	211000	190	0.097
29/09/2009	245000	190	0.13
29/09/2009	245000	190	0.12
29/09/2009	269000	190	0.16
06/09/2010	231000	190	0.081
06/09/2010	232000	190	0.06
06/09/2010	232000	190	0.12
06/09/2010	232000	190	0.18
06/09/2010	241000	190	0.085
06/09/2010	245000	190	0.16
06/09/2010	245000	190	0.075
06/09/2010	269000	190	0.054
06/09/2010	269000	190	0.076
5/07/2011	211000	190	0.065
5/07/2011	211000	190	0.23
5/07/2011	211000	190	0.14
5/07/2011	241000	190	0.064
5/07/2011	245000	190	0.01
5/07/2011	245000	190	0.063
5/07/2011	260000	190	0.01
5/07/2011	260000	190	0.1
7/09/2011	211000	190	0.01
23/11/2011	211000	190	0.087
23/11/2011	223000	190	0.097
23/11/2011	223000	190	0.15
23/11/2011	241000	190	0.23
23/11/2011	241000	190	0.054
23/11/2011	241000	190	0.056
23/11/2011	245000	190	0.023

23/11/2011	245000	190	0.064
23/11/2011	269000	190	0.01
23/11/2011	269000	190	0.16

APPENDIX 4.

Table 18 DPM exposure levels by job titles from Personal Monitoring

Date	**Position**	**EC mg/m3**	**OC mg/m3**	**TC mg/m3**
02.03.11	Bogger Op	0.006	0.02	0.02
15.06.11	Bogger Op	0.089	0.05	0.14
03.03.11 n	Bogger Op	0.097	0.04	0.13
15.06.11	Bogger Op	0.13	0.05	0.18
02.03.11	Bogger Op	0.14	0.05	0.2
24.02.11	Bogger Op	0.18	0.06	0.24
03.03.11 n	Bogger Op	0.18	0.07	0.25
24.02.11	Bogger Op	0.2	0.08	0.28
14.02.12 n	Bogger Op	0.2	0.08	0.28
03.03.11 n	Bogger Op	0.21	0.06	0.22
09.03.11	Bogger Op	0.22	0.08	0.31
09.03.11	Bogger Op	0.31	0.11	0.11
15.06.11 n	Bogger Op	0.35	0.12	0.47
08.03.11	Charge Up	0.006	0.02	0.02
23.02.11	Charge Up	0.064	0.03	0.1
23.02.11	Charge Up	0.095	0.04	0.14
08.03.11	Charge Up	0.1	0.04	0.15
15.02.12	Charge Up	0.14	0.05	0.19
24.02.11	Charge Up	0.19	0.05	0.24
09.03.11	Grader Op	0.022	0.03	0.05
03.03.11 n	Jumbo Op	0.028	0.03	0.05
08.03.11	Jumbo Op	0.054	0.03	0.08
14.02.12 n	Jumbo Op	0.057	0.05	0.11
15.02.12	Jumbo Op	0.085	0.04	0.12
03.03.11 n	Jumbo Op	0.12	0.06	0.19
09.03.11	Jumbo Op	0.12	0.04	0.16
03.03.11 n	Jumbo Op	0.13	0.07	0.2
15.02.12	Jumbo Op	0.13	0.05	0.18
24.02.11	Jumbo Op	0.16	0.06	0.22
24.02.11	Jumbo Op	0.17	0.05	0.23
24.02.11	Long Hole Op	0.02	0.02	0.04
08.03.11	Long Hole Op	0.045	0.04	0.08

