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Efficiency of respirator filter media against diesel particulate matter

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EFFICIENCY OF RESPIRATOR FILTER MEDIA AGAINST DIESEL PARTICULATE MATTER

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ABSTRACT

Diesel engines have been a mainstay within many industries since the early 1900's. Exposure to diesel particulate matter (DPM) is a major issue in many industrial workplaces given the potential for serious health impacts to exposed workers, including lung cancer and adverse cardiovascular and irritant effects. Personal respiratory protective devices are a common safety measure to mitigate worker exposure against the damaging health impacts of DPM, and to protect they need to act as effective filters.

Filtering efficiency of respiratory protection is determined by challenging filter media with specified test aerosols to calculate penetration at designated flow rates. However, the methodology outlined in AS/NZS1716 (Standards Australia International Ltd & Standards New Zealand 2009) does not account for the differences in structure, particle size and chemical characteristics of DPM and the specified test aerosol sodium chloride, nor increased breathing rates typical in labour intensive work environments. For these reasons, a more effective test strategy / model is required.

Three commonly used AS/NZS certified respirator filters were challenged with diesel emissions from both a small diesel generator and an industrial sized diesel engine to assess the filter efficiency of these varying sources of diesel emissions. Penetration of elemental carbon (EC), total carbon (TC) and Total Particulate Matter (TPM) at the standard designated flow rate, as well as a higher flow rate representative of heavy work, was determined for the small diesel generator. Penetration of EC, TC and TPM at the standard designated flow rate was determined for the larger engine. Results indicate that filtering efficiency assumed by P2 certification in Australia was achieved for two of the three respirator models at the designated flow rate, and for potentially only one respirator model at a higher flow rate for the smaller diesel generator. For the larger diesel engine at the standard designated flow rate, filtering efficiency by EC, TC and TPM met the requirements for P2 certification. These findings indicate that current respiratory protection certification standards may not ensure adequate protection for respirator users against diesel particulate matter.

PUBLICATIONS AND PRESENTATIONS

Burton, K, Whitelaw, J and Jones, A 2013, Filtering efficiency of respirators against diesel particulate matter, *Australian Institute of Occupational Hygienists (AIOH) Conference*, Sydney, Australia, December 2013.

Burton, K, Whitelaw, J and Jones, A 2014, Efficiency of respirator filter media against diesel particulate matter, *University of Wollongong 3M Thesis Competition,* Wollongong, Australia, June 2014. Runner up Faculty of Social Sciences Heat, Participant in University Final.

Burton, K, Whitelaw, J and Jones, A 2014, Efficiency of respirator filter media against diesel particulate matter, *International Society for Respiratory Protection (ISRP) Conference*, Prague, Czech Republic, September 2014.

Burton, K, Whitelaw, J and Jones, A 2014, Efficiency of respirator filter media against diesel particulate matter, *Australian Institute of Occupational Hygienists (AIOH) Conference*, Melbourne, Australia, December 2014.

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DECLARATION

I, Kerrie Burton, declare that this thesis, submitted in the fulfilment of the requirements for the award of Masters in Science (Research) to the School of Health and Society, University of Wollongong, is wholly my own work unless otherwise referenced or acknowledged. This thesis has not been submitted for a degree or diploma in any other academic institution.

Kerrie Burton

Date: 30/3/2015

ABBREVIATIONS

CMTS – Coal Mines Technical Services

CO – carbon monoxide

CVD – cardiovascular disease

DOP – di-octyl phthalate

DPM – diesel particulate matter

EC – elemental carbon

EN – European Norms

FF – filtering facepiece

IHD – ischaemic heart disease

ISO – International Standards Organisation

MI – myocardial infarction

MSHA – Mine Safety and Health Administration

NaCl – sodium chloride

NIOSH – National Institute of Occupational Safety and Health

OC – organic carbon

OSHA – Occupational Safety and Health Administration

PAH –polycyclic aromatic hydrocarbon

PEL – Permissible Exposure Limit

PM – particulate matter

PMR – Proportional Mortality Ratio

ROS – reactive oxygen species

RR – Relative Risk

SMR – Standardised Mortality Ratio

STEL – Short Term Exposure Limit

TC – total carbon

TPM – total particulate matter

TIL – Total Inward Leakage

UCL – Upper Confidence Level

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1. INTRODUCTION

Diesel engines are used in a variety of contemporary workplaces, ranging from heavy industrial machinery to light passenger vehicles. Exposure to emissions from diesel engines occurs occupationally when working in the vicinity of diesel sources and environmentally via exposure to polluted air. Diesel engine emissions are known to cause irritant effects as well as being confirmed human carcinogens (World Health Organisation 2013). The emissions are also associated with an increase in cardiovascular mortality and morbidity (Brook et al. 2010).

Respirators are a widely used control measure to mitigate exposure to diesel particulate matter (DPM), the particulate fraction of diesel engine emissions. In Australia AS/NZS 1715 (Standards Australia International Ltd & Standards New Zealand 2009) provides guidance on the appropriate selection of respiratory protection. DPM is generated by diesel engine combustion processes, AS/NZS1715 recommends for thermally generated particles like DPM, a minimum P2 or P3 rated respirator filter for worker exposures up to 10 times the occupational exposure standard.

Minimum certification requirements for air-purifying particulate respirators include testing penetration through the filter media to evaluate filtering efficiency, using prescribed challenge aerosols and flow rates (CEN 2001; Code of Federal Regulations 1995; Standards Australia International Ltd & Standards New Zealand 2012). Internationally, test protocols in standards to evaluate filtering efficiency differ in relation to challenge aerosols and flow rates.

Two published international studies evaluated filtering efficiency of half face respirators against diesel engine emissions. The first study (Janssen and Bidwell 2006) measured filtering efficiency as a function of elemental carbon (EC) using National Institute of Occupational Safety and Health (NIOSH) rated filters and found that P and R filters met filtering efficiency requirements, however N rated filters did not. N series filters are designated for workplaces free of oil aerosols, whilst R and P rated filters are rated for removal of oil-based liquid particulates (Code of Federal Regulations 1995). The second study (Penconek, Drążyk and Moskal 2013) found that DPM was more penetrating than the challenge aerosols designated for European Norm (EN) certified filters and the tested filters did not meet the specified filtering efficiencies.

Increasing the flow rate through the respirator filter has been shown to decrease the filtering efficiency in multiple studies (Balazy et al. 2006; Eninger, Honda, Adhikari, et al. 2008; Eshbaugh et al. 2009) . Peak inspiratory flow rates for various work rates range from 124L/min

for moderate work with no speech to 275.4L/min for heavy work with speech (ISO 2007). The flow rates outlined in the ISO technical specification are consistent with work place studies (Caretti & Coyne 2006; Smith, Whitelaw & Davies 2013).

In summary, Standards Australia approved respirator filters are not challenged with workplace contaminants at flow rates representative of moderate to heavy work rates. Published research does not exist which evaluates whether the current test for filtering efficiency specified in AS1716 (Standards Australia International Ltd & Standards New Zealand 2012) ensures workers are adequately protected against DPM. These limitations are confirmed by a US and a European study which reported that not all tested filters met the filtering efficiency requirements outlined in the relevant standards when challenged with diesel engine emissions (Janssen & Bidwell 2006; Penconek, Drążyk & Moskal 2013). Furthermore, there were no studies where penetration using DPM as the challenge aerosol was evaluated at flow rates representative of moderate to heavy workloads. However studies measuring filtering efficiency using other challenge aerosols demonstrate decreased filtering efficiency as flow rate increases (Eninger, Honda, Adhikari, et al. 2008; Eshbaugh et al. 2009).

1.1 KEY RESEARCH QUESTIONS

Two research aims were identified:

- To ascertain whether current NaCl penetration test requirements are adequate to assess whether respirator filter media effectively filters out DPM as per AS / NZS 1716 Section 4.3.5 Appendix I.
- To determine whether Standards Australia certified respirator filter media effectively filter out DPM at a flow rate representative of a moderate to heavy work rate.

1.2 SIGNIFICANCE

In order to ascertain whether Standards Australia certified respirators effectively filter out DPM, this study aimed to determine filtering efficiency when using the hazardous contaminant itself as the challenge particulate, at flow rates and over a time period representative of workplace conditions. Studies of filter penetration against diesel engine emissions have been limited to European and US rated respirator filters, and these did not consider flow rates consistent with workplace use.

This new research will contribute to policy making, particularly with respect to certification testing protocols for Australian and International Standards. Another desired outcome is improved protection for workers using respirators to protect against the known adverse health impacts associated with DPM exposure by informing users of the limitations in selection of respiratory protection. The research will also contribute to manufacturers' and suppliers' knowledge in the selection and design of respirator filters.

1.3 HYPOTHESES

Following a review of the literature it was hypothesised that:

- Hypothesis 1: Penetration of DPM through Standards Australia P2 and P3 certified filters, when measured as EC, will not meet Standards Australia filtering efficiency requirement of 94% when tested at 95 L/min, the upper flow rate specified in AS/NZS 1716 for all tested filters. This means that the measured penetration of EC through the respirator filters will exceed 6%.
- Hypothesis 2: Penetration of DPM through Standards Australia P2 and P3 certified filters, when measured as EC, will not meet filtering efficiency requirement of 94%, when tested at 270 L/min, a flow rate representative of moderate to heavy work. This means that the measured penetration of EC through the respirator filters will exceed 6%.

1.4 LIMITATIONS AND CONSTRAINTS OF THE STUDY

- Filters were mounted inside an experimental chamber, with filtering efficiency evaluated at a constant air flow rate through the filter. These conditions were used to represent workplace use however whilst a constant air flow rate is used in Standard penetration test protocols, air flow rates would fluctuate for the respirator wearing worker.
- The number of replicates for each filter and flow rate was limited, leading to results with wide confidence intervals.

1.5 STATEMENT OF ASSUMPTIONS

Humidity and air pressure were not measured inside the experimental dilution chamber, however were assumed to be consistent with local weather data for the purpose of determining compliance with the Standards specified limits and converting the measured sampling volumes to Standard Temperature and Pressure.

2. REVIEW OF THE LITERATURE

A literature review was initially undertaken using the Scopus Database with the aim of identifying published research related to DPM health effects; methods of evaluation; effect of challenge aerosol and flow rate on respirator filter efficiency and methods of evaluating respirator filtering efficiency.

Diesel engine exhaust emissions are complex, containing particulate matter and gaseous phase components formed from the incomplete combustion of diesel fuel. Over one hundred individual constituents have been identified (US EPA 2002). Gases include carbon dioxide (CO_2), carbon monoxide (CO), oxygen (O_2), nitrogen oxides (NO_x), sulphur compounds (SO_X), low molecular weight hydrocarbons such as polycyclic aromatic hydrocarbons (PAH) and aldehydes, including formaldehyde and acrolein (US EPA 2002).

DPM includes carbonaceous particles, sulphates, ash and metals. The core carbonaceous matter, elemental carbon (EC), can agglomerate to form clusters and also adsorb other constituents. Adsorbed hydrocarbon material is termed organic carbon (OC) and includes known carcinogens such as PAH (Davies & Rogers 2004; US EPA 2002). Typical DPM composition is shown in Figure 2.1.

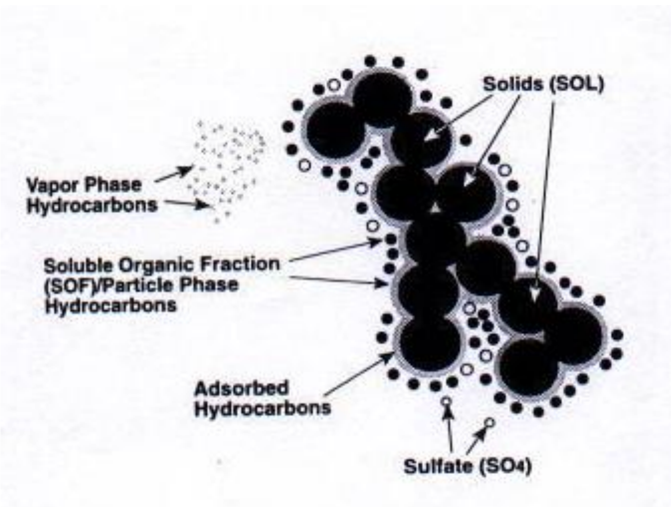

Figure 2.1: Schematic representation of DPM and vapour-phase compounds (Sawyer & Johnson 1995)

Chemical and physical processes occur during formation of DPM in the diesel combustion process (Amman & Siegla 1981; Cantrell & Rubow 1992). The initial nucleation phase involves

primary particle formation as a result of hot vapours from the exhaust condensing (Cantrell and Rubow 1992). Other components adsorb onto nucleation particles including volatile organic, sulphur and metal compounds formed during exhaust dilution and cooling. Nucleation phase particles, often described as soot, are of a size range between 0.005 – 0.05µm diameter. This mode contains a minor proportion of the particle mass (between 1-20%) but between 50-90% of the particle number (Kittelson 1998).

Nucleation particles further agglomerate to form clusters in the accumulation mode; hydrocarbons and other components continue to be adsorbed onto the nuclei. The number of particles in this phase is decreased compared to the initial nucleation phase however the particles are of larger diameter (0.1-0.3µm) (Kittelson 1998; US EPA 2002).

The coarse mode contains particles ranging from 1-10µm in diameter that have been formed during accumulation and deposited and then re-entrained in the exhaust (Kittelson 1998). A higher particle mass with fewer particles occurs in this phase, compared with the nucleation and accumulation modes.

Air quality standards define Particulate Matter (PM) in terms of the aerodynamic diameter of the particle with $PM_{0.1}$ describing particles less than 0.1 µm (ultrafine particles); $PM_{2.5}$ particles less than 2.5 µm (fine particles) and PM_{10} particles less than 10 µm (coarse particles). DPM is often a constituent of PM in the urban environment. The majority of DPM mass is in the fine - ultrafine range of PM, with a relatively high surface area to mass ratio. Particles such as sulphates can be adsorbed onto the carbon core for transfer into the respiratory system (US EPA 2002). The composition and characteristics of DPM vary depending on such factors as the engine age, engine load and fuel source (Burtscher 2005).

Figure 2.2 shows the relationship between various characteristics including size, mass and number of particles during the nucleation, accumulation and coarse phases of DPM formation, note 1 µm = 1000 nm. The overlaid lung deposition profile demonstrates a higher concentration of particles less than 0.1µm are deposited in the alveolar and tracheobronchial region of the lungs, compared with the larger size particles.

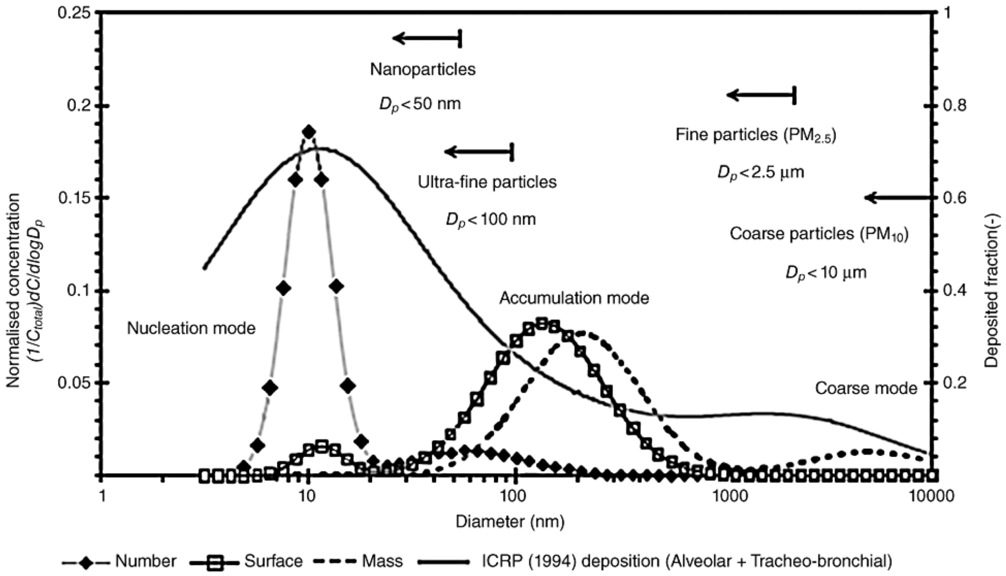

Figure 2.2: Relationship between aerosol size fractions and DPM metrics of particle number, surface area and mass, as well as deposition of particles in the human lung (Ristovski et al. 2012).

2.1 HEALTH EFFECTS ASSOCIATED WITH DIESEL PARTICULATE MATTER

The primary route of worker exposure to DPM is via inhalation. Chemical composition and physical morphology of diesel engine emissions are important determinants of health effects as these impact the amount of DPM inhaled, where it is deposited in the lung and the toxic effects (Reed et al. 2013). Particle size and morphology influence residence time in the atmosphere and reactivity of the particle (Ristovski et al. 2012). DPM is a significant contributor to air pollution and in the respirable range is easily inhaled by workers and members of the public (Zielinska 2005).

Inhaled particles in the size range 5-30µm are generally deposited in the upper lining of the airways where they can be further absorbed, whilst 1-5µm particles in the respirable fraction will be deposited more deeply in the bronchi and bronchioles. Respirable particles less than 1-2µm will more readily travel further into the lower bronchioles and gas exchange area where they will undergo diffusion (Winder and Stacey 2004). Due to the range in size of DPM particles they undergo different mechanisms of lung deposition, as well as deposit in different regions of the respiratory system as shown in Figure 2.3

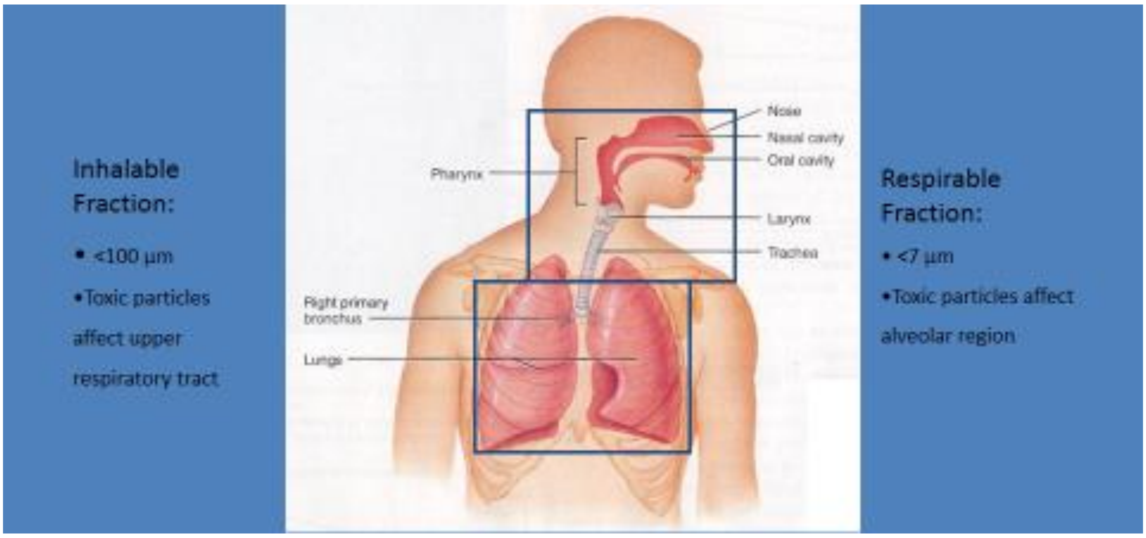

Figure 2.3: Respiratory Tract and Lungs adapted from Tortora and Graboswski (2003).

The carbonaceous component of DPM reportedly contributes to adverse health effects (Rohr & Wyzga 2012). In a review of population based epidemiological studies to associate adverse health outcomes from exposure to $PM_{2.5}$ with individual constituents, EC and OC association was reported in many of the studies, particularly with respect to cardiovascular mortality and morbidity (Rohr & Wyzga 2012). EC was linked to heart rate variability. This review did not clarify whether EC and OC are indicators for other contaminants or are directly responsible for the health impacts.

Animals and humans exhibit different characteristics with respect to deposition of particles in the lung. Various models have been developed to allow comparison between species, however in many cases the validity of these models is not absolute (US EPA 2002). Much of the published literature relates to animal testing, meaning that the relevance of these data to human exposure remains at best open to interpretation and potentially misleading.

2.1.1 Short Term, Acute Effects

Acute effects from exposure to emissions from diesel exhaust, include eye, nose and bronchial irritation as well as nausea and light-headedness (US EPA 2002).

Exacerbation of asthmatic effects is reported with one study exposing healthy workers to diesel exhaust at high concentrations and finding airway inflammatory responses (Pourazar et al. 2005). The mechanism proposed is that Reactive Oxygen Species (ROS) are generated on contact with DPM, causing oxidative stress, leading to pulmonary inflammation. It has been hypothesised that the particles adsorbed onto the core elemental carbon spherule enhance ROS production, described as the particle

overload effect (Diaz-Sanchez & Riedl 2005; Health Effects Institute 2013; Hunter, Mills & Newby 2012).

2.1.2 Cardiovascular Effects

There is a reported association between exposure to polluted air and increased incidence of cardiovascular events (Brook et al. 2010). Fine and ultrafine particles are linked to these adverse health outcomes, in particular $PM_{2.5}$ is associated with increased risks of myocardial infarction (MI), stroke, arrhythmia, and heart failure exacerbation even after short periods of exposure (Brook et al. 2010).

The biological mechanisms relating to cardiovascular outcomes are still under debate. Different pathogenic mechanisms may occur for DPM, potentially leading to differing health impacts. Plausible biological pathways linking particulate matter (PM) and cardiovascular disease (CVD) are outlined in Figure 2.4.

Coarse, fine and ultrafine PM can induce oxidative stress and inflammation in the lungs. This inflammatory response can spread systemically and promote vascular damage. Coarse, fine and ultrafine PM can also favour other Cardiovascular Disease (CVD) mechanisms. Additionally ultrafine PM (<0.1µm) can translocate into the blood stream and cells, interacting directly with endothelial cells and platelets with potentially harmful effects (Martinelli, Olivieri and Girelli 2013).

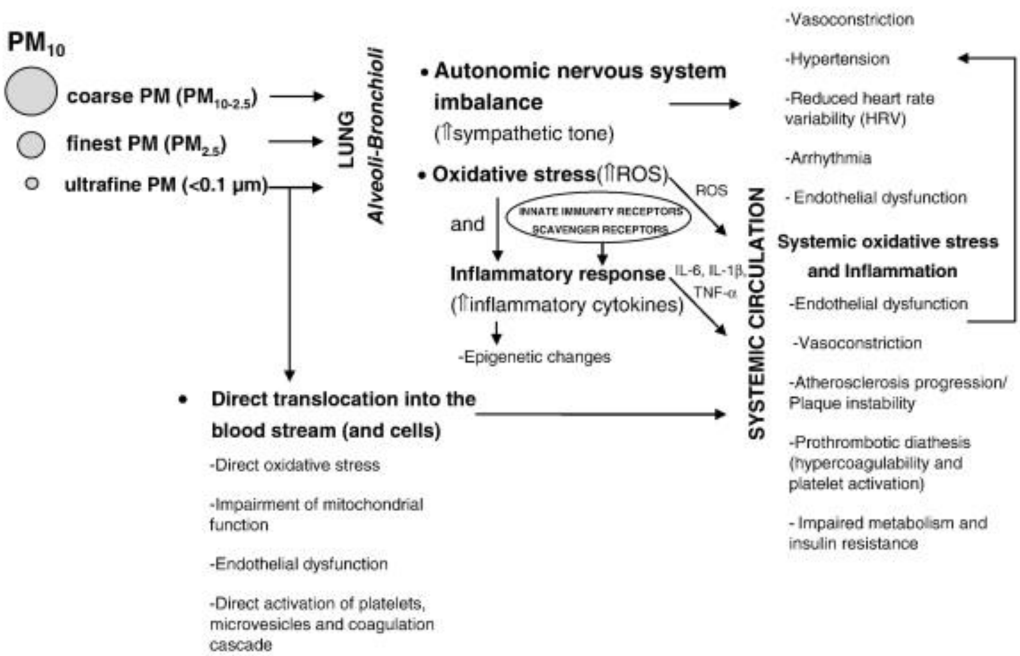

Figure 2.4: Biological pathways linking particulate matter (PM) and cardiovascular diseases (CVD) (Martinelli, Olivieri and Girelli 2013).

The contributory risk of DPM causing adverse health outcomes is difficult to accurately quantify. Mortality amongst a cohort of approximately 54,000 employees in the US trucking industry was evaluated with a mean elevated risk of ischemic heart disease (IHD) with Standardised Mortality Ratio (SMR) of 1.49, 1.32 and 1.34 for drivers, dockworkers and shop workers respectively (Laden et al. 2007). Whilst there was an elevation of smokers in this population above background, the authors do not believe this alone would explain the increase in observed IHD.

A study of heavy vehicle operators in the US compared to other workers found higher mortality rates due to IHD with the proportional mortality ratio (PMR) calculated as 1.09 as compared to 0.89 for workers in other job categories (Finkelstein et al. 2004).

DPM was the contaminant investigated in a study of construction workers in Sweden. This study reported an elevated risk of IHD with exposure to diesel exhaust with a relative risk (RR) of 1.18 and a 95% confidence interval (CI) (Torén et al. 2007). There was no increased risk noted for cerebrovascular disease RR of 0.97 with a 95% CI (Torén et al. 2007).

2.1.3 Carcinogenicity

2.1.3.1 Lung Cancer

In a 2012 press release, the International Agency for Research on Cancer (IARC) announced that it has classified diesel engine exhaust as carcinogenic to humans (Group 1), on the basis that exposure is linked with an increased risk for lung cancer (World Health Organisation 2012). This was upgraded from the 1989 classification as probably carcinogenic to humans (Group 2A) (World Health Organisation 1989). The 2012 press release referenced epidemiological studies, including the Diesel Exhaust in Miner’s study which evaluated 198 lung cancer deaths out of 278 041 person years (Attfield, Lubin, et al. 2010; Attfield et al. 2012; Attfield, Vermeulen, et al. 2010; Lubin et al. 2010; Silverman et al. 2012; Stewart et al. 2012; Vermeulen et al. 2010). An increased risk of lung cancer mortality was associated with diesel exhaust exposure and was prevalent for underground workers, after accounting for smoking and other confounders. Elemental carbon exposure estimates were determined by comparing available EC data with CO data, determining the correlation, and subsequently extrapolating historic EC measurements using the CO emissions data and engine

horsepower. Criticisms of the study include the weak correlation between the available CO and EC data. Some of the CO data were collected using detector tubes which have limited validity in assessing occupational exposures and this also casts doubt over the validity of the extrapolation methodology (Borak et al. 2011).

