EVALUATING RESPIRABLE COAL DUST CONCENTRATIONS AT THE FACE OF SOUTH AFRICAN COAL MINES

By

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DECLARATION

I, Ernest French Ferreira, do hereby declare that this dissertation is my own work. It is being submitted for the degree of Master of Public Health – Occupational Hygiene in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at this or any other University.

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E F Ferreira

Signed on this________day of _____________2008

ABSTRACT

Introduction

The Department of Minerals and Energy (DME) in South Africa issued a Directive B7, titled “A Guideline for the Ventilating of Mechanical Miner Sections” to the coal mining industry. The main purpose of this directive was to reduce respirable dust exposures at the coal face with the long term objective of reducing the incidence of Coal Workers Pneumoconiosis (CWP). This study attempts to evaluate the appropriateness of the DME approach by comparing respirable coal dust results from personal samples from occupations at the coal face to the results obtained from engineering samples at the continuous miner.

Objectives

The objectives of this study are to:

- Describe personal respirable coal dust concentrations of the occupations within the continuous miner Homogeneous Exposure Group (HEG) in five underground coal mines in Mpumalanga from January 2005 to December 2006.
- Describe environmental engineering respirable coal dust concentrations of the continuous miner operator position in five underground coal mines in Mpumalanga from January 2005 to December 2006.
- Compare personal respirable coal dust concentrations to Environmental Engineering Dust (EED) concentrations in five coal mines in Mpumalanga from January 2005 to December 2006.

Methodology

This study is descriptive in nature and was carried out utilizing historical respirable coal dust data from underground coal bord and pillar production sections. Data was supplied by Collieries Environmental

Control Services (CECS) who provided a coal sampling and analysis service to South African collieries. Data provided was from five large underground coal mines in the Mpumalanga coal fields.

The study population consisted of occupations within the HEG of workers deployed at the coal face who were linked to Continuous Miner (CM) production activities and results from EED sampling.

Results

When comparing the personal sampling results to EED sampling results for each individual mine, it is evident that all the mines had lower personal sampling results than EED results, thus establishing a definite trend. When combining all the mines in the two data sets it is also evident that EED sampling results are significantly higher than personal sampling results confirming the trend observed on individual mines. Correlation tests carried out between the two data sets indicated that there is no correlation between the personal and EED sampling results. The poor correlation between the two data sets indicates that the EED sampling position is not ideal and does not take account of the actual contaminant levels leaving the coal-winning heading.

Discussion and conclusion

The DME directive by way of a simple calculation took the countries personal Occupational Exposure Limit (OEL) of 2 mg/m^3 and formulated a limit of 5 mg/m^3 for EED sampling results.

Simple extrapolation of the EED results indicates that personal exposure is exceeded more than two-fold and thus the limit of 5 mg/m^3 as set by Directive B7 cannot be compared to the personal respirable coal dust OEL of 2 mg/m^3. The basis of the initial calculation used to derive the 5 mg/m^3 limit assumed that the shift lengths were in the region of 8 hours and cutting times around 40% of the shift, while most coal mines now have shift lengths ranging from 9 to 10 hours.

In conclusion it is evident that the required limit of 5 mg/m^3 as set out by Directive B7 cannot be related to the personal exposures limit of 2 mg/m^3. Poor correlation results observed indicate that the EED sampling position does not account for the respirable dust concentrations leaving coal-winning headings and may be affected by the re-circulation of contaminated air over the sampling position. In addition the EED sampling position does not give an indication of the respirable dust capture efficiency of scrubber fans.

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GLOSSARY

Activity Area: Areas into Activity Areas as per the Activity Area Code List found under Part B, Generic Codes of the SAMOHP Guidelines i.e. continuous mining, crushing, screening etc.

Anderson Darling Normality Test: A statistical test which compares the cumulative data distribution to an expected distribution expected if the data were normal. If the observed difference is significantly large then the test rejects the null hypothesis of population normality.

Coal-Winning Heading: A coal-winning heading is any face, regardless of its distance from through ventilation, which is in the process of being advanced.

Confidence Interval: A range of values, derived from sample statistics that is likely to contain the value of an unknown population parameter.

EED Sampling: Samples collected from the main production shift only, calculated for the full shift period. Sampling pumps positioned on the continuous miner at the operator's cab position or at a position where the continuous miner operator would be seated if on board the machine.

Homogenous Exposure Group: A group of people, generally performing the same task for the same period of time, such that exposure measured on any one person within the group will be representative of the exposure of the whole group.

Last Through Road: The closest holing to the working faces between two companions, which carry a unidirectional flow of air from the intake to the return of the section.

Mechanical Miner / Continuous Miner: A mechanical miner is an electrically driven machine designed to cut coal by means of a cylindrical drum which has picks mounted on it and rotates against the coal on the face. The coal that is cut from the face falls onto a chain conveyor which tips the coal onto a shuttle car. The machine is equipped with a high pressure directional water spray system and a machine mounted scrubber system.

Median: The middle of the data. Half of the observations are less than or equal to it.

Personal Sampling: Samples collected randomly over all shifts placed in the operators breathing zone, calculated back to an eight hour shift.

Return Airways: Airways conveying air, which has scrubbed a face in a section and is contaminated.

Roof Bolt Machine: A roof bolt machine is an electrically driven machine used to install roof bolt support in areas where the continuous miner has cut. The roof is bolted to prevent pieces of strata from dislodging and falling from the roof.

Sampling Areas: An area derived from the breakdown of a mine into a ventilation district or combination of ventilation districts with a common intake and return of which the return is not used as an intake to another ventilation area.

Scrubber System: A device using a fan to draw dust-laden air through an irrigated internal fill material to clean the air of particulate pollutants.

Shuttle Car: A self-propelled mobile electrically driven machine with power supplied by a trailing cable that is used to transport coal in the section.

Upcast Ventilation: Return air that is exiting the mine via ventilation shafts to surface.