16.06.11	Long Hole Op	0.093	0.05	0.14
08.03.11	Service Crew	0.092	0.08	0.18
15.02.12	Service Crew	0.021	0.03	0.05
15.06.11 n	Service Crew	0.054	0.03	0.08
03.03.11 n	Service Crew	0.063	0.04	0.11
14.06.11 n	Service Crew	0.077	0.04	0.11
02.03.11	Service Crew	0.11	0.04	0.15
08.03.11	Service Crew	0.11	0.05	0.16
02.03.11	Service Crew	0.13	0.04	0.17
16.06.11	Service Crew	0.13	0.06	0.19
15.02.12	Service Crew	0.14	0.05	0.19
02.03.11	Shift Boss	0.009	0.02	0.02
14.06.11 n	Shift Boss	0.051	0.03	0.08
15.06.11	Shift Boss	0.057	0.04	0.1
09.03.11	Shift Boss	0.11	0.03	0.14
03.03.11 n	Shift Boss	0.14	0.06	0.2
24.02.11	Shift Boss	0.17	0.05	0.22
14.02.12 n	Shotcreter	0.093	0.56	0.66
03.03.11 n	Shotcreter	0.099	0.04	0.14
02.03.11	Truck Driver	0.006	0.02	0.02
16.06.11 n	Truck Driver	0.016	0.02	0.04
23.02.11	Truck Driver	0.017	0.02	0.03
16.06,11n	Truck Driver	0.017	0.03	0.05
16.06.11	Truck Driver	0.028	0.03	0.06
14.06.11 n	Truck Driver	0.034	0.03	0.07
16.06.11 n	Truck Driver	0.035	0.03	0.07
15.06.11	Truck Driver	0.037	0.03	0.07
16.06.11 n	Truck Driver	0.037	0.03	0.07
14.06.11 n	Truck Driver	0.038	0.08	0.11
15.06.11	Truck Driver	0.038	0.06	0.1
23.02.11	Truck Driver	0.044	0.03	0.08
09.03.11	Truck Driver	0.047	0.03	0.08
01.03.11	Truck Driver	0.05	0.04	0.09
02.03.11	Truck Driver	0.053	0.04	0.1
23.02.11	Truck Driver	0.054	0.04	0.09
02.03.11	Truck Driver	0.056	0.04	0.1
08.03.11	Truck Driver	0.056	0.04	0.1
14.06.11 n	Truck Driver	0.056	0.04	0.09
14.06.11 n	Truck Driver	0.061	0.03	0.09
02.03.11	Truck Driver	0.062	0.02	0.08

23.02.11	Truck Driver	0.063	0.04	0.1
01.03.11	Truck Driver	0.066	0.07	0.14
08.03.11	Truck Driver	0.067	0.04	0.1
03.03.11 n	Truck Driver	0.078	0.03	0.11
16.06.11	Truck Driver	0.081	0.05	0.13
01.03.11	Truck Driver	0.083	0.05	0.14
01.03.11	Truck Driver	0.085	0.06	0.15
14.02.12 n	Truck Driver	0.089	0.05	0.14
09.03.11	Truck Driver	0.11	0.06	0.17
15.06.11	Truck Driver	0.14	0.07	0.21

APPENDIX 5

Western Australian Mines Safety and Inspection Regulations 1995. Part 9 – Ventilation and control of dust and atmospheric contaminants. Division 4 – Diesel Units

The Western Australian Mines Safety and Inspection Regulations 1995 specific requirements for diesel units for underground mines. The relevant Regulations are documented below and include:

- ‘No internal combustion engine, other than a diesel engine is used underground’
- ‘Only automotive diesel fuel is used in diesel engines
- ‘No diesel engine is used underground unless it conforms with AS 3584 (for coal mines)
- ‘No diesel unit is used underground in the mine until notice of registration has been issued for the diesel unit’
- ‘If a person applies to the district inspector, the district inspector may issue notice of registration for a diesel unit that is to be used underground.’
- ‘Notice of registration may be issued subject to conditions specified by the district inspector relating to the use of the diesel unit including
    a) The minimum ventilation requirement for operation of the unit, in cubic metres per second;
    b) The maximum permissible levels of atmospheric contaminants in the exhaust gases and exhaust gas opacity;
    c) The maximum rated engine capacity of the unit; and
    d) In the case of any diesel unit rated, for the purposes of the notice, at more than 125kW, a requirement that the engine of the diesel unit be fitted with a specified exhaust treatment device before it is used underground.
- ‘A condition specified in a notice of registration may at any time be deleted, varied or added to by the district inspector.
- ‘If in an inspector’s opinion a condition specified in a notice of registration is not being complied with, the inspector may direct that the diesel unit must be

immediately withdrawn from service and must not be used again until the condition is complied with.’

- ‘An inspector must make a record in the record book of any direction given under sub regulation (5)
- ‘The manager of an underground mine must ensure that a direction given under sub regulation (5) is complied with as soon as is practicable.
- ‘The district inspector must specify in the notice of registration for a diesel unit:
  a) The mine or mines at which the unit may be used; and
  b) The registration number for the unit.
- ‘Each responsible person at an underground mine must ensure that a diesel unit is used only at the mine or mines specified in the notice of registration.’
- ‘Each responsible person at an underground mine must ensure that the registration number of the diesel unit is clearly marked on the unit.’
- ‘If the engine of a diesel unit is of a rating, type or manufacture that is not familiar to the district inspector, the district inspector may require an application for registration of the unit to be accompanied by information detailing the complete specifications of the engine.’
- ‘The information may include an analysis of the undiluted exhaust gas composition with respect to carbon monoxide, nitric oxide and nitrogen dioxide conducted with calibrated instruments and showing under what engine load and speed the maximum emission of each gas occurs.
- ‘For the purposes of an analysis referred to in sub regulation (2), automotive diesel fuel of a similar specification to that in regular use at the mine must be used.
- ‘If a diesel unit at an underground mine is fitted with a replacement engine, each responsible person at the mine must ensure that —
  a) The maximum engine rating of the new engine does not exceed that recommended by the supplier or manufacturer of the unit;
  b) A competent person confirms in writing that all fire prevention and fire fighting equipment on the unit has been properly replaced and adjusted and is fully operational; and

