Coal Services

Health and Safety Trust

Project No. 20391

Final Report

A Ten Mine Study into Diesel Particulate Exposure to Mine Personnel Involved in Longwall Transfers

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Abstract

This report constitutes a continuation of similar work on measurement and control that had been conducted during the 1990's at Tower Colliery and some other mines in NSW. The results of which had been incorporated into Guidelines for Minimising Exposure to Diesel Emissions in Underground Coal Mines endorsed by the NSW Minerals Council and are available on the following website www.coalservices.com.au

The data from the previous projects highlighted the relatively higher exposures of mine and contractor personnel involved in longwall transfers. The aim of the project was to enhance the DP exposure database and assist in providing information that could possibly be eventually used to determine standards for DP exposure in the mining industry and link to the Cancer Surveillance Study of the Health and Safety Trust.

The establishment of a readily available internationally validated Laboratory to provide timely results for diesel particulate was a cornerstone of the project, as was the set up of a comprehensive database for diesel particulate exposure, similar to the Coal Services dust and noise databases for current and future interrogation of results.

The establishment of the laboratory was carried out in NSW by the Coal Services Health Environmental Monitoring Service and Ben Cary from Sunset Laboratories (USA); and the testing of the ten mine sites carried out by CSH EMS personnel. This report details the project parameters, sampling methodology and results of testing.

This report also presents the results of the testing with statistical analysis, a review of the control measures that were in use at the mine sites tested and a critical analysis of those control measures that were effective in ensuring that even in the potentially higher exposure environment of a longwall transfer that levels of DP exposure were below current recommended guidelines.

Abbreviations

CO	Carbon Monoxide
CO2	Carbon Dioxide
DPM	Diesel particulate matter
EC	Elemental carbon
EC/TC	Elemental carbon to Total carbon ratio
FID	flame ionisation detector
NOx	Oxides of Nitrogen
OC	Organic carbon
OEM	Original Equipment Manufacturer
PAH	Polycyclic Aromatic Hydrocarbons
TC	Total Carbon the sum of the elemental carbon and the organic carbon content of the sub micron fraction of the mine aerosol captured in the single use SKC cassette sampler measured by thermal optical carbon analyser (NIOSH Method 5040).
UCL	95% Upper Confidence Limit

Definitions

Diesel particulate matter defined as sub micron fraction of mine aerosol

Elemental carbon content of the sub micron fraction of the mine aerosol captured in the single use SKC cassette sampler measured by thermal optical carbon analyser (NIOSH Method 5040).

EC/TC Ratio the ratio of elemental carbon to total carbon of the sub micron fraction of the mine aerosol captured in sub micron virtual impactor sampler measured by thermal optical carbon analyser (NIOSH Method 5040).

Organic carbon content of the sub micron fraction of the mine aerosol captured in the single use SKC cassette sampler measured by thermal optical carbon analyser (NIOSH Method 5040).

Total Carbon the sum of the elemental carbon and the organic carbon content of the sub micron fraction of the mine aerosol captured in the single use SKC cassette sampler measured by thermal optical carbon analyser (NIOSH Method 5040).

Introduction

Measurement of workplace exposures is an essential first step in eliminating disease caused by overexposure to contaminants.
In respect to diesel particulate (DP), previous studies by Rogers and Davies have quantified exposures over a range of coal mining operations and activities. These studies have also determined the most effective measurement tool for assessing personal DP exposure via the SKC diesel impactor cassette (Rogers 2005).

The formation and composition of diesel particulate, its size selective criteria in relation to coal mines exposure monitoring have been well covered in these previous studies, as have the health effects of diesel exposure. This study was to quantify the exposures across a variety of mine sites (10) utilising differing measures to control DP exposure during the mining operation that provides for the highest use of diesel machine activity in a concentrated area the Longwall transfer, typically where ventilation rates are modified or spilt between the recovery face and the installation face, where due to the surface area of the drivages, air velocity is typically low, reducing the ability to disperse diesel emissions further.

A secondary goal of this study was to provide a viable and technically validated laboratory that could provide accurate and timely analysis of diesel particulate exposure monitoring in Australia that previously would have been analysed in Canada or the United States. The first part of this report outlines the set up of this service in the Coal Services Corrimal Laboratory.

Eleven mines were contacted as each was due for a longwall transfer with one mine eventually choosing not be involved, due to operational problems and one other not being included due to timing delays due to geological conditions, causing an overlap with a mine in a different district. This gave us nine mine sites utilised in the study with one operation sampled twice due to change in equipment and practices that had the potential to show improved results.

All of the sampling was conducted by Coal Services Environmental Monitoring Technicians throughout the course of the study and led to an increased awareness generally in the industry of the ability to monitor for DPM and the request for toolbox talks to educate personnel on both the health effects and control measures.

Analysis of all samples was undertaken by the Coal Services Corrimal laboratory with all initial analysis conducted by and later overseen by Bill Whelan (University of NSW). Bill and Alan Rogers (Alan Rogers OH&S) were also heavily involved in the initial project design and the establishment of analytic procedures and validation testing of the Sunset industries Thermal Optical Carbon Analyser along with Ben Cary (Sunset Industries). Sunset industries also conducted validation testing of ten random samples at their Portland laboratory.

Project Time Line

An initial project time line was established by Coal Services Environmental Monitoring group based on expected Longwall transfers and to fit in with the statutory monitoring requirement of the industry. The time line broken into two tables is shown below.

	2003									2004								
Task	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec
Determine Lab location	■																	
Purchase of OC/EC Analyser		■																
Set up of Laboratory facility			■															
Purchase of sampling equipment				■	■	■												
Consultation with ist group of mines		■	■	■	■													
Sampling of Mines						■	■	■										
Confirmation of analytical procedures						■	■											
Analysis of Samples							■	■	■	■	■							
Interim results										■	■							
Interim Report											■							
Project review with Peer group											■	■	■					
Consultation with 2nd group of mines												■	■					
Sampling of Mines												■	■	■	■	■	■	
Analysis of Samples													■	■	■	■	■	■
Collation of all elevant data																■	■	■
Consultation with 3rd group of mines																		■
Sampling of Mines																		■
Analysis of Samples																		
Collation of all elevant data																		
Statistical Analysis of results																		
Report Writing																		
Disemination of results/recommendations																		

As is shown an initial set up period of 6 months was envisaged and this was achieved along with initial sampling of mines, analysis and interim results for the first three sites.

	2005									2006							
Task	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Analysis of Samples	■																
Collation of all elevant data	■																
Consultation with 3rd group of mines	■																
Sampling of Mines	■	■	■	■	■												
Analysis of Samples	■	■	■	■	■	■	■										
Collation of all elevant data				■	■	■	■										
Statistical Analysis of results						■	■	■	■	■							
Report Writing									■	■	■	■	■				
Disemination of results/recommendations													■	■	■	■	

Establishment of the Analytical Laboratory

At the outset of the project one of the primary objectives was to establish a laboratory in NSW that could undertake diesel particulate analysis, to not only assist in the H&ST project, but ultimately to provide the industry with a commercial resource not previously used on a non-research basis.

An early version of the Sunset Industries 'Thermal optical OCEC Carbon Aerosol Analyser had been established at the University by Alan Rogers and Bill Whelan for previous studies into diesel particulate undertaken by Alan and Brian Davies. These studies also reviewed differing methods of analysis and established that this analyser using NIOSH method 5040 was scientifically valid and repeatable, particularly in respect to elemental carbon results.

Since the commencement of these early HS&T projects in the 1990's there had been some significant upgrades in the instrumentation associated with the thermal optical carbon analyser. These upgrades relate to a number of key components in the instrument and the software that controls the instrument operating sequence and calculates the end result. In particular the gas flow control and monitoring equipment has been through a number of upgrades to eliminate early problems with rotameter flow control devices.