ACRONYMS

ACGIH:	American Conference of Governmental Industrial Hygienists
AIDS:	Acquired Immunodeficiency Syndrome
BZ:	Breathing Zone
CECS:	Collieries Environmental Control Services
CEN:	European Committee for Standardisation
CI:	Confidence Interval
CM:	Continuous Miner
CSIR:	Council for Scientific and Industrial Research
CWP:	Coal Workers Pneumoconiosis
DME:	Department of Minerals and Energy
EED:	Environmental Engineering Dust
GSD:	Geometric Standard Deviation
GW:	General Worker
HEG:	Homogenous Exposure Group
HIV:	Human Immunodeficiency Virus
ISO:	International Organisation for Standardisation
MBOD:	Medical Bureau for Occupational Diseases
NIOSH:	National Institute for Occupational Safety and Health
OEL:	Occupational Exposure Limit
OSHA:	Occupational Safety and Health Administration
PEL:	Permissible Exposure Limit
PMF:	Progressive Massive Fibrosis

RB: Roof Bolter

REL: Recommended Exposure Limit

SAMOHP: South African Mines Occupational Hygiene Programme Codebook

SANAS: South African National Accreditation System

SC: Shuttle Car

SIMRAC: Safety in Mines Research Advisory Committee

TB: Tuberculosis

TLV: Threshold Limit Values

TWA: Time Weighted Average

UK: United Kingdom

SYMBOLS

m^3/s: Cubic meters per second

mg/m^3: Milligrams per cubic meter

l/m: Litres per minute

CHAPTER 1 - INTRODUCTION

This chapter gives a brief history of the coal mining industry and the health hazards associated with coal mining with special emphasis on CWP, its cause, health effects and methods of detection. This chapter also highlights how South African legislation and control standards were formulated and what standards are applied. Concerns with regard to the application of the legislated CM engineering dust control strategy are explained along with the reason for carrying out this study. Literature review findings are discussed and summarised, these included both an international and local perspective. The chapter closes with an overview of the study objectives.

1.1 Background

Coal has been used worldwide for many centuries as fuel. In the 1800's it became the main energy source and has been utilised since. Coal is found almost exclusively underground, for this reason it must be extracted from underground or mined before it can be used. Coal mining methods have evolved over the years ranging from primitive methods to the highly mechanised methods of late. The first reported discovery of coal in South Africa was in the mid 1830's when coal was mined in Natal. Coal production grew at an alarming rate to satisfy the growing demand from the mushrooming population in new established towns. In more recent times, the country's domestic consumption of coal, specifically for power generation, has become an important economic resource.

South Africa's coal mining industry is the second largest mining sector after gold. South Africa is the world's second largest coal exporter, after Australia, as well as second lowest cost producer, after Indonesia. South Africa's coal reserves are becoming limited with an estimated 34 billion tons remaining. If calculated on current consumption rates, South Africa could have only 7 billion tons remaining by 2040. South Africa's coal mines are situated in the Mpumalanga, Free State, Northern Kwazulu Natal and the Northwest provinces (1).

The necessity to meet the growing electricity demands of South Africa has resulted in an increase of coal production. Mechanization of the mining methods has led to an increased risk of persons contracting occupational diseases. Among these diseases is a disease which is caused by the inhalation of respirable coal dust known as CWP.

Dust is generally formed when fine particles are released into the atmosphere through the turbulent action of ventilating air, by the mechanical disturbances of fine materials, or through the release of particulate rich gaseous emissions. Dust generated during the coal mining activity usually occurs as a result of the pulverization of the coal strata and from the disturbance of fine particles of coal, soil and surrounding strata. The generation of dust depends on numerous factors such as the coal seam geology and the mining methods.

Particles of fine coal dust inhaled by miners cannot be destroyed within, or removed from the lungs, thereby causing a build up inside the lungs. Over time this build up of impurities in the lung eventually leads to thickening and scarring, resulting in a decreased supply of oxygen to the blood. Lung diseases are diagnosed by means of chest X-rays, while spirometry tests are carried out to monitor the extent of the damage to the lungs.

Simple CWP shows up as small spots on a chest x-ray. It is caused by the collection of coal dust around the respiratory bronchioles which lead to the alveoli. Coal miners with simple CWP may not appear ill and this is why x-rays and a detailed work history in coal mines are important in making an early diagnosis. The early detection of the disease is of utmost importance as this allows preventative measures to be introduced, that is, the worker may be moved to a less dusty atmosphere. It is important to note that there is no cure for CWP and exposure prevention is the only alternative. Studies have shown that CWP can be progressive even after exposure has stopped. An advanced stage of the disease occurs with continued exposure to high levels of respirable coal dust and this is known as Progressive Massive Fibrosis (PMF). Miners with PMF experience a feeling of shortness of breath on exertion and have a persistent cough which may also be accompanied by night sweats. This shortness of breath worsens as the disease progresses, eventually restricting the affected persons ability to perform work. CWP has been known to cause an enlargement of the heart which can lead to heart failure, as well as lung infections such as pneumonia or tuberculosis (TB) which attack the weakened lungs (2).

Since the first discovery of CWP there has been ongoing research into the disease and initiatives have been implemented to control coal dust emissions and occupational exposures in the workplace. This has led to the promulgation of legislation which was aimed at reducing the incidence of CWP. There have been many initiatives both locally and internationally aimed at controlling and reducing the disease, however, there is still room for improvement. The challenge, however, is to find an optimal solution that is practical and sustainable while maintaining business goals.

In 1910, Occupational Exposure Levels (OEL's) were first proposed by Emhurst Duckering in the UK as a way of equating worker exposure to dust. Many agencies have provided values to serve as a guide to controlling exposure levels, some examples are: Permissible Exposure Limits (PEL) of Occupational Safety and Health Administration (OSHA), Recommended Exposure Limits (REL) of the National Institute of Occupational Safety and Health (NIOSH) and the Threshold Limit Values (TLV) of American Conference of Governmental Industrial Hygienists (ACGIH), which are intended to be used to evaluate worker exposure. These limits are considered as levels that will protect most workers taking individual susceptibility into account. These limits are based mainly on health considerations (3). South Africa's OEL for respirable coal dust has been set at 2 mg/m^3 and is legislated in Schedule 22 of the Mine Health And Safety Act 29 of 1996 (4). Although no scientific study has been conducted in South Africa to determine adverse respiratory health outcomes in coal miners, statistics supplied by the DME regarding pneumoconiosis indicate that no cases were reported during the 2006 reporting period while there were two cases reported for the 2007 reporting period (5).

The Occupational Diseases in Mines and Works Act makes provides for autopsy examinations for occupation related respiratory pathology among deceased coal workers. Statistics for 2007 indicate that the overall disease rate of 3 per 1000 autopsies for CWP (6).

Growing concern about dust related illnesses, together with the Leon Commission Report (7), led the South African DME to review legislation aimed at protecting the health and safety of mine employees.

Directive B7, titled “A Guideline for the Ventilating of Mechanical Miner Sections” was issued by the DME to the South African coal mining industry with an effective date of 25 April 1994 (8).

This Directive stipulated that one daily dust sample was required to be taken at every Mechanical Miner. The sampling pumps were to be positioned on the CM at the operator’s position or at a position where the CM operator would be seated if on board the machine.

A compliance dust limit of $5mg/m^3$ was assigned for this sampling programme. This limit was based on the regulated eight hour Time Weighted Average (TWA) personal exposure limit of $2mg/m^3$. The $5mg/m^3$ limit approximates the personal exposure limit of $2mg/m^3$ due to an estimation made that Mechanical Miners generally operate for only 40% of the shift. An assumption was made that there would be no further exposures to coal dust following the completion of the cutting cycle of the CM (8).