    c) The district inspector is advised, within one week of the changeover, of the details of the new engine (including the engine number).

- ‘In an underground mine in which diesel units are used, the principal employer at, and the manager of, the mine must ensure that the requirements of this regulation are complied with in each separate ventilation circuit in which diesel units are required to be operated.’
- ‘The total primary airflow must be determined having due regard to the total number of diesel units required to be operated in the mine and how they are to be utilized and the requirement to reduce recirculation of air from workplaces into the primary ventilation circuit, to the lowest practicable level.’
- ‘The airflow in any workplace in which a diesel unit is operated must be not less than 2.5 cubic metres per second.’
- ‘A sufficient volume flow of air must be maintained in each workplace in which a diesel unit is operated to dilute the engine exhaust gases to the lowest practicable levels, and this volume flow must not in any case be less than the minimum ventilation flow specified in this regulation.’
- ‘The minimum ventilation volume rate of air required for each diesel unit is:
    a) If the maximum exhaust gas emissions of the engine in a diesel unit contain less than 1 000 ppm of oxides of nitrogen and less than 1 500 ppm of carbon monoxide, the amount set out in sub regulation (6) or such other amount as the district inspector may determine under sub regulation (8); or
    b) If the maximum exhaust gas emissions of the engine of a diesel unit contain not less than 1 000 ppm oxides of nitrogen or not less than 1 500 ppm of carbon monoxide, the amount set out in sub regulation (7) or such other amount as the district inspector may determine under sub regulation (8).
- ‘A diesel unit referred to in sub regulation (5)(a) must have a ventilation volume rate of not less than 0.05 cubic metres per second per kilowatt of the maximum rated engine output specified by the manufacturer, for the fuelling and timing configuration at which the engine has been set.’

- ‘A diesel unit referred to in sub regulation (5)(b) must have a ventilation volume rate of not less than 0.06 cubic metres per second per kilowatt of the maximum rated engine output specified by the manufacturer for the fuelling and timing configuration at which the engine has been set’
- ‘If the district inspector is satisfied that because of all or any of the following:
    a) Special design features on an engine;
    b) Exhaust gas monitoring methods and equipment;
    c) Particular operating and engine maintenance practices; and
    d) Use of low emission fuel, exhaust gases from any engine or engines will be diluted to an acceptable level at a reduced ventilating volume rate, the district inspector may determine that a ventilating volume rate per kilowatt of engine output less than that specified in sub regulation (6) or (7) applies to a specified diesel unit or to any specified underground mine or mines.
- ‘The ventilating volume rate determined under sub regulation (8) must not in any case be less than:
    a) In relation to a diesel unit referred to in sub regulation (5)(a) — 0.03 cubic metres per second per kilowatt; and
    b) In relation to a diesel unit referred to in sub regulation (5)(b) — 0.05 cubic metres per second per kilowatt.
- ‘If more than one diesel unit is operating in any ventilation circuit of a mine at the same time, the total ventilation volume rate of air in that circuit must be not less than the aggregate of the volume requirement for the individual diesel units.’
- ‘In calculating the aggregate volume requirement in any given ventilation circuit under sub regulation (10), light four wheel drive vehicles and drill jumbos and other diesel units of small engine capacity which are operated intermittently, may be disregarded.’
- ‘Each responsible person at an underground mine must ensure that the engine of each diesel unit used underground in the mine that is turbocharged or that is rated at 125 kW or more, is fitted with an exhaust treatment device.

- ‘Each responsible person at an underground mine must ensure that each exhaust treatment device that is fitted to the engine of a diesel unit in use at the mine:
    - a) Is monitored and maintained in accordance with the manufacturer’s recommendations; and
    - b) Is immediately replaced if it is found to be defective or inefficient.