Following a tour and early training at the NIOSH and MSHA test facilities in Pittsburgh by Gary Mace in July 2002, approaches were made to purchase and install one of the new generation analysers in NSW. A review of the Coal Services facilities and consultation with Alan Rogers and Bill Whelan led to the Corrimal laboratory being chosen as having suitable facilities and location for early training and supervision of the laboratory and analysis.

A suitable room was made available, bench space, gases and a computer sourced prior to the delivery of the analyser. In July 2003, following delivery of the Sunset Industries Thermal Optical Analyser, Ben Cary from Sunset Industries arrived in Australia to complete the set up and provide training in the maintenance and running of the new instrument. Training was conducted for Gary Mace (Coal Services Health), Bill Whelan (University of NSW) and Alan Rogers (Alan Rogers OH&S).

Initial set-up problems were encountered in power supply issues as a primary control component of the analyser (main oven) was configured for 120V operation, whereas all other components had been set up for 240V power supply. A transformer was sourced from the obsolete 1995 instrument (University of NSW), which has since donated a number of electrical components as spare parts.

The set-up consisted of installing the flow furnace ovens, heating coils and thermocouples, ensuring that these were thermally insulated from each other and outside temperature variables. The laser was then installed and aligned before connecting the valve box to the CPU unit and establishing power. Following this high grade gas lines were installed and purged before installing the operational software on the computer.

Some four versions of the software were installed before the correct versions allowed initiation of the CPU.

Gas flows were established and the flow meters calibrated before the system was purged and the oven gradually heated to check control levels and thermocouple accuracy. The gas control was found to be far more stable than the older instrument and allowed for the writing of far simpler operating procedures manual for the training of future operators of the analyser. These procedures and all initial analysis was overseen by Bill Whelan and reviewed by Alan Rogers as part of the early assessment and validation process undertaken by Coal Services. After three days the analyser installation (see figure 1 below) and training was complete and validation testing could commence.

Figure 1 – The Sunset Industries Thermal/Optical Carbon Analyser

Operating procedures and parameters were established before commencing exhaustive testing of the analyser in preparation for the study. All initial tests were based on repeated analysis of blanks and standards, and reanalysis of previously analysed samples for comparative results.

In order to test the instrument calibration standards were mixed using measured quantities of reagent grade sucrose (C12H22O11) to demineralised water to create a calibration solution (2.375 mg sucrose/ml of demineralised water). 10microlitres of this solution is placed onto a punched section of a preburnt quartz filter, which is then analysed in the standard manner. As the amount of carbon introduced to the analyser is a known quantity, a record of results can quickly be utilised to review the instrument sensitivity by adjusting the relative proportion of helium and hydrogen delivered to the FID. "Decreasing the hydrogen flow increases the sensitivity (higher result per unit of carbon). Helium flow has the opposite effect" (Rogers 2005)

The initial test and validation results are discussed later in this report.

Analysis by NIOSH Method 5040

In the laboratory the SKC DPM Cassettes are disassembled to reveal the exposed filter (see Figure 4). Carbon speciation analysis is carried out by placing a 1.5cm2 punched section of the quartz fibre filter (see Figure 5) from the sampling cassette in a flow furnace. The remaining filter material can be stored for later re-analysis.

Figure 2 – unloaded filter prior to analysis

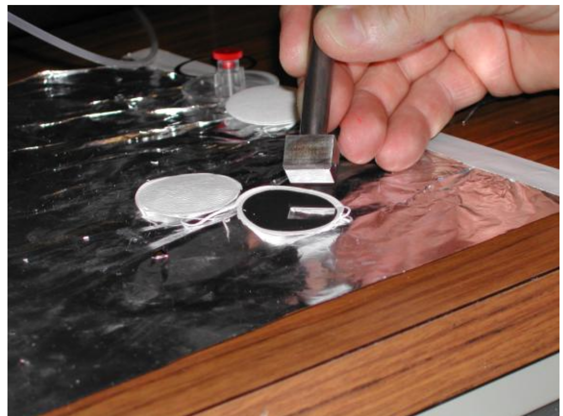


Figure 3 – 1.5cm^2 punch taken filter for analysis

The front oven (furnace) is initially run in an oxygen free helium atmosphere and is increased in temperature steps from 1000C to 7000C to volatise the entire organic fraction of the material on the filter. The pyrolised products are flushed off in the gas flow as CO2, which is catalytically converted in the methanometer to methane (CH4) which is detected by the flame ionisation detector (FID).

In the second stage of the analysis, the oven is cooled to 1000C, a mixture of 2% O2/He is introduced and the temperature raised in steps to 8500C at this stage the remaining elemental carbon is oxidised and flushed off with the gas flow, converted to CH4 and detected with the FID.

The various species of organic carbons, carbonates, and elemental carbon are observed as a series of peaks on the thermogram readout (see figure 4). A pulsed diode laser beam is used to monitor the amount of transmission through the sample filter during the cycle; this allows minimisation of interferences caused by charring (coking) of some of the higher temperature organic carbons (such as coal) which form or interfere with elemental carbon.

At the end of each analysis cycle a known volume of CH4 is injected into the furnace for internal calibration purposes. (Rogers 2005) Analysis time takes approximately 12 minutes per sample with a limit of detection (LOD) of ~0.001-0.002 mg/m3 (1-2 microgram per cubic metre) for organic, elemental or total carbon.

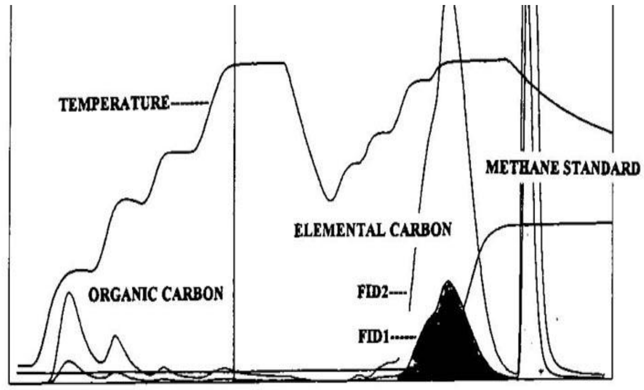


Figure 4 – Thermogram from OCEC Analyser

The quartz filters adsorb organic compounds from the atmosphere, which can influence the results of sampling for OC and therefore the EC/TC ratio. As a result it is advisable to utilise a field blank filter for each batch of samples taken. This is particularly relevant where low levels of diesel particulate are present.

Some of the organic carbon levels experienced in a number of situations have been significantly higher than the 10-25 micrograms identified in previous studies. This may have been due in part to unburnt fuel vapours or the use nearby of volatile organic compounds (VOC's) used in belt splicing operations at a number of locations.

The blanks used in the research project were assigned a sampling volume of 1m3 of air to assist in the blank subtraction process, with results of the blank subtracted from the field results to ensure proper comparison of results for diesel particulate.

A simple Excel program was developed by Gary Mace to perform blank subtractions and given the air details of sampling time and pump flow rate volume sampled, calculate the concentration of elemental carbon (EC), organic carbon and total carbon (TC) and the EC/TC ratio in the air sample.

Initial Analysis and Validation of Results

This process was continued for a number of months with some initial DP monitoring undertaken at Southern Coalfields mines, and ten filters with a variety of exposures (figure 2) sent to Sunset Industries laboratory to validate results (Table 1).

Figure 5 – 10 analysed samples sent to US for validation testing

While there was some variation in the results returned from direct analysis (Table 1 below) the correlation of results in most cases was well within the level of uncertainty (generally 5%) and when added to the spreadsheet to calculate reportable results to 0.01mg/m3 gave a 99.5% correlation for elemental and 98.5% for total carbon results. Subsequent testing in 2005 and 2007 has returned similar results which have indicated the reliability of the analyser and the effectiveness of the maintenance and operating procedures established at the commencement of the project.