During the literature review it was determined that the EED methodology applied in South Africa is not practiced in other parts of the world.

Table 1-1 DME example of dust calculation

$$\text{Dose} = \frac{(\text{Concentration 1} \times \text{Time 1}) + (\text{Concentration 2} \times \text{Time 2})}{8}$$

$$= \frac{(5 \times 3{,}2) + (0 \times 4{,}8)}{8}$$

$$= 2\frac{\text{mg}}{\text{m}^3}$$

Where:

Concentration 1 = 5 mg/m^3 prescribed limit

Time 1 = 3,2 hours (40% of shift)

Concentration 2 = 0 mg/m^3

Time 2 = 4,8 hours (60% of shift)

Dust sampling for compliance purposes has been a requirement at coal mines using mechanical miners since 1994. The purpose of this compliance sampling was to ascertain the effectiveness of the ventilation and dust suppression systems employed at CM's. Initially the mines were generally reluctant to undertake this sampling programme, but it has subsequently become an integral part of the management system on mines.

The DME directive prompted the coal mining industry in South Africa to respond, which led to a research project, COL 518 being carried out through the Safety in Mines Research Advisory Committee (SIMRAC). The outcome from this was a detailed guidance document on various approaches available to control dust levels to below the DME maximum required limit of 5 mg/m^3 at double pass CM coal-winning operations (9).

Environmental engineering sampling was instituted as a means to monitor existing control measures daily at all CM's utilised at coal-winning operations. Good ventilation practice supported auxiliary ventilation systems which force intake air over the operator's position to the coal face. Effective systems are prescriptive as to how and where auxiliary systems need to be positioned and/or placed in order to divert contaminated air from the coal face to the scrubber fan system and finally to the return airways. Contaminated air coming from the face was scrubbed by mainly wet scrubber fan systems with claimed dust capture efficiencies of approximately 95% for respirable dust. Initial determinations of these efficiencies were carried out by the Council for Scientific and Industrial Research (CSIR) many years ago and were still being claimed by manufacturers as being applicable based on the consistency in design parameters which were accepted as being comparable. As a means to determine dust scrubbing effectiveness the ventilation rates through scrubber fans were measured routinely. This gave an indication of the fan efficiency and potential load which may have resulted from blockages to the system, worn impeller tracks, leakages and or too much water through the system where wet fans were utilised.

1.2 Literature review

1.2.1 International perspective

1.2.1.1 Coal workers pneumoconiosis / lung impairment

There have been numerous studies that have reported adverse respiratory health effects among miners which could be attributed to the inhalation of respirable coal dust.

A study addressing Emphysema in CWP was carried out between the pathological, physiological and radiological findings among deceased coal miners and ex-coal miners who were diagnosed with CWP. Findings were obtained from large lung sections and detailed case histories of these were then compared to similar findings from a non-mining population.

The findings from the study showed that emphysema was more common among coal miners and that the extent of emphysema was closely related to lung ventilatory impairment (10).

In 1986 a study was carried out to determine whether exposure to coal mine dust could cause severe impairment of lung function. This study compared ex-coal miners without PMF and a sub-group who had been exposed to greater than average effects previously shown among more representative groups of coalminers dust exposure.

The findings from this study was that the miners who had been exposed to greater than average effects showed a relation between exposure and lung function, this was consistent with the view that in some miners even moderately high exposures caused severe lung impairment (2).

In the United States a study was carried out on coal miners to establish an association of respirable coal dust exposure with pulmonary function and symptoms of airway obstruction. The study population included miners who had started mining after 1970 when comprehensive exposure regulations were first promulgated.

The study involved quantitative estimates of cumulative respirable dust exposure measurements taken by the Mine Safety and Health Administration.

Findings from this study showed statistically significant associations of cumulative exposure with a decrease of lung function. The study concluded that respirable coal mine dust continues to affect respiratory health in coal mines (11).

1.2.1.2 Relationship between pneumoconiosis and exposure to coal dust

A study was carried out in the 1980's in British collieries in the field of pneumoconiosis over a twenty year period at ten collieries in order to further clarify the following two questions.

- Are data consistent with the estimates of long term pneumoconiosis risks derived from the previous ten years using results from only a ten year observation period?
- Is there evidence that the chance of developing simple pneumoconiosis is affected by the quartz content of coal mine dust to which workers are exposed?

The study included the examination of serial chest radiographs spanning two consecutive ten year periods by a number of experienced physicians. Respirable coal dust exposures were calculated from records of individuals in occupational groups utilising the average respirable dust concentrations.

The study established unambiguous correlation between estimates of cumulative exposure to coal dust and indices of CWP.

The study concluded that the probability of long term pneumoconiosis risks was one or two percentage points higher than corresponding predictions made ten years earlier using data on radiologic changes.

It was further concluded that there was evidence that some miners would react unfavourably when exposed to high levels of quartz in respirable coal mine dust (12).

1.2.1.3 Coal dust monitor

NIOSH conducted a study in 1997 where a machine mounted continuous dust monitor was evaluated. The objective of the study was to continuously monitor, display and record concentrations of coal mine dust. For this study the dust particle pre-selector was specifically designed to match the size penetration curve of the sampler currently used for coal mine respirable dust compliance measurements. This compliance sampler used a 10 mm Dorr Oliver cyclone operated at a flow rate of 2 l/min. The findings were that the instrument did not meet the accuracy criteria and, therefore, could not be used to represent workers exposure to respirable dust (13).

NIOSH conducted a study in 2003 where a new technology for controlling dust at CM personnel was evaluated. These technologies included a wet head cutting drum on a CM. Results indicated that dust results were reduced significantly by the use of wet cutter head application, reducing the dust levels by 0.5 mg/m^3 at the operator position and 0.3 mg/m^3 in the return when adjusted for intake levels. Results, however, were likely to be confounded by ventilation systems, gravimetric sampling data, production and geological interferences (14).

1.2.1.4 Occupational exposures and respirable coal dust

A recent study was carried out with the aim of evaluating dust concentrations in underground Turkish coal mines and the risks associated with exposures to respirable dust.

Data used in the study was obtained from dust measurement studies carried out in various coal mines over the period between 1978 and 2006. The degree of occupational coal dust exposures was investigated by means of dividing areas into occupational job categories namely, production workers, gate road-stone drift workers and haulage workers.

From the study it was concluded that upon statistical analysis production workers were exposed to higher concentrations than the other categories of workers and also concluded that workers who had doubtful CWP diagnosis were employed in production areas such as longwall and heading faces (15).