Other studies have concluded that exposure to diesel exhaust contributes to an increased lung cancer risk (Health Effects Institute 1995, 1999; Laden et al. 2007; US EPA 2002). However there remains uncertainty around the level of risk to workers (Rogers and Davies 2005). The IARC monograph determined that there was a positive association between the lung cancer risk and exposure to diesel engine exhaust emissions, but was not able to delineate between components of the exhaust emissions due to the complex nature of the emissions and the carcinogenicity or tumour promoting effects of some of those components (World Health Organisation 2013).

2.1.3.2 Bladder Cancer

International Agency for Research on Cancer (World Health Organisation 2012) noted an association with an increased bladder cancer risk and exposure to diesel exhaust. However supporting evidence was limited (World Health Organisation 2013). Occupational exposure to PAH, a component of DPM has been investigated and workers in the trucking industry have a relative risk of bladder cancer linked to exposure to PAH 1.2 – 2.3 times higher than the general population. However risk estimates for other studies vary slightly above or below 1.0. A confirmed link and plausible biological mechanism has not been established and many of the retrospective studies do not have accurate exposure assessment data available (Kellen et al. 2007; Kiriluk et al. 2012; World Health Organisation 2013).

2.1.3.3 Mechanism of Carcinogenicity

The mechanism by which diesel particulate matter causes carcinogenicity is still unclear. Particle overload, leading to an inflammatory response has been reported in some animal studies and postulated for humans, indicating that higher exposed workers may be more at risk (World Health Organisation 2013).

2.2 IMPLICATIONS OF NEW TECHNOLOGY DIESEL EMISSIONS FOR HISTORICAL DATA

Standards exist for on road diesel vehicle emissions and fuel quality, both in Australia and internationally (DieselNet 2014). These standards are becoming increasingly stringent to reduce overall emissions of diesel exhaust, generating significant improvements to engine technology and fuel sources. The emission profile of diesel exhaust differs between new technology diesel engines and their historical predecessors. A reduction in the overall particle mass of DPM has been measured in new technology diesel engines (Hesterberg et al. 2011; Kittelson et al. 2010; Kittelson 1998). As an example use of Diesel Particulate Filters, whilst lowering the overall particle mass, increases the likelihood for nucleation (Maricq 2007) and therefore the number of smaller sized particles may increase.

Most epidemiological studies to date are based on exposure from older technology diesel sources. Work is currently funded by the Health Effects Institute under the Advanced Collaborative Emissions Study (ACES) to evaluate the hypothesis that 2007 emissions from compliant on-road diesel vehicles "*…will not cause an increase in tumour formation or substantial toxic effects in rats and mice at the highest concentration of exhaust that can be used … although some biological effects may occur*." (McDonald et al. 2012). Initial results from the study indicate that exposing rats to DPM did not cause identifiable differences in mortality and morbidity rates, nor generate other significant differences. However, some statistically significant effects, such as early signs of lung changes and oxidative stress, were evident at the high exposures (McDonald et al. 2012). How these findings translate to human exposure remains to be determined.

2.3 CURRENT LEGISLATION AND STANDARDS FOR OCCUPATIONAL EXPOSURE TO DPM

Safe Work Australia has not designated an occupational exposure standard for diesel particulate matter (Safe Work Australia 2014). DPM is not specifically referenced in the Model Work Health and Safety regulations, however is a relevant consideration under the requirements of Part 3.1 Managing Risks to Health and Safety; specifically Clause 34 where a duty holder must identify reasonably foreseeable risks to health and safety and Clause 35 where a duty holder must eliminate those risks or minimise those risks as far as reasonably practicable (SafeWork Australia 2011).

The Australian Institute of Occupational Hygienists (AIOH 2013) states that "*In the absence of any more definitive data, the AIOH supports the use of an exposure standard of 0.1 mg/m³ DPM (measured as submicron elemental carbon) as being a balance between the factors of primarily minimising irritation, secondarily minimising any potential for risk of lung cancer to a level that is not detectable in a practical sense in the work force, and finally on the basis of setting a level achievable as best practice by industry and government*".

Various Australian mining industry regulatory bodies have adopted an exposure standard of 0.1mg/m^3 EC including NSW under MDG 29 (NSW Department of Primary Industries 2008) (NSW Trade and Investment Mine Safety 2013); Queensland Department of Natural Resources and Mines (2012) and in Western Australia the Department of Mines and Petroleum Safety (Department of Mines and Petroleum 2013).

Internationally, a number of countries have assigned exposure standards for DPM measured in various forms, as prescribed limits or guideline values, outlined in Table 2.1.

TABLE 2.1: INTERNATIONAL OCCUPATIONAL EXPOSURE STANDARDS FOR DPM

Country	Standard	8 hour limit value (mg/m^3)
United States (MSHA 2001)	MSHA - Permissible exposure level	0.16 TC (equivalent to 0.12 EC)
Austria (IFA 2014)	TRK value, respirable aerosol - Underground mining	0.3 (STEL 1.2)
	TRK value, respirable aerosol – other exposures	0.1 (STEL 0.4)
Ireland (IFA 2014)	Diesel Exhaust dust, respirable	0.15 (Particulates <0.1µm)
Poland (IFA 2014)	Diesel Exhaust dust, respirable	0.5
Germany (DieselNet 2014)	Whole diesel particulate – Underground non coal mines	0.3 EC
	Whole diesel particulate – All other activities	0.1 EC

IFA - Institute for Occupational Safety and Health of the German Social Accident Insurance

TC – Total carbon   TRK – Technical Guidance Concentration   STEL – Short Term Exposure Limit

2.4 PUBLISHED EXPOSURE DATA

2.4.1 Australian Workplaces

Exposure data for various coal mines in NSW reported DPM exposures measured as EC ranging from 0.01-0.55 mg/m^3 (Mace 2008; Rogers & Davies 2005). Underground metalliferous mine exposures range from 0.01-0.42mg/m^3 EC (AIOH 2013).

The Australian Government Department of Defence, in a fact sheet regarding diesel exhaust emissions for a specific army vehicle states that "*levels of exposure to DPM were well within the AIOH recommended occupational exposure standard of 0.1mg/m^3, measured as submicron elemental carbon*" (Defence Work Health and Safety 2012). Data on other diesel exposures within Defence were not publicly available.

2.5 CONTROL OF EXPOSURE TO DPM

Control of exposure to DPM should be via the Hierarchy of Control, with priority given to controlling exposures at the source, rather than at the receiver (SafeWork Australia 2011). Increasing regulatory requirements aimed at reducing emissions from diesel engines, including more stringent emissions and testing criteria, have led to better technologies with regard to the engines themselves, cleaner burning fuels and more effective exhaust treatment systems. In Australia these requirements are specific to on road vehicles, and there is a range of new and old technology diesel engines in workplaces.

Respiratory protection, whilst at the lowest level of the control hierarchy, remains an important workplace control to supplement other management strategies or where higher order controls are not effective (Cherrie 2009; Standards Australia International Ltd & Standards New Zealand 2009).

The nine NSW coal mines for which exposure data were reported (Mace 2008) utilised a number of control strategies including low sulphur fuel, ventilation techniques, engine maintenance programs, exhaust filters, a tag board system to monitor the number of engines in the common space, road design improvements and an education system to raise awareness of how to minimise exposure to DPM during operation of equipment. Personal protective equipment was also identified as a control for these mine sites with a P2 respirator filter impregnated with charcoal recommended.

2.6 RESPIRATORY PROTECTION TO MITIGATE EXPOSURE TO DPM

2.6.1 Selection

Diesel particulate matter consists of thermally generated particles, hence a P2 or P3 filter is required, providing a minimum protection factor of 10 times the occupational exposure standard (Standards Australia International Ltd & Standards New Zealand 2009). Depending on the facepiece that is used in conjunction with the filter, the protection factor can increase to 100 times the occupational exposure standard. These protection factors assume that the respirator has been well fitted and the wearer is clean shaven and trained in its use (Standards Australia International Ltd & Standards New Zealand 2009). A search of key Australian manufacturer / supplier websites revealed that from an end user perspective there is little specific guidance available for the selection of a respirator against DPM, summarised in Table 2.2.

TABLE 2.2: AUSTRALIAN RESPIRATOR SUPPLIER'S RECOMMENDATIONS FOR RESPIRATORY PROTECTION

Supplier	Recommendation for DPM
3M Australia	A search for diesel recommends the 9923V P2 disposable respirator with nuisance level organic vapour relief.
Draeger Safety Pacific	A technical brochure recommends the Dräger X-plore 1320V and 1720V, with and without odour, and provides filtration efficiency data for these filters
Moldex	A search for diesel recommends the 2400P2 disposable respirator with nuisance odour relief
MSA Australia	No specific recommendation for DPM
Paftec	No specific recommendation for DPM
S.E.A. Group	No specific recommendations for DPM
Scott Safety	No specific recommendations for DPM

(3M 2013; Draeger Safety Pacific Pty Ltd 2011; Moldex Oceania 2015; MSA Australia 2015; Paftec 2014; Scott Safety Australia 2014; The S.E.A. Group 2015)

Anecdotal evidence from suppliers and end users in the mining sector indicates that users are selecting a range of P2 and P3 respirators, often with a carbon layer to

provide some additional protection against volatile organics contained in diesel exhaust emissions.

2.6.2 Current test protocols to evaluate filtering efficiency

Minimum certification requirements for air-purifying particulate respirators include testing penetration through the filter media to evaluate filtering efficiency, using prescribed challenge aerosols and flow rates (CEN 2001; Code of Federal Regulations 1995; Standards Australia International Ltd & Standards New Zealand 2012).

In Australia, respiratory protection is evaluated in accordance with AS/NZS 1716 (Standards Australia International Ltd & Standards New Zealand 2012). A number of criteria are evaluated to gain Australian Standards approval, including Total Inward Leakage (TIL). TIL is defined as the combination of contaminated air that leaks through the respirator from various sources, including face seal, valves and gaskets and penetration through the filter media. It is measured using sodium chloride (NaCl) aerosol particles as described in Appendix D of AS / NZS 1716 (Standards Australia International Ltd & Standards New Zealand 2012).

For particulate filters, filtering efficiency is determined by challenging the filter with aerosolised NaCl and measuring the concentration before and after the filter. Penetration of particles through the filter media is tested in accordance with Appendix I of AS/NZS 1716 (Standards Australia International Ltd & Standards New Zealand 2012) and calculated using the following equation:

$$Penetration \ = \frac{Concentration\ after\ filter}{Concentration\ before\ filter}\ x\ 100\%$$

A P2 rating for the filter is achieved if the penetration through the filter media is less than 6% and for P3 less than 0.05% (i.e. filtering efficiency is greater than 94% and 99.95% respectively).

Internationally, test protocols in standards to evaluate filtering efficiency differ in relation to challenge aerosols and flow rates as summarised in Table 2.3 (CEN 2001; Code of Federal Regulations 1995). US test certification protocols differentiate between oil and non-oil based contaminants, and specify use of di-octyl phthalate (DOP) as the challenge aerosol for oil based contaminants like DPM (Code of Federal Regulations 1995). NIOSH R series filters are rates as oil proof, and P series filters as oil resistant

for short periods, whilst N series rated filters would not be recommended for oil based contaminants. European Standards require filters to be tested with both NaCl and Paraffin Oil (CEN 2001). ISO are currently developing respiratory protection standards, with published drafts available for review and comment. The aim of these new standards is to align respirator testing protocols and specifications internationally (ISO 2012a, 2013). Consistent with European Standards, they are recommending NaCl and Paraffin Oil as the challenge aerosols for certification testing.

TABLE 2.3: REQUIRED FILTER EFFICIENCY, FLOW RATES AND CHALLENGE AEROSOLS

Reference Standard	Filter	Filtering Efficiency (%)	Flow Rate (L/min)	Challenge Aerosol
AS / NZS 1716: 2012	P2	94	30 / 95	NaCl
	P3	99.5		
NIOSH 42CFR84: 1995	N, P or R95	95	85	NaCl (N) DOP (P and R)
	FFN, P or R100	99.7	85	NaCl (N) DOP (P and R)
EN 149: 2001 and EN143: 2000 (CEN 2000)	P2 / FFP2	94	95	NaCl / Paraffin Oil
	P3 / FFP3	99	95	
ISO / FDIS 16900-3: 2012 **ISO/CD 17420-2.2: 2013**	F1-F5	80-99.99	85 / 135 / 205 / 255	NaCl / Paraffin Oil

(CEN 2000, 2001; Code of Federal Regulations 1995; ISO 2012a, 2013; Standards Australia International Ltd & Standards New Zealand 2012)

2.6.3 Limitations of current testing protocols

The Diesel Exhaust in Miner's study reported on use of protective equipment for workers. Whilst this information was obtained primarily from interviews with next of kin and hence does not provide specific and accurate data, the authors observed that "*subjects who reported having used protective equipment appeared to experience risks similar to the estimates for all workers combined*" (Silverman et al. 2012). This finding could be attributed to a number of causes, however highlights important factors in the use of protective equipment, including selection of the correct respirator, ensuring it is fitted correctly and that it is effective against the agents associated with the adverse health outcome.

AS/NZS1716 outlines the minimum requirements for approval of respiratory protection in Australia and New Zealand. Recognition of potential limitations of the current testing protocol by the Joint Technical Committee SF-010 is indicated by the preface of AS/NZS 1716, stating that "*It is anticipated that a new series of ISO standards will be published in the next few years that will incorporate major developments that will address most, if not all, concerns highlighted in the previous edition. When such ISO standards are published, it is planned that they will be adopted as the next revision of AS/NZS 1716*" (Standards Australia International Ltd & Standards New Zealand 2012). The specific concerns are not highlighted in the document, however limitations of the current standard with respect to challenge aerosol and flow rate are discussed below.

2.6.3.1 Challenge Aerosol

Filtering efficiency is tested using a designated challenge aerosol that is not specific to the contaminant for which protection is being sought. DPM differs from NaCl in both chemical structure and morphology. NaCl particles are either single crystals or compact agglomerations of crystals (Cho et al. 2011) whilst DPM has various spherical and agglomerated particles (Davies & Rogers 2004) which may have different mechanisms of filtration and hence potentially varying penetrations through the filter.

These differences were considered by Penconek, Drążyk & Moskal (2013) who evaluated European Standard-certified half masks against DPM and reported that the DPM was more penetrating than the standard challenge particles of NaCl, paraffin oil and DOP. Filtering efficiency of DPM mass did not meet the standards set for certification, with 11-16 % of particles measured as penetrating the filtering facepiece (FF) FFP2 filters and 14-25 % penetration of particles for the FFP3. The method used the gravimetric load on the respirator filter to evaluate penetration, which would not be specific to DPM. Additionally they did not report whether they evaluated the efficacy of the seal to the respirator headform. It is unclear why the FFP3 filters had a higher penetration that the FFP2 rated filters. Another limitation of the study is that the testing was conducted at a flow rate through the filter of 30L/min which is lower than the flow rate of 95L/min designated in the standard (CEN 2000).

In another study by the same authors (Penconek et al. 2013) fibrous filters used for aerosol filtration were challenged with DPM, using varying fuel sources, to generate particles of different morphology. The authors reported that "*small (<0.1 µm) more spherical in shape aggregates are filtered with higher efficiency than small dendrite-like aggregates*".

Contrary to this finding, Janssen and Bidwell (2006) evaluated the performance of US NIOSH certified electret filters by exposing them to DPM and measuring particle size distribution and penetration of EC. EC penetration was not detected for the P95 filter. The R95 filters met certification requirements for filtering efficiency. For both P and R filters, EC penetration was lower than the standard test challenge aerosols. N95 filters did not demonstrate acceptable filtration efficiency, however are not rated for use against DPM given it is an oily residue. P and R respirators are rated as efficient against atmospheres containing oily residues, however an R respirator should only be used for one shift in this type of atmosphere (Code of Federal Regulations 1995). A confounding factor in this study was that the DPM load on the filter was determined to be higher than typical workplace exposures. The testing was however conducted at a flow rate of 25L/min which is lower than the 95L/min designated in the NIOSH standard (Code of Federal Regulations 1995).

Gorman, from 3M, noted that that 3M 9913V respirators, the predecessor to the 9923V filters currently available in Australia were also evaluated utilising the testing protocol outlined above (Gorman 2013), and penetration of elemental carbon met certification limits specified in AS/NZS 1716 (Standards Australia International Ltd & Standards New Zealand 2009). These results are unpublished.

Cho (2011) compared pressure drop and filtering efficiency of NaCl and welding fumes and found that efficiency was higher for NaCl, however the pressure drop increased due to accumulation of welding fumes on the filter.

2.6.3.2 Flow Rate

As summarised in Table 2.3 filtering efficiency is measured at designated flow rates internationally, including 30, 85 and 95 L/min. International Standards Organisation (ISO) provide reference tables of peak flow rate for

various body sizes and work rates, both with and without speech (ISO 2007), as adapted and summarised in Table 2.4.

TABLE 2.4: ESTIMATION OF PEAK INSPIRATORY FLOW RATES FOR CONDITIONS OF SPEECH AND NO SPEECH, FOR A PERSON WITH A BODY SURFACE AREA OF 2.11m^2 (ADAPTED FROM ISO 2007).

Work Rate	Average Metabolic Rate (W/m^2)	Peak Flow Rate (no speech) L/min	Peak Flow Rate (speech) L/min
Resting	65	57	141.6
Light work	100	82.2	177.6
Moderate work	165	124.2	231
Heavy work	230	163.8	275.4
Very heavy work	290	198.6	310.8
Very, very heavy work (2 h)	400	259.8	367.8
Extremely heavy work (15 min)	475	300	402.6
Maximal work (5 min)	600	364.2	455.4

These data demonstrate that the flow rates used in the current testing protocols underrepresent workers required to work at moderate or greater work rates, especially if communication is required. Even at rest, the peak flow rate exceeds the 95L/min designated in the AS/NZS test protocol if communication is required.

The technical specification data are supported by workplace studies, such as (Smith, Whitelaw and Davies 2013) who report that for a cohort of respirator wearing miners the peak inspiratory airflow ranged from 80.5 L/min at rest to 323 L/min for the highest work rate measured, during speech. Berndtsson Howie (2002), Jannsen (2003) and Caretti and Coyne (2006) also suggest that a higher airflow breathing rate occurs in the workplace than the flow rates at which filtering efficiency is evaluated.

The newly drafted International standards aim to provide a consistent approach and recommend a range of Protection Classes for a range of Work

Rates. The work rates at which testing will be required are aligned with the flow rates reported in 2.6.3.2 (ISO 2012b, 2013)

In a study where penetration of nanoparticles was measured (Balazy et al. 2006), two types of N95 respirators were challenged with NaCl particles at 30 L/min and 85 L/min. Whilst the filtering efficiency met certification requirements at the lower flow rate, filtering efficiency did not meet the 95% threshold required for certification at the higher flow rate as shown in Figure 2.5. Additionally, penetration was found to increase with increasing flow rate.

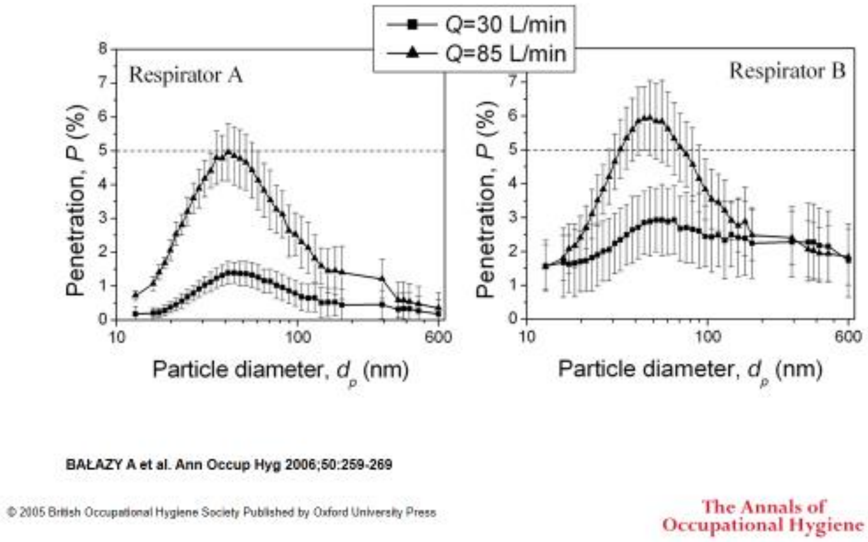

Figure 2.5: Effect of the inhalation flow rate on the penetration of particles through Respirator A and Respirator B (n = 10) (Balazy et al. 2006).

Eshbaugh and co-workers (2009) evaluated N95 and P100 respirators at flow rates of 85, 270 and 360 L/min. Their findings demonstrated that penetration of NaCl increased as flow rate increased. Similar trends were reported when performance of N95 and N99 respirators against NaCl and viruses at varying flow rates were evaluated (Eninger, Honda, Reponen, et al. 2008) and when N95 respirators were evaluated against nanoparticles at flow rates ranging from 85 - 360 L/min, using NaCl as the challenge aerosol (Haghighat et al. 2012). In a study where P 100 filters were challenged with combustion aerosols from various sources, penetration as a function of particle size increased when the flow rate increased from 30L/min to 85L/min, however

decreased when the flow rates were increased from 85 to 135 L/min (He et al. 2013).

2.6.4 Impact of flow rate and challenge aerosol on filter performance

Revoir and Bien (1997) outline that properties influencing the capture of particles by filter media are related to:

- the characteristics of the particle including size, shape, density and electrical charge;
- the properties of the filter media including diameter, density and electrical charge
- the mechanisms of how the filter media capture particles (as described below and shown in Figure 2.6):
    - inertial impaction – large particles with too much inertia are captured when the airstream flow is diverted by the filter
    - interception – larger particles may be intercepted by the filter fibres
    - diffusion – smaller particles are bombarded by the airstream and diverted into contact with the fibre filter
    - electrostatic attraction – oppositely charged particles to fibre filter are captured, most effective for smaller particles.

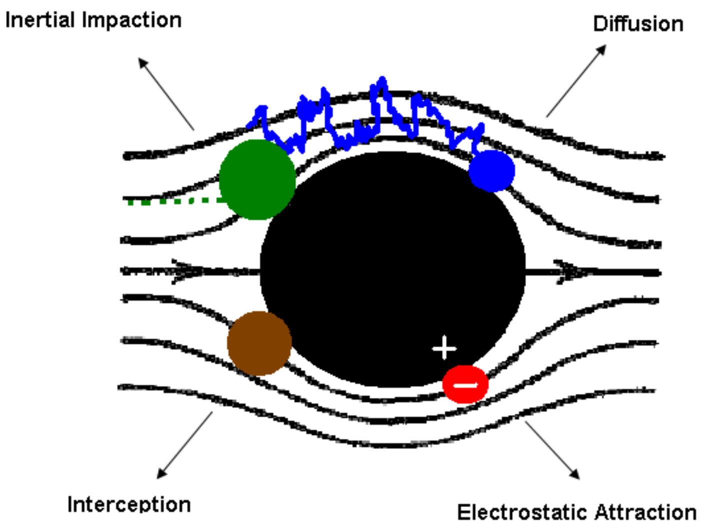

Figure 2.6: Filtration mechanisms for capture of particles (Hinds 1999)

Each of these different filter capture mechanisms will play a more dominant role at various particle sizes. The most penetrating particle size (MPPS) describes the particle size range that is most difficult to remove from the air stream, illustrated by the

example provided in Figure 2.7. If penetration is evaluated at the most penetrating particle size, then this provides a worst case evaluation of filtering efficiency.

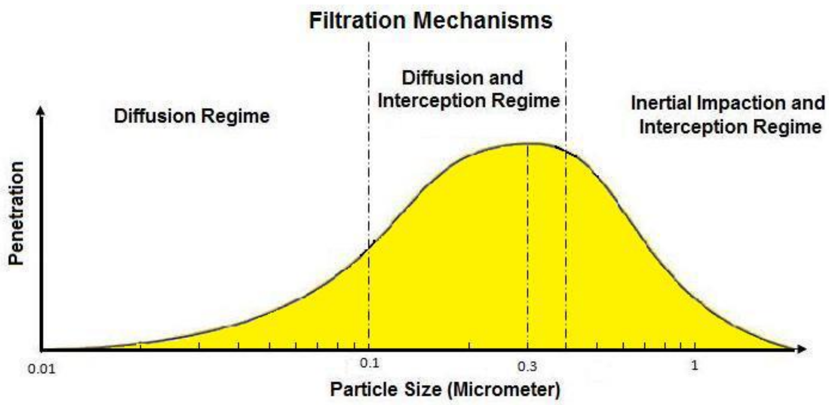

Figure 2.7: Example of most penetrating particle size and filtration mechanisms that apply with respect to particle size and filter efficiency (Haghighat et al. 2012)

Various studies reporting impact of flow rate and/or challenge aerosol are outlined in Appendix A, including a summary of the test parameters and outcomes. The study by Balazy et al. (2006) demonstrates that penetration of particles through the filter media is linked to particle size and flow rate, with a parabolic like curve around the Most Penetrating Particle Size, as shown in Figure 2.7. The MPPS calculated varied with respirator type.

He et al. (2013) evaluated the performance of a half face respirator with P100 filters at a range of flow rates. The filter was challenged with combustion products from burning wood, paper and plastic and penetration was determined as a function of particle number. The results demonstrated that the variables of flow rate, particle size and aerosol source affected filter performance with penetration most significant in the ultrafine range between 0.04-0.2 µm diameter.

The Institut de recherche Robert-Sauvé en santé et en Sécurité du Travail (IRSST) reported on a procedure developed to measure the effectiveness of respirator filters against nanoparticles (Haghighat et al. 2012). This study identified that penetration through the filter media at variable flow rates impacted on filtration performance. By challenging the filter media with nanoparticles of NaCl, the researchers measured the MPPS for various filter media over a period of time and found that it varied with flow rate, properties of the filter media and length of exposure.

Penetration has been shown to increase at the most penetrating particle size at higher flow rates, in a study conducted by measuring Total inward leakage for N95 and P100 cartridge respirators. The authors conclude that "*most penetrating particle size should be considered as a key factor in the development of respirator standards and recommendations for protection against nanoparticles*" (Rengasamy, BerryAnn and Szalajda 2013).