Sample ID	OC(ug/sq cm)		EC(ug/sq cm)		TC(ug/sq cm)		Average Correlation of Results
	Sunset Ind	CSPL	Sunset Ind	CSPL	Sunset Ind	CSPL	
17318	**6.06**	6.51	**12.65**	12.28	**18.72**	18.79	98.6%
17319	**5.67**	5.61	**8.35**	7.78	**14.02**	13.39	104.4%
17321	**5.46**	5.32	**5.38**	5.55	**10.84**	10.88	99.7%
17337	**7.91**	8.03	**27.38**	27.03	**35.29**	35.06	100.2%
17342	**4.83**	5.87	**2.47**	2.40	**7.30**	8.27	91.2%
17350	**6.17**	6.95	**15.42**	13.41	**21.60**	20.37	103.3%
18047	**5.03**	5.46	**4.76**	4.89	**9.79**	10.35	94.7%
18058	**4.15**	3.35	**5.62**	7.05	**9.77**	10.40	99.2%
18096	**3.32**	3.10	**1.85**	1.87	**5.16**	4.97	103.3%
18100	**5.59**	6.78	**11.77**	10.63	**17.36**	17.41	97.6%
							99.2%

Table 1 – Results of samples sent to US for validation testing

Coal Services NSW Project Mine Sites

Eleven mines were contacted as each was due for a longwall transfer with one mine eventually choosing not be involved, due to operational problems and one other not being included due to timing delays due to geological conditions, causing an overlap with a mine in a different district. This gave us nine mine sites utilised in the study with one operation sampled twice due to change in equipment and practices that had the potential to show improved results.

Mine A – Typified by splitting air between recovery and installation faces, boggy road conditions along installation face slowed chock movements. Mule used to locate chocks into position. Additional diesel machines were in use during the chock movement process for man transport and site services including road compaction and belt construction.

Mine B – Limited air to installation face due to splitting with recovery face and used a combination of vehicles. Low sulphur fuels used in vehicles and other vehicle controls included diesel tag boards, however elevated operating hours on most machines and no controls such as exhaust filters.

Mine C – Separate air available for both installation and recovery faces provided a good example of a potential control measure. High number of hired vehicles with elevated engine hours and use of standard fuel with no other vehicle control measures in place nullified any effect of separate air.

Mine D – Typified by splitting air between recovery and installation faces. Primarily used own vehicles with fair maintenance, some hire vehicles in use, used Eromanga fuel on site, however no other vehicle controls used.

Mine E – Highest quantity of air available at any of the sites tested, good travelling roads and roadway airlocks separated outbye vehicle movements from contaminating installation face air.

Mine F – Air spilt between installation and recovery faces. Road conditions were good with a mix of mine and hire vehicles used in the transfer process. No machines were fitted with diesel exhaust filters.

Mine G – Poor road conditions meant that vehicles had to work harder during the installation process, air was limited to both faces due to need to share the air across both faces. Low sulphur fuels were in use and a controlled diesel maintenance program.

Mine H – The first mine tested with established diesel control measures including diesel tag boards, low sulphur fuels, rigid maintenance program and all vehicles fitted with diesel exhaust filters. Air volume was split between installation and recovery faces.

Mine I – The second test for one of the previously sampled mines, a number of control measures had been implemented to improve issues identified in the first round of testing

Mine J – longwall equipment was delivered primarily from surface and outbye storage areas, air was not split with a recovery face. Roads were boggy, however a comprehensive diesel control program was in place including tag boards, low sulphur fuel, and maintenance program. Most vehicles were fitted with exhaust filters, however a number of hire vehicles utilised were not.

Training

Prior to commencement of the project the Coal Services Monitoring Technicians undertook training in the sampling protocols established for the project.

All sampling was to be personal and undertaken utilising the principles of AS2985 as the primary methodology.
Training was provided by Gary Mace – Occupational Hygienist for Coal Services Pty Ltd and consisted of

1.0 hours	Background to project and development
0.5 hours	fitting of the SKC diesel impactor cassettes to the modified SKC respirable cylones
0.5 hours	flow testing of equipment including leak checks
0.5 hours	Sealing and transport of cassettes for analysis
1.0 hours	Information collection and recording
1.0 hours	Overview of previous testing and analysis.

This covered of all sampling practices and procedures, cleaning, recording and interpretation of data that were required to undertake the project. A number of trial laboratory runs were conducted to ensure that all relevant staff were conversant with the practical use and maintenance of the SKC sampling equipment.

Training in the analytical technique is covered elsewhere in this report.

Sampling Methodology

As outlined in HST Research Project 20000 Exposure Measurement and Risk Estimation from Diesel Particulates in Underground Coal Mines (Rogers 2005), the development of the single use DP cassette (SKC DPM cassette w/impactor 225-317) in conjunction with the modified SKC respirable dust cyclone made it possible to conduct sub-micron DP sampling using the well established sampling procedures in compliance with AS2985 – Workplace atmospheres – Method for sampling and gravimetric determination of respirable dust.

In keeping with the flow rate of 1.7 – 2.0 litres per minute recommended by SKC for the cassette, the flow rate utilised for sampling was 2.0 lpm, rather than the 2.2 lpm required by AS2985-2004, however in all other respects the sampling procedures for AS2985 were followed. The “different flow rates make little difference to the size selective cut point necessary to separate diesel particulate from the host rock such as coal dust” (Rogers 2005)

The SKC DPM cassette cassette incorporates a "plate with precision sapphire nozzles, an oiled impactor, and a quartz fibre filter to collect the sub micron aerosol fraction to meet the sampling requirements listed by MSHA (MSHA, 2001b)" (Rogers 2005). The efficiency of these cassettes in measuring DP was well described by Rogers who stated that "Providing the monitoring was conducted using sub micron samplers in combination with specific elemental carbon (EC) analysis then the sub-micron coal dust arising from the typical levels of respirable coal dust experienced in NSW mines would introduce a positive interference to the diesel particulate result of only 0.5% or less.", well within experimental error of respirable sampling".

The modified SKC plastic DPM cyclone is only slightly larger and in addition lighter than the normal metal respirable dust cyclone and resulted in reasonable worker acceptance when used for personal monitoring. The usual compliant from workers during the sampling process was related to the size and weight of the sampling pumps rather than the cyclones, however the interest in knowing what personal DP exposure was generally high and therefore most personnel approached to take part in the study at all mine sites involved in the study were willing participants.

Sampling was generally conducted for a minimum of five hours to comply with standard sampling practices under the Coal Mines Health and Safety Act.

Instrumentation:

The instrumentation used for the monitoring program included:

- Dupont P2500A Air sampling pumps: serviced and calibrated in January each year. Pump rates set at 2.0 litres per minute (respirable).
- SKC PCMA8 (Exi) Air sampling pumps: serviced and calibrated in January each year. Pump rates set at 2.0 litres per minute (respirable).
- SKC (Higgins Dewell style) cyclone sampling heads fitted with SKC impactor cassettes.

The calibration of all pumps was checked prior to and following sampling using a Cassella rotameter (flowmeter).

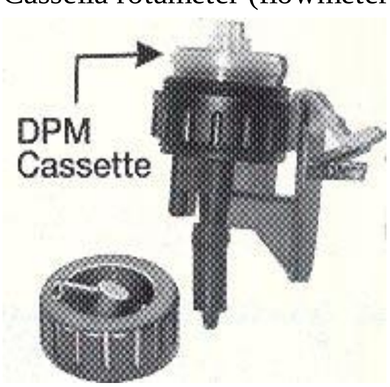


Figure 6 – SKC Cyclone with cassette fitted

Figure 7 – SKC Air Sampling Pump

Field Data & Recording Sheets

A comprehensive amount of data was collected in the field, during the sampling period including details of each sampling work location, persons sampled, job description, mobile equipment used hours of use, work tasks and ventilation readings and operating conditions. All of this information was recorded in the diesel monitoring log sheet as per Figure 6 below.

Much of this data is traditionally recorded during a statutory dust sample.