1.2.2 South African perspective

1.2.2.1 Coal workers pneumoconiosis

As described in a text book by Guild, R, et al (2001), addressing the Epidemiology of CWP was analysed. CWP certification rates obtained from the Medical Bureau of Diseases (MBOD) indicated a decline in certified cases since 1980. A positive association was highlighted between the presence of pneumoconiosis and length of service of coal miners, and the presence of TB was more common among workers with CWP than those without. The prevalence of CWP varied substantially depending on the X-Ray reader used.

It was also stated that the MBOD certification rates underestimated the occurrence of CWP and that the limited availability of information in South Africa makes it difficult to determine the actual degree of underestimation (16).

In a SIMRAC report compiled by Belle in 1999 the ventilation and dust control systems at CM's was evaluated. This report evaluated the on-board dust-suppression systems at double pass CM's, with the aim of providing optimal dust suppression system solutions for the coal mining industry. This study did not consider personal exposures in occupations in adjacent areas and included an evaluation of last through road air velocities, water spray configurations, spray nozzle sizes and types, scrubber fan volumes, heading ventilation methodologies, water spray configurations, water flow rate, water pressure and mining parameters.

The outcome from the project was a detailed guidance document on various approaches available to the mining industry for controlling dust levels to below the DME maximum required limit of 5 mg/m^3 at double pass CM coal-winning operations (9).

1.2.2.2 Coal dust exposure reduction methods in collieries

In the South African mining industry, related work was done through SIMRAC. Report Number COL 027 evaluated methods of reducing workers exposure to coal dust.

The study outputs were specified as:

- Evaluation of current and alternative dust suppression systems, as well as assisting in the development of new systems.
- Determination of the potential for reducing dust generation through the application of the latest coal-cutting technologies.
- Preparation of guidelines and procedures for reducing worker exposure to dust.
- Investigation into solutions to address future technology requirements.

Although the above study focuses primarily on the conditions at the coal-winning face, confounding factors with regard to the conditions outside of the coal-winning heading were also discussed at length (17).

1.2.3 Conclusion of literature review

Studies carried out both internationally and locally on CWP have been well documented. Studies in the past have indicated that there is a positive association between the presence of pneumoconiosis and the length of service in a relatively young workforce. In addition, there are findings which indicate that TB is more common among workers with CWP than those without the illness. Furthermore, the prevalence of Human Immunodeficiency Virus (HIV) / Acquired Immunodeficiency Syndrome (AIDS) places coal miners at a higher risk of becoming ill as there is a positive association between the incidence of TB and HIV/AIDS.

No studies were observed that could be directly related to EED sampling as practiced in South Africa. Furthermore, no studies attempted to draw a correlation between the Homogenous Exposure Group

(HEG) for workers at the coal face and engineering sampling for respirable dust. One study evaluated a real-time monitoring system on the CM and correlated the results to the traditional coal mine respirable sampling method. This was, however, proven to be inaccurate.

1.3 Problem statement

Due to the ventilation methods applied at coal-winning headings, the applicability of the stipulated sampling position on board of the CM, as a comparative indication of personal respirable coal dust exposure can be questioned. Due to the dynamics inside the heading being cut caused by ventilation systems, water sprays, cutter drum rotation, falling coal at the face, the energy from the scrubber fan and air re-circulation it is suggested that the 5 mg/m^3 limit cannot be correlated to the respirable OEL (8 hour TWA) of 2 mg/m^3. Furthermore, the EED sampling position situated on the CM is inside the heading close to the face being cut for extended periods of the shift, and is not situated in the return air leaving the heading and thus may not give a true reflection of the dust contaminants in the air leaving the heading. The scrubber fan respirable dust capture efficiency may, therefore, not be measured accurately due to the fact that not all the air re-circulated inside the heading passes through the scrubber fan system. The dust contaminated air leaving the heading is distributed throughout the section where various activities are taking place thus exposing persons to the contaminant concentrations. Should contaminated air leaving the heading contain high or low contaminant concentrations then workers outside of the heading may be over or under-exposed. The continued focus at the CM operator's position by the mines and the DME since the inception of Directive B7 may have led to the neglect of other parts of the dust suppression and management system, and may have resulted in increased exposures elsewhere, for example, the SC operator.

1.4 Motivation for the study

Although coal dust control methodologies and personal exposures are well documented, the methodology used in South Africa surrounding engineering control sampling for respirable dust has not been evaluated against personal exposures for the occupations within the face area.

The results obtained from the sampling position may be influenced significantly by section ventilation availability, extended shift times (> 8 hours), influences on sampling equipment such as excessive vibration, status of the dust suppression system, mining parameters and airflow dynamics.

It is with the above in mind that the appropriateness of the method be evaluated to establish what the true situation is and what these results are actually telling us. In addition, while the drive initiated by Directive B7 has shown a significant improvement in respirable dust readings at the face, the coal mining industry must continue to strive towards continual improvement thereby protecting the health of workers.

1.5 Objectives of the study

Respirable coal dust is a well recognised health hazard in the coal mining industry associated with various occupational illnesses which include CWP. The DME in South Africa has set a limit of 5 mg/m^3 for EED results which was based on the legislated OEL of 2 mg/m^3 for respirable coal dust. The sampling position for EED is on the CM at the operator position inside the heading where dust control methods are influenced by numerous confounders. EED sampling pumps do not accurately quantify air that is exiting the scrubber fan system. The occupations in the CM HEG are required to work or operate equipment in contaminated air leaving the heading and, therefore, their exposure is dependant on the quality of contaminated air leaving the heading.

The objectives of this study are to:

- Describe personal respirable coal dust concentrations of the occupations within the continuous miner homogeneous exposure group in five underground coal mines in Mpumalanga from January 2005 to December 2006.
- Describe environmental engineering respirable coal dust concentrations of the continuous miner operator position in five underground coal mines in Mpumalanga from January 2005 to December 2006.
- Compare personal respirable coal dust concentrations to environmental engineering dust concentrations in five coal mines in Mpumalanga from January 2005 to December 2006.

CHAPTER 2 - MATERIALS AND METHODS

In this chapter the study design along with the study settings will be discussed. This discussion includes a brief overview of the ventilation methods and dust control strategies that were practiced at the time of the study. An explanation is given to clarify the roles of the occupations included in the study at the time. Respirable dust monitoring methodologies are discussed to provide information on the standards applied during the sampling process as well as how samples were selected and taken over the period. The analysis methods that were used in the study to analyse the data are discussed in detail. The chapter continues with the quality control methods that were applied in the study and concludes with the ethical considerations for the study.

2.1 Study design

The study design was descriptive in nature and evaluated historical respirable coal dust data from underground coal mine production sections. The study included EED monitoring and personal sampling results of five underground mines in Mpumalanga from January 2005 to December 2006.