2.7 EVALUATION OF RESEARCH METHODS

2.7.1 Measurement of DPM

Given the complex composition of DPM and the varying physical and chemical characteristics, there are a variety of methods available to assess exposure. Measurement of EC concentration, a mass based method, is currently a preferred option because EC is a major constituent of the particulate mass, can be quantified at low levels and in most workplaces the source of EC is diesel (Birch & Cary 1996; Bunn et al. 2002; Liukonen, Grogan & Myers 2002) . EC has also been linked to potential adverse health outcomes and has an exposure standard in Australian mining regulations based on minimizing these adverse health outcomes.

Noll (2006) agrees that Elemental Carbon is a good marker for DPM but queries whether it is still as effective with newer diesel technology, given lower levels of particulate mass and hence EC emissions. Currently there are no occupational exposure standards specific to metrics such as particle number, surface area and particle size which are also characteristics associated with exposure to DPM. Therefore whilst measurement of these parameters is feasible, there are no guidelines to determine whether the measured exposures are acceptable, making interpretation of the results difficult.

The measurement of EC relies on a Thermo-optical method of analysis (NIOSH 2003). This analysis reports both EC and OC, whilst TC can be calculated by summing EC and OC.

Direct measurement techniques are also available to measure EC, including instruments such as the aethelometer and Flirtec DPM monitor. These techniques rely on Laser light scattering and use an internal instrument calibration factor to convert the TPM (Total Particulate Matter) to EC. This internal calibration factor is problematic as it will vary with the characteristics of the engine (Davies 2013). Whilst

more convenient and inexpensive to use a direct reading instrument to measure EC, until a direct reading device can be validated, NIOSH 5040 is the preferred method.

In the US, the exposure limit is for TC, however in recognition that TC concentration may be increased by other carbon sources, such as cigarette smoke, the EC concentration is measured and a conversion factor is used to calculate TC. This conversion factor will vary depending on the diesel engine source (MSHA 2001). A recent study explored the relationship between EC and TC and found a strong correlation for metal / non metal underground mines in the US, but did not go so far as to recommend an accurate ratio. For underground coal mines in Australia, the study reported a conversion factor of 1.27 (equivalent to an EC/TC ratio of 0.78) with a range of about 19% (Noll et al. 2014). However, available data at lower exposure levels were excluded when determining the TC/EC ratio which may have incorrectly weighted the reported findings.

3. METHODOLOGY

A method based on the protocol for testing filtering efficiency of particulate filters outlined in AS1716 Appendix I (Standards Australia International Ltd & Standards New Zealand 2012), was developed in order to evaluate the key research questions. Reference was also made to International Standards ISO16900-3 Part 3: Determination of Particle Filter Penetration (ISO 2012a). Unlike these referenced standards, DPM was used in place of sodium chloride as the challenge aerosol. The sampling methodology required the use of an experimental chamber which was purpose built.

The study was confined to the efficiency of filter media with respect to challenge aerosol and flow rate and did not consider other factors which influence the level of protection provided to users, such as Total Inward Leakage (TIL). Additionally, the particulate matter component of diesel engine emissions was the focus of the study, given the adverse health impacts that have been associated with this phase. Gaseous components of the emissions, such as carbon \ monoxide, were not considered.

The study was conducted in 3 parts. Following an initial small scale Pilot Study, Study 1 and Study 2 were conducted to compare the results for 2 diesel engines. Materials and methods for each study are described below. Calibration certificates are attached as Appendices B - L.

3.1 RESPIRATOR FILTER MEDIA

Three respirator filter models used in Australian workplaces to protect workers from exposure to DPM were tested, including respirator filters classified as P2 and P3, which utilise electret and mechanical type filter media, shown in Figure 3.1.

Figure 3.1: Respirator Filters Mounted onto Adapter with Exhalation Valve Sealed (1320V, 9923V & SR510)

3.1.1 1320V Particulate Respirator

The Dräger X-plore 1320V Odour respirator is manufactured by Dräger and supplied by Draeger Safety Pacific in Australia. It is a P2 rated respirator in accordance with AS1716 (Standards Australia International Ltd & Standards New Zealand 2012), as well as a FFP2 rated filter in accordance with European Norm EN149:2001/AC (CEN 2001). CoolSAFE™ filter material is used with the addition of an activated carbon layer to protect from nuisance odours.

According to the supplier, filtering efficiency of this respirator for DPM exceeds 95.6% (Draeger Safety Pacific Pty Ltd 2011). Limited information on the test method is provided, however it is reported as a loading on the filter of acetylene, ethylene and methane. Whilst these gases are known to be present in diesel emissions (US EPA 2002), the basis for which they are used as markers for DPM exposure is unclear.

3.1.2 9923V Particulate Respirator

The 9923V respirator, manufactured by 3M™ and supplied by 3M™ Australia, is rated as a P2 particulate respirator (Standards Australia International Ltd & Standards New Zealand 2012) with nuisance level organic vapour relief provided by the activated carbon filter. It's suggested use is "*Mining – underground coal and metalliferous, exposure to diesel particulate matter, odours and unburned fuel vapours*" (3M 2013). It is an electret filter fitted with an exhalation valve, with polyester / polypropylene and carbon.

3.1.3 SR510 Particulate Filters

The SR510 particle filter is a mechanical filter manufactured by Sundström and supplied by the S.E.A. Group in Australia with a P3 rating (Standards Australia

International Ltd & Standards New Zealand 2012). The filter also has CE0194 rating and EN149:2000 as an FFP3 filter (CEN 2001).

3.2 PILOT STUDY

A small scale Pilot Study was initially conducted and aimed to:

- determine the suitability of the experimental chamber;
- assess the exposure time required to measure a detectable sample of EC on the downstream side of the filter media;
- evaluate use of the direct reading instrument to estimate EC concentration in the experimental chamber; and
- conduct replicate sampling to consider sample size for subsequent studies.

3.2.1 Materials

3.2.1.1 Generation of Diesel Emissions

A 6kVA portable powered generator powered by a 1 cylinder air cooled diesel engine was used to generate diesel emissions. Two 2000W heaters at high setting were used to place a 100% load on the generator (Davies 2013). The generator was fuelled with Shell Diesel obtained from the local service station.

3.2.1.2 Temperature and Flow Rate

A Dick Smith KJ Model Q1437 calibrated thermometer was used to measure temperature in the experimental chamber. Flow rate through the respirator filter was measured using calibrated TSI4040 flow meters Serial Numbers 40400438011, 40400419008. The accuracy of the flow meters is reported as ± 2%.

3.2.1.3 Measurement of EC and TC

Vacuum pumps AQ065 and YNA were used to draw air through the SKC225-401 37mm preloaded 3 piece sample cassettes as outlined in NIOSH 5040 (NIOSH 2003). The pump flow rate was approximately 10L/min as measured by calibrated Gas Meter 42 (Serial Number AMPY 75031376) and Gas Meter 45 (Serial Number 750613), with an uncertainty error of ±0.25%. A calibrated stop watch was used to measure the elapsed sampling time.

Two blank samples were also collected each sampling day and submitted for analysis with the test samples.

3.2.1.4 Measurement of TPM

A calibrated TSI Model 8520 DustTrak™ Aerosol Monitor Serial No 85201865 was used to measure TPM pre and post the respirator filters, resolution was ± 0.1%. This direct reading instrument allowed penetration by TPM to be calculated as an indicative result, given the collected samples had to undergo further analysis for EC and OC. The DustTrak™ was zeroed at the beginning of each sampling day and checked periodically throughout the sampling, by comparing the pre and post filter readings, without a respirator filter in place.

3.2.2 Determination of Sampling Requirements

To determine the Pilot Study sampling requirements, calculations were conducted using known parameters. NIOSH Method 5040 (NIOSH 2003) outlines a minimum sample volume of 142L @ 0.04mg/m^3 and reports the limit of detection as 0.002mg/m^3 for a 960L air sample. At the designated sampling flow rate of 10L/min, sample collection time is approximately 15 minutes to achieve the required sampling volume.

For EC to be measurable after the respirator filter a concentration exceeding the detection limit of 0.04mg/m^3 is required. P2 rated filters require a minimum 94% filtering efficiency therefore the EC concentration in the chamber (i.e. pre the respirator filter) must exceed 0.7mg/m^3. TPM concentration in the exhaust whilst the generator is at load is approximately 5-6mg/m^3 (Davies 2013), hence the required concentration of EC is theoretically possible.

3.2.3 Method

The diesel generator was operated at 100% load, and the exhaust emissions were directed into the experimental chamber. The generator was allowed to run for a minimum of fifteen minutes prior to sampling and until the TPM reading in the experimental chamber had stabilised. The volume of the chamber was known to be approximately 1 m^3. An air conditioning unit was used to cool the dilution air in the chamber to 23±2ºC, as per AS1716 (Standards Australia International Ltd & Standards New Zealand 2012).

The respirator filters were placed inside the chamber and attached via an adapter with a DIN thread for the P2 filters and a Sundström SR280-3 Adapter for the P3 filter. The exhalation valves of the P2 filters were sealed using Bostik Blu Tac. The P2 filters were sealed onto the adapter around the facial seal by applying Tecbond 2 using a hot melt gun.

Diesel emissions were drawn through the respirator filter by constant flow vacuum pumps. Flow through the filter was adjusted to 95L/min or 360L/min ± 5L/min, as measured by the TSI flowmeters. These flow rates were chosen to represent the upper flow rate in the current Standards Australia penetration test as well as the flow rate outlined in the ISO technical standard representing heavy work (ISO 2007; Standards Australia International Ltd & Standards New Zealand 2012). DPM was collected simultaneously before and after the particulate filter, in accordance with NIOSH Method 5040 (NIOSH 2003). Coal Mines Technical Services Pty Ltd (CMTS) analysed the collected samples for EC and OC, using Test Method: Thermal Optical Organic Carbon / Elemental Carbon.

The test sequence for the Pilot Study is shown in Table 3.1. Three replicate tests were conducted, with four consecutive fifteen minute samples collected for the 9923V filter at 95 L/min. This total one hour sample period was considered to be representative of the time that a worker may reasonably use a negative pressure respirator in a workplace environment without removal and is recommended by the UK HSE as the maximum continuous wear time (HSE 2013). However, it was unclear how penetration would vary over the one hour sampling period, hence samples were collected for consecutive 15 minute periods.

Pre and post filter samples were collected for the SR510 filter at 95L/min at 15 and 30 minutes. As there was no observable breakthrough on the post filter sample, nor readings on the DustTrak^{TM}, the third consecutive sample was collected over a 30 minute period (i.e. from 30-60 minutes) to increase the sample volume.

The 9923V filter was not tested at 360L/min flow rate through the filter as given the observed breakthrough at the lower flow rate for 9923V it was assumed a detectable level of EC post filter would also be achieved at a higher flow rate. For the SR510 filter, sampling at 360L/min was conducted over 15 minutes only. Visually there was no observable breakthrough at the higher flow rate and there were difficulties in sample collection due to a higher back pressure during sampling.

Total particulate matter (TPM) concentration was measured pre and post filter in real time with a DustTrak™ Aerosol Monitor. The setup was tested prior to any samples being collected by comparing the pre filter and post filter TPM measurements, without a respirator filter in place. This was to confirm that the pre and post filter sampling lines were giving comparable results. Used respirators were retained and evaluated post sampling to ensure that there was no leakage via the seals to the adapter and exhalation valve, as outlined in Section 3.5.1.2. The sampling configuration is shown in Figures 3.2, 3.3 and 3.4.

TABLE 3.1: TEST SEQUENCE - PILOT STUDY

Test Sequence	Flow Rate	Number of Samples	Sampling Time	Filter
1	95L/min	3 replicates x 4 consecutive samples	60 minutes (15 minute intervals)	9923V
2	95L/min	1 replicate x 3 consecutive samples	60 minutes (15, 30 and 60 minutes)	SR510
3	360L/min	1 replicate x 1 consecutive sample	15 minutes	SR510
4	95L/min	1 replicate x 2 consecutive samples	30 minutes (15 and 30 minutes)	None

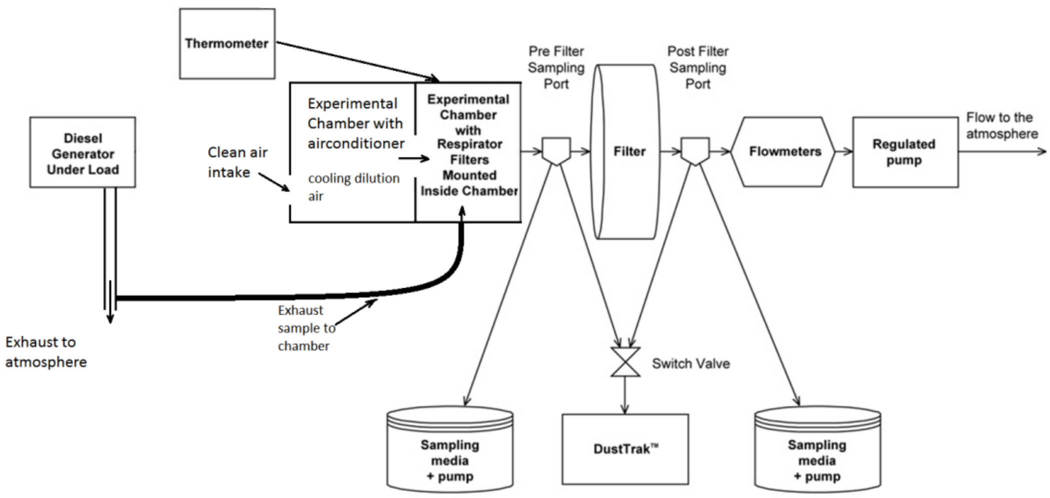

Figure 3.2: Initial Project Design

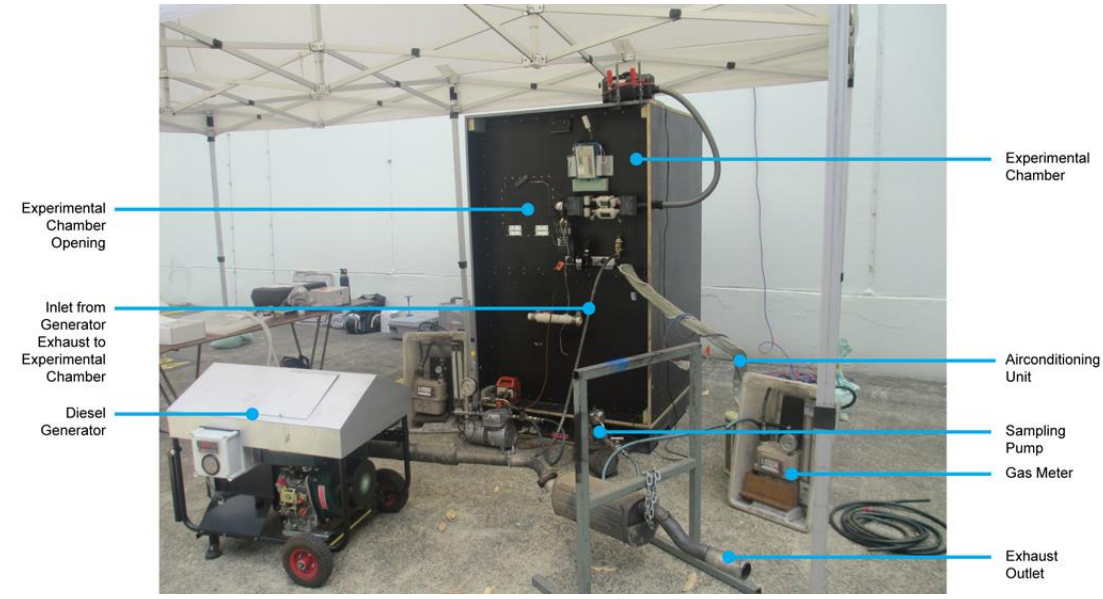

Figure 3.3: Sampling Configuration - Pilot Study

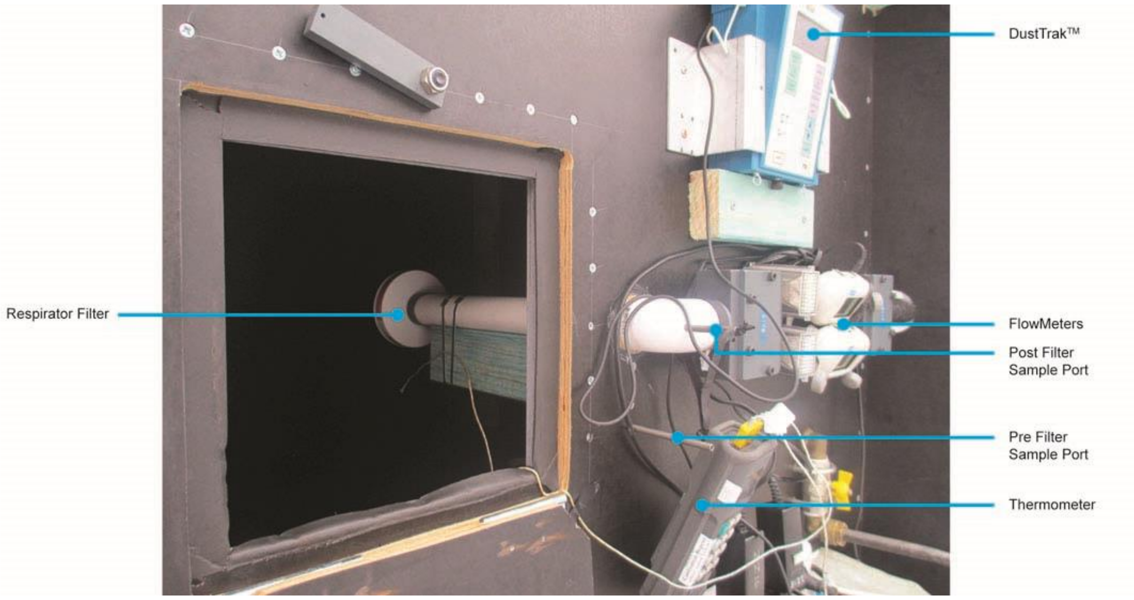

Figure 3.4: Filter Mounted Inside the Experimental Chamber - Pilot Study

3.3 STUDY 1: DIESEL GENERATOR

Study 1 was conducted at an industrial facility in Port Kembla, NSW on the 28th, 29th and 30th of April, 2014. The aim was to determine whether a selection of P2 and P3 respirators, including the 9923V and SR510 filter tested in the Pilot Study, as well as the 1320V P2 filter, effectively filter out EC, using the same diesel generator used in the Pilot Study as a source of diesel emissions. Testing was conducted at flow rates through the respirator filter of 95L/min, consistent with the Pilot Study, as well as 270L/min, which was reduced from the 360L/min due to difficulties in maintaining the higher flow rate in the Pilot Study.

The basis for methodological changes between the Pilot Study and Study 1 is outlined in Section 4.1.7.

3.3.1 Materials

Materials that differ from those used in the Pilot Study are described below.

3.3.1.1 Measurement of EC and TC

SKC AirChek Sampler Model 224-PCXR7 and 224-PCX1 pumps were used to draw air through the SKC225-401 37mm preloaded 3 piece cassettes as outlined in NIOSH 5040 (NIOSH 2003). The pumps operated at a flow rate of approximately 5L/min, with accuracy of ±1%, as measured by a calibrated BIOS Defender 510.

3.3.2 Method

Based on a review of the Pilot Study the following modifications were made to the method described in Section 3.2.3:

- The experimental chamber was modified to include a top and bottom port for the post filter samples. Sampling of two respirator filters simultaneously decreased the overall sampling time and reduced analysis costs as one pre filter sample result was used for two post filter samples.
- The flow meters were reconfigured to operate independently, enabling the flow through the filters in both the top and bottom port to be separately adjusted to the desired flow rate
- The pre filter concentration in the experimental chamber was reduced to ensure the challenge concentration of EC for the P2 filters met the rated protection factor of the filters. The relationship between the TPM concentration measured

by the DustTrak™ and EC concentration obtained during the Pilot Study was used to estimate EC concentration in Study 1.

- The challenge concentration for the P3 filter was increased, given the higher protection factor of the P3 filter (Standards Australia International Ltd & Standards New Zealand 2009).
- The sampling protocol was modified to collect two consecutive 30 minute samples rather than the four 15 minute samples collected during the Pilot Study. This allowed the sampling flow rate to be reduced to 5L/min and alternative air sampling pumps and calibrator to be utilised. Given that the required sampling times were longer based on the lower challenge concentrations, the flow rate for sampling was also reduced. This had a number of benefits as the sampling flow rates were more consistent with occupational exposure monitoring for DPM and the equipment was more portable and readily available.
- To combat high back pressure at 360L/min through the P3 filter in the Pilot Study, the desired flow rate through the filter was reduced to 270L/min, which approximates a moderate to heavy work rate (ISO 2007). This work rate was considered to be representative for work rates in industry based on the literature review findings.

Figure 3.5: Sampling Configuration - Study 1

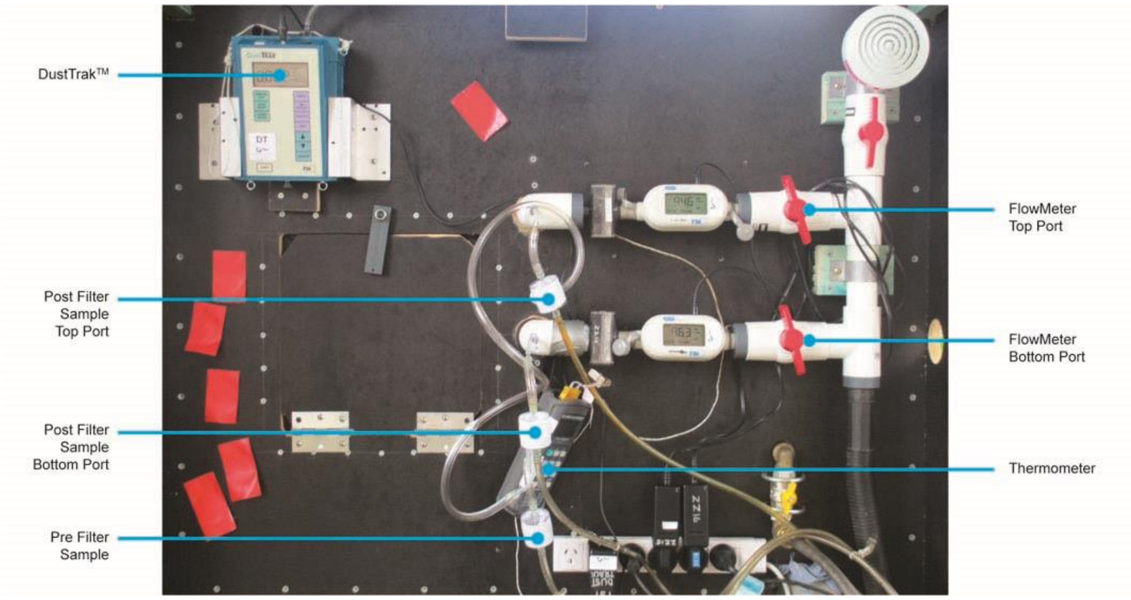

Figure 3.6: Equipment Used to Measure Sampling Parameters

Figure 3.5 and 3.6 show the revised sampling configuration for Study 1, whilst Table 3.2 outlines the test sequence.

TABLE 3.2: TEST SEQUENCE - STUDY 1

Test Sequence	Flow Rate	Number of Samples	Sampling Time	Filter
1	95 L/min	5 replicates x 2 consecutive samples	60 minutes (30 minute intervals)	9923V
2	95 L/min	5 replicates x 2 consecutive samples	60 minutes (30 minute intervals)	1320V
3	95 L/min	2 replicates x 2 consecutive samples	60 minutes (30 minute intervals)	SR510
4	270 L/min	5 replicates x 2 consecutive samples	60 minutes (30 minute intervals)	9923V
5	270 L/min	5 replicates x 2 consecutive samples	60 minutes (30 minute intervals)	1320V
6	270 L/min	2 replicates x 2 consecutive samples	60 minutes (30 minute intervals)	SR510
7	95 L/min	1 replicate	30 minutes	No Filter

3.4 STUDY 2: INDUSTRIAL SCALE DIESEL ENGINE

Study 2 took place at the Queensland University of Technology (QUT) Diesel Testing Laboratory between the 18th and the 21st August 2014. The aim was to replicate the testing undertaken in Study 1 using a larger scale engine more representative of mining applications.

3.4.1 Materials

The materials used were consistent with Study 1, with the following variations:

3.4.1.1 Diesel Engine

A Perkins 1104C-44 Diesel engine (4.4 litres / non turbo) fitted with a water cooled, wet scrubbed exhaust conditioner and dynamometer was used (Surawski et al. 2011); engine speed was between 1500 – 2000 rpm and engine load was 25%. The engine was fuelled with a mix of Caltex and BP Diesel Fuel which was delivered by mini-tanker. The change in fuel and engine load was beyond the control of the researcher and introduced additional variables to the research project.

3.4.2 Method

Samples were analysed for EC and OC by Sunset Laboratories, USA, using NIOSH Method 5040 (NIOSH 2003). The testing laboratory was changed from the Pilot Study and Study 1 due to a lack of consistency with the reported blank results (refer Section 4.2.10).

Table 3.3 depicts the test sequence for Study 2 and Figures 3.7 and 3.8 show the sampling configuration.