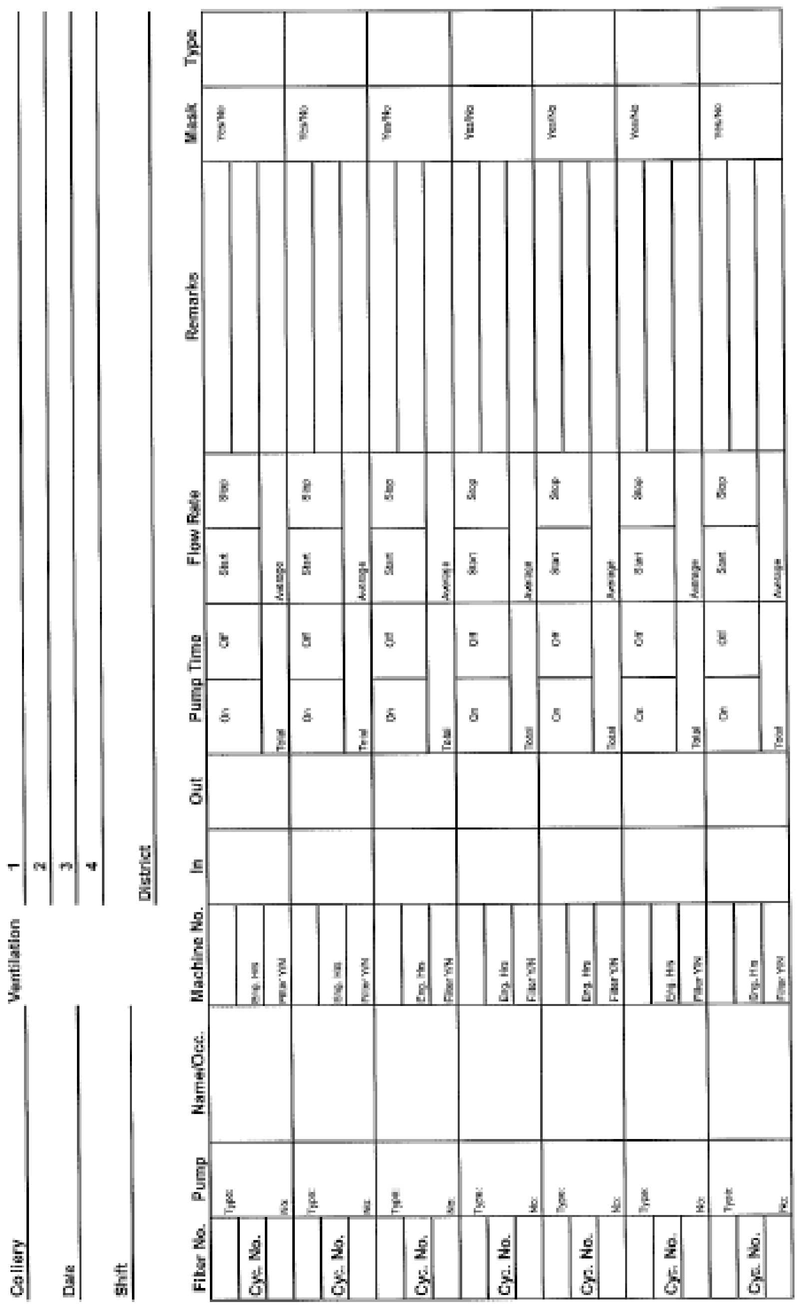


Figure 8 – Diesel monitoring logsheet

In-Mine Testing

Sampling was conducted along the lines of statutory dust sampling where the technician travelled into either the recovery or the installation face with the crew and the sampling equipment is fitted in the crib room, following the pump warm up period and pre-test air flow calibration.

Operators names, job description and all pre-test information were recorded at this point before the technician accompanied the crew to the face where ventilation reading were taken and all machine details recorded (eg type, identifying numbers, engine hours, whether a DPM exhaust filter was fitted etc). Throughout the shift, the technician attempted to record the actual time that a machine was operating in the district, however this was particularly difficult on the installation face where a chock transporter left the district for an unknown period depending upon where the chocks were stored. In some cases this was on the recovery face, at other times it was at travelling road cut-throughs and on occasion from the surface or pit bottom.

Factors that in particular may have influenced results that was not well recorded was the amount of mine traffic outbye that may have contributed to dpm coming into the district in the intake air. While this was addressed later in the study at a number of mine sites tested it was not part of the initial project parameters, and this factor does warrant further investigation.

Seven CS Health sampling technicians collected 47 sets of samples over a two year period at ten mine sites commencing in January 2004 and finishing in January of 2006. At each of the sites every attempt was made to capture 5 personnel on each crew over 5 to six shifts covering all working shifts (ie Dayshift, Afternoon and Nightshift). In some cases due to operational difficulties or timing constraints, the technicians were unable to meet the required number of samples, however sufficient data was capture to enable some valid comparisons between operations.

Initial observations during the sampling indicated that ventilation volume and road conditions had a significant impact upon visible working conditions. In a number of operations where the number of machines operating in the district was not supervised also appeared to be a contributing factor to worker complaint. Comments made by operators were not recorded as part of the study in order to keep the recorded data completely objective.

Sampling was conducted over a minimum period of 5 hours and a maximum period of seven hours. The sampling did not include travelling time into the Longwall face as is the practice for sampling under the Coal Mines Health and Safety Regulation.

At the end of each shift the sampling cassettes and all sampling equipment were conveyed to the CS Health laboratories where the pumps were cleaned and placed on charge for the next shift while the cyclones were unloaded, cleaned and the cassettes were sealed, packed and sent to the CS Health Corrimal laboratory for analysis.

Figure 9 – Pump on charge between shifts

Elemental Carbon Analysis

Filters from each set of tests were forwarded by the sampling technician to the Corrimal laboratory for analysis. These were normally batched as a group as the tests were in most cases conducted over a period of time in other districts.

Early analysis was conducted by Gary Mace and Bill Whelan with Bill and Alan Rogers reviewing calculation results and parameters. Following the formalising of the analytic procedures and the set up of a spreadsheet with specific formulas for calculation of results including blank subtraction and standards adjustment, all analysis and results calculation from March 2004 on was conducted by Gary Mace and Peter Adlington.

Three standards were used in each days analysis with one blank filter analysed and one random filter for each group of ten analysed again to ensure integrity of results.

The method of analysis is covered elsewhere in this report

Figure 10 – Technician analysing filters

All results were double checked and recorded to two significant figures for comparison with the recommended exposure standard and/or Minerals Council guideline of 0.1 mg/m^3 Elemental Carbon.