This study made use of the respirable dust data that is routinely collected in underground coal mine CM operations for personal exposures and EED monitoring, in line with the DME requirements. These requirements stipulate that for personal respirable monitoring purposes the mine must be divided into HEG's based on exposure risk from which a stipulated minimum number of samples must be taken from occupations within the HEG over a pre-determined period. These samples are then analysed to obtain a representative exposure which is then assigned to all the occupants within the HEG. For EED monitoring it is prescribed that respirable dust be measured at all underground coal mines at the CM operator's position on a daily basis as a means to measure the engineering efficiency of the dust suppression systems at the coal-winning face.

Data for the study was supplied by CECS who provide a coal sampling and analysis service to South African collieries. Data provided was from five underground coal mines in the Mpumalanga coal fields. These five mines were selected from a total of twenty three potential sites. Permission was granted by CECS for the use of the data for research purposes.

The selection of mines for the study was carried out by CECS on a random basis considering the following:

- All were underground coal mines,
- All mines utilised CM mechanical mining methods,
- Mines could be described as being typical of coal mines utilising CM mechanical mining methods.

2.2 Study settings

CM's operate in underground coal bord-and-pillar sections. These sections are ventilated by means of air which is drawn through the mine by large main fans situated on surface. The volume of air handled by the main fans varies in accordance with the ventilation requirements determined by the number of coal-winning sections and other areas where additional air is required for dilution purposes. The volume of air for dilution purposes supplied to the sections is calculated based on the required last through road velocities, gas dilution requirements and bord widths and seam heights. Typical air volumes range from in the region of 35 meters cubed per second (m^3/s) for 2.0 meter and 70 m^3/s for 4.5 meter seam heights.

Ventilating air is drawn down the downcast shaft and travels along intake airways to production sections. In the section the air is channelled along the last through road using ventilation controls. From the last through road air is projected into coal-winning headings by means of auxiliary fans. The air that has scrubbed the face leaves the section via the return airway to the upcast shaft where it is drawn through the main fan and discharged into ambient air.

Figure 2-1 is a schematic diagram of a typical mine ventilation layout.

In the coal-winning section, coal is cut from the face using CM's. The pillars are mined according to a pre-determined cutting sequence which compliments the ventilation and is designed to limit the CM operator's exposure to dust. Coal is then loaded onto SC's which in turn transport the coal to a feeder-breaker. Dust suppression is applied mainly by means of water sprays and dilution ventilation. The CM is equipped with an on-board dust scrubber fan with a design volume in the region of 0.4 m^3/s for each square meter of face area. Air which is projected into the coal-winning heading travels over the CM operator's position and is then swept across the coal-winning face.

Figure 2-2 is a typical board-and-pillar section and a typical coal-winning scenario. Dust is further managed by a spray fan system which consists of water sprays mounted on the cutter head angled in the direction of the dust scrubber to divert airflow across the face while cutting is in progress. Additional water sprays are mounted at strategic points along the CM to prevent dust rollback. Optimal water spray systems operate at a water pressure of around 2 MPa which is achieved by a booster pump in the main water line or mounted on the CM. COL 518 was used as a guide to equip CM's with dust suppression systems (9).

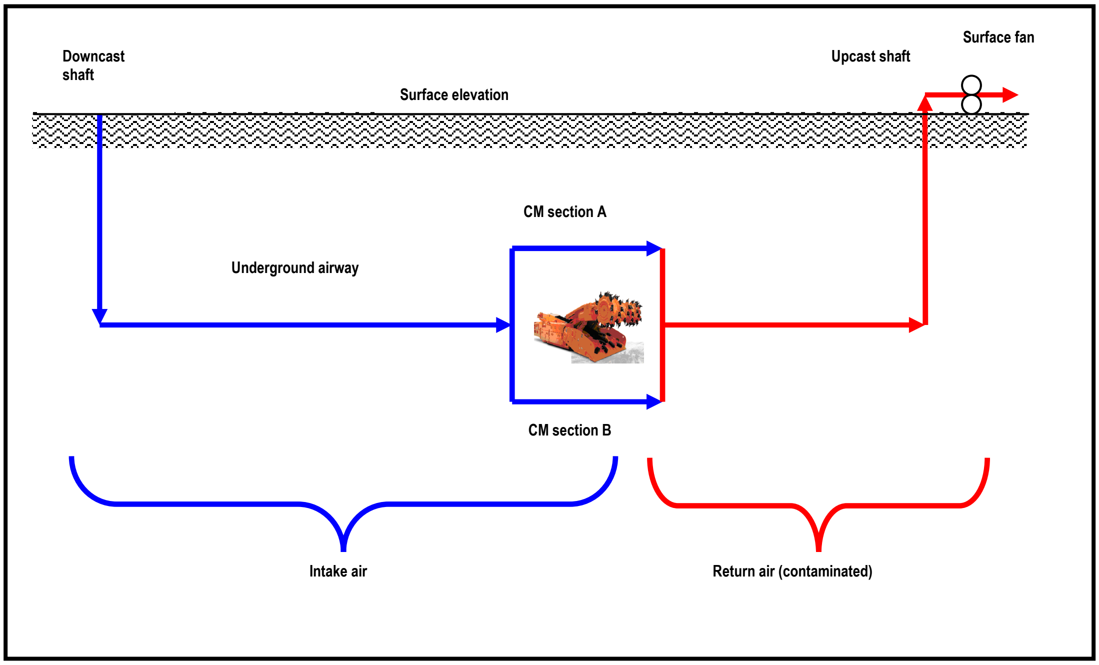

Figure 2-1 Schematic diagram showing a typical underground coal mine ventilation network.