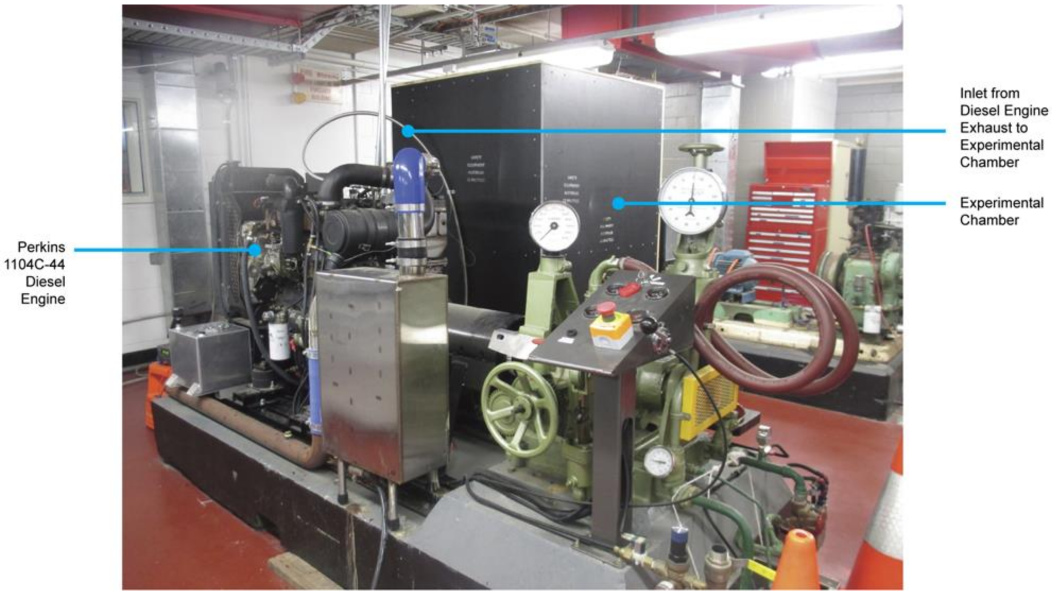

Figure 3.7 Perkins 1104C-44 engine, with experimental chamber in background – Study 2

Figure 3.8: Sampling Configuration - Study 2

TABLE 3.3: TEST SEQUENCE - STUDY 2

Test Sequence	Flow Rate	Number of Replicates	Sampling Time	Filter
1	95 L/min	6 replicates x 2 consecutive samples	60 minutes (30 minute intervals)	9923V
2	95 L/min	6 replicates x 2 consecutive samples	60 minutes (30 minute intervals)	1320V
3	95 L/min	5 replicates x 2 consecutive samples	60 minutes (30 minute intervals)	SR510
4	270 L/min	1 replicate	30 minute	9923V
5	270 L/min	1 replicate	30 minutes	1320V
6	270 L/min	1 replicate	60 minutes	SR510

3.5 METHOD VALIDATION FOR PILOT STUDY, STUDY 1 AND STUDY 2

3.5.1 Testing without filter in place

Prior to sampling, DustTrak^{TM} readings were taken and compared without filters in place in each of the sampling ports, to ensure the readings were comparable. Additionally the respirator filter position was alternated between the top and bottom sampling port. Samples were also collected without respirator filters in place and analysed for EC and TC to confirm that there was no sampling bias from the experimental set up.

3.5.2 Leak Testing of Used Filters

Leak testing of the used filters was undertaken following the Pilot Study and Study 1, as shown in Figure 3.9. The outside filter material was coated in paint and once dry, immersed in a container of water. A manometer was used to verify the pressure applied by blowing air into the adapter and visually observing whether there were any bubbles emanating from the seal to the adapter. Bubbles were not observed from this seal for the tested filters.

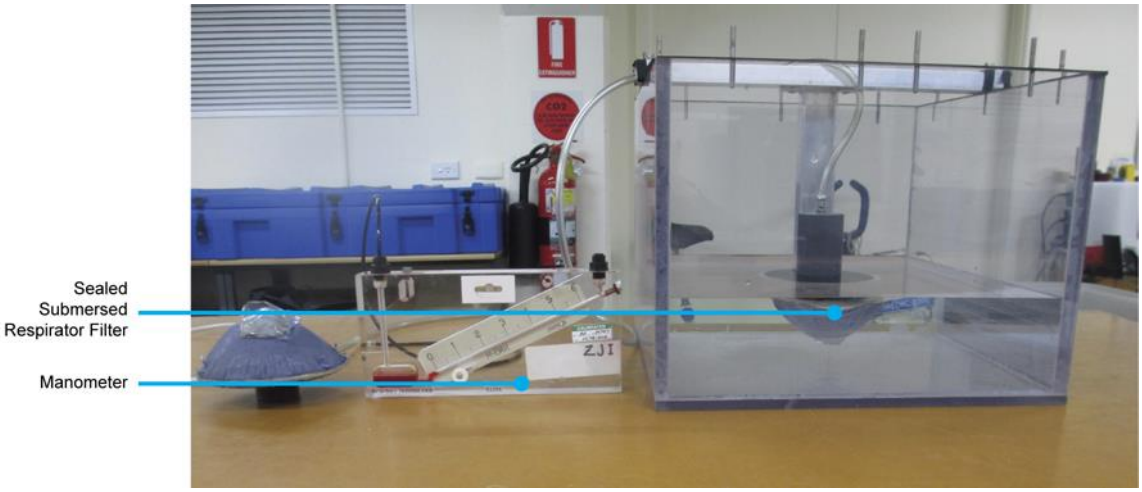

Figure 3.9: Leak Testing of Used Respirator Filters

3.6 OUTCOME PARAMETERS AND DATA TREATMENT

The key variables obtained directly during the study were TPM, temperature inside the chamber, flow rate through the filter media, sampling time and sampling flow rate.

The airborne concentration of EC and TC were calculated using the recorded time and flow rate, as well as the analytical sample mass results from the equation (NIOSH 2003):

$$Concentration\ (mg/m^3) = \frac{W - W_b}{V}$$

Where W (µg) = mass of elemental carbon on the filter for elemental carbon

= mass of elemental carbon and organic carbon on the filter for total carbon

W_b (µg) = average mass on blank filters

Volume (L) = Sampling time (minutes) multiplied by sampling flow rate (L/min), corrected to Standard Temperature and Pressure.

Each of the consecutive sample results were summed for the dependent variables of EC, TC and TPM to determine the time-weighted-average concentration over the total respirator exposure period using the formula (American Conference of Governmental Industrial Hygienists Inc 2014):

$$Concentration\ (mg/m^3) = \frac{C_1T_1 + C_2T_2}{T}$$

Where C_1 = concentration for first 30 minutes of exposure (T_1)

C_2 = concentration for subsequent 30 minutes of exposure (T_2)

T = total period of exposure (60 minutes)

Penetration of EC, TC and TPM was calculated using the equation described in Section 2.6.2.

3.6.1 Treatment of Results At or Below the Limit of Detection

A number of results were below the detection limit for the method and for some the total weight was less than zero after subtracting the blank result. These results were substituted with a value of 0.85µg, being half of the limit of detection (NIOSH 2003). Similarly, for zero results obtained using the DustTrak™, a value of $0.0005 mg/m^3$ was substituted (TSI Incorporated 2010). Given the low number of samples in the study, this substitution method was considered to represent those sampling results most appropriately for the purposes of this study (Bullock, Ignacio & American Industrial Hygiene Association Exposure Assessment Strategies Committee 2006).

3.6.2 Data Analysis

3.6.2.1 Management of Data

Microsoft Excel 2013 (Microsoft Corporation) was used to collate the data obtained during the 3 studies and calculate the airborne concentrations and percentage penetration. Data was reviewed for any errors or inconsistencies in this format. SPSS Statistics Version 22 (IBM) was used for further analysis of the data.

3.6.2.2 Statistical analysis

Box plots were utilised to identify outliers within the tabulated data, which were reviewed to check for errors in data entry or processing. These identified outliers were subsequently determined to be valid and as such were used in further data analysis. Descriptive statistics of mean (M), standard deviation (SD) and number of samples (n) were used to summarise the sampling data (temperature, pre filter EC concentration and EC, TC and TPM penetration).

Data from Study 1 and Study 2 were compared using Q-Q plots and the Kolmogorov-Smirnov test ($p < 0.05$) with these normality tests showing the data as most consistent with a normal distribution. The mean and 95% Upper Confidence Level (UCL) were used to determine whether the hypotheses were accepted. A significance level of $p < 0.05$ applied for all statistical tests.

4. RESULTS

4.1 PILOT STUDY

The Pilot Study was conducted at an industrial warehouse facility on the 4th February 2014. Eighteen paired pre and post filter samples were collected, as well as two consecutive samples with no filter in place, as outlined in Table 3.1. Results from the Pilot Study are summarised in Appendix M.

4.1.1 Temperature

The temperature averaged 24.4°C in the experimental chamber (*SD* = 1.7, *n* = 15), this mean is within the range specified in Appendix L of AS1716 of 23±2ºC to test filtering efficiency of particulate respirators using NaCl aerosol (Standards Australia International Ltd & Standards New Zealand 2012).

4.1.2 Pre Filter EC Concentration

The aim was to achieve a pre filter concentration of approximately 1mg/m^3 for the P2 rated filters, based on the rated protection factor of 10 times the TWA occupational exposure standard for P2 and P3 filters in a disposable or half facepiece respirator (Standards Australia International Ltd & Standards New Zealand 2009). The pre filter EC concentration in the experimental chamber averaged 2.0mg/m^3 (*SD* = 0.8, *n* = 18). The Pilot Study pre filter EC concentration exceeded the desired concentration as there was no direct reading instrument to measure EC. However, despite some of the measured pre filter EC levels exceeding a TWA of 1mg/m^3 over the measurement period, when the results are averaged as an 8 hour TWA concentration they remained within the guidance for excursions above the Exposure Standard (SafeWork Australia 2012), therefore results are valid for inclusion in the study.

4.1.3 Visual observations

Samples collected for the first fifteen minutes of exposure for the SR510 filter and the three replicates for the 9923V filter at 95L/min are shown in Figure 4.1.

Discolouration was evident on the 3M9923V post filter samples after the relatively short exposure time of 15 minutes, increasing markedly up to 60 minutes. The SR510 samples showed no discolouration for any samples, including those collected at the higher flow rate. These visual observations gave an indication that there was some

penetration of diesel emissions through the respirator filter media, although it is not clear whether it was due to the DPM or the vapour phase component of the emissions.

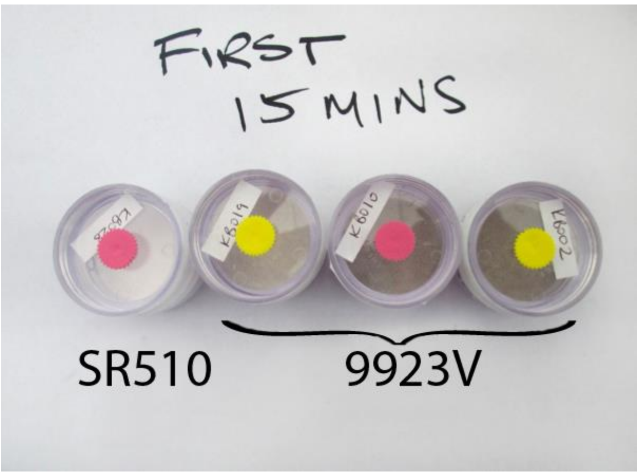

Figure 4.1: Samples collected pre and post respirator filters at 95L/min – Pilot Study

4.1.4 Penetration Test Results

4.1.4.1 Average Penetration for 9923V filter at 95L/min

The Pilot Study results for EC, TC and TPM penetration through the 9923V filter at 95L/min, when averaged over the 60 minutes of filter exposure to the diesel emissions are reported in Table 4.1 and shown in Figure 4.2.

TABLE 4.1: MEAN PENETRATION THROUGH 9923V FILTER AT 95L/MIN – PILOT STUDY

Filter	EC Penetration (%) 95L/min				TC Penetration (%) 95L/min				TPM Penetration (%) 95L/min			
	M	*SD*	*95% UCL*	*n*	*M*	*SD*	*95% UCL*	*n*	*M*	*SD*	*95% UCL*	*n*
9923V	16.9	1.3	20.0	3	25.2	5.9	39.8	3	16.3	1.4	19.9	3

The certification requirement for P2 filters is that penetration shall not exceed 6% (Standards Australia International Ltd & Standards New Zealand 2012). The mean and 95% UCL penetration values measured for EC, TC and TPM for the Pilot Study exceeded this requirement. The confidence intervals were wide due to the limited number of samples.

4.1.4.2 Effect of exposure time for 9923V filter at 95L/min

A 60 minute exposure time of the respirator filter to the diesel emissions was chosen as representative of a typical time that a worker may wear a respirator without replacement (HSE 2013). Figure 4.2 shows penetration for the 9923V filter at 95L/min for each of the consecutive 15 minute sampling periods up to 60 minutes, with a reference line at the standard certification limit of 6% penetration. This level was reached at approximately 15 minutes of exposure of the filter to the diesel emissions.

An Analysis of Variance between the four 15 minute sampling periods and the averaged 60 minutes demonstrated that penetration differences were statistically different for EC $F(14,4) = 3.60$, $p = 0.046$ and TPM: $F(14,4) = 4.61$, $p = 0.023$ however were not significantly different for TC ($p = 0.18$). When penetration values for the initial sampling period (0-15 minutes) were compared to the averaged 60 minute result, significant variation was shown for EC ($F(5,1) = 89.58$, $p = 0.001$ and TC $F(5,1) = 29.65$, $p = 0.006$), but not for TPM ($p = 0.066$).

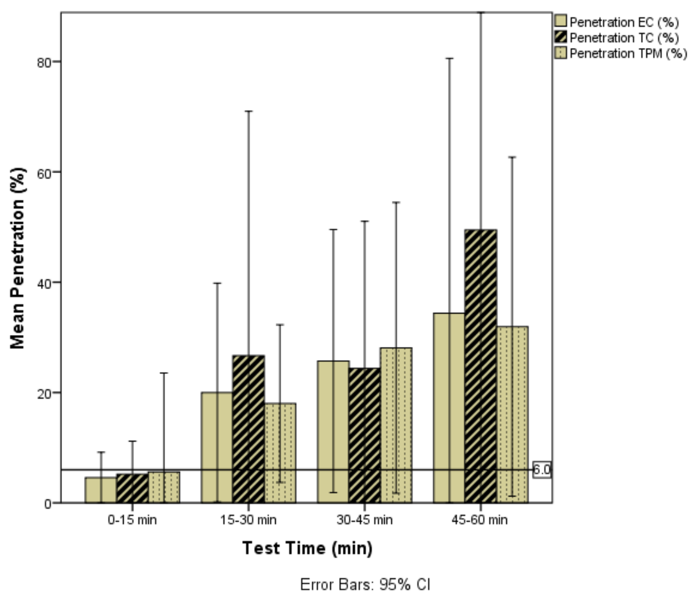

Figure 4.2: 9923V Filter Penetration by EC, TC and TPM for consecutive 15 minute samples - Pilot Study; Mean ± 95% Confidence Interval, n = 3, Standard Certification Line is 6% Penetration

4.1.4.3 Penetration for SR510 filter at 95L/min and 360L/min

The penetration over 60 minutes for the SR510 filter at 95L/min and 15 minutes at 360L/min is reported in Table 4.2.

TABLE 4.2: PENETRATION THROUGH SR510 FILTER AT 95L/MIN AND 360L/MIN - PILOT STUDY

	Sampling Time (min)	*n*	EC Penetration (%)	TC Penetration (%)	TPM Penetration (%)
SR510 95L/min	60	1	0.2	2.1	<0.1
SR510 360L/min	15	1	0.7	1.9	<0.1

The single result at each flow rate for EC, TC and TPM penetration through the SR510 filter was below the 6% penetration limit specified for a P2 filter.

4.1.5 Correlation between EC and TPM concentration

A primary aim of the Pilot Study was to determine whether a detectable sample of EC could be measured post filter. Therefore the pre filter concentration of TPM was high (M = 9.4 mg/m^3, SD = 2.59, n = 18). A secondary aim was to determine whether there was any significant correlation between the calculated pre filter EC concentration and the pre filter TPM concentration obtained from the direct reading DustTrak™ instrument.

The ratio between EC and TPM was calculated, a Pearson two-tailed test of significance was used to determine the strength of the correlation. Despite the weak correlation between EC and TPM for the pre filter measurements (r = 0.23, p = 0.338), given the absence of other validated methods to estimate the EC concentration during sampling, the Pilot Study EC/TPM ratio of 0.22 was subsequently used to estimate the EC concentration in the experimental chamber during Study 1.

4.1.6 Leak test of respirator filters after sampling

Leak testing of the used respirator filters was undertaken as described in Section 3.3.3.2. Observations of the lack of bubbles emanating from the seal onto the adapter and over the exhalation valve, as well as a lack of pressure change confirmed the integrity of the seal for the 9923V and 1320V respirators used. This was not conducted for the SR510 filter, given the custom adapter which allowed direct attachment to the filter and sampling port.

4.1.7 Pilot Study Outcomes and Limitations

Following a review of the Pilot Study methodology and results, a number of potential improvements were identified for refinement prior to Study 1 as outlined below. The resulting modifications to the methodology for Study 1 are described in Section 3.3.2.

- The pre filter concentration for the P2 filters was approximately double their rated capacity. Therefore the desired pre filter TPM concentration for P2 filters was reduced to achieve an EC concentration of 1mg/m^3, so that the assigned protection factor for a P2 respirator was met.
- As a result of the reduction in pre filter TPM concentration, the sampling time was increased from 15 to 30 minutes, reducing the number of consecutive samples from four to two. Additionally, due to the reduced flow rate, the smaller and more accurate Airchek pumps and BIOS Defender were able to be used in place of the vacuum pumps and Gas Meters to collect the samples.
- A flow rate of 360L/min through the SR510 filter was difficult to achieve and maintain in the Pilot Study because of back pressure whilst sampling. The flow rate through the respirator filter was reduced to 270L/min for Study 1, which approximates a moderate to heavy work rate (ISO 2007).
- The 9923V EC, TC and TPM penetration results were assumed to follow a linear distribution. An increased number of replicate samples are required to confirm this assumption in subsequent studies.

4.2 STUDY 1

Based on the Pilot Study observations and the initial literature review, it is hypothesised that three factors influence penetration of DPM through the filter media, being flow rate through the filter media, filter model and length of exposure. It is further hypothesised that EC penetration will not meet filtering efficiency requirement at 95L/min and 270L/min for all of the tested filters.

Study 1 was conducted to evaluate these hypotheses, using the same diesel generator used in the Pilot Study as the source of diesel emissions. Fifty paired pre and post filter samples were collected, half for the first 30 minutes of filter exposure to the diesel emissions (0-30 minutes) and half for a subsequent period of exposure (30-60 minutes). These samples were collected for the two respirator models used in the Pilot Study (9923V and SR510), as well as an additional P2 filter (1320V), at two flow rates (95L/min and 270L/min). Five of the collected samples were invalid due to flow faults with the sampling pump during sampling, these were all for filters sampled at a flow rate of 270L/min.

Additionally, the sampling results for the SR510 filter at 95L/min collected during the Pilot Study were incorporated into the data analysis for Study 1. This was considered to be appropriate given sampling conditions during the Pilot Study were consistent with sampling conditions for Study 1, the two initial 15 minute samples were summed as described below to provide a 30 minute sample result.

Each of the consecutive 30 minute sample results were summed for the dependent variables of EC, TC and TPM concentration, to determine the time-weighted-average concentration over the 60 minute exposure period as described in Section 3.6. Study 1 results are reported in Appendix N.

4.2.1 Temperature

The temperature averaged 23.8°C within the experimental chamber (SD = 1.6 n=51) which was within the acceptable range of 23±2ºC (Standards Australia International Ltd & Standards New Zealand 2012).

4.2.2 Pre filter EC Concentration

The EC concentration in the experimental chamber averaged 1.3mg/m^3 (SD = 0.4, n = 73). For the 9923V and 1320V P2 rated filters the concentration slightly exceeded the desired concentration of 1.0mg/m^3 (M = 1.1mg/m^3, SD = 0.3, n = 56). Pre filter EC concentration was elevated for the SR510 P3 rated filters (M = 1.8 mg/m^3, SD = 0.2, n = 15). Both of these concentrations are within the advised protection factor for a P3 filter, depending on its use (Standards Australia International Ltd & Standards New Zealand 2009).

4.2.3 Visual Observations

The samples were inspected and compared prior to being sent for analysis (Figure 4.3). At 95L/min, slight discolouration was evident for the 9923V filter samples collected between 0 - 30 minutes, with the discolouration increasing for the 30 - 60 minute sample. There was no observable discolouration for the 1320V filters at 95L/min between 0 and 30 minutes increasing to a slight discolouration for the sample collected between 30 and 60 minutes. The samples for the SR510 filters showed no discolouration for either sampling period.

As the flow rate though the filters increased to 270L/min, there was no observable discolouration for the SR510 filter samples, however increased discolouration was evident for the 9923V and 1320V filter samples.

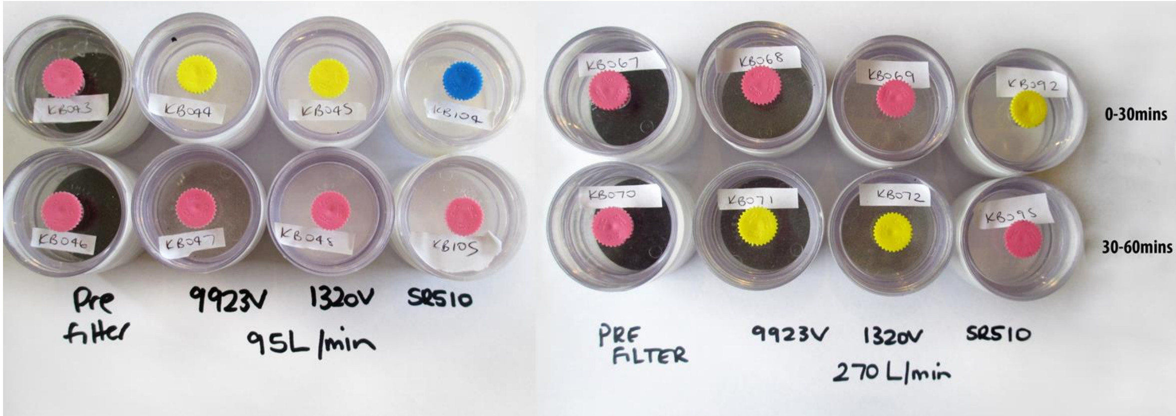

Figure 4.3: Samples collected pre and post respirator filters at 95L/min and 270L/min – Study 1

4.2.4 Penetration Test Results

4.2.4.1 EC, TC and TPM Penetration

Table 4.3 and 4.4 report the EC, TC and TPM penetration, for the one hour that the filters were exposed to diesel emissions, for all filters combined and for each of the filter models individually.

TABLE 4.3: EC, TC AND TPM PENETRATION AT 95L/MIN - STUDY 1

Filter	**EC Penetration (%) 95L/min**				**TC Penetration (%) 95L/min**				**TPM Penetration (%) 95L/min**			
	M	***SD***	***95% UCL***	***n***	***M***	***SD***	***95% UCL***	***n***	***M***	***SD***	***95% UCL***	***n***
All Filters	2.7	2.8	4.4	13	2.4	4.3	5.0	13	4.0	4.3	6.6	13
9923V	4.5	3.2	8.5	5	4.5	6.6	12.7	5	8.6	2.5	11.7	5
1320V	2.1	2.3	5.0	5	1.2	1.4	3.0	5	1.8	2.3	4.6	5
SR510	0.5	0.5	1.8	3	0.9	0.9	3.1	3	<0.1	<0.1	<0.1	3

Collectively for all filters, requirements for penetration to be less than 6% at 95L/min for EC and TC were met, however the UCL exceeds 6% when penetration by TPM is calculated. When considered by individual filter model, the mean EC and TC penetration for the 9923V filter are below 6%, however the 95% confidence interval extends above 6% for EC, TC and TPM, and as such this filter does not meet the penetration requirements outlined in AS1716

(Standards Australia International Ltd & Standards New Zealand 2012) using the research methodology in this study. For the 1320V and SR510 filter models, the mean and 95% UCL for penetration of EC, TC and TPM were below 6%.

TABLE 4.4: EC, TC AND TPM PENETRATION AT 270L/MIN - STUDY 1

Filter	**EC Penetration (%) 270L/min**				**TC Penetration (%) 270L/min**				**TPM Penetration (%) 270L/min**			
	M	***SD***	***95% UCL***	***n***	***M***	***SD***	***95% UCL***	***n***	***M***	***SD***	***95% UCL***	***n***
All Filters	14.4	15.4	26.2	9	19.3	21.6	35.9	9	19.2	16.6	32.0	9
9923V	30.4	17.4	73.7	3	40.6	26.3	105.9	3	36.2	15.8	75.6	3
1320V	9.4	2.8	13.7	4	12.9	5.4	21.5	4	15.9	4.7	23.5	4
SR510	<0.1	-	-	2	0.2	0.1	0.8	2	<0.1	-	-	2

EC and TPM penetration constant for SR510 therefore no *SD* or 95% Upper Confidence Level *(UCL)* given

At a continuous air flow rate through the respirator filter of 270L/min the mean EC, TC and TPM penetration exceeded 6% for all filters. When considered by individual filter model, this requirement appeared to be met for the SR510 filter for the two samples, however was exceeded for the 9923V and 1320V P2 filters. The confidence intervals are wide due to the small number of samples and variability within the results.

4.2.5 Effect of Filter Model on Penetration through the Respirator Filter

Consistent with the variation in penetration shown in Tables 4.3 and 4.4 and Figure 4.4, respirator filter model was shown to have a significant effect on filter penetration by a one-way repeated measures ANOVA:

EC $F\ (2,67) = 9.27,\ p < 0.001$

TC $F\ (2,67) = 5.56,\ p < 0.001$

TPM $F\ (2,74) = 18.93,\ p < 0.001$

4.2.6 Effect of Flow Rate on Penetration through the Respirator Filter

Flow rate also had a significant effect on penetration through the respirator filter media, when results were compared using an ANOVA for all filters between the flow rates of 95 and 270L/min. For each individual filter model, the effect of flow rate remained significant for the 9923V and 1320V filters, however was not significant for the SR510 filter, as reported in Table 4.5. Mean penetration by respirator filter is shown in Figure 4.4 for filters tested at 95L/min and 270L/min. This figure demonstrates an increased penetration of diesel emissions measured as EC, TC and TPM at the higher flow rate.