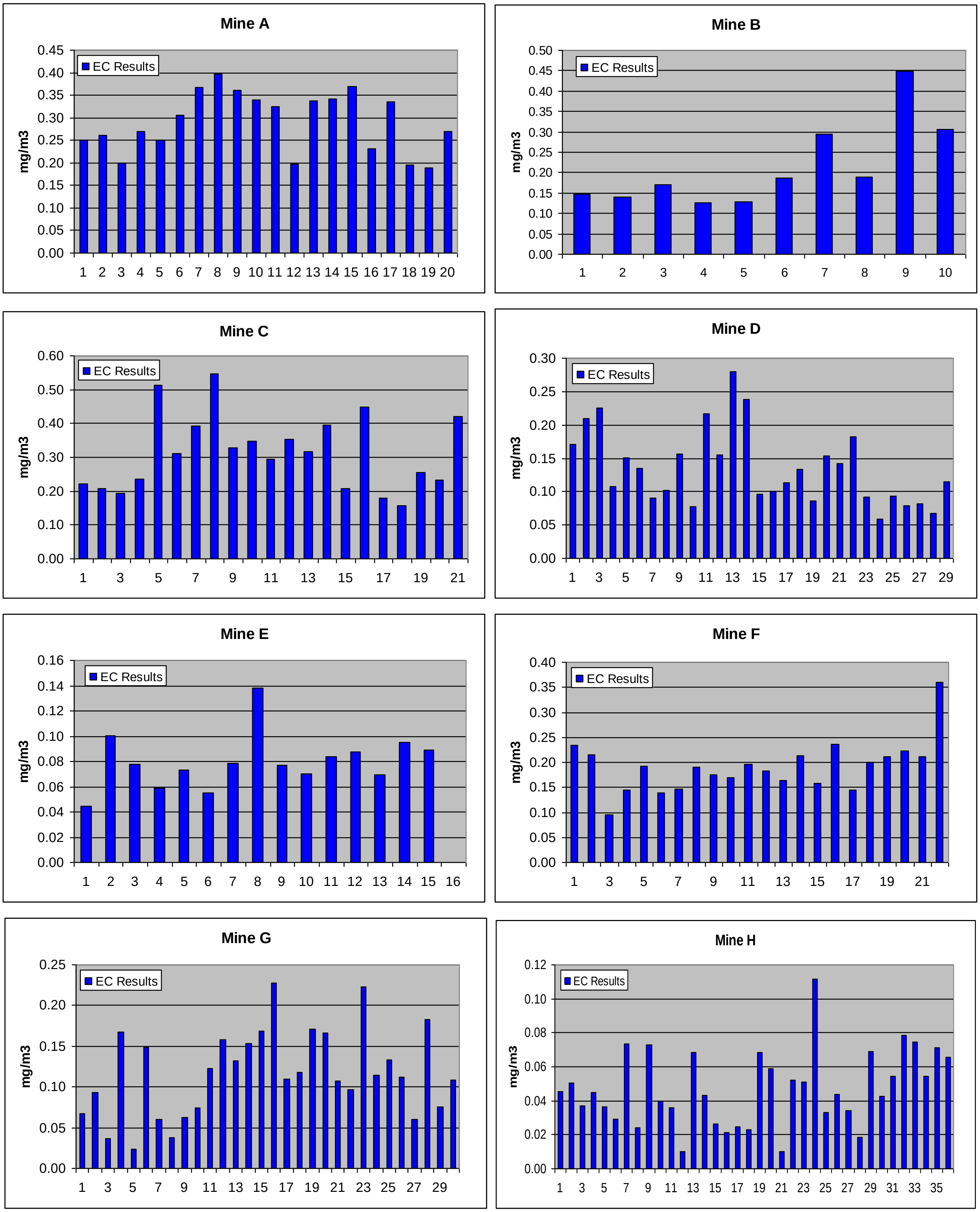
Results

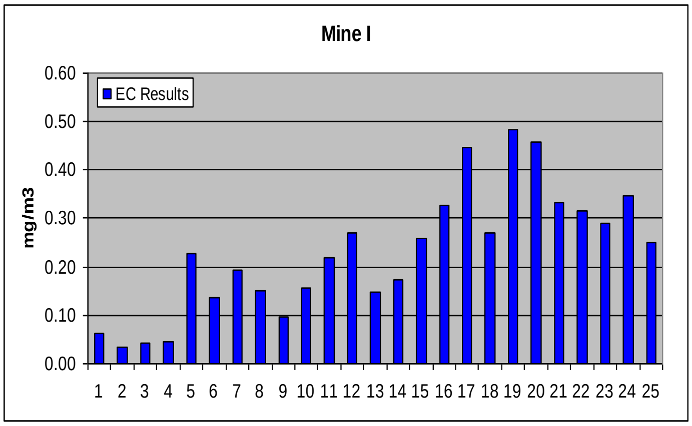
The table below provides the comparative test results for the samples conducted as part of this study. Following the table of each set of results is presented graphically to provide a visual interpretation of results.

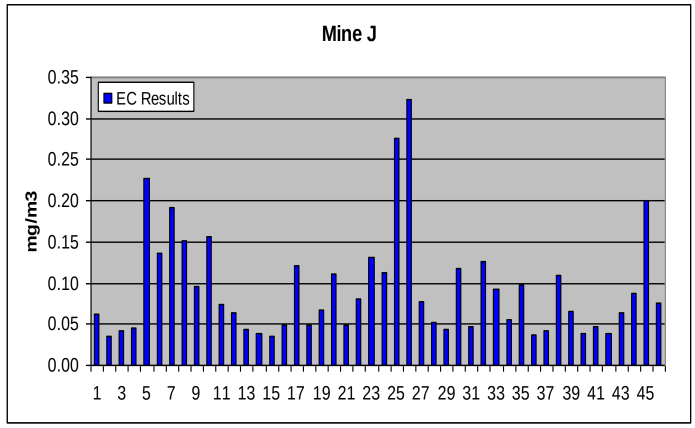
Mine A	Mine B	Mine C	Mine D	Mine E	Mine F	Mine G	Mine H	Mine I	Mine J
0.25	0.15	0.22	0.17	0.04	0.23	0.07	0.05	0.06	0.06
0.26	0.14	0.21	0.21	0.1	0.21	0.09	0.05	0.04	0.04
0.2	0.17	0.19	0.22	0.08	0.1	0.04	0.04	0.04	0.04
0.27	0.13	0.23	0.11	0.06	0.15	0.17	0.04	0.05	0.05
0.25	0.13	0.51	0.15	0.07	0.19	0.02	0.04	0.23	0.23
0.31	0.19	0.31	0.13	0.06	0.14	0.15	0.03	0.14	0.14
0.37	0.3	0.39	0.09	0.08	0.15	0.06	0.07	0.19	0.19
0.4	0.19	0.55	0.1	0.14	0.19	0.04	0.02	0.15	0.15
0.36	0.45	0.33	0.16	0.08	0.17	0.06	0.07	0.10	0.10
0.34	0.31	0.35	0.08	0.07	0.17	0.07	0.04	0.16	0.16
0.32		0.29	0.22	0.08	0.2	0.12	0.04	0.22	0.07
0.2		0.35	0.16	0.09	0.18	0.16	0.01	0.27	0.06
0.34		0.32	0.28	0.07	0.16	0.13	0.07	0.15	0.04
0.34		0.39	0.24	0.09	0.21	0.15	0.04	0.17	0.04
0.37		0.21	0.1	0.09	0.16	0.17	0.03	0.26	0.03
0.23		0.45	0.1		0.24	0.23	0.02	0.33	0.05
0.33		0.18	0.11		0.14	0.11	0.02	0.45	0.12
0.2		0.16	0.13		0.2	0.12	0.02	0.27	0.05
0.19		0.26	0.09		0.21	0.17	0.07	0.48	0.07
0.27		0.23	0.15		0.22	0.17	0.06	0.46	0.11
		0.42	0.14		0.21	0.11	0.01	0.33	0.05
			0.18		0.36	0.1	0.05	0.32	0.08
			0.09			0.22	0.05	0.29	0.13
			0.06			0.11	0.11	0.35	0.11
			0.09			0.13	0.03	0.25	0.28
			0.08			0.11	0.04		0.32
			0.08			0.06	0.03		0.08
			0.07			0.18	0.02		0.05
			0.12			0.08	0.07		0.04
						0.11	0.04		0.12
							0.05		0.05
							0.08		0.13
							0.07		0.09
							0.05		0.05
							0.07		0.10
							0.07		0.04
									0.04
									0.11
									0.07
									0.04
									0.05
									0.04
									0.06
									0.09
									0.20
									0.08

Table 2 – Results of all samples by Mine

Figure 11 – results of Table 2 presented graphically







As can be seen from the results graphed above no general pattern is discernable, with some graphs showing good correllation across the sampling program and others exibiting some significant peaks on various shifts for specific personnel. A further table and graph pulling together all the results is presented before a statistical analysis of the results is given. It should be noted that the results were tabulated for the dates they were sampled and graphed for exposure are presented in historical order and therefore will demonstrate the high level of differentiation between sites, as shown below in Table three and the corresponding graph – Figure 12.