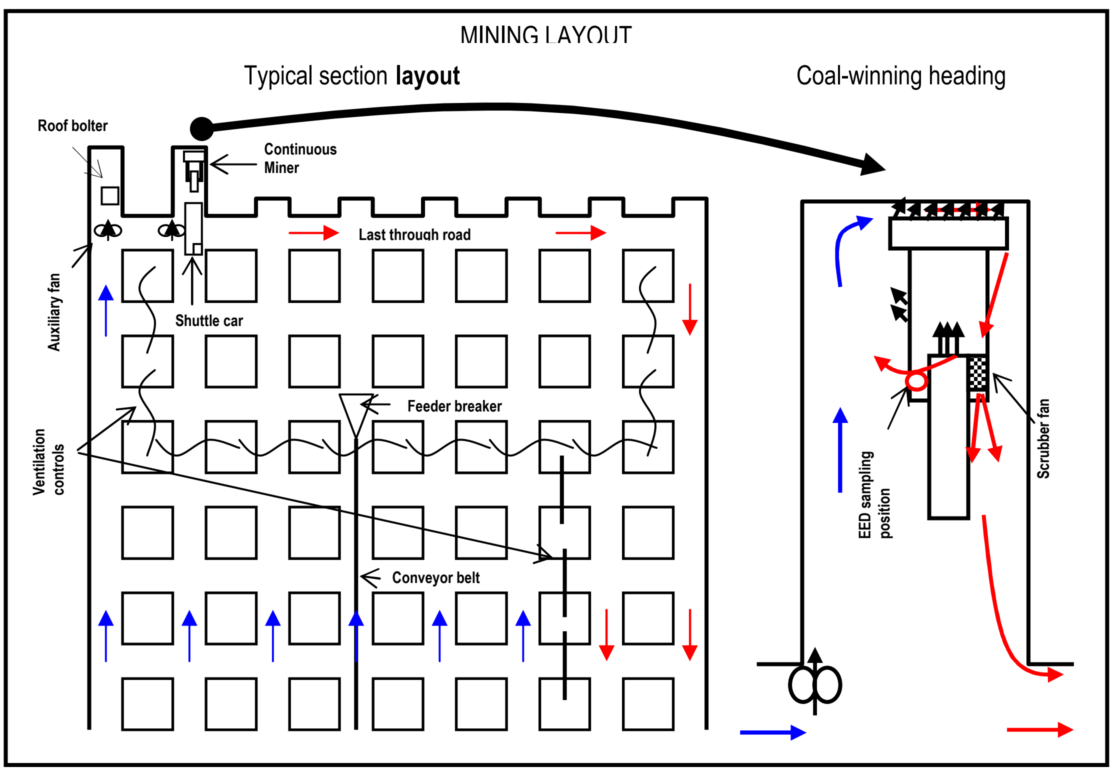

Figure 2-2 Schematic diagram showing a typical bord-and-pillar section and coal-winning heading.

Figure 2-3 is a typical CM dust suppression system and Figure 2-4 shows typical operational spray systems on CM's.

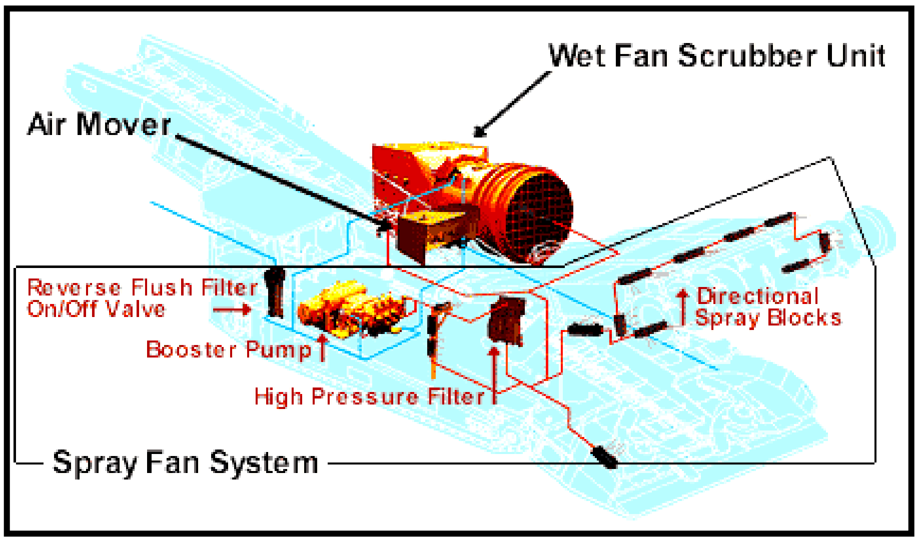

Figure 2-3 Schematic diagram showing a typical CM dust suppression system.

Figure 2-4 Illustration of typical operational spray systems on CM's.

2.3 Study population

The study population consisted of occupations within the HEG for workers deployed at the coal face who were linked to CM production activities. The following occupations formed part of the study:

2.3.1 Continuous miner operators

CM operators were positioned on the upstream air side of the coal-winning heading on board the CM.

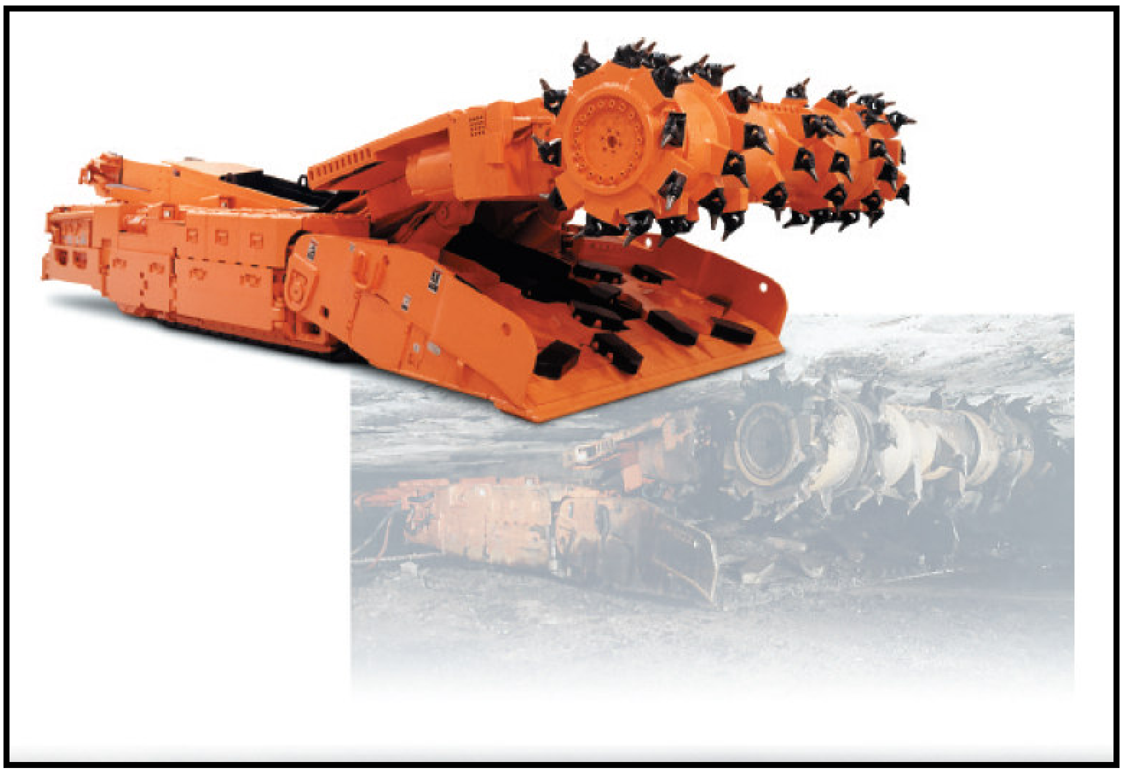

Figure 2-5 Illustration of a typical CM.