TABLE 4.5: EFFECT OF FLOW RATE ON PENETRATION THROUGH RESPIRATOR FILTERS - STUDY 1

	EC Penetration (%)	TC Penetration (%)	TPM Penetration (%)
All Filters	$F(1,67) = 20.49$, $p < 0.001$	$F(1, 67) = 15.41$, $p = 0.001$	$F(1,74) = 40.30$, $p < 0.001$
9923V	$F(1,24) = 29.89$, $p < 0.001$	$F(1,24) = 13.88$, $p = 0.001$	$F(1,29) = 52.76$, $p < 0.001$
1320V	$F(1,27) = 16.13$, $p < 0.001$	$F(1,27) = 21.63$, $p < 0.001$	$F(1,29) = 48.04$, $p < 0.001$
SR510	$F(1,14) = 0.15$, $p = 0.706$	$F(1,14) = 2.84$, $p = 0.116$	$F(1,14) = 2.60$, $p = 0.131$

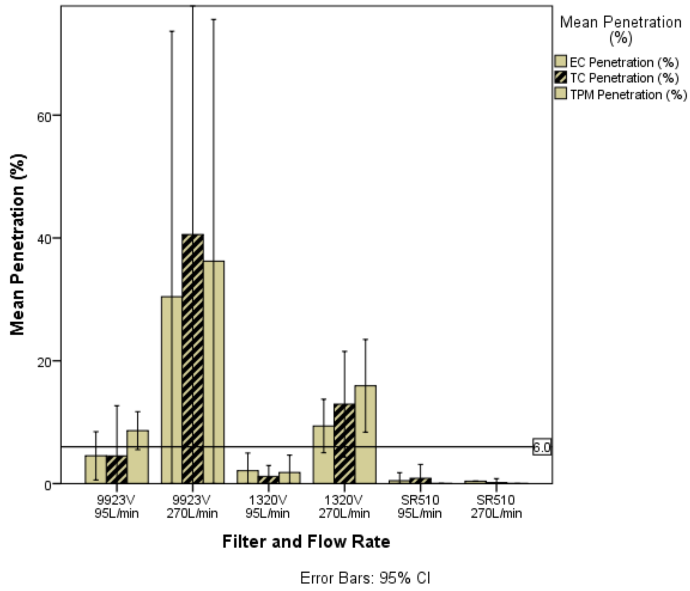

Figure 4.4: Effect of Flow Rate on EC, TC and TPM Penetration by Respirator Filter Model – Study 1, Mean ± 95% Confidence Interval, n = 2-4, Standard Certification Line is 6% Penetration

4.2.7 Effect of Exposure Time on Penetration through the Respirator Filters

Results were compared for samples collected for 0-30 minutes, 30-60 minutes and the summed values from 0-60 minutes, for penetration by EC, TC and TPM, to determine if exposure time had a significant effect on filter penetration (refer Table 4.6 and Figures 4.5 and 4.6). Mean penetration results were not found to be significantly different between the exposure times, except for the 1320V filter penetration by EC.

TABLE 4.6: EFFECT OF EXPOSURE TIME ON PENETRATION THROUGH RESPIRATOR FILTERS - STUDY 1

	EC Penetration (%)	TC Penetration (%)	TPM Penetration (%)
All Filters	$F(2,67) = 1.95$, $p = 0.151$	$F(2, 67) = 2.21$, $p = 0.117$	$F(2,74) = 1.55$, $p = 0.219$
9923V	$F(2,24) = 0.95$, $p = 0.404$	$F(2,24) = 1.31$, $p = 0.269$	$F(2,29) = 1.01$, $p = 0.376$
1320V	$F(2,27) = 4.74$, $p = 0.018$	$F(2,27) = 2.97$, $p = 0.070$	$F(2,29) = 1.73$, $p = 0.196$
SR510	$F(2,14) = 0.37$, $p = 0.702$	$F(2,14) = 0.12$, $p = 0.885$	$F(2,14) = 0.00$, $p = 1.000$

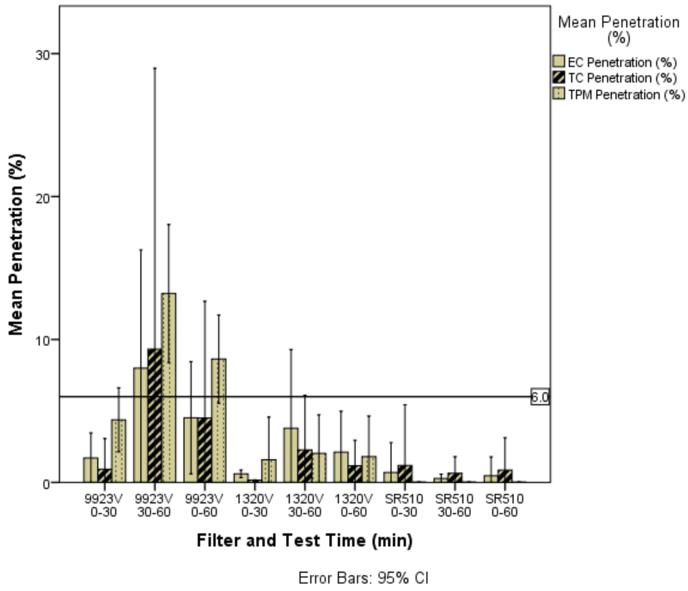

Figure 4.5: Effect of Exposure Time on EC, TC and TPM Penetration at 95L/min – Study 1

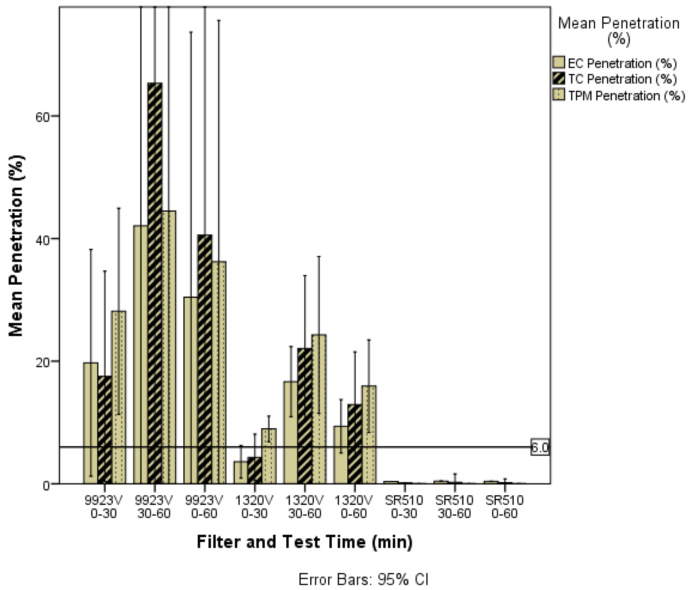

Figure 4.6: Effect of Exposure Time on EC, TC and TPM Penetration at 270L/min – Study 1

4.2.8 Comparison of times at which TPM Penetration reached 6% for 1320V and 9923V filters at 95L/min and 270L/min

Despite the finding that the EC, TC and TPM penetration were not significantly different between exposure times, penetration by TPM for the P2 filters was evaluated to determine the time at which penetration exceeded 6%. Pre and post filter TPM

concentrations were recorded every 3 minutes until penetration exceeded 6%. Figure 4.7 shows that for the 9923V filter, TPM penetration exceeded 6%, the displayed reference line, between 33 and 36 minutes at 95L/min and between 9 and 12 minutes at 270L/min. For the 1320V filter, TPM penetration did not breach 6% at 95L/min, however exceeded 6% between 24 and 27 minutes at 270L/min.

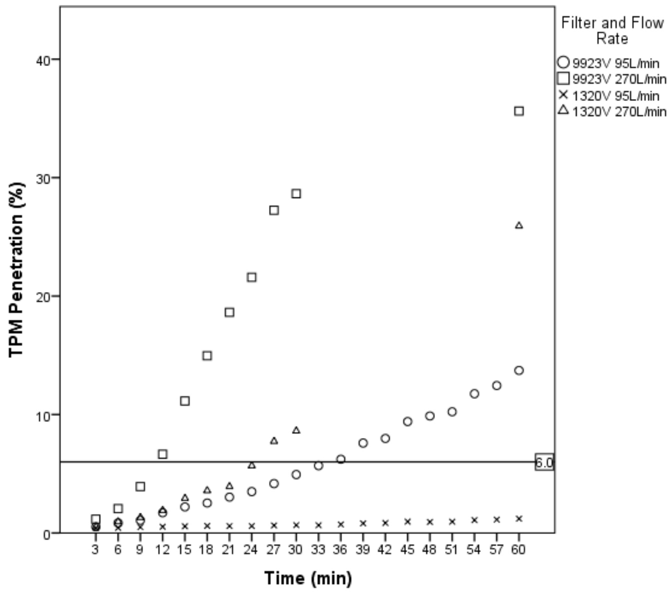

Figure 4.7: TPM Penetration over time for 1320V and 9923V filters at 95 and 270L/min – Study 1

4.2.9 Correlation between EC and TPM concentration

The relationship between EC and TPM was explored, the strength of the relationship was determined using a Pearson, 2-tailed test of significance, refer to Table 4.12. The correlations in Study 1 were stronger for the prefilter EC/TPM and TC/TPM than in the Pilot Study. The pre filter EC / TPM relationship of 0.32 was slightly higher than the 0.22 obtained during the Pilot Study which may be due to slight variations in engine operating conditions.

4.2.10 Blanks

Raw results obtained from CMTS indicated readings for EC on the blank samples which were higher than anticipated for the Pilot Study and Study 1. This was discussed with CMTS and they subsequently reviewed their data and data manipulation to determine whether there were any potential errors, they reported there were none. CMTS reanalysed the available blank samples and the results showed a variation from the initial results. A review of the sampling conditions indicated that

some of the sample cassettes in Study 1 had been repacked by CMTS, a standard process. A comparison of the blank sample results is shown in Table 4.7.

TABLE 4.7: COMPARISON OF BLANK SAMPLE RESULTS FROM PILOT STUDY, STUDY 1 AND REANALYSIS OF STUDY 1 SAMPLES

	Pilot Study		Study 1		Study 1 Reanalysis	
	EC µg	**TC µg**	**EC µg**	**TC µg**	**EC µg**	**TC µg**
Replicate 1	0.8	17.8	3.4	141.2	6.3	130.1
Replicate 2	0.1	13.9	1.4	78.1	0.2	44.8
Replicate 3	0.8	19.5	2.8	43.6	<0.1	36.1
Replicate 4	0.9	12.7	0.9	39.5	<0.1	35.6
Replicate 5	Not Collected	Not Collected	0.2	10.6	NA	NA
Replicate 6	Not Collected	Not Collected	0.1	12.6	NA	NA
M	0.7	15.9	1.5	54.3	1.0	26.6
SD	0.4	3.2	1.4	49.2	3.1	45.8

NA – Not Available. The remaining sample had been destroyed and was not available for further analysis.

To understand these anomalies further, an interlaboratory comparison was conducted to compare the results obtained from blank samples between CMTS and Sunset Laboratory Inc, an alternative laboratory based in the US with significant experience in analysis using NIOSH 5040.

Two replicates of each type of sample filter were cut in half, with one half sent to each laboratory for analysis (*n*=6). The samples compared were:

1. A sample filter from the Study 1 batch
2. A repacked sample filter from the Study 1 batch
3. A sample filter from a different batch not associated with Study 1.

This allowed consideration of whether there was inconsistency in the analysis methods between the two laboratories, different sample batches and or potential contamination of the repacked sample filters. The results are reported in Table 4.8.

TABLE 4.8: INTERLABORATORY COMPARISON TESTING OF BLANK FILTER SAMPLES

	CMTS EC µg	Sunset EC µg	CMTS TC µg	Sunset TC µg
Unused filter Study 1: Replicate 1	0.4	<0.1	27.4	26.1
Unused filter Study 1: Replicate 2	2.2	<0.1	93.1	28.4
Repacked filter Study 1: Replicate 1	0.5	<0.1	36.1	80.7
Repacked filter Study 1: Replicate 2	1.0	<0.1	33.4	49.1
New filter: Replicate 1	<0.1	<0.1	11.0	12.3
New filter: Replicate 2	<0.1	<0.1	11.1	17.3

A paired *t*-test was conducted with results showing the difference between the blank sample results for the two laboratories was not significant for EC ($p = 0.144$) and TC ($p = 0.985$). Therefore the standard protocol of subtracting the mean blank sample results from the test sample results was followed for Pilot Study, Study 1 and Study 2.

Despite this finding, to avoid further anomalies and given the differences in analytical results between the initial blank sample results and subsequent reanalysed blank sample results by CMTS, samples from Study 2 were sent to Sunset Laboratories Inc in the USA for analysis. Repacked filters were not used.

4.3 STUDY 2

Study 2 was undertaken at Queensland University of Technology between the 18th and 21st August 2014. The aim was to repeat the testing, using an industrial scale diesel engine more typical of mining operations. The hypotheses were consistent with Study 1.

Thirty eight paired pre and post filter samples were collected, consisting of 18 samples for the first 30 minutes of filter exposure to the diesel engine emissions (0-30 minutes) and 18 samples for a subsequent period of exposure (30-60 minutes) (refer Table 3.3). Samples were collected for the three respirator filters at the two flow rates, however due to circumstances beyond the researcher's control, there was only one sample collected for each P2 respirator filter at 270 L/min, and one sample for 60 minutes for the P3 filter at this higher flow rate. Two of the P2

samples at 270 L/min, for the 30-60 minute sampling period, were not analysed. The samples were invalid due to flow faults with the sampling pump, caused by increased humidity in the experimental chamber. During one test at 95L/min, a fire alarm occurred, so two sets of samples ran for a 60 minute period due to the researcher evacuating the building for a short period.

Consecutive 30 minute sample results were summed for the dependent variables of EC, TC and TPM to determine the time-weighted-average concentration over the 60 minute exposure period as described in Section 3.6. Study 2 results are reported in Appendix O.

4.3.1 Temperature

The temperature averaged 24.6°C within the experimental chamber (*SD* = 2.6, *n* = 15), the mean was within the acceptable range however some results slightly exceeded the upper limit of this range (Standards Australia International Ltd & Standards New Zealand 2012).

4.3.2 Pre Filter EC Concentration

The pre filter EC concentration in the experimental chamber averaged 5.0mg/m^3 (*SD* = 2.3, *n* = 52). For the 9923V and 1320V P2 rated filters the mean concentration was slightly lower at 4.0mg/m^3 (*SD* = 1.8, *n* = 38). EC was elevated for the SR510 P3 rated filters (*M* = 7.7 mg/m^3, *SD* = 1.2, *n* = 14), which is within the advised protection factor for a P3 filter, depending on its use (Standards Australia International Ltd & Standards New Zealand 2009). These values exceeded the desired EC level of 1mg/m^3 for the P2 rated filters, indicating that the EC / TPM correlation used in Study 1 was not appropriate for Study 2, which was expected given the variation in engines and engine operating conditions. However they remained within the guideline for general excursions above the exposure standard (SafeWork Australia 2012).

4.3.3 Visual Observations

The samples were inspected and compared prior to being sent for analysis (Figure 4.8 and 4.9). Minimal discolouration was evident for all samples collected during Study 2, other than for the 9923V filter at 270L/min which showed some discolouration after 30 minutes of exposure.

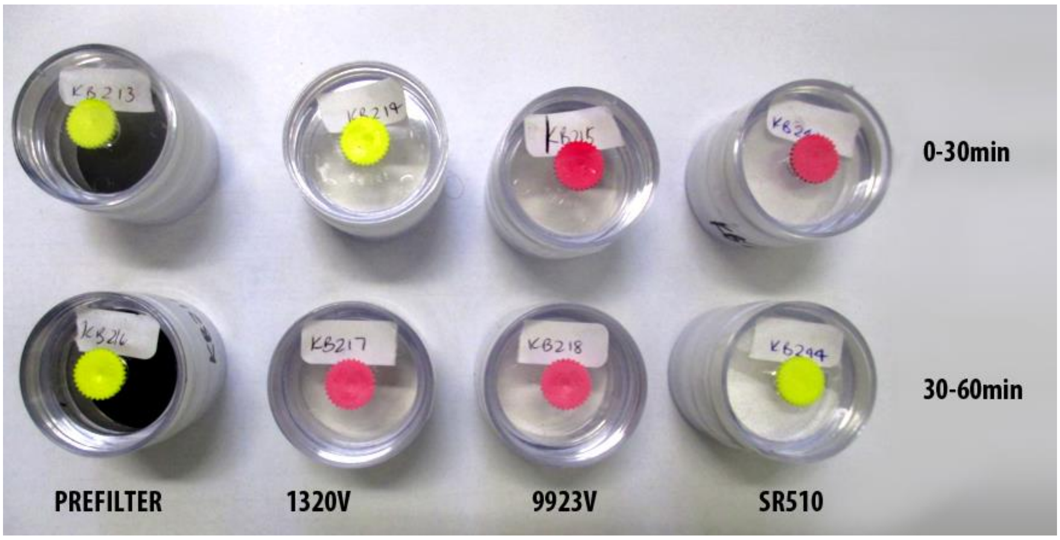

Figure 4.8: Samples collected pre and post respirator filters at 95L/min - Study 2

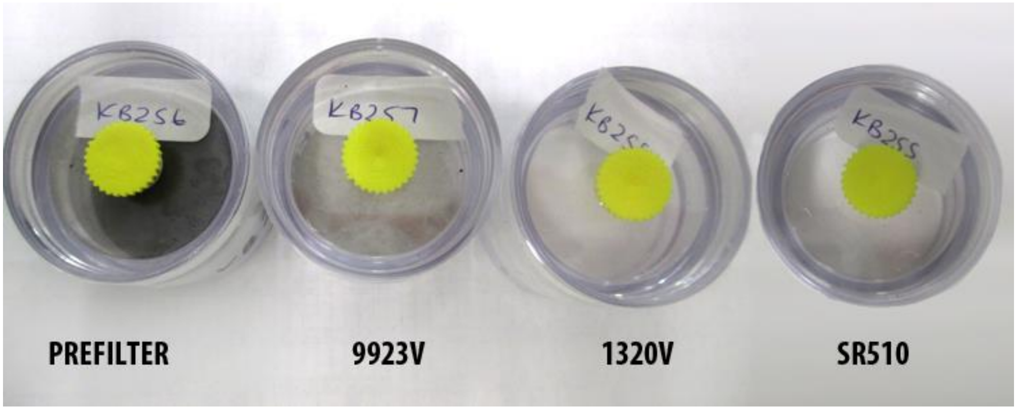

Figure 4.9: Samples collected pre and post respirator filter, at 270L/min after 30 minutes of exposure for the 9923V and 1320V filters and at 95L/min after 60 minutes of exposure for the SR510 filter – Study 2

4.3.4 Penetration Test Results

4.3.4.1 EC, TC and TPM Penetration at 95L/min

Table 4.9 reports EC, TC and TPM penetration, for all filters collectively and for each of the filters individually, for results calculated over the one hour that the filters were exposed to diesel emissions.

TABLE 4.9: EC, TC AND TPM PENETRATION AT 95L/MIN - STUDY 2

Filter	**EC Penetration (%) 95L/min**				**TC Penetration (%) 95L/min**				**TPM Penetration (%) 95L/min**			
	M	***SD***	***95% UCL***	***n***	***M***	***SD***	***95% UCL***	***n***	***M***	***SD***	***95% UCL***	***n***
All Filters	0.3	0.3	0.5	12	2.3	0.8	2.9	12	0.2	0.2	0.3	12
9923V	0.3	0.2	0.6	4	1.4	0.3	1.8	4	0.4	0.1	0.6	4
1320V	0.2	0.1	0.4	5	2.9	0.7	3.8	5	0.1	0.1	0.2	5
SR510	0.5	0.5	1.8	3	2.6	0.2	3.2	3	0.1	<0.1	0.1	3

Based on the means and 95% Upper Confidence Levels for these filters the hypothesis that penetration exceeds 6% at a flow rate of 95L/min was rejected for Study 2.

4.3.4.2 EC, TC and TPM Penetration at 270L/min

There were no valid samples for the 9923V and 1320V filters over the 60 minute period and only one valid sample for the SR510 filter, hence no interpretation has been made of the samples collected at 270L/min.

4.3.5 Effect of Filter Type at 95L/min on Penetration through the Respirator Filter

Filter type had a significant effect on filter penetration by a one-way repeated measures ANOVA for TPM (F (2,12) = 17.06 , p = 0.001) however the effect was not significant for EC and TC (p = 0.505 and 0.457), as shown in Figure 4.10.

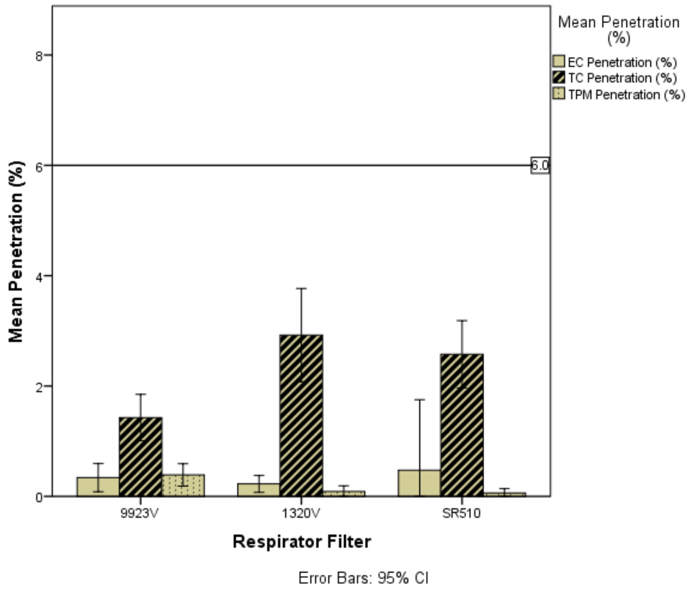

Figure 4.10: Mean EC, TC and TPM Penetration by Filter Model at 95L/min – Study 2

4.3.6 Effect of Flow Rate on Penetration through the Respirator Filter

Effect of flow rate could not be determined as there was only one sample collected for each filter at the higher flow rate.

4.3.7 Effect of Exposure Time at 95L/min on Penetration through the Respirator Filter

Exposure time did not have a significant effect on penetration by EC, TC and TPM (p = 0.585, 0.685 and 0.589).

4.3.8 Correlation between EC, TC and TPM Concentration at 95L/min

The ratio between the prefilter dependent variables EC and TPM was 0.28 for this study.

4.4 RESULTS OF METHOD VALIDATION

During the Pilot Study, two consecutive 15 minute samples were collected without filters in place. For Study 1, 30 minute sampling occurred with no filter in place for the top and bottom port. Additionally on each sampling day for the Pilot Study, Study 1 and Study 2, TPM was measured at each of the sample ports without a filter in place. The purpose of these samples was to verify that there was minimal sample bias between the pre filter sample port and the post

filter top and bottom sample port. Significant correlation is shown between the EC, TC and TPM concentrations for the pre and post filter sampling ports (Table 4.10).

TABLE 4.10: EC, TC AND TPM CORRELATIONS BETWEEN PRE AND POST FILTER SAMPLES AT 95L/MIN WITH NO FILTERS IN PLACE

Filter	**EC Correlation (%) 95L/min**				**TC Correlation (%) 95L/min**				**TPM Correlation (%) 95L/min**			
	M	***r***	***p***	***n***	***M***	***r***	***p***	***n***	***M***	***r***	***p***	***n***
No Filter	98.3	0.98	0.025	4	88.4	0.95	0.048	4	98.2	1.00	<0.001	17

4.5 COMPARISON BETWEEN STUDIES

Whilst the aims of Study 1 and Study 2 were the same, there were significant variations between the two studies which need to be considered when comparisons are made. These include:

- The fuel used for the studies varied, Study 2 required a greater volume of fuel and hence reliance was placed on a tanker delivery, for which the source of the fuel could not be specified.
- The load on the engines varied. In Study 1 a 100% load was placed on the diesel generator to enable a high concentration of EC in the chamber and hence ensure that the penetration could be measured after the respirator filter. The intent was to also operate the diesel engine in Study 2 under a 100% load, however this was not possible and Study 2 was conducted at 25% load.
- The EC levels in the experimental chamber varied as described in Section 4.5.1.1.
- Due to difficulties with backpressure and humidity in the experimental chamber, testing at 270L/min for Study 2 was limited to one 60 minute sample for the SR510 filter and one 30 minute sample for the 1320V and 9923V filters, which was not sufficient for comparison between the two studies at this flow rate.

4.5.1.1 Pre Filter EC Concentration in Experimental Chamber

The EC levels in the experimental chamber were higher in Study 2 (M = 5.0, SD = 2.3, n = 52) than in the Pilot Study (M=2.0, SD = 0.8, n = 18) and Study 1 (M = 1.3, SD =

0.4, n = 73), as shown in Figure 4.11. The variation between Study 1 and Study 2 was shown to be significant (F (1,122) = 172.71, p < 0.001). This variation occurred due to an issue with the measured TPM settings on which the expected EC concentration was set for Study 2. However the results remained within the Guidance for General Excursions above the Occupational Exposure Standard and as such are still valid (SafeWork Australia 2012).

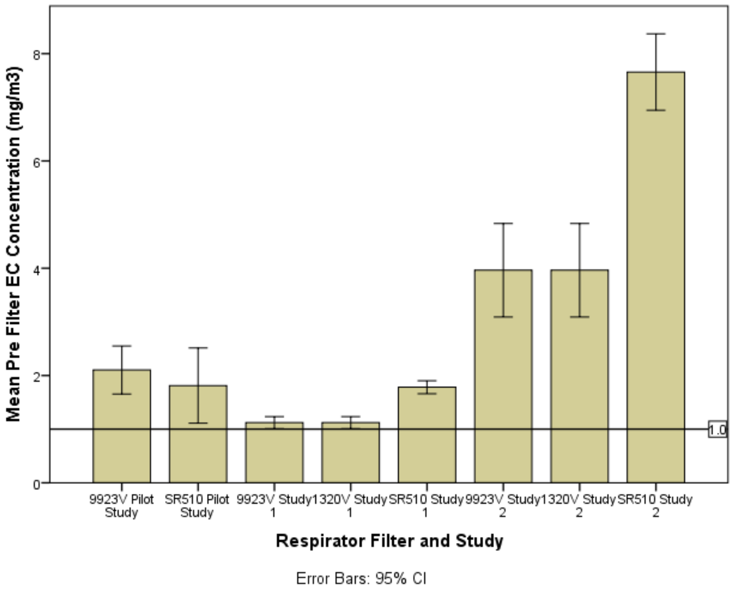

Figure 4.11: Pre Filter EC Concentration in Experimental Chamber – Pilot Study, Study 1 and Study 2

4.5.1.2 Penetration of EC, TC and TPM through the Respirator Filter

Variation between Study 1 and Study 2 for penetration of EC, TC and TPM through the respirator filter at 95L/min was measured by one-way ANOVA as reported in Table 4.11. This showed that for all filters combined as well as each individual filter model results were significantly different for EC and TPM penetration. The TC penetration results were also significantly different for the 1320V and SR510 filters, but were not for all filter models combined nor the 9923V filter.