Full Table of Results

0.25	0.17	0.21	0.1	0.08	0.24	0.23	0.02	0.04	0.33	0.04	0.10
0.26	0.13	0.45	0.11	0.07	0.14	0.11	0.07	0.05	0.45	0.04	0.04
0.2	0.13	0.18	0.13	0.08	0.2	0.12	0.04	0.08	0.27	0.03	0.04
0.27	0.19	0.16	0.09	0.09	0.21	0.17	0.04	0.07	0.48	0.05	0.11
0.25	0.3	0.26	0.15	0.07	0.22	0.17	0.01	0.05	0.46	0.12	0.07
0.31	0.19	0.23	0.14	0.09	0.21	0.11	0.07	0.07	0.33	0.05	0.04
0.37	0.45	0.42	0.18	0.09	0.36	0.1	0.04	0.07	0.32	0.07	0.05
0.4	0.31	0.17	0.09	0.23	0.07	0.22	0.03	0.06	0.29	0.11	0.04
0.36	0.22	0.21	0.06	0.21	0.09	0.11	0.02	0.04	0.35	0.05	0.06
0.34	0.21	0.22	0.09	0.1	0.04	0.13	0.02	0.04	0.25	0.08	0.09
0.32	0.19	0.11	0.08	0.15	0.17	0.11	0.02	0.05	0.06	0.13	0.20
0.2	0.23	0.15	0.08	0.19	0.02	0.06	0.07	0.23	0.04	0.11	0.08
0.34	0.51	0.13	0.07	0.14	0.15	0.18	0.06	0.14	0.04	0.28	
0.34	0.31	0.09	0.12	0.15	0.06	0.08	0.01	0.19	0.05	0.32	
0.37	0.39	0.1	0.04	0.19	0.04	0.11	0.05	0.15	0.23	0.08	
0.23	0.55	0.16	0.1	0.17	0.06	0.05	0.05	0.10	0.14	0.05	
0.33	0.33	0.08	0.08	0.17	0.07	0.05	0.11	0.16	0.19	0.04	
0.2	0.35	0.22	0.06	0.2	0.12	0.04	0.03	0.22	0.15	0.12	
0.19	0.29	0.16	0.07	0.18	0.16	0.04	0.04	0.27	0.10	0.05	
0.27	0.35	0.28	0.06	0.16	0.13	0.04	0.03	0.15	0.16	0.13	
0.15	0.32	0.24	0.08	0.21	0.15	0.03	0.02	0.17	0.07	0.09	
0.14	0.39	0.1	0.14	0.16	0.17	0.07	0.07	0.26	0.06	0.05	

Table 3 – All Results tabulated chronologically

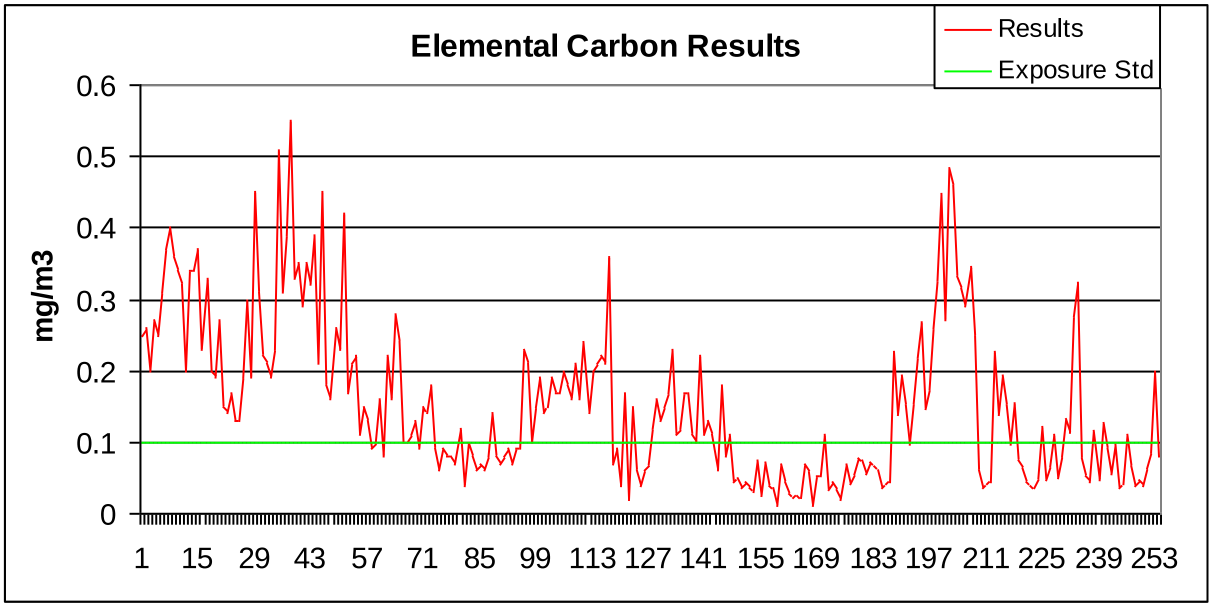


Figure 12 – results of Table 3 presented graphically

Statistical Analysis of Results

A statistical review of results was conducted by Dr Brian Davies using the statistical program LogNorm 2. Due to the variety in some of the sample sizes and the results distributions, three different analytic reviews were undertaken for the results.

- Lognormal analysis
- Normal analysis and
- Non-parametric analysis.

A Shapiro-Wilk W Test and a Skewness comparison was undertaken on each set of results to determine the analysis of best fit for the distribution of results with a mix of Normal and Lognormal proposed as the better fit as a distribution of results (see Table below). All three sets of analysis are included in the appendices for each mine site with the summary of the best fit reslts included.

	Mine A	Mine B	Mine C	Mine D	Mine E	Mine F	Mine G	Mine H	Mine I	Mine J
Samples taken	20	10	21	29	15	22	30	36	25	46
	Recommended Best fit									
W Test Results	Normal	Log normal	Log normal	Log normal	Log normal	Log normal	Normal	Normal	Normal	Non Parametric
Skewness	Normal	Log normal	Log normal	Log normal	Log normal	Log normal	Normal	Normal	Normal	Log normal

Table 4 – Results of Statistical Review

Log Normal results provided the best fit for the majority of results and for comparative purposes a summary of those results are provided in Table 5 below. The precision of the analysis was sufficient make a valid statistical determination on the results supplied in relation to the recommended exposure standard of 0.1 mg/m^3.

	Mine A	Mine B	Mine C	Mine D	Mine E	Mine F	Mine G	Mine H	Mine I	Mine J
Samples taken	20	10	21	29	15	22	30	36	25	46
Results EC										
Minimum	0.19	0.13	0.16	0.06	0.04	0.10	0.02	0.01	0.04	0.03
Maximum	0.40	0.45	0.55	0.28	0.14	0.36	0.23	0.11	0.48	0.32
Geometric Mean	0.28	0.20	0.29	0.12	0.08	0.18	0.10	0.04	0.19	0.08
MVUE	0.29	0.21	0.31	0.13	0.08	0.19	0.12	0.05	0.24	0.08
Geometric S. D.	1.27	1.53	1.42	1.49	1.32	1.29	1.74	1.81	2.08	1.83