2.3.2 Shuttle car operators

SC's were loaded via coal from the CM boom and operators drove their vehicles between the feeder breaker and the heading being cut conveying coal from the face to the conveyor belt system. SC's entered the headings in contaminated air which had been scrubbed by the on-board scrubber fan, the scrubber fan outlet was fitted with deflector vanes which deflected scrubbed air towards the roof or side.

Figure 2-6 Illustration of typical shuttle cars.

2.3.3 Roof bolt installers

RB installers operated RB machines as part of the systematic roof support process. RB's were installed in recently cut areas and took place primarily on the fresh air side of the section. RB machines were equipped with internal water feed systems via the drill steel for dust control purposes.

Figure 2-7 Illustration of a typical roof bolting machine.

2.3.4 Miners

Miners were in charge of the day to day running of the section, including responsibilities such as, adhering to the cutting sequence, dust suppression systems, ventilation control etc. The miner conducted routine examinations throughout the shift to ensure that both safety and production targets were pursued and he was also responsible for checking the dust sampling equipment.

2.3.5 General labourer

GL's assisted in moving CM trailing cables, moving water pumps, installing ventilation controls etc.

2.4 Monitoring of respirable dust

The OEL for respirable coal dust in South Africa is set at 2 mg/m^3 and this is applied uniformly to every coal type. The OEL's for pollutants in South Africa are legislated in Schedule 22 of the Mine Health and Safety Act 29 of 1996 (4), while Directive B7 stipulated a maximum of 5mg/m^3 for EED sampling (8).

Sampling for respirable coal dust must be carried out to ensure that the sample is collected from the breathing zone (BZ). This is the imaginary hemisphere of approximately 300 mm, extending in front of the face and measured from the midpoint of an imaginary line joining the ears (18). Figure 2-8 shows the various regions of the lungs where dust may be deposited and a schematic diagram of the BZ. It should be noted that respirable dust is able to reach the deepest regions of the lung which include the alveoli.

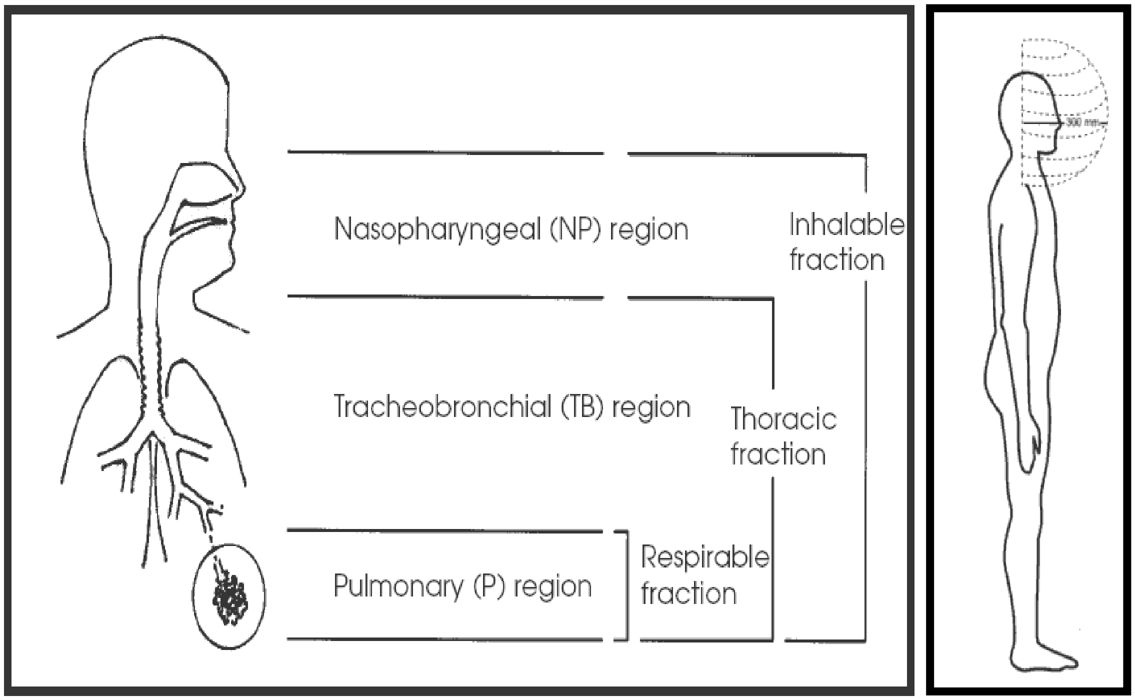

Figure 2-8 Regions of the respiratory tract and breathing zone schematic diagram (19).

The sampling methodology used for collecting samples included in the study was by means of air sampling pumps via sampling cassettes, having a DME approved cyclone (Higgins-Dewell type) to enable respirable dust sampling. The sampling flow rate was set at 2.2 l/m to ensure compliance to the requirements of the ISO/CEN/ACGIH respirable dust curve (18) as illustrated in Figure 2-9.

Filters were 37mm in diameter, supported with a support pad in a two piece 37 mm cassette holder sealed with cellulose shrink band. Personal samples were collected on cellulose ester filters as they are relatively cheap and easy to handle and also better equipped for silica analysis via infra-red spectrometry, while EED samples were collect on glass fibre filters which have lower water absorption properties and are better suited for the purpose. Figure 2-10 shows typical equipment used during the sampling process.

The sampling train was connected to ensure that air enters only at the cyclone inlet. Sampling and analysis was carried out in accordance with the NIOSH 7602 method.

Sample collection and data accumulation was carried out in accordance the Guideline for the Compilation of a Mandatory Code of Practice for an Occupational Health Program on Personal Exposures to Airborne Pollutants (20). The actual number of samples collected for personal sampling was selected on a random basis over all working shifts in accordance with the South African Mines Occupational Hygiene Programme (SAMOHP) Guidelines issued by the DME (21).