TABLE 4.11: COMPARISON OF EFFECT ON PENETRATION THROUGH RESPIRATOR FILTERS AT 95L/MIN FOR STUDY 1 AND STUDY 2

	EC Penetration (%)	TC Penetration (%)	TPM Penetration (%)
All Filters	$F(1,87) = 11.96$, $p = 0.001$	$F(1,87) = 0.88$, $p = 0.352$	$F(1,75) = 23.25$, $p = <0.001$
9923V	$F(1,32) = 10.19$, $p = 0.003$	$F(1,32) = 0.95$, $p = 0.337$	$F(1,27) = 43.18$, $p = <0.001$
1320V	$F(1,32) = 7.34$, $p = 0.011$	$F(1,32) = 8.73$, $p = 0.006$	$F(1,28) = 8.96$, $p = 0.006$
SR510	$F(1,32) = 7.34$, $p = 0.011$	$F(1,32) = 8.73$, $p = 0.006$	$F(1,28) = 8.96$, $p = 0.006$

Figure 4.12 shows the mean penetration results by respirator filter model for the Pilot Study, Study 1 and Study 2 at a flow rate of 95L/min. For the 9923V filter mean penetration was highest in the Pilot Study, followed by Study 1 and Study 2. During the Pilot Study, sampling for elemental and total carbon was conducted at a higher flow rate, however for a shorter sampling period, compared to Study 1. The challenge concentration was also higher in the Pilot Study than in Study 1 and this may explain the variability in results for the 9923V filter. For Study 2, the engine and operating conditions varied from the Pilot Study and Study 1, which appears to be impacting the filtering efficiency of the 9923V respirator in particular.

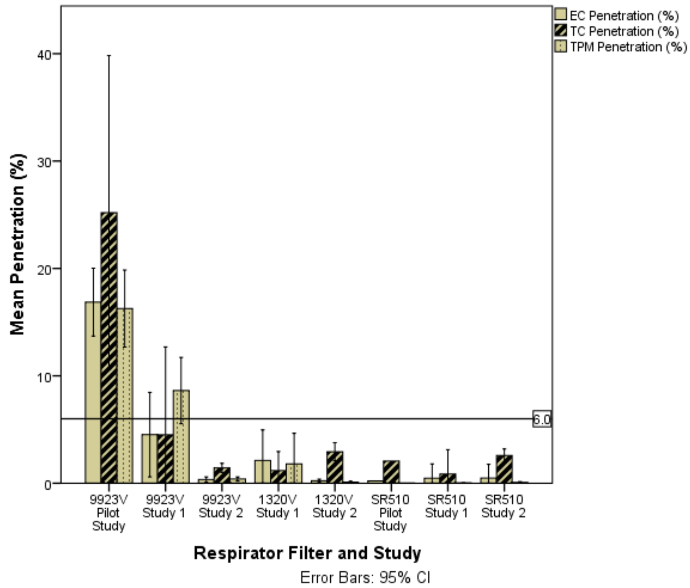

Figure 4.12: Mean EC, TC and TPM Penetration at 95L/min for Pilot Study, Study 1 and Study 2

4.5.1.3 Correlation between EC, TC and TPM for Pilot Study, Study 1 and Study 2

Correlation between EC, TC and TPM concentrations for the 3 studies are reported in Table 4.12. The EC/TPM did not show significant correlation for the pre filter measurements in the Pilot Study and Study 2, whilst the TC/TPM ratio did not show significant correlation for the pre filter Pilot Study results. Post filter results showed strong correlation for all relationships, except for Study 2.

TABLE 4.12: CORRELATION BETWEEN EC, TC AND TPM CONCENTRATION PILOT STUDY, STUDY 1 AND STUDY 2

	EC / TPM	TC / TPM	EC / TC
Pre Filter Pilot Study	*M* = 0.22, *n* = 20 *r* = 0.23, *p* = 0.338	*M* = 0.89, *n* = 20 *r* = 0.41, *p* = 0.071	*M* = 0.25, *n* = 20 *r* = 0.84, *p* < 0.001
Pre Filter Study 1	*M* = 0.32, *n*=71 *r* = 0.67, *p* < 0.001	*M* = 1.20, *n* = 71 *r* = 0.85, *p* < 0.001	*M* = 0.27, *n*=71 *r* = 0.79, *p* < 0.001
Pre Filter Study 2	*M* = 0.28, *n*=38 *r* = 0.36, *p* = 0.028	*M* = 0.44, *n* = 38 *r* = 0.73, *p* < 0.001	*M* = 0.63, *n*=52 *r* = 0.90, *p* < 0.001
Post Filter Pilot Study	*M* = 0.23, *n*=20 *r* = 0.74, *p* < 0.001	*M* = 0.89, *n* = 20 *r* = 0.79, *p* < .001	*M* = 0.26, *n* = 20 *r* = 0.96, *p* < 0.001
Post Filter Study 1	*M* = 0.22, *n* = 68 *r* = 0.92, *p* < 0.001	*M* = 1.11, *n* = 68 *r* = 0.75, *p* < 0.001	*M* = 0.20, *n* = 68 *r* = 0.91, *p* < 0.001
Post Filter Study 2	*M* = 1.56, *n* = 42 *r* = -0.08, *p* = 0.636	*M* = 10.87, *n* = 42 *r* = -0.29, *p* = 0.061	*M* = 0.14, *n*=52 *r* = 0.83, *p* < 0.001

In addition to use of the EC/TPM correlation data to set the concentration in the experimental chamber, the EC/TC ratio is reported in a number of studies and can be used to compare engine operating conditions. The difference in pre filter EC/TC ratio between Study 1 and Study 2 was found to be significant by a one-way ANOVA (F (1,124) = 978.01, $p < 0.001$), indicating that the operating conditions of the engines and hence the composition of the diesel emissions differed.

5. DISCUSSION AND CONCLUSION

5.1 OVERVIEW

The aims of this research were two-fold; firstly to determine whether current NaCl penetration test requirements adequately ascertain if Standards Australia certified respirator filters effectively filter out DPM, and secondly to determine whether Standards Australia certified respirator filters effectively filter out DPM at a flow rate representative of a moderate to heavy work rate.

The research was conducted in three phases. An initial Pilot Study was undertaken to evaluate the sampling methodology, Study 1 utilised the same small diesel generator as the Pilot Study, whilst Study 2 used a larger diesel engine as the source of diesel emissions. DPM penetration was measured as a function of EC penetration in accordance with NIOSH 5040 (NIOSH 2003). Penetration through the respirator filters by TC and TPM was also measured.

5.2 KEY FINDINGS

5.2.1 DPM Penetration at Standard Designated Flow Rate

Hypothesis 1: Penetration of DPM through Standards Australia P2 and P3 certified filters, when measured as EC, will not meet Standards Australia filtering efficiency requirement of 94% when tested at 95 L/min, the upper flow rate specified in AS/NZS 1716. This means that the measured penetration of EC through the respirator filters will exceed 6%.

To evaluate this hypothesis, the filters were tested with the diesel emissions as the challenge aerosol, in place of NaCl. The concentration of the challenge aerosol was set at 1mg/m^3 EC, which is at the upper end of the exposures typically reported in workplace studies, and the rated protection factor for the P2 filters.

Hypothesis 1was accepted for the 9923V filters in the Pilot Study. Penetration of EC, TC and TPM through the 9923V P2 respirators exceeded 6% over the 60 minute testing period. This was not determined for the SR510 filter in the Pilot Study as only one sample run occurred.

Hypothesis 1 was rejected for Study 1 when the mean value and 95%UCL for all tested filters was considered. For the individual filter models, this hypothesis was accepted for the 9923V filter, however was rejected for the 1320V and SR510 filter.

In Study 2, hypothesis 1 was rejected for all filters combined and when considered as individual filter models, given that the mean and UCL's were all below 6% penetration.

Therefore the findings indicate that filtering efficiency met standard certification requirements when all filters were considered for both the small scale diesel generator and the larger diesel engine, with the exception of the 9923V filter for the small scale diesel engine.

5.2.2 DPM Penetration at a flow rate representative of moderate to heavy work

Hypothesis two: Penetration of DPM through Standards Australia P2 and P3 certified filters, when measured as EC, will not meet filtering efficiency requirement of 94% when tested at 270L/min, a flow rate representative of moderate to heavy work. This means that the measured penetration of EC through the respirator filters will exceed 6%.

When all filters were considered, this hypothesis was accepted for Study 1. When considering individual filter models, this hypothesis was accepted for the P2 filters, as EC penetration through the filter media exceeded 6%. For the P3 filter, the mean EC, TC and TPM penetrations were low, however due to the two results being constant, an upper confidence limit was not available.

Hypothesis two could not be evaluated for Study 2, as due to time constraints with the equipment, the testing did not incorporate the higher flow rate.

These findings are consistent with studies using various challenge aerosols that have also reported penetration increases as flow rate increases (Balazy et al. 2006; Eshbaugh et al. 2009). P3 filters are certified to a higher protection factor than P2 filters, hence they were expected to exhibit a lower filter penetration than the P2 filters, however it was not clear prior to testing how these filters would perform at the higher flow rate.

5.2.3 Effect of Increased Flow Rate on EC Penetration

Flow rate through the respirator filter was found to have a significant effect on filter penetration in Study 1, consistent with published literature. This was not tested for Study 2 due to a lack of samples at the higher flow rate.

Recognition of the importance of considering work rate in the selection of appropriate respiratory protection, and subsequent certification testing at these work rates, is being incorporated into the updated ISO Performance Standard (ISO 2013). The Draft ISO Performance Standard proposed four work rate classes, with the test specification varying with testing for Work Rate 1 to be conducted at the flow rate of 85L/min, Work Rate 2 at 135 L/min, Work Rate 3 at 205L/min and Work Rate 4 at 255L/min.

Adoption of the ISO Performance Standard by Standards Australia will require manufacturers and suppliers to incorporate these new requirements into certification testing regimes and filter ratings. Respirator users will also be required to consider work rate when they select the appropriate respirator filter. Further validation testing should be undertaken to ensure that respirator filters effectively filter out DPM using the newly developed ISO test criteria, at the various work rates applicable to respirator wearing workers.

5.2.4 Effect of Respirator Filter Model on EC Penetration

The specific respirator filter model was found to have a significant impact on measured EC, TC and TPM penetration through the respirator filter in Study 1. In Study 2, the filter model had a significant effect for penetration by TPM, however was not significant for EC and TC, due to the low penetration values measured in Study 2. The finding that measured penetration varies with filter model is not unexpected as filter media vary in design properties, which use different mechanisms of particle capture, as described in Section 2.6.4. The three respirator filter models used in the study differ in filter capture design properties with the 9923V being an electret type filter, 1320V a combination of mechanical and electret properties and the SR510 relying on mechanical mechanisms of filter capture.

Interestingly when results from Study 1 and Study 2 were compared, measured EC and TPM penetration was significantly different between the two studies, as well as TC penetration for the 1320V and SR510 filters. It could be inferred that the change in experimental conditions between Study 1 and 2 had a significant influence on penetration for the filter models tested. It is proposed that the smaller engine is

producing more oil, which is interfering with the electret properties of the 9923V filter in particular.

The US NIOSH standard recognises different challenge aerosols will have differing effects on respirator filter media, incorporating a rating scheme which distinguishes between oil based and non oil based contaminants. In the specific case of DPM, a US research study found that penetration did not meet certification requirements for N rated filter media, however the criteria were met for P and R rated filters (Janssen & Bidwell 2006), when measured at a flow rate lower than that specified in the standard. European Standards specify penetration tests for particle filters using both NaCl and Paraffin Oil. In Australia there is no distinction between the types of aerosol that the filter is rated for, other than mechanically generated compared with thermally generated particles, and the protocol specifies NaCl for filter penetration tests.

This potential limitation with the Standards Australia test protocol could be addressed by adopting the ISO Standards currently being developed. However, at present there is limited research to confirm that the test protocols specified in the ISO standard ensure certified filters effectively protect workers from inhaling DPM.

5.2.5 Effect of Exposure Time on EC Penetration

EC penetration did not show a statistically significant difference, when comparing results for the measured exposure times of 0-30 and 30-60 minutes, nor the summed 0-60 minute results in Study 1 and Study 2. However in Study 1, TPM penetration through the filter media exceeded 6% after 30 minutes of exposure for the 9923V filter, which is well within a realistic time frame that a worker may wear a respirator filter without replacement. Current Standards Australia penetration tests are conducted over a much shorter time period, and therefore may not adequately assess whether the respirator is effective for the wear time of the worker. Therefore future testing should also be conducted for a representative time that a worker is required to wear the respirator.

5.3 STUDY IMPLICATIONS

The research findings identified potential shortcomings in the current Standards Australia test protocols for evaluation of filtering efficiency against DPM. This has implications for workers and employers who rely on Standards certified filters to prevent exposure to diesel engine emissions. Furthermore, data from the literature review suggest that certification testing is not

conducted at flow rates representative of moderate to heavy work, with the experimental findings from Study 1 indicating that measured penetrations increase at the higher flow rate.

The study used a methodology which relied on challenging the respirator filters with diesel engine emissions, the hazardous contaminant of concern, rather than the standard challenge aerosol of NaCl. A custom built experimental chamber was used to expose the respirator filters to the diesel emissions, over a time period representative of user wear time.

The implication that the current test methodology has some limitations has been acknowledged by Standards Australia in the preface to AS/NZS 1716. The fact that international test criteria distinguish between oil and non-oil based substances should not be ignored by Australian manufacturers and suppliers, especially when published research supports the findings that filter penetration may differ when challenged with DPM (Janssen 2003). Given the current work to develop aligned International Standards it is important that these standards adequately ensure protection against hazardous contaminants such as DPM, by utilising test protocols that are representative of the hazardous contaminants and consistent with worker respirator usage. It should be noted that the draft ISO standards specify NaCl or Paraffin Oil as a challenge aerosol, but do not specify under what scenarios each one should be used. They do however, require selection of an appropriate respirator with consideration of work rate.

5.4 STUDY LIMITATIONS

It is well documented that diesel exhaust emissions vary in characteristics based on variables such as engine size, load, exhaust treatments and operating condition as well as the type of fuel used. This research was conducted for two sources of diesel engine emissions. As such the reported findings represent the conditions under which the testing was conducted. Due to constraints with the study design, it was not possible to keep all parameters between the two studies constant to enable a direct comparison between the sampling results. These variations included operating load and fuel source. It is therefore difficult to establish which factors are contributing to the variability between the measured EC penetrations for the respirator filters.

The significantly different EC/TC ratio for the engine used in Study 1 and Study 2 may explain some of the variability in results between the two studies. An EC/TC ratio of approximately 0.78 was reported for nine coal mines in Australia (Noll et al. 2014), which is comparable with the EC/TC ratio measured for the engine used in Study 2. A lower EC/TC ratio, consistent with the EC/TC ratio for the engine used in Study 1, was interpolated from data for other mining equipment in Australia (Rogers 2005), although the lower EC/TC ratio may also indicate

overfuelling of the engine. It is therefore suggested that the variability in results obtained for the study is consistent with variability which would be seen in the variety of industries and workplaces that may require respiratory protection.

Another factor which may differentiate between Study 1 and 2 results is the particle size of the emissions. Measurement of EC by NIOSH 5040 is a mass based method, and one of the known limitations with this method is that as the particle size reduces, the mass on the filter is less, even though an increased number of particles may be present. As the potential health impacts of nanoparticles are of concern, it is important to determine the size of the particles that are penetrating through the respirator filter and compare the measured penetration by NIOSH 5040, with the measured penetration at the Most Penetrating Particle Size.

The lack of a validated direct reading instrument to measure EC concentration was a limitation of the study. Whilst the correlation between EC and TPM was used, a higher than desired pre filter concentration occurred during Study 2. The lack of instantaneous sampling results meant that required methodological adjustments, such as reducing the pre filter EC concentration, were not apparent until the results were received after the sampling was complete.

5.5 RECOMMENDATIONS FOR FUTURE RESEARCH

Recommendations for further research include:

- Complete testing of EC, TC and TPM penetration on a large scale diesel engine at a flow rate representative of moderate to heavy work.
- Align the flow rates at which further testing is conducted with work rates in proposed ISO standards
- Conduct testing utilising filters meeting ISO test requirements, to determine if the proposed ISO standards adequately ascertain whether certified filters effectively filter out DPM.
- Test filter penetration by NaCl, DOP and Paraffin Oil for respirator filters used in future studies, to be able to compare test results when DPM is used as the challenge agent, to these Standard Challenge aerosols.
- Determine the Most Penetrating Particle Size (MPPS) of DPM for each of the filters and calculate whether penetration at the MPPS meets certification requirements.
- Determine whether a Direct Reading Instrument for EC can be validated against Diesel Engine emissions.

5.6 CONCLUSION

This research suggests that limitations in the current test protocols for filtering efficiency specified in AS/NZS 1716, may not ensure workers are adequately protected against DPM. Furthermore, certification testing is not conducted at flow rates representative of moderate to heavy work, despite indications of increased filter penetration with increasing flow rate. These findings have implications for workers required to wear respiratory protection, particularly those who are required to work at moderate to heavy work rates.

Further work is needed to validate the outcomes of this study. This research will assist the development of improved Australian and International standards relating to the selection and evaluation of DPM respiratory protection equipment, so as to better manage the health risk for personnel exposed to this workplace carcinogen. In particular, these findings should be considered when determining whether the ISO standards currently being drafted, which incorporate alternative challenge aerosols and work rates, should be adopted in Australia. The findings will inform users of the limitations in selection of respiratory protection and contribute to manufacturers' and suppliers' knowledge in the selection and design of respirator filters.

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Appendix A: Studies Reporting Impact of Flow Rate and/or Challenge Aerosol on Penetration through Respirator Filter Media.

Reference	Filter Media	Challenge Aerosol	Flow Rate L/min	Outcomes (Filtering Efficiency)	Comments
(Penconek, Drążyk and Moskal 2013)	FFP2 and FFP3 EN certified respirators	3 types of diesel fuel 4 replicates Pressure drop and total mass Number size distribution Engine Idling 40 minute filter exposure, 80 minute testing, 5 minute intervals	30	DPM mass penetration > Standard test aerosol penetration	Filtering Efficiency Certification requirements not met
(Janssen and Bidwell 2006)	4 NIOSH respirators P95 R95 N95 x 2	Laboratory Aerosol Penetration (%) EC Penetration (%) 7-10 replicates Pressure drop Particle Size Distribution measured	25	Exposure: 1-2 hours 8 hours 2 Samples summed to 8 hours (Intermittent) Unexposed controls	Penetration <1% Up to 11% lab aerosol penetration 8h 0.79%, up to 19.7% (8hr) EC all acceptable Pressure Drop no significant difference Mean results for R and P acceptable, N not acceptable but not rated for DPM Note 1
(He et al. 2013)	P100 respirators challenged with Combustion aerosols at medium, high and strenuous workloads	4 replicates Particle concentrations measured for 90 mins	30 85 135	90 mins of sampling after exposure	Penetration highest at 85L/min.
(Balazy et al. 2006)	N95 respirators – 2 types		30		Penetration may exceed 5% at higher flow

Reference	Filter Media	Challenge Aerosol	Flow Rate L/min	Outcomes (Filtering Efficiency)	Comments
	Challenged with NaCl		85		rates
(Brochot et al. 2012)	2 EN certified P2 and P3 filters	Constant and cyclic flow 2 different methods to measure particle size distribution of NaCl	84 Mean Inspiratory Flow Rate		↑ the average filtration flow rate causes a shift toward smaller particles at MPPS – explained by increase in the inertial capture of the largest particles
(Rengasamy, BerryAnn and Szalajda 2013)	N95, N100, 4 x P100	NaCl – N95 and N100 DOP – P100	85		MPPS should be considered as a key factor
(Cho et al. 2011)	15 respirators 3 replicates	NaCl Welding Fume Particle Size Distribution	85 42.5 dual filter	Penetration and pressure drop recorded every minute	Met certification Peak Weld Fume Penetrations ≤ peak NaCl concentrations. Therefore NaCl conservative surrogate for weld fume penetration
(Eninger, Honda, Adhikari, et al. 2008)	2 x N99 1 x N95 3 replicates of each	NaCl Virion (Ultrafine)	30 85 150	Penetration	Penetration ↑ as Flow Rate ↑
(Eshbaugh et al. 2009)	4 x N95 4 x P100	Constant and cyclic flow Polystyrene latex spheres DOP	85 270 360		Penetration ↑ as Flow Rate ↑

Note 1: NIOSH N-series filters are not acceptable to use in workplace atmospheres that contain oily residues as they are not required to demonstrate resistance to the potentially degrading effects of oils.

FFR – Full facepiece respirator

Appendix B: Calibration Record Dick Smith Q1437 Thermometer

Certificate of Calibration

SmartCal Calibration & Repair

ABN 68 161 707 213

CUSTOMER: SAFETY EQUIPMENT AUSTRALIA (CASH ACCOUNT)

SAFETY EQUIPMENT AUSTRALIA (CASH ACCOUNT)
1/35 JUBILEE AVENUE
WARRIEWOOD NSW 2102

Job Number: 36184
Certificate No: 36184-3/1
Customer Ref: 21357
Laboratory Location:
SmartCal Pty Ltd
Unit 35/9 Salisbury Rd,
Castle Hill NSW 2154

INSTRUMENT DESCRIPTION:

Product: DICK SMITH Q1437
Description: THERMOMETER
Serial Number: 02000273
Asset Number: X1

Calibration Date: 24 Oct 2013
Calibration Due: 24 Oct 2014

TEST CONDITIONS:
Temperature: 23 ± 5°C
Relative Humidity: 50 ± 30%

INSTRUMENT CONDITION:
Received: Performance verified - see data report
Returned: As received - no adjustments performed

Calibration Procedure: DICK SMITH Q1437 THERMOMETER.CDR
Attachment: Calibration Data Report #36184-3/1

CALIBRATION EQUIPMENT USED:

Asset No	Description	Calibration Due
NTE214	AMETEK CTC-650A Temperature Well	14 Jun 2014
NTE220	FLUKE 744 Process Calibrator	16 Aug 2014
NTE331	TEMPERATURE CONTROLS RTD 3MM DIA PROBE	07 Dec 2013

SmartCal Pty Ltd certifies that the instrument listed herein was tested to all published specifications and the calibration has been performed using standards traceable to Australian national standards of measurement. The quality systems of SmartCal Pty Ltd are accredited to ISO 9001:2008.

Tested By: Mr Kevin Fraser

Authorised Signatory: Mr Tony Tong

www.smartcal.com.au
Ph: 1300 134 091 Fax: 1300 134 109

Report date: 24 Oct 2013

Revision: 1.1 Issued: 19 Jul 2012

Appendix C: Calibration Record TSI Flowmeter 40400438011 17th September 2013

Mass Flowmeter Calibration Certificate

Model 4040 Revision F
Serial Number 40400438011

Flowmeter Calibration Verification

Calibration Date Tue 17-Sep-2013 21:11
Verification Date Tue 17-Sep-2013 21:27
Temperature 21.0 °C
Pressure 14.23 psia

Air - As Left
Tolerance: 1.75% reading or 0.050 SLPM

Actual (SLPM)	Measured (SLPM)	Difference (%)	Tolerance (%)
0.552	0.510	-7.7	-85
2.057	2.028	-1.4	-59
6.021	5.962	-1.0	-56
14.47	14.35	-0.9	-50
28.86	28.77	-0.3	-17
45.31	45.14	-0.4	-21
61.51	62.21	1.1	65
79.98	80.26	0.3	20
100.1	101.6	1.5	85
124.7	125.0	0.3	18
160.2	160.7	0.3	16
200.5	200.1	-0.2	-10
239.5	240.2	0.3	18
280.3	281.9	0.6	32

Oxygen - As Left
Tolerance: 1.75% reading or 0.050 SLPM

Actual (SLPM)	Measured (SLPM)	Difference (%)	Tolerance (%)
0.555	0.510	-8.1	-90
2.055	2.030	-1.2	-50
6.201	6.158	-0.7	-40
14.48	14.39	-0.6	-33
28.97	29.01	0.1	8
45.57	45.36	-0.5	-26
61.52	62.56	1.7	97
79.93	80.06	0.2	9
99.27	99.58	0.3	18
124.5	125.1	0.5	29
159.6	160.4	0.5	28
199.5	199.2	-0.1	-8
240.4	239.3	-0.5	-26
279.9	281.4	0.5	31

Temperature - As Left
Tolerance: ±1.000 °C

Actual (°C)	Measured (°C)	Difference (%)	Tolerance (%)
21.01	20.24	-3.64	-77

Pressure - As Left
Tolerance: ±0.110 psia

Actual (psia)	Measured (psia)	Difference (%)	Tolerance (%)
14.23	14.23	-0.04	-5
22.72	22.72	-0.02	-5

This flowmeter has been calibrated on the TSI Flowmeter Calibration Facility (TSI 9120254) using the procedures outlined in TSI 9010471. The calibration of the Flowmeter Calibration Facility maintains NIST traceability in accordance with TSI 9120254.

TSI Standard Conditions: 70 °F (21.11 °C) and 14.7 psia

Verified By:

Calibration Standard:	FLOWCAL5
Std. Last Verified:	24-Jul-2013
Std. Next Verify Due:	22-Oct-2013

Shipping Address: TSI Inc., 500 Cardigan Rd, Shoreview, MN 55126 USA

Appendix D: Calibration Record TSI Flowmeter 40400438011 17th June 2014

Mass Flowmeter Calibration Certificate

Model 4040 Revision F
Serial Number 40400438011

Flowmeter Calibration Verification

Calibration Date Tue 17-Jun-2014 10:25
Verification Date Tue 17-Jun-2014 10:42
Temperature 21.0 °C
Pressure 14.16 psia

Air - As Left
Tolerance: 1.75% reading or 0.050 SLPM

Actual (SLPM)	Measured (SLPM)	Difference (%)	Tolerance (%)
0.550	0.558	1.5	16
2.047	2.060	0.6	26
6.003	5.980	-0.4	-22
14.54	14.45	-0.6	-36
29.08	29.11	0.1	6
45.42	45.57	0.3	19
61.27	60.80	-0.8	-43
79.89	79.94	0.1	4
100.1	100.9	0.9	49
124.6	124.6	0.0	0
160.2	161.5	0.8	46
199.5	199.0	-0.2	-13
239.7	241.7	0.8	47
279.9	280.9	0.4	21

Oxygen - As Left
Tolerance: 1.75% reading or 0.050 SLPM

Actual (SLPM)	Measured (SLPM)	Difference (%)	Tolerance (%)
0.553	0.550	-0.6	-6
2.049	2.052	0.1	5
5.763	5.762	-0.0	-1
14.51	14.45	-0.4	-23
28.93	28.99	0.2	13
45.66	45.75	0.2	11
61.66	61.39	-0.4	-25
79.94	79.23	-0.9	-51
99.35	99.00	-0.4	-20
124.9	125.4	0.4	22
160.1	161.6	0.9	51
200.1	199.5	-0.3	-19
240.2	240.5	0.1	6
281.0	283.6	0.9	51

Temperature - As Left
Tolerance: ±1.000 °C

Actual (°C)	Measured (°C)	Difference (%)	Tolerance (%)
20.89	19.93	-4.57	-96

Pressure - As Left
Tolerance: ±0.110 psia

Actual (psia)	Measured (psia)	Difference (%)	Tolerance (%)
14.15	14.15	-0.04	-5
21.50	21.50	-0.01	-2

This flowmeter has been calibrated on the TSI Flowmeter Calibration Facility (TSI 9120254) using the procedures outlined in TSI 9010471. The calibration of the Flowmeter Calibration Facility maintains NIST traceability in accordance with TSI 9120254.