Table 5 – Results of Lognormal statistical Analysis

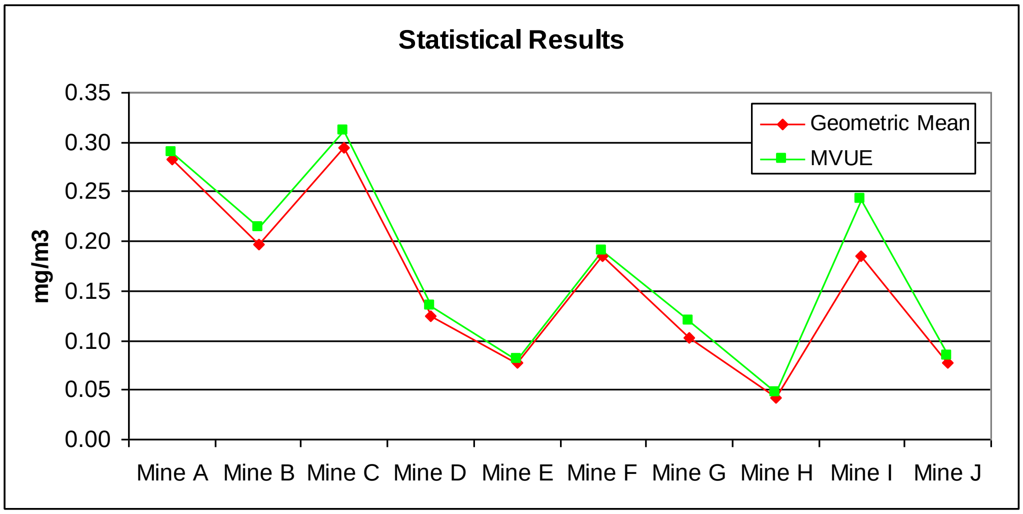


Figure 13 – Statistical results of Table 5 presented graphically

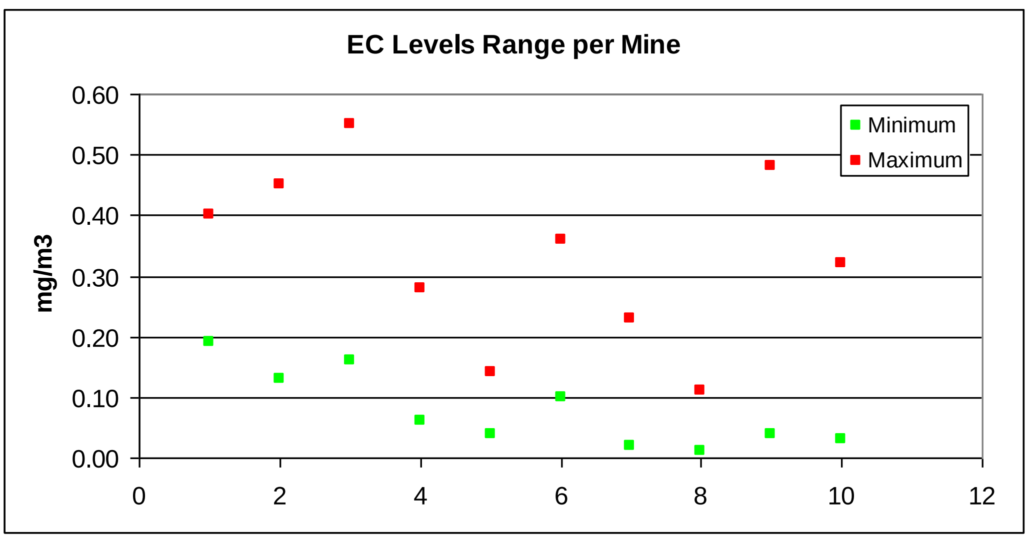


Figure 14 – Maximum and Minimum results of Table 5 presented graphically

Comments

Using the 95% upper confidence limit for the results against the proposed exposure standard of 0.1mg/m3 EC, nine out of ten of the mines returned unacceptable results.

Control Measures

A range of control measures are available to reduce exposure including the use of low emission engines and fuels, implementing appropriate maintenance programs, retro fitting of exhaust filtration systems, adequately designed ventilation systems, modifications to work practices, education of operators and as a final resort personal protective equipment.

The primary control measures noted during the study consisted of.

- Fuel Quality
- Air Quantity
- Ventilation systems in use
- Road Conditions
- Use of non-diesel vehicles
- Vehicle Maintenance
- Vehicle Diesel Particulate (Exhaust) Filters
- Administrative Controls – Diesel Tag Boards (No. of vehicle movements)
- Education
- PPE

A brief discussion is provided on each below and a table on the subjective (authors opinion) of the effectiveness of each in the control of exposure to diesel particulate at each mine during the program.

Fuel Quality: Consideration should be given to the use of a petroleum diesel with lower sulphur content due to the role that sulphur plays in the formation of particulate (such as Eromanga), however the potential for engine damage should be considered prior to any change in fuel. It should be noted that diesel fuel specifications are becoming stricter, with sulphur content of fuels being reduced with a 20% reduction planned in the next two years.

Parameter	Specification	Eromanga Diesel	Mobil Diesel
Density (kg/L)	0.79- 0.84	0.795	0.82-0.85
T95 Distillation (°C)	371 (max)	348	360
Sulphur (ppm)	200 (max)	100	50
Aromatics (%)	<10	2	11 (max)
Flash Point (°C)	61.6 (min)	64	61.5
Viscosity@40 °C (cSt)	2.0 – 4.7	-	2-4.5
Cetane Index	50 (min)	66	46 (min)

Table 6 – Comparison of diesel fuel composition

Air Quantity: This should be calculated by the Ventilation officer. The volumetric quantity of air available to the ventilation district and should take into consideration the total number of vehicles that may be expected to be in use in a 'worst-case' scenario (eg diesel tag board full). When determining the quantity of air required the following formula is recommended: $0.06 m/s^3$ x kW power or $3.5 m/s^3$ per vehicle minimum.

Ventilation system: This refers primarily to the ventilation split between districts and the use of stoppings to direct the flow and quantity of air to an area dependant upon the vehicle use expected in that district. The ability to isolate extraneous vehicle activity from a ventilation district can have a significant affect on the quantity of diesel particulate entering the district from outbye. Two of the mines tested had the ability to isolate the recovery and installation faces from outbye diesel machine activity, however the results returned were influenced by other factors.

Road Conditions: The better the road conditions, particularly when transporting heavy machinery can have a significant effect on how hard the diesel machinery needs to work to move equipment and time required to operate within the ventilation district.

*Use of non-diesel machinery***:** A number of operations employed electric powered mules to locate chocks and other equipment to the installation face, reducing the reliance on heavy diesel machinery and the associated exposure issues. The results returned could be reliably compared due to the number of machines in operation on some shifts involved in outbye road maintenance, belt installations and/or man-transport.

Vehicle Maintenance: Engine maintenance has been identified in a number of major studies including the Canadian DEEP study as being critical to the control and reduction of diesel particulate, particulaly in engines excceding 4000 engine hrs since a major overhaul. When undertaking gaseous exhaust tests, consideration should also be given to the monitoring of Diesel particulate emissions testing concurrently. This monitoring may be undertaken by way of a monitoring device such as

- SKC Diesel detective (when commercially available)
- TSI Dust track with moisture remover
- BOSCH Smoke meter

The Bosh smoke meter can also be used to develop a colourmetric table of results which can allow estimation of EC content of a respirable dust filter, saving on sampling and analytical costs.

Figure 15 – Air Quality Industries DPM in Exhaust Measurement Instrument

MSHA published in 2003 a guidancline on the maintenance of diesel equipment used in underground coal mines to minimise diesel particulate generation. The recommended actions include checking for:

- Clogged air filters and leaks in the air intake system.
- Correct fuel injection rate.
- Correct fuel injection timing.
- Correct operation of all fuel injection system components (fuel filters, water separators, fuel pumps and fuel injectors).
- Correct operation of electronic engine controls.
- High oil consumption.
- Increased carbon monoxide emissions.
- Clogged disposable diesel exhaust filters.

(Rogers& Davies 2004)

Diesel Particulate (exhaust) filters: The option of retrofitting of exhaust filtration systems should be investigated in association with the OEM. Significant studies and development of this technology has been undertaken in the NSW Coal industry by BHP-Billiton Illawarra coal in conjunction with Steve Pratt and Brian Davies. The resultant filters have been shown to reduce DP level from raw exhaust by up to 85%, however they must be fitted in suitably accesable housings and should preferably be used in conjunction with a tell-tale backpressure system to ensure optimum performance and effectiveness.

Figure 16 – Disposable filter assembly fitted to an underground mining machine *(Source: B Davies)*

Diesel Tag Boards: This is a simple system that limits the number of machines that may operate in a given ventilation district based on the quantity of air available. The tag board should be located at the start of the ventilation split.

The NSW DPI recommend a value of 0.06 m3/s/kW for the control of gaseous emissions and an additional value based on the emission of diesel particulate for individual items of plant in order to control particulate levels below the exposure standard. Using this a a guideline a simple table can be created to determine the number of tags allocated to a machine should be based on the power of the machine (see guidance Table 6 below).).