‘Each responsible person at an underground mine must ensure that the undiluted exhaust gas produced, under all standard conditions of engine speed or load, by the engine of a diesel unit underground at the mine is sampled and analysed:

- a) At intervals of not more than 250 hours as measured by the diesel unit hour meter, or at intervals not exceeding one month if the unit does not have an hour meter;
- b) After any maintenance work is done on the turbocharger or fuel injection system on the engine of a diesel unit (other than cleaning or replacing filters); and
- c) When required to do so by an inspector.

- ‘The manager of an underground mine must ensure that if sampling of undiluted exhaust gases from the engine of a diesel unit shows that exhaust emissions from an engine contain more than 2 000 ppm of carbon monoxide or more than 1 800 ppm of the oxides of nitrogen, the diesel unit is not returned to service until the exhaust emissions are reduced to levels below those specified and as low as is practicable.’
- ‘After the expiry of 24 months from the commencement day, the exhaust gas emission levels for the prevention of the return of the engine to service in sub regulation (2) are 1 000 ppm of oxides of nitrogen or 1 500 ppm of carbon monoxide, under any condition of engine speed or load.
- ‘The manager of an underground mine must ensure that the undiluted emission produced by the engine of a diesel unit used underground at the mine undergoes an opacity measurement —
    - a) at intervals of not more than 250 hours as measured by the diesel unit hour meter, or at intervals not exceeding one month if the unit is not provided with an hour meter; and

    b) After any maintenance work (other than cleaning or replacing filters) is done on the turbocharger or fuel injection system on the engine of a diesel unit.

- ‘The manager of an underground mine must ensure that if the opacity measurement (using a snap idle test) for the engine of a diesel unit used in the mine shows that —
    a) Any condition relating to opacity specified in the notice of registration is not being complied with; or
    b) The opacity is greater than 50% as measured on the United States Public Health Service smoke meter percent opacity scale, or the equivalent value shown on the Smoke Meter Conversion Chart, the diesel unit is not returned to service until the opacity complies with that condition or is reduced below that level (as the case may be).
- ‘The principal employer is responsible for all costs incurred in obtaining information on the characteristics of diesel exhaust emissions required under this Division.’
- ‘The manager of an underground mine must ensure that the equipment and methods used for testing undiluted exhaust gases or workplace atmospheres conform with any standards that the district inspector specifies in writing for that purpose.’
- ‘The manager of an underground mine must ensure that sampling smoke with a smoke meter or determining opacity with an opacity meter is done in accordance with the meter manufacturer’s recommendations.’
- ‘The manager of an underground mine must ensure that a copy of the notice of registration for each diesel unit used at the mine is kept at the mine.’
- ‘The manager of an underground mine must ensure that a record is kept at the mine of the result of each undiluted gas analysis and opacity meter measurement carried out in relation to a diesel unit at the mine.’
- ‘The manager of an underground mine must ensure that the district inspector is notified in writing of the location and details of each proposed automotive diesel fuel service and storage facility that is to be installed underground in the mine.’

- ‘The manager of an underground mine must ensure that the location, method of construction and means of ventilation of an automotive diesel fuel service and storage facility that is underground in the mine is such as to reduce the risk of hazards from that facility and conforms to AS 1940.’
- ‘The manager of an underground mine must ensure that each diesel unit at the mine that is turbocharged or rated at 125 kW or more, and each loader or grader at the mine, is equipped with an effective and properly maintained AFFF or FFFP fire suppression system with a minimum of 2 activators.’
- ‘If a diesel unit in an underground mine is controlled by remote control, the manager of the mine must ensure that the unit is equipped with an automatically operated AFFF or FFFP fire suppression system that has the facility to be activated from the operator’s remote control unit.’
- ‘The manager of an underground mine must ensure that, so far as is practicable, automatic fixed fire suppression systems are installed and properly maintained at all underground locations in the mine where oils, fuels or lubricants are stored or dispensed.’
- ‘Subregulation (3) does not apply to an underground coal mine.’
- ‘If in the manager’s opinion it is not practicable in a particular case to install a fire suppression unit in an underground mine as required under sub regulation (3), the manager must —
    a) notify an inspector accordingly and advise the inspector of the reasons why it is not practicable to do so;
    b) ensure that alternative precautions are taken to minimize the hazards to any person in the event of a fire; and
    c) Notify the inspector of the alternative precautions that have been taken as required under paragraph (b).
- ‘The manager of an underground mine must ensure that if any liquid that is a flammable liquid or combustible liquid under AS 1940 is taken underground in the mine, the liquid —
    a) Is taken underground in a container that does not leak; and
    b) Is transported in a secure manner.

c) ‘The manager of an underground mine must ensure that at any time the quantity of automotive diesel fuel stored underground at the mine does not exceed the quantity required to do one week of work at the mine.’