TSI Standard Conditions: 70 °F (21.11 °C) and 14.7 psia

Verified By: Cody H. Coller

Calibration Reference(s)	
Reference	Due for Calibration
E005067	22-Jul-2014
E005068	22-Jul-2014
E005069	22-Jan-2015

Shipping Address: TSI Inc., 500 Cardigan Rd, Shoreview, MN 55126 USA

Printed: Tuesday 17-Jun-2014 10:51

Appendix E: Calibration Record TSI Flowmeter 40400419008 8th May 2013

WHEN COMPLETE, PLEASE RETURN TO QUALITY & MANUFACTURING ASSISTANT FOR FILING

Maintenance Record

ID **ZZ15**		Description	Flow Meter 4000 Series / Model 4040D							
		Calibration Reference Source *(if 'External' see certificate for calibration results)*	Internal (ZZ16)							
Serial Number 4040 0419 008		Calibration Reference Points Liters/min	0	100	200	300			Maintenance Period 1 year	
		Required Accuracy (liters/min) Gain error (± 2%FS) 0% offset error	-0.1 to 0.1	97.9 to 102.1	195.9 to 204.1	293.9 to 306.1				
Maint. Date	Next Due	Resolution = 0.1 Comments	Readings Taken						Result	Calibrated By:
13/6/08	13/6/09		0.0	100	199	298			PaSS	TC
12/6/09	12/6/10		0.0	100.3	199.6	298.7			PASS	RA
11/5/10	11/5/2011		0.0	100.0	199.5	299.0			PASS	RA
11/5/2011	11/5/2012		0.0	100.2	200	299.0			PASS	RA
22/05/12	22/05/13		0.0	100.2	199.6	298.0			PASS	RA
08/05/13	08/05/14	@ Temp = 22.6°C	0.0	100.1	199.6	298.9			PASS	RA
06/06/14	06/06/14	sent to TSI for Calibration / 22.4°C	0.0	108.2	222.0	320			FAIL	RA
17/06/14	17/06/15	AS FOUND (AIR)								
		Actual Check Points	0.549	114.6	180.0	260.2				
temp =	20.6°C	Measured	0.548	112.1	174.0	248.2			FAIL	
		AS LEFT (AIR)								
		Actual check Points	0.559	100.0	199.9	279.1				
Temp =	21.3°C	Measured	0.570	100.3	199.0	281.9			PASS	
3/11/14	3/11/15	AS FOUND (AIR)								
Temp = 21.9°C		Actual check points	0.555	99.66	199.8	280.7				
		Measured	210.1	209.8	209.8	269.7			FAIL	
		AS LEFT (AIR)								
		Actual check points	0.549	100.2	199.8	281.0				
		Measured	0.590	100.4	198.9	281.6			PASS	

Note: 1. Record on separate line each indicative value required for calibration.
2. Use a new form whenever changes will be made on Maintenance Period, Calibration Reference, and/or Required Accuracy.

CMT-001 F/2 Revision 3 (CN 1176) Page 1 of 1

Appendix F: Calibration Record TSI Flowmeter 40400419008 17th June 2014

Mass Flowmeter Calibration Certificate

Model 4040 Revision F
Serial Number 40400419008

Flowmeter Calibration Verification

Calibration Date Tue 17-Jun-2014 11:19
Verification Date Tue 17-Jun-2014 11:36
Temperature 21.3 °C
Pressure 14.16 psia

Air - As Left
Tolerance: 1.75% reading or 0.050 SLPM

Actual (SLPM)	Measured (SLPM)	Difference (%)	Tolerance (%)
0.559	0.570	2.0	23
2.064	2.070	0.3	12
6.004	5.948	-0.9	-53
14.55	14.45	-0.7	-41
29.00	28.96	-0.1	-7
45.50	45.43	-0.1	-8
61.46	62.31	1.4	79
79.81	79.79	-0.0	-2
100.00	100.3	0.3	19
124.4	124.6	0.1	8
160.2	162.0	1.1	63
199.9	199.0	-0.5	-26
240.9	240.7	-0.1	-6
279.1	281.9	1.0	56

Oxygen - As Left
Tolerance: 1.75% reading or 0.050 SLPM

Actual (SLPM)	Measured (SLPM)	Difference (%)	Tolerance (%)
0.550	0.550	-0.1	-1
2.075	2.070	-0.2	-9
6.027	6.040	0.2	12
14.53	14.50	-0.2	-11
29.01	29.04	0.1	7
45.50	45.32	-0.4	-23
61.27	62.23	1.6	89
79.99	79.71	-0.4	-20
100.3	100.2	-0.1	-3
125.0	125.8	0.7	39
159.9	161.4	0.9	54
199.4	197.9	-0.7	-42
240.5	239.2	-0.5	-31
279.9	281.6	0.6	35

Temperature - As Left
Tolerance: ±1.000 °C

Actual (°C)	Measured (°C)	Difference (%)	Tolerance (%)
21.23	20.60	-2.95	-63

Pressure - As Left
Tolerance: ±0.110 psia

Actual (psia)	Measured (psia)	Difference (%)	Tolerance (%)
14.16	14.15	-0.04	-5
21.32	21.32	-0.03	-6

This flowmeter has been calibrated on the TSI Flowmeter Calibration Facility (TSI 9120254) using the procedures outlined in TSI 9010471. The calibration of the Flowmeter Calibration Facility maintains NIST traceability in accordance with TSI 9120254.

TSI Standard Conditions: 70 °F (21.11 °C) and 14.7 psia

Verified By: Cody H. Colles

Calibration Reference(s)	
Reference	Due for Calibration
E005055	15-Jul-2014
E005056	15-Jul-2014
E005057	15-Jan-2015

Shipping Address: TSI Inc., 500 Cardigan Rd, Shoreview, MN 55126 USA

Printed: Tuesday 17-Jun-2014 14:21

Appendix G: Calibration Record Gas Meter 42

Air Quality
Laboratory Services
BlueScope Steel

GAS METER CALIBRATION WORKSHEET (ISOKINETIC ONLY)

Date :	1/10/2013
Calibrating Officer :	DL
Date Last Calibrated :	17/10/2012
Next Calibration Due :	1/10/2014

Calibration Equipment

Working Gas Meter Nº :	42
Standard Gas Meter Nº :	GM41(L+G)
Barometric Pressure (kPa):	100.2

Standard Gas Meter — **Pressure Drop :** 0.80 **kPa**

Run	Initial Reading (L)	Final Reading (L)	Total Volume (L)	Total Time (min)	Flow Rate (Th)	Flow Rate (Act)	±% Fast ±% Slow	Corrected Volume
1	67125.0	67156.8	31.8	10	3	3.2	-0.2	31.9
2	67156.8	67187.0	30.2	10	3	3.0	-0.2	30.3
3	67187.0	67216.1	29.1	10	3	2.9	-0.2	29.2
1	67236.1	67335.6	99.5	10	10	10.0	-0.01	99.5
2	67335.6	67434.6	99.0	10	10	9.9	-0.01	99.0
3	67434.6	67533.9	99.3	10	10	9.9	-0.01	99.3
1	67590.2	67790.5	200.3	10	20	20.0	0.02	200.3
2	67790.5	67991.1	200.6	10	20	20.1	0.02	200.6
3	67991.1	68190.1	199.0	10	20	19.9	0.02	199.0

Working Gas Meter — **Pressure Drop :** 0.85 **kPa**

Run	Static Reading (kPa)	Initial Reading (L)	Final Reading (L)	Total Volume (L)	Flow Rate (L/min) (Th)	Flow Rate (L/min) (Act)	Calibration Coefficient
1	0.06	398137.4	398168.2	30.8	3	3.1	1.035
2	0.06	398168.2	398197.3	29.1	3	2.9	1.041
3	0.06	398197.3	398225.6	28.3	3	2.8	1.031
1	0.14	398245.1	398342.2	97.1	10	9.7	1.026
2	0.14	398342.2	398439.0	96.8	10	9.7	1.024
3	0.14	398439.0	398536.1	97.1	10	9.7	1.024
1	0.29	398591.6	398789.7	198.1	20	19.8	1.014
2	0.29	398789.7	398987.6	197.9	20	19.8	1.016
3	0.29	398987.6	399184.0	196.4	20	19.6	1.016
						Average Coefficient :	1.025

Gas Meter Coefficient: 1.03

Comments : **Gas Meter pressure drop measured at 20 l/min.**
The acceptance range of the coefficient is between 0.95 and 1.05

Daniel List
Calibrating Officer

Mirek Gudz
Approved Signatory

Section No: 223.02 **DS.MA.SP-LABS-AQ-01**

Appendix H: Calibration Record Gas Meter 45

BLUESCOPE STEEL

Air Quality
Laboratory Services
BlueScope Steel

GAS METER CALIBRATION WORKSHEET (ISOKINETIC ONLY)

Date :	26/06/2013
Calibrating Officer :	DL
Date Last Calibrated :	26/06/2012
Next Calibration Due :	26/06/2014

Calibration Equipment	
Working Gas Meter Nº :	45
Standard Gas Meter Nº :	GM41(L+G)
Barometric Pressure (kPa):	102.2

Standard Gas Meter — **Pressure Drop :** 0.83 **kPa**

Run	Initial Reading (L)	Final Reading (L)	Total Volume (L)	Total Time (min)	Flow Rate (Th)	Flow Rate (Act)	±% Fast ±% Slow	Corrected Volume
1	59123.2	59149.1	25.9	10	3	2.6	-0.04	25.9
2	59152.0	59177.0	25.0	10	3	2.5	-0.04	25.0
3	59178.0	59205.5	27.5	10	3	2.8	-0.04	27.5
1	59205.5	59318.0	112.5	10	10	11.3	0.04	112.5
2	59318.0	59426.0	108.0	10	10	10.8	0.04	108.0
3	59426.0	59531.5	105.5	10	10	10.6	0.04	105.5
1	59531.5	59725.0	193.5	10	20	19.4	-0.02	193.5
2	59725.0	59889.0	164.0	10	20	16.4	-0.02	164.0
3	59889.0	60059.0	170.0	10	20	17.0	-0.02	170.0

Working Gas Meter — **Pressure Drop :** 0.84 **kPa**

Run	Static Reading (kPa)	Initial Reading (L)	Final Reading (L)	Total Volume (L)	Flow Rate (L/min) (Th)	Flow Rate (L/min) (Act)	Calibration Coefficient
1	0.39	208638.0	208663.5	25.5	3	2.6	1.020
2	0.39	208665.0	208689.5	24.5	3	2.5	1.025
3	0.39	208690.0	208716.5	26.5	3	2.7	1.042
1	0.59	208716.5	208829.0	112.5	10	11.3	1.005
2	0.59	208829.0	208935.5	106.5	10	10.7	1.020
3	0.59	208935.5	209039.5	104.0	10	10.4	1.020
1	0.98	209039.5	209231.5	192.0	20	19.2	1.018
2	0.98	209231.5	209395.0	163.5	20	16.4	1.013
3	0.98	209395.0	209565.0	170.0	20	17.0	1.010
					Average Coefficient :		1.019

Gas Meter Coefficient: 1.02

Comments : **Gas Meter pressure drop measured at 20 l/min.**
The acceptance range of the coefficient is between 0.95 and 1.05

Daniel List
Calibrating Officer

MG
Approved Signatory

Section No: 223.02 **DS.MA.SP-LABS-AQ-01**

Appendix I: Calibration Record DustTrak™

24th June 2013

Kenelec Scientific

TSI Dusttrak - Model 8520

Calibration Certificate

Report Number: DT110393

Page 1 of 2

Customer	Safety Equipment Australia
Address	North Shore Business Park, 35/1 Jubilee Avenue
	Warriewood NSW 2012
Contact	
Equipment	TSI Dustrak
Model	8520
Serial Number	85201865
Calibration Date	24/06/2013
Condition as Received	*As Left*

Reference Instruments			
Measurement Variable	**Model No.**	**Serial No.**	**Calibration Date**
Photometer	8587A	71002264	8/01/2013
DC Voltage (Keithley)	2700	1260416	3/01/2013
Pressure	276140-SP	4146296	9/01/2013
Flow and Temperature	4140	41400951036	16/04/2013
1 um PSL		36795	Not Applicable
2.8 um PSL		580457	Not Applicable
10 um PSL		612530	Not Applicable

ENVIRONMENTAL CONDITIONS	
Ambient Temp	21ºC
Humidity	42%RH
Barometric Pressure	995hPa

Kenelec Scientific Pty Ltd Certifies That :-

All performance and acceptance tests required were successfully conducted according to required specifications. All test and calibration data suppled by Kenelec Scientific has been obtained using emery oil and has been nominally adjusted to respirable mass standard ISO 12103-1 Al Test Dust (Arizona Dust)

Procedures Followed:	LABP1
Approved Signatory:	M Walker
Date:	24-6-2013

KENELEC SCIENTIFIC PTY LTD
ABN 88 064 373 717

23 Redland Drive
Mitcham Vic 3132

T 03 9873 1022
F 03 9873 0200

info@kenelec.com.au www.kenelec.com.au

Kenelec Scientific

TSI Dusttrak - Model 8520

Calibration Certificate

Report Number: DT110393

CALIBRATION RESULTS				
As Found Verification Data				
Testing Number	Calibration Reference mg/m3	Instrument Output	Allowable Range +/-10%	
1	0.045	0.012	0.041	0.050
2	0.301	0.094	0.271	0.331
3	2.331	0.735	2.098	2.564
4	13.778	4.401	12.400	15.156

CALIBRATION RESULTS				
Calibration Verification Data				
Testing Number	Calibration Reference mg/m3	Instrument Output	Allowable Range +/-10%	
1	0.065	0.061	0.059	0.072
2	0.445	0.461	0.401	0.490
3	3.408	3.486	3.067	3.749
4	20.356	21.159	18.320	22.392

KENELEC SCIENTIFIC PTY LTD
ABN 88 064 373 717
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Appendix J: Calibration Record DustTrak™

3rd July 2014

Kenelec Scientific

TSI Dusttrak - Model 8520

Calibration Certificate

Document	KF500
Revision	A

Report Number: DT113188

Page 1 of 2

Customer	Safety Equipment Australia
Address	North Shore Business Park
	35/1 Jubilee Avenue, Warriewood, NSW 2102
Contact	
Equipment	TSI Dustrak
Model	8520
Serial Number	85201865
Calibration Date	3/07/2014
Condition as Received	*As Left*

Reference Instruments

Measurement Variable	Model No.	Serial No.	Calibration Date
Photometer	8587A	71002264	23/12/2013
DC Voltage (Keithley)	2700	1260416	21/01/2014
Pressure	276140-SP	4146296	1/01/2014
Flow and Temperature	4140	41401118008	16/09/2013
1 um PSL		36795	Not Applicable
2.8 um PSL		580457	Not Applicable
10 um PSL		612530	Not Applicable

ENVIRONMENTAL CONDITIONS

Ambient Temp	19.2°C
Humidity	51.4%RH
Barometric Pressure	1002hPa

Kenelec Scientific Pty Ltd Certifies That :-

All performance and acceptance tests required were successfully conducted according to required specifications. All test and calibration data suppled by Kenelec Scientific has been obtained using emery oil and has been nominally adjusted to respirable mass standard ISO 12103-1 AI Test Dust (Arizona Dust)

Procedures Followed:	LABP1
Approved Signatory:	
Date:	3/07/2014

KENELEC SCIENTIFIC PTY LTD
ABN 88 064 373 717

23 Redland Drive
Mitcham Vic 3132

T 03 9873 1022
F 03 9873 0200

info@kenelec.com.au www.kenelec.com.au

This Calibration Certificate shall not be reproduced except in full, without the written approval of Kenelec Scientific Pty Ltd

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CALIBRATION RESULTS				
As Found Verification Data				
Testing Number	Calibration Reference mg/m3	Instrument Output	Allowable Range +/-10%	
1	0.043	0.054	0.039	0.047
2	0.302	0.413	0.272	0.332
3	2.279	3.085	2.051	2.507
4	13.804	18.934	12.424	15.184

CALIBRATION RESULTS				
Calibration Verification Data				
Testing Number	Calibration Reference mg/m3	Instrument Output	Allowable Range +/-10%	
1	0.041	0.038	0.037	0.045
2	0.293	0.294	0.264	0.322
3	2.194	2.188	1.975	2.413
4	13.294	13.284	11.965	14.623

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Appendix K: Calibration Record SW-2

Stopwatch

STOP WATCH CALIBRATION RECORD.

1) To compare the accuracy of the stop watch with Telecom time signals ring the switchboard (dial 9) and ask to be connected to the Telecom time line.

2) At the third stroke precisely, start the stop watch, record the time and hang up the telephone.

3) Once 15 minutes has elapsed, ring the time line again. When 16 minutes has elapsed, at the third stroke precisely, stop the watch and record the Telecom finish time and stop watch time.

COMPARISON WITH TELECOM TIME SIGNALS

STOP WATCH No: SW 2

DATE	Telecom Time Start	Telecom Time Finish	Telecom Time Total time (xx:xx:xx)	Stop Watch Elapsed Time Total time (xx:xx:xx)	% Difference	Operator	Checked By
24/04/12	9:29:50	9:51:40	21m 50sec	21m 51secs ·66	·13%	[signature]	KLT
✓	10:37:00	10:53:00	16m : 00s	16:00:37	·04%	[signature]	KLT
8th May 2013	9:41:10	9:58:40	17m : 30s	17:29:87	·01%	[signature]	KLT
16th May 14	13:03:00	13:15:50	12m : 50s	12:50 .05	·06%	[signature]	KLT

Appendix L: Calibration Record BIOS Defender 510M

AirMet Scientific P/L
7-11 Ceylon Street
Nunawading
Victoria 3131, Australia
Tel: 61 3 8878 3300 *Fax: 61 3 8878 3344*

Calibration Certificate

This document hereby certifies that this instrument detailed has been calibrated to the parameters listed below.

Certificate Print Date: 20 September, 2013 **Call ID: 00142663**

Arrow Job Code:

Calibration Date: 20 September, 2013
Next Calibration Due: 20 September, 2014

Customer: AMS NSW RENTAL **Type** Port Gas Det
Model: DEFENDER **Serial No:** 113619
Frequency:
Description Defender 510 M

Time Sec	Vol mL or Cat*	Indicated flow	Actual Flow	Error %	Comments
		495.50	495.5		Instruments within manufacturers specifications of ±1%
		1,013.00	1,012.3	-0.1	Instruments within manufacturers specifications of ±1%
		1,995.00	1,997.6	0.1	Instruments within manufacturers specifications of ±1%
		2,526.00	2,532.8	0.3	Instruments within manufacturers specifications of ±1%
		3,028.00	3,025.8	-0.1	Instruments within manufacturers specifications of ±1%
		3,531.00	3,525.2	-0.2	Instruments within manufacturers specifications of ±1%
		4,047.00	4,062.8	0.4	Instruments within manufacturers specifications of ±1%
		4,994.00	5,013.4	0.4	Instruments within manufacturers specifications of ±1%

This instrument has been calibrated against a DryCal DC Lite. The DryCal has been calibrated against an SKC flowmeter 311-1000 that has been calibrated by the CSIRO National measurement laboratory. (Ref 1116) and timed with a traceable Seiko Digital Stopwatch Model S23299 S/N 290025. Calibration of the DryCal was conducted using the Manufacturers calibration/test procedures with a constant flow pump using the soap film technique.

Completed by: *Wentao Zhang* Signed : Zhang Weatan

* Volume Category A 494.7 +/- 0.7ml
B 995.2 +/- 0.7ml

Page 1 of 2

Appendix M: Results - Pilot Study

Filter	Date	Time (min)	Flow Rate (L/min)	Pre Filter Sample Volume (L)	Post Filter Sample Volume (L)	Pre Filter EC (µg)	Post Filter EC (µg)	Pre Filter EC (mg/m³)	Post Filter EC (mg/m³)	Penetration EC (%)	Pre Filter TC (µg)	Post Filter TC (µg)	Pre Filter TC (mg/m³)	Post Filter TC (mg/m³)	Penetration TC (%)	Pre Filter TPM (mg/m³)	Post Filter TPM (mg/m³)	Penetration TPM (%)
9923V	4/2/14	0-15	95	141	131	329	16	2.3	0.1	5.1	1791	104	12.6	0.7	5.4	15.2	2.1	13.8
9923V	4/2/14	15-30	95	134	129	278	68	2.1	0.5	25.0	1329	318	9.8	2.3	23.7	8.8	2.1	23.9
9923V	4/2/14	30-45	95	136	135	254	92	1.9	0.7	36.3	1294	473	9.4	3.4	35.8	10.8	4.3	40.2
9923V	4/2/14	45-60	95	140	136	193	105	1.4	0.8	55.8	1122	413	7.9	2.9	37.0	11.7	5.4	46.2
9923V	4/2/14	0-60	95	-	-	-	-	1.9	0.5	30.6	-	-	9.9	2.3	25.5	11.6	3.5	31.0
9923V	4/2/14	0-15	95	131	132	260	17	2.0	0.1	6.1	1079	97	8.1	0.6	7.5	10.1	0.3	2.8
9923V	4/2/14	15-30	95	89	136	99	37	1.1	0.3	24.2	233	168	2.4	1.1	45.8	8.4	1.5	17.7
9923V	4/2/14	30-45	95	135	131	291	50	2.2	0.4	17.6	1148	175	8.4	1.2	14.5	7.4	1.8	23.7
9923V	4/2/14	45-60	95	140	128	287	59	2.0	0.5	22.4	1077	204	7.6	1.5	19.4	7.4	1.8	24.2
9923V	4/2/14	0-60	95	-	-	-	-	1.8	0.3	17.6	-	-	6.6	1.1	21.8	8.3	1.3	17.1
9923V	4/2/14	0-15	95	136	132	255	7	1.9	<0.1	2.5	980	41	7.1	0.2	2.7	7.5	<0.1	0.2
9923V	4/2/14	15-30	95	128	126	237	26	1.8	0.2	10.8	990	117	7.6	0.8	10.5	8.3	1.0	12.4
9923V	4/2/14	30-45	95	136	135	642	149	4.7	1.1	23.2	2424	563	17.8	4.0	22.8	8.9	1.8	20.4
9923V	4/2/14	45-60	95	133	130	250	61	1.9	0.5	24.9	269	243	1.9	1.7	92.0	9.3	2.4	25.4
9923V	4/2/14	0-60	95	-	-	-	-	2.6	0.5	15.4	-	-	8.6	1.7	32.0	8.5	1.3	14.6
SR510	4/2/14	0-15	95	131	136	243	<1	1.8	<0.1	0.3	1096	47	8.2	0.2	2.8	8.7	<0.1	<0.1
SR510	4/2/14	15-30	95	127	136	227	1	1.8	<0.1	0.2	907	50	7.0	0.2	3.5	10.6	<0.1	<0.1
SR510	4/2/14	30-60	95	152	255	369	1	2.4	<0.1	0.1	1653	43	10.8	0.1	1.0	10.7	<0.1	<0.1

Filter	Date	Time (min)	Flow Rate (L/min)	Pre Filter Sample Volume (L)	Post Filter Sample Volume (L)	Pre Filter EC (µg)	Post Filter EC (µg)	Pre Filter EC (mg/m³)	Post Filter EC (mg/m³)	Penetration EC (%)	Pre Filter TC (µg)	Post Filter TC (µg)	Pre Filter TC (mg/m³)	Post Filter TC (mg/m³)	Penetration TC (%)	Pre Filter TPM (mg/m³)	Post Filter TPM (mg/m³)	Penetration TPM (%)
SR510	4/2/14	0-60	95	-	-	-	-	2.1	<0.1	0.2	-	-	9.2	0.2	2.1	10.2	<0.1	<0.1
SR510	4/2/14	0-15	360	146	134	134	<1	0.9	<0.1	0.7	612	26	4.1	0.1	1.9	2.5	<0.1	<0.1
No Filter	4/2/14	0	95	-	-	-	-	-	-	-	-	-	-	-	-	12.5	12.8	102.4
No Filter	4/2/14	0-15	95	143	134	259	243	1.8	1.8	100.6	1486	1548	10.2	11.5	111.9	11.5	11.0	95.7
No Filter	4/2/14	15-30	95	152	130	269	203	1.8	1.6	88.3	1222	783	7.9	5.9	74.5	11.0	11.0	100.0
No Filter	4/2/14	0-30	95	-	-	-	-	1.8	1.7	94.5	-	-	9.1	8.7	93.2	11.3	11.0	97.8