Machine	Power (kW)	Air Required (m/s^3)	Tags Required
Domino Pet (4cyl)	48	3.5	1
Domino Pet (6cyl)	74	4.4	1
SMV Driftrunner	75	4.2	1
Eimco 913	75	4.5	1
Eimco 915	112	6.7	2
Eimco 936	112	6.7	2
LHD ED7	150	9	2
LHD ED10	150	9	2
Noyes Grader	75	4.5	1
Power Tram	168	10.1	3
Clark Minecat	20	3.5	1

Table 7 **-** Example of Vehicle Tag Requirements

When a tag board for a district is full, there should be a system in place to determine whether the machines are in use or ‘parked up’, before another vehicle can enter the district. Although this is an administrative measure, the control and effectiveness of this system is almost wholly depent on the acceptance and utilisation of it by the operational workforce, and the implementation of such a system should be accompanied by a suitable education program.

Education: A well designed and presented education system that details, the health effects, the mines own sampling results (if available) control measures, operator activities that influence diesel particulate and PPE, should form the basis of any drive to control or reduce exposures to DP, particularly before a longwall move where the potential for elevated exposures is increased.

PPE: The use of a P2 mask will provide effective protection to below the exposure standard up to concentrations of 1.0mg/m3. A P2 mask with charcoal imptregnation will assist in the absorption of organic compounds associated with diesel exhaust (odour). Personal Protective Equipment should be worn for tasks or circumstances that have been identified or suspected as being above the exposure standard.

Discussion

The statistical review of the results indicated that nine out of the ten mines could be deemed to have returned unacceptable exposures, despite three of the mines returning MVUE and Mean results below the recommended exposure standard. Some of the results were particularly disappointing when an initial overview of control measures and inherent ventilation design suggested that better results were certainly possible.

The study is based on standard occupational hygiene monitoring practices, and as such no allowance has been considered for operations that used PPE as part of their control strategy. This is common practice as operator wear time may not have been accurately measured in relation to exposure time.

A number of the mines involved in this study had implemented a number of the listed control measures. A number of single mine studies have been undertaken since this study commenced (and completed) and have returned mixed results, however a further review of the control measures has allowed for the development of a recommended program to assist most operators to reduce exposure to personnel undertaking long wall changeouts. The table below indicates the effective use of control measures by mine utilised throughout the period of the study.

Control Measure	Mine A	Mine B	Mine C	Mine D	Mine E	Mine F	Mine G	Mine H	Mine I	Mine J
Low Sulphur Fuel										
Ventilation >$30m^3$										
Separate Air Split										
Maintenance Prog.										
Exhaust Filters										
Good Roads										
Tag Board System										
Education Prog.										
PPE Prog.										

Table 8 – Control Measures utilised at each mine

The program forms the basis of the recommendations below. The implementation and use of a program such as this is already in place in a number of NSW Coal Mines and appear to be very effective at controlling exposure to diesel particulate. There has been some increase in operational costs, however Pratt (2005) demonstrated that the adoption of a holistic program around DP control had significant savings in both the short and long-term for operations.

Recommendations

The approach to the management of diesel particulate should be to reduce exposures to as low as reasonably practicable with the 0.1mg/m^3 used as a guide to measure performance.

- Planning for the Longwall move should include measures to control exposure to personal to dust, noise and DPM as part of the process.
- Vehicle maintenance should be conducted prior to commencement of the move, the requirement for well maintained engines with preferably gas and exhaust particulate monitoring as part of the program should apply to hire vehicles (as part of the supply contract).
- Road maintenance should be optimised, this will not only reduce the exposure to DPM, but assist in the efficiency of the changeout with the potential for significant savings.
- If a low sulphur fuel is not already part of the mine's normal operations, the implementation should be considered for inclusion in the planning process.
- A review of the number of machines likely to be in use on the recovery and installation faces and on the travelling roads should form the basis of determining the ventilation rates in each district for optimum control of diesel particulate. Where possible isolation of the district from outbye diesel activity should be considered.
- A diesel tag board system should be trialled (if not already in use) and streamlined before the longwall move commences to assist the smooth operation during the high vehicle activity and operational requirements of the mine.
- A mine specific diesel training program should take place as part of the build up to the move and involve as many operational personnel as possible. The program should highlight how certain activities can have a significant effect upon exposure to other personnel and workmates. The training should target the mines' own control measures and situation including PPE.
- Monitoring for DP exposure should take place, with a requirement for timely results and feedback, to measure the effectiveness of the control measures and highlight any deficiencies. These are sometimes based around specific tasks and or specific machines.
- When replacing machinery, consideration should always be given to the engine emissions for not only gases, but diesel particulate, noise and heat.

Adherence to MDG 29, the DPI guideline for diesel particulate in underground mines will assist in reducing exposures to DPM, heat, noise, and vibration.

References

ACGIH, 2000, Documentation of TLV's, Diesel Exhaust Particulate, 15 March 2000.

AS2985 – 2004, Workplace Atmospheres-Method of Sampling and Gravimetric Determination of Respirable Dusts. Standards Australia.

Australian Safety and Compensation Council, 1995, 'Guidance Note on the Interpretation of Exposure Standards for Atmospheric Contaminants in the Occupational Environment 3rd Edition [NOHSC:3008(1995)]

BHP Billiton, 2005, 'Diesel Emissions Management' BHP Billiton

Coal Services 2004, Annual Report 2003 - 04. Coal Services Pty Limited: Sydney

Coal Services 2005, Australian Black Coal Statistics 2004. Coal Services Pty Limited: Sydney

Davies B and Rogers A, 2004, A Guideline for the Evaluation & Control of Diesel Particulate in the Occupational Environment, Australian Institute of Occupational Hygienists Inc,

Gillies 2005, Queensland Mining Industry Health & Safety Conference: Townsville, August 2005

Grantham D., 2001, Simplified Monitoring Strategies- A Guideline on how to apply NOHSC's Exposure Standards for Atmospheric Contaminants in the Occupational Environment to Australian Hazardous Substance Legislation. published by AIOH.

MSHA, 2001, Mine Safety and Health Administration 30 CFR Part 72 Diesel Particulate Matter Exposure of Underground Coal Miners; Final Rule, US Federal Register January 19, 5526-5706.

NIOSH, 2003, Diesel Particulate Matter (as Elemental Carbon), NIOSH Manual of Analytical Methods, Fourth Edition, NIOSH Publication 2003-154.

Noll J and Birch E., 2004, Evaluation of the SKC DPM cassette for monitoring diesel particulate in coal mines, J Environ Monit, 6: 973-978.

NSW Govt. 2001, Coal Industry Act 2001. NSW Govt. Printer: Sydney

NSW Govt. 1984, Coal Mines Regulation Act 1982 No 67. NSW Govt. Printer: Sydney

NSW Govt. 1999, Coal Mines (Underground) Regulation 1999. NSW Govt. Printer: Sydney

NSW Govt. 2008, Guideline for the Management of Diesel Engine Pollutant in Underground Environments, MDG 29, Mine Safety Operations Division, Dept. of Primary Industries, NSW Govt. Printer: Sydney.

Rogers A and Whelan W., 1996, Elemental Carbon as a Means of Measuring Diesel Particulate Matter Emitted from Diesel Engines in Underground Mines, proceedings of 15th Annual Conference of Australian Institute of Occupational Hygienist, Perth, December 1996.

Rogers A., 2001, Exposure to Diesel Particulate Under Various Operating Conditions in Queensland Underground Coal Mines, JCB Health & Safety Trust Research Project 20080, September 2001.

Rogers A., 2005, Diesel Particulate (soot) in Some Australian Underground Metalliferous Mines – Exposures and Methods of Control, Proceedings of Annual Conference of Australian Institute of Occupational Hygienists, Terrigal, December 2005.

US EPA, 2002, Health Assessment document for diesel engine exhaust. US Environmental Protection Agency, Document EPA/600/8-90/057F May 2002.

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