Appendix N: Results - Study 1

Filter	Date	Time (min)	Flow Rate (L/min)	Pre Filter Sample Volume (L)	Post Filter Sample Volume (L)	Pre Filter EC (µg)	Post Filter EC (µg)	Pre Filter EC (mg/m^3)	Post Filter EC (mg/m^3)	Penetration EC (%)	Pre Filter TC (µg)	Post Filter TC (µg)	Pre Filter TC (mg/m^3)	Post Filter TC (mg/m^3)	Penetration TC (%)	Pre Filter TPM (mg/m^3)	Post Filter TPM (mg/m^3)	Penetration TPM (%)
1320V	28/4/14	0-30	95	132	132	95	1	0.7	<0.1	0.9	574	23	3.9	<0.1	0.2	3.1	<0.1	0.4
1320V	28/4/14	30-60	95	132	135	98	12	0.7	0.1	11.0	490	86	3.3	0.2	7.0	2.5	<0.1	0.9
1320V	28/4/14	0-60	95	-	-	-	-	0.7	<0.1	5.9	-	-	3.6	0.1	3.6	2.8	<0.1	0.7
1320V	28/4/14	0-30	95	127	129	190	<1	1.5	<0.1	0.4	561	9	4.0	<0.1	0.2	3.4	0.2	5.9
1320V	28/4/14	30-60	95	120	120	125	8	1.0	0.1	5.3	574	74	4.3	0.2	3.8	4.0	0.2	5.9
1320V	28/4/14	0-60	95	-	-	-	-	1.3	0.1	2.9	-	-	4.2	0.1	2.0	3.7	0.2	5.9
1320V	28/4/14	0-30	95	133	127	128	1	1.0	<0.1	0.7	576	46	3.9	<0.1	0.2	3.7	<0.1	0.3
1320V	28/4/14	30-60	95	134	127	116	1	0.9	<0.1	0.8	488	45	3.2	<0.1	0.2	3.4	<0.1	0.7
1320V	28/4/14	0-60	95	-	-	-	-	0.9	<0.1	0.7	-	-	3.6	<0.1	0.2	3.5	<0.1	0.5
1320V	28/4/14	0-30	95	138	134	237	1	1.7	<0.1	0.4	725	41	4.8	<0.1	0.1	3.8	<0.1	0.6
1320V	28/4/14	30-60	95	137	132	150	2	1.1	<0.1	0.6	652	53	4.4	<0.1	0.1	4.5	0.1	1.4
1320V	28/4/14	0-60	95	-	-	-	-	1.4	<0.1	0.5	-	-	4.6	<0.1	0.1	4.1	<0.1	1.0
1320V	29/4/14	0-30	270	140	137	126	8	0.9	<0.1	5.5	652	94	4.3	0.3	6.8	3.2	0.3	10.4
1320V	29/4/14	30-60	270	140	136	141	22	1.0	0.1	14.8	650	241	4.3	1.4	32.1	3.1	1.1	34.7
1320V	29/4/14	0-60	270	-	-	-	-	0.9	0.1	10.4	-	-	4.3	0.8	19.5	3.1	0.7	22.6
1320V	29/4/14	0-30	270	139	136	247	1	1.8	<0.1	0.4	765	18	5.1	<0.1	0.1	3.3	0.2	6.8
1320V	29/4/14	30-60	270	140	136	156	21	1.1	0.2	13.2	659	137	4.3	0.6	14.0	3.1	0.5	16.2
1320V	29/4/14	0-60	270	-	-	-	-	1.4	0.1	6.8	-	-	4.7	0.3	7.1	3.2	0.4	11.5

Filter	Date	Time (min)	Flow Rate (L/min)	Pre Filter Sample Volume (L)	Post Filter Sample Volume (L)	Pre Filter EC (µg)	Post Filter EC (µg)	Pre Filter EC (mg/m^3)	Post Filter EC (mg/m^3)	Penetration EC (%)	Pre Filter TC (µg)	Post Filter TC (µg)	Pre Filter TC (mg/m^3)	Post Filter TC (mg/m^3)	Penetration TC (%)	Pre Filter TPM (mg/m^3)	Post Filter TPM (mg/m^3)	Penetration TPM (%)
1320V	29/4/14	0-30	270	137	136	182	8	1.2	<0.1	3.9	739	80	5.0	0.2	3.8	3.5	0.4	10.8
1320V	29/4/14	30-60	270	134	138	NA	NA	-	-	-	NA	NA	-	-	-	2.8	0.5	18.6
1320V	29/4/14	0-60	270	-	-	-	-	-	-	-	-	-	-	-	-	3.2	0.4	14.7
1320V	29/4/14	0-30	270	132	137	211	7	1.6	<0.1	2.7	746	76	5.2	0.2	3.0	4.0	0.3	8.6
1320V	29/4/14	30-60	270	134	137	157	35	1.2	0.2	21.4	697	192	4.8	1.0	20.9	3.1	0.8	25.9
1320V	29/4/14	0-60	270	-	-	-	-	1.4	0.1	12.1	-	-	5.0	0.6	11.9	3.5	0.6	17.3
1320V	30/4/14	0-30	95	140	139	144	1	1.0	<0.1	0.6	594	41	3.9	<0.1	0.2	3.8	<0.1	0.7
1320V	30/4/14	30-60	95	142	137	122	3	0.9	<0.1	1.3	462	39	2.9	<0.1	0.2	2.8	<0.1	1.2
1320V	30/4/14	0-60	95	-	-	-	-	0.9	<0.1	1.0	-	--	3.4	<0.1	0.2	3.3	<0.1	0.9
1320V	30/4/14	0-30	270	137	138	149	9	1.1	0.1	5.4	748	108	5.1	0.4	7.7	3.1	0.2	8.0
1320V	30/4/14	30-60	270	136	136	142	26	1.0	0.2	17.3	694	189	4.7	1.0	21.2	2.7	0.5	20.3
1320V	30/4/14	0-60	270	-	-	-	-	1.1	0.1	11.3	-	-	4.9	0.7	14.4	2.9	0.4	14.2
9923V	28/4/14	0-30	95	132	145	95	3	0.7	<0.1	1.2	574	46	3.9	<0.1	0.2	3.1	0.2	5.6
9923V	28/4/14	30-60	95	132	144	98	<1	0.7	<0.1	0.8	490	14	3.3	<0.1	0.2	2.5	0.4	17.0
9923V	28/4/14	0-60	95	-	-	-	-	0.7	<0.1	1.0	-	-	3.6	<0.1	0.2	2.8	0.3	11.3
9923V	28/4/14	0-30	95	127	139	190	10	1.5	0.1	4.1	561	77	4.0	0.2	4.0	3.4	0.1	2.6
9923V	28/4/14	30-60	95	120	133	125	9	1.0	0.1	5.7	574	64	4.3	0.1	1.8	4.0	0.4	10.6
9923V	28/4/14	0-60	95	-	-	-	-	1.3	0.1	4.9	-	-	4.2	0.1	2.9	3.7	0.3	6.6
9923V	28/4/14	0-30	95	133	133	128	3	1.0	<0.1	1.5	576	40	3.9	<0.1	0.2	3.7	0.2	6.4
9923V	28/4/14	30-60	95	134	134	116	14	0.9	0.1	11.1	488	85	3.2	0.2	7.2	3.4	0.6	16.7

Filter	Date	Time (min)	Flow Rate (L/min)	Pre Filter Sample Volume (L)	Post Filter Sample Volume (L)	Pre Filter EC (µg)	Post Filter EC (µg)	Pre Filter EC (mg/m^3)	Post Filter EC (mg/m^3)	Penetration EC (%)	Pre Filter TC (µg)	Post Filter TC (µg)	Pre Filter TC (mg/m^3)	Post Filter TC (mg/m^3)	Penetration TC (%)	Pre Filter TPM (mg/m^3)	Post Filter TPM (mg/m^3)	Penetration TPM (%)
9923V	28/4/14	0-60	95	-	-	-	-	0.9	0.1	6.3	-	-	3.6	0.1	3.7	3.5	0.4	11.6
9923V	28/4/14	0-30	95	138	136	237	2	1.7	<0.1	0.4	725	43	4.8	<0.1	0.1	3.8	0.1	2.3
9923V	28/4/14	30-60	95	137	139	150	8	1.1	<0.1	4.5	652	56	4.4	<0.1	0.3	4.5	0.4	8.0
9923V	28/4/14	0-60	95	-	-	-	-	1.4	<0.1	2.0	-	-	4.6	<0.1	0.2	4.1	0.3	5.2
9923V	29/4/14	0-30	270	140	149	126	42	0.9	0.3	30.7	652	241	4.3	1.3	29.4	3.2	1.2	36.6
9923V	29/4/14	30-60	270	140	148	141	78	1.0	0.5	52.1	650	377	4.3	2.2	51.2	3.1	2.0	64.0
9923V	29/4/14	0-60	270	-	-	-	-	0.9	0.4	42.0	-	-	4.3	1.7	40.3	3.1	1.6	50.1
9923V	29/4/14	0-30	270	139	147	247	11	1.8	0.1	3.8	765	79	5.1	0.2	3.3	3.3	0.4	13.5
9923V	29/4/14	30-60	270	138	147	156	36	1.1	0.2	21.0	659	229	4.4	1.2	27.3	3.1	0.8	24.7
9923V	29/4/14	0-60	270	-	-	-	-	1.3	0.2	12.4	-	-	4.7	0.7	15.3	3.2	0.6	19.1
9923V	29/4/14	0-30	270	137	143	182	38	1.3	0.3	19.2	739	177	5.0	0.9	17.2	3.5	1.0	27.4
9923V	29/4/14	30-60	270	134	140	NA	NA	-	-	-	NA	NA	-	-	-	2.8	0.8	28.1
9923V	29/4/14	0-60	270	-	-	-	-	-	-	-	-	-	-	-	-	3.2	0.9	27.8
9923V	29/4/14	0-30	270	132	139	211	NA	1.6	-	-	746	NA	5.2	-	-	4.0	1.1	28.6
9923V	29/4/14	30-60	270	134	-	157	NA	1.2	-	-	697	NA	4.8	-	-	3.1	1.1	35.6
9923V	29/4/14	0-60	270	-	-	-	-	1.3	-	-	-	-	4.6	-	-	3.5	1.1	32.1
9923V	30/4/14	0-30	95	140	140	144	3	1.0	<0.1	1.3	594	39	3.9	<0.1	0.2	3.8	0.2	4.9
9923V	30/4/14	30-60	95	142	138	122	22	0.8	0.2	17.9	462	202	2.9	1.1	37.2	2.8	0.4	13.7
9923V	30/4/14	0-60	95	-	-	-	-	0.9	0.1	9.6	-	-	3.4	0.5	18.7	3.3	0.3	9.3
9923V	30/4/14	0-30	270	137	138	149	39	1.1	0.3	25.2	748	195	5.1	1.0	20.2	3.1	1.1	35.1

Filter	Date	Time (min)	Flow Rate (L/min)	Pre Filter Sample Volume (L)	Post Filter Sample Volume (L)	Pre Filter EC (µg)	Post Filter EC (µg)	Pre Filter EC (mg/m^3)	Post Filter EC (mg/m^3)	Penetration EC (%)	Pre Filter TC (µg)	Post Filter TC (µg)	Pre Filter TC (mg/m^3)	Post Filter TC (mg/m^3)	Penetration TC (%)	Pre Filter TPM (mg/m^3)	Post Filter TPM (mg/m^3)	Penetration TPM (%)
9923V	30/4/14	30-60	270	136	138	142	77	1.0	0.5	53.1	694	813	4.7	5.5	117.5	2.7	1.2	44.8
9923V	30/4/14	0-60	270	-	-	-	-	1.1	0.4	39.1	-	-	4.9	3.3	68.8	2.9	1.1	39.9
SR510	28/4/14	0	95	-	-	-	-	-	-	-	-	-	-	-	-	3.2	<0.1	0.2
SR510	28/4/14	0	95	-	-	-	-	-	-	-	-	-	-	-	-	3.2	<0.1	0.1
SR510	29/4/14	0-30	270	134	138	227	1	1.7	<0.1	0.4	703	49	4.8	<0.1	0.1	4.5	<0.1	<0.1
SR510	29/4/14	30-60	270	134	137	200	1	1.5	<0.1	0.4	723	57	5.0	<0.1	0.3	4.4	<0.1	<0.1
SR510	29/4/14	0-60	270	-	-	-	-	1.6	<0.1	0.4	-	-	4.9	<0.1	0.2	4.4	<0.1	<0.1
SR510	29/4/14	0-30	270	134	138	227	<1	1.7	<0.1	0.4	703	45	4.8	<0.1	0.1	4.5	<0.1	<0.1
SR510	29/4/14	30-60	270	134	138	200	<1	1.5	<0.1	0.4	723	52	5.0	<0.1	0.1	4.4	<0.1	<0.1
SR510	29/4/14	0-60	270	-	-	-	-	1.6	<0.1	0.4	-	-	4.9	<0.1	0.1	4.4	<0.1	<0.1
SR510	30/4/14	0-30	95	140	138	282	6	2.0	<0.1	1.7	877	57	5.9	<0.1	0.3	5.1	<0.1	<0.1
SR510	30/4/14	30-60	95	138	137	246	1	1.8	<0.1	0.3	860	34	5.8	<0.1	0.1	5.8	<0.1	<0.1
SR510	30/4/14	0-60	95	-	-	-	-	1.9	<0.1	1.0	-	-	5.9	<0.1	0.2	5.4	<0.1	<0.1
SR510	30/4/14	0-30	95	140	138	282	2	2.0	<0.1	0.3	877	52	5.9	<0.1	0.1	5.1	<0.1	<0.1
SR510	30/4/14	30-60	95	138	137	246	1	1.8	<0.1	0.4	860	61	5.8	<0.1	0.8	5.8	<0.1	<0.1
SR510	30/4/14	0-60	95	-	-	-	-	1.9	<0.1	0.3	-	-	5.9	<0.1	0.5	5.4	<0.1	<0.1
SR510	4/2/14	0-30	95	129	136	235	<1	1.8	<0.1	0.3	1001	48	7.6	0.2	3.2	9.7	<0.1	<0.1
SR510	4/2/14	30-60	95	152	255	369	1	2.4	<0.1	0.1	1653	43	10.8	0.1	1.0	10.7	<0.1	<0.1
SR510	4/2/14	0-60	95	-	-	-	-	2.1	<0.1	0.2	-	-	9.2	0.2	2.1	10.2	<0.1	<0.1
No Filter	28/4/14	0	95	-	-	-	-	-	-	-	-	-	-	-	-	2.6	2.5	95.0

Filter	Date	Time (min)	Flow Rate (L/min)	Pre Filter Sample Volume (L)	Post Filter Sample Volume (L)	Pre Filter EC (µg)	Post Filter EC (µg)	Pre Filter EC (mg/m^3)	Post Filter EC (mg/m^3)	Penetration EC (%)	Pre Filter TC (µg)	Post Filter TC (µg)	Pre Filter TC (mg/m^3)	Post Filter TC (mg/m^3)	Penetration TC (%)	Pre Filter TPM (mg/m^3)	Post Filter TPM (mg/m^3)	Penetration TPM (%)
No Filter	28/4/14	0	95	-	-	-	-	-	-	-	-	-	-	-	-	2.6	2.6	98.8
No Filter	29/4/14	0	95	-	-	-	-	-	-	-	-	-	-	-	-	2.6	2.5	96.9
No Filter	29/4/14	0	95	-	-	-	-	-	-	-	-	-	-	-	-	2.6	2.6	96.9
No Filter	30/4/14	0-30	95	137	136	121	133	0.9	1.0	111.6	775	643	5.3	4.3	82.5	1.6	1.4	91.7
No Filter	30/4/14	0-30	95	137	138	121	129	0.9	0.9	105.4	775	581	5.3	3.8	72.3	1.6	1.6	99.4

NA – Invalid Sample therefore sample not analysed

Appendix O: Results - Study 2

Filter	Date	Time (min)	Flow Rate (L/min)	Pre Filter Sample Volume (L)	Post Filter Sample Volume (L)	Pre Filter EC (µg)	Post Filter EC (µg)	Pre Filter EC (mg/m^3)	Post Filter EC (mg/m^3)	Penetration EC (%)	Pre Filter TC (µg)	Post Filter TC (µg)	Pre Filter TC (mg/m^3)	Post Filter TC (mg/m^3)	Penetration TC (%)	Pre Filter TPM (mg/m^3)	Post Filter TPM (mg/m^3)	Penetration TPM (%)
1320V	18/08/2014	0-30	95	136	135	122	1.0	0.9	<0.1	0.5	187	22	1.4	0.2	11.8	NR	NR	-
1320V	18/08/2014	30-60	95	134	138	122	0.9	0.9	<0.1	0.3	187	29	1.4	0.2	15.1	NR	NR	-
1320V	18/08/2014	0-60	95	-	-	-	-	0.9	<0.1	0.4	-	-	1.4	0.2	13.4	-	-	-
1320V	19/08/2014	0-30	95	91	137	238	0.9	2.6	<0.1	0.2	350	17	3.9	0.1	3.2	3.8	<0.1	0.1
1320V	19/08/2014	30-60	95	100	135	285	0.9	2.9	<0.1	0.2	424	21	4.3	0.2	3.6	2.8	<0.1	0.1
1320V	19/08/2014	0-60	95	-	-	-	-	2.7	<0.1	0.2	-	-	4.1	0.1	3.4	3.3	<0.1	0.1
1320V	19/08/2014	0-30	95	117	152	533	1.0	4.6	<0.1	0.2	723	31	6.2	0.2	3.3	3.4	<0.1	0.2
1320V	19/08/2014	30-60	95	87	114	392	4.0	4.5	<0.1	0.8	528	30	6.1	0.3	4.3	3.2	<0.1	0.2
1320V	19/08/2014	0-60	95	-	-	-	-	4.5	<0.1	0.4	-	-	6.1	0.2	3.7	3.3	<0.1	0.2
1320V	19/08/2014	0-30	95	102	129	512	0.9	5.0	<0.1	0.1	708	33	7.0	0.3	3.6	3.5	<0.1	<0.1
1320V	19/08/2014	30-60	95	92	117	440	0.9	4.8	<0.1	0.2	591	5	6.4	<0.1	0.7	3.6	<0.1	<0.1
1320V	19/08/2014	0-60	95	-	-	-	-	4.9	<0.1	0.1	-	-	6.7	0.2	2.3	3.5	<0.1	<0.1
1320V	19/08/2014	0-30	95	110	144	527	0.9	4.8	<0.1	0.1	709	25	6.5	0.2	2.6	3.5	<0.1	<0.1
1320V	19/08/2014	30-60	95	95	124	443	2.0	4.7	<0.1	0.3	581	25	6.1	0.2	3.3	3.4	<0.1	<0.1
1320V	19/08/2014	0-60	95	-	-	-	-	4.7	<0.1	0.2	-	-	6.3	0.2	2.9	3.4	<0.1	<0.1
1320V	20/08/2014	0-30	95	134	168	526	0.9	3.9	<0.1	0.1	696	22	5.2	0.1	2.5	NR	NR	-
1320V	20/08/2014	30-60	95	109	140	566	0.9	5.2	<0.1	0.1	789	20	7.2	0.1	2	3.1	<0.1	0.1
1320V	20/08/2014	0-60	95	-	-	-	-	4.5	<0.1	0.1	-	-	6.1	0.1	2.2	-	-	-
1320V	21/08/2014	0-30	270	97	125	802	0.9	8.3	<0.1	0.1	1193	25	12.3	0.2	1.6	4.6	<0.1	0.1

Filter	Date	Time (min)	Flow Rate (L/min)	Pre Filter Sample Volume (L)	Post Filter Sample Volume (L)	Pre Filter EC (µg)	Post Filter EC (µg)	Pre Filter EC (mg/m^3)	Post Filter EC (mg/m^3)	Penetration EC (%)	Pre Filter TC (µg)	Post Filter TC (µg)	Pre Filter TC (mg/m^3)	Post Filter TC (mg/m^3)	Penetration TC (%)	Pre Filter TPM (mg/m^3)	Post Filter TPM (mg/m^3)	Penetration TPM (%)
1320V	21/08/2014	30-60	270	-	-	NA	NA	-	-	-	NA	NA	-	-	-	6.3	<0.1	<0.1
1320V	21/08/2014	0-60	270	-	-	-	-	-	-	-	-	-	-	-	-	5.5	<0.1	<0.1
9923V	18/08/2014	0-30	95	136	137	122	6.0	0.9	<0.1	4.8	187	18	1.4	0.1	9.8	NR	NR	-
9923V	18/08/2014	30-60	95	134	125	122	4.0	0.9	<0.1	3.2	187	12	1.4	0.1	6.6	NR	NR	-
9923V	18/08/2014	0-60	95	-	-	-	-	0.9	<0.1	4.0	-	-	1.4	0.1	8.2	-	-	-
9923V	19/08/2014	0-30	95	91	136	238	0.9	2.6	<0.1	0.1	350	17	3.9	<0.1	1.4	3.8	<0.1	0.3
9923V	19/08/2014	30-60	95	100	136	285	1.0	2.9	<0.1	0.2	424	5	4.3	<0.1	1.0	2.8	<0.1	0.1
9923V	19/08/2014	0-60	95	-	-	-	-	2.7	<0.1	0.2	-	-	4.1	<0.1	1.2	3.3	<0.1	0.2
9923V	19/08/2014	0-30	95	117	149	533	3.0	4.6	<0.1	0.5	723	11	6.2	0.1	1.2	3.4	<0.1	0.5
9923V	19/08/2014	30-60	95	87	111	392	1.0	4.5	<0.1	0.2	528	10	6.1	0.1	1.4	3.2	<0.1	0.3
9923V	19/08/2014	0-60	95	-	-	-	-	4.5	<0.1	0.3	-	-	6.1	0.1	1.3	3.3	<0.1	0.4
9923V	19/08/2014	0-30	95	102	134	512	3.0	5.0	<0.1	0.4	708	12	7	0.1	1.3	3.5	<0.1	0.4
9923V	19/08/2014	30-60	95	92	122	440	1.0	4.8	<0.1	0.2	591	13	6.4	0.1	1.7	3.6	<0.1	0.2
9923V	19/08/2014	0-60	95	-	-	-	-	4.9	<0.1	0.3	-	-	6.7	0.1	1.5	3.5	<0.1	0.3
9923V	19/08/2014	0-30	95	110	139	527	5.0	4.8	<0.1	0.8	709	18	6.5	0.1	2.0	3.5	<0.1	0.7
9923V	19/08/2014	30-60	95	95	119	443	2.0	4.7	<0.1	0.3	581	11	6.1	0.1	1.5	3.4	<0.1	0.2
9923V	19/08/2014	0-60	95	-	-	-	-	4.7	<0.1	0.5	-	-	6.3	0.1	1.8	3.4	<0.1	0.5
9923V	20/08/2014	0-30	95	134	178	526	3.0	3.9	<0.1	0.4	696	12	5.2	0.1	1.3	NR	NR	-
9923V	20/08/2014	30-60	95	109	145	566	2.0	5.2	<0.1	0.3	788	14	7.2	0.1	1.4	3.1	<0.1	0.1
9923V	20/08/2014	0-60	95	-	-	-	-	4.5	<0.1	0.3	-	-	6.1	0.1	1.4	-	-	-
9923V	21/08/2014	0-30	270	97	132	802	11.0	8.3	0.1	1.0	1192	36	12.3	0.3	2.2	4.6	<0.1	0.1

Filter	Date	Time (min)	Flow Rate (L/min)	Pre Filter Sample Volume (L)	Post Filter Sample Volume (L)	Pre Filter EC (μg)	Post Filter EC (μg)	Pre Filter EC (mg/m^3)	Post Filter EC (mg/m^3)	Penetration EC (%)	Pre Filter TC (μg)	Post Filter TC (μg)	Pre Filter TC (mg/m^3)	Post Filter TC (mg/m^3)	Penetration TC (%)	Pre Filter TPM (mg/m^3)	Post Filter TPM (mg/m^3)	Penetration TPM (%)
9923V	21/08/2014	30-60	270	-	-	-	-	-	-	-	-	-	-	-	-	6.3	<0.1	0.3
9923V	21/08/2014	0-60	270	-	-	-	-	-	-	-	-	-	-	-	-	5.5	<0.1	0.2
SR510	20/08/2014	0-30	95	103	137	897	<0.1	8.7	<0.1	0.1	2483	56	24.2	0.4	1.7	15.3	<0.1	<0.1
SR510	20/08/2014	30-60	95	85	114	548	49.0	6.4	0.4	6.7	847	127	9.9	1.1	11.2	NR	<0.1	-
SR510	20/08/2014	0-60	95	-	-	-	-	7.7	<0.1	2.6	-	-	17.7	0.7	4.1	NR	<0.1	-
SR510	20/08/2014	0-30	95	103	131	897	<0.1	8.7	<0.1	0.1	2483	38	24.2	0.3	1.2	15.3	<0.1	<0.1
SR510	20/08/2014	30-60	95	85	109	548	<0.1	6.4	<0.1	0.1	847	47	9.9	0.4	4.4	NR	<0.1	-
SR510	20/08/2014	0-60	95	-	-	-	-	7.7	<0.1	0.1	-	-	17.7	0.4	2.0	-	<0.1	-
SR510	21/08/2014	0-30	95	99	135	940	<0.1	9.5	<0.1	0.1	1560	42	15.7	0.3	2.0	4.9	<0.1	<0.1
SR510	21/08/2014	30-60	95	93	127	658	6.0	7.1	<0.1	0.7	1019	48	11.0	0.4	3.4	3.8	<0.1	<0.1
SR510	21/08/2014	0-60	95	-	-	-	-	8.3	<0.1	0.3	-	-	13.4	0.3	2.6	4.4	<0.1	<0.1
SR510	21/08/2014	0-30	95	99	141	940	<0.1	9.5	<0.1	0.1	1560	34	15.7	0.2	1.6	4.9	<0.1	<0.1
SR510	21/08/2014	30-60	95	93	132	658	23.0	7.1	0.2	2.5	1019	69	11.0	0.5	4.8	3.8	<0.1	<0.1
SR510	21/08/2014	0-60	95	-	-	-	-	8.3	0.1	1.1	-	-	13.4	0.4	2.8	4.4	<0.1	<0.1
SR510	21/08/2014	0-60	95	182	246	1077	<0.1	5.9	<0.1	0.1	1469	46	8.1	0.2	2.3	3.6	<0.1	<0.1
SR510	21/08/2014	0-60	270	182	237	1077	<0.1	5.9	<0.1	0.1	1469	46	8.1	0.2	2.4	3.6	<0.1	0.1
No Filter	18/08/14	0	95	-	-	-	-	-	-	-	-	-	-	-	-	3.3	3.2	96.7
No Filter	18/08/14	0	95	-	-	-	-	-	-	-	-	-	-	-	-	3.3	3.1	94.4
No Filter	19/08/14	0	95	-	-	-	-	-	-	-	-	-	-	-	-	3.1	3.0	98.6
No Filter	19/08/14	0	95	-	-	-	-	-	-	-	-	-	-	-	-	3.1	3.1	100.1
No Filter	20/08/14	0	95	-	-	-	-	-	-	-	-	-	-	-	-	3.3	3.2	97.4

Filter	Date	Time (min)	Flow Rate (L/min)	Pre Filter Sample Volume (L)	Post Filter Sample Volume (L)	Pre Filter EC (µg)	Post Filter EC (µg)	Pre Filter EC (mg/m^3)	Post Filter EC (mg/m^3)	Penetration EC (%)	Pre Filter TC (µg)	Post Filter TC (µg)	Pre Filter TC (mg/m^3)	Post Filter TC (mg/m^3)	Penetration TC (%)	Pre Filter TPM (mg/m^3)	Post Filter TPM (mg/m^3)	Penetration TPM (%)
No Filter	20/08/14	0	95	-	-	-	-	-	-	-	-	-	-	-	-	3.3	3.2	95.8
No Filter	21/08/14	0	95	-	-	-	-	-	-	-	-	-	-	-	-	4.2	4.1	97.8
No Filter	21/08/14	0	95	-	-	-	-	-	-	-	-	-	-	-	-	4.2	4.1	97.1

NA – Invalid Sample therefore sample not analysed

NR – No result recorded