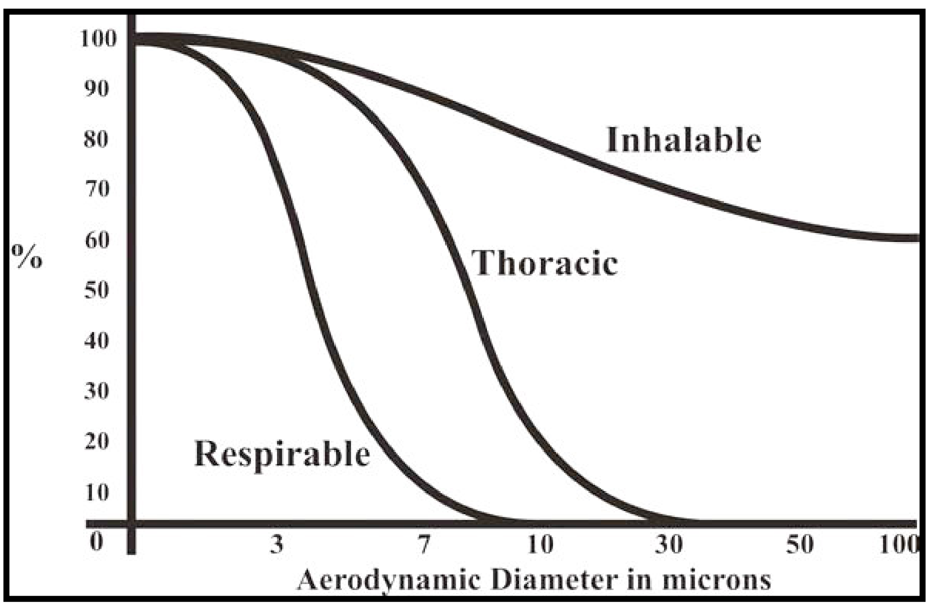

Figure 2-9 ISO/CEN/ACGIH respirable dust curve (18).

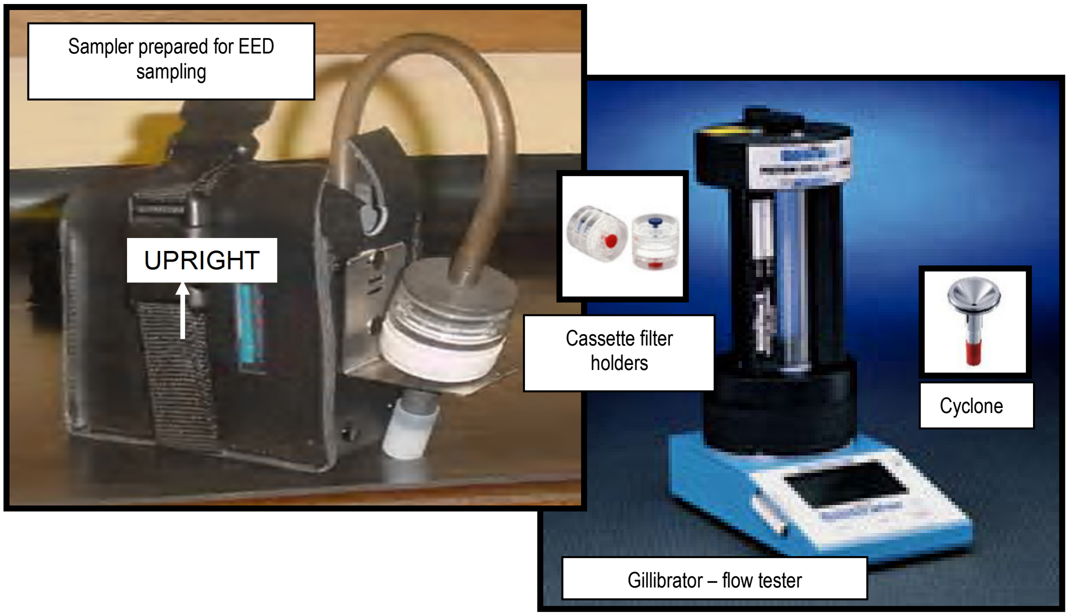

Figure 2-10 Typical equipment used during the dust sampling process.

2.5 Sampling strategies used to collect data for the study

Sampling was carried out by means of two strategies and each approach used is discussed in turn.

2.5.1 Personal sampling strategy

Samples were collected from occupations within the CM sampling HEG's. The generic approach used to establish these HEG's and sampling frequencies is prescribed by the SAMOHP guidelines issued by the DME (21).

This guideline describes a sequential method for determining HEG classification bands, this process is described briefly as follows:

Step 1 - Sub-divide the mine into sampling areas,

Step 2 - Sub-divide the sampling areas into activity areas,

Step 3 - Ensure that an adequate number of personal exposure measurements are available to identify significant airborne pollutants for each activity area. If professional judgement concluded that insufficient historical personal exposure data is available regarding the extent of the risk, a personal monitoring survey must be undertaken for each significant airborne pollutant,

Step 4 - Compare the results of the significant pollutants present, either from historical data or from measured data during the personal monitoring survey, in that particular activity area to their respective OEL values, and

Step 5 - Once the personal exposures within each activity area have been compared to their respective OEL values, each activity area can now be categorised into classification bands to determine the various HEG's within that activity area. The classification bands for airborne pollutants are depicted in Table 2-1 below.

Table 2-1 Classification bands based on OEL categories

	Classification Bands
Category	**Personal exposure level**
A	Exposures ≥ the OEL or mixtures of exposures ≥1
B	Exposures ≥ 50% of the OEL and < OEL or mixtures of exposures ≥ 0,5 and <1
C	Exposures ≥ 10% of the OEL and < 50% of the OEL or mixtures of exposures ≥ 0,1 and < 0,5

For each of the classification bands derived from the Table 2-1 above there is a mandatory sampling frequency prescribed.

Table 2-2 depicts the relevant sampling frequencies for classification band categories.

Table 2-2 Sampling frequency for classification band categories

Category	Minimum Frequency
A	Sample 5% of employees within a HEG on a 3 monthly basis with a minimum of 5 samples per HEG, whichever is the greater.
B	Sample 5 % of employees within a HEG on a 6 monthly basis with a minimum of 5 samples per HEG, whichever is the greater
C	Sample 5 % of employees within a HEG on an annual basis with a minimum of 5 samples per HEG, whichever is the greater

From the tables above it can be expected that most CM HEG's would fall into the A or B category. HEG's are re-classified based on the evaluation of historical sampling data, professional judgement and/or an annual analysis based on the 90th percentile of the sampling results within each HEG. Sampling from these HEG's is carried out as per a pre-determined strategy for occupations within each HEG on a random basis covering all production shifts. Sampling was carried out in accordance with the DME Guideline for Airborne Pollutants and was calculated back to an equivalent 8 hour shift. This is known as a TWA which refers to a concentration of airborne particulates which have been weighted for time duration, usually eight hours.

Occupations selected for sampling collected sampling instruments from the lamproom at the start of their shift and return them to the lamproom at the end of the shift.

2.5.1.1 Selection of participants for the study

Participants selected for the study were based on occupations within the CM HEG's that are required to perform work in the near vicinity of the CM during coal-winning operations and who were exposed to contaminated air from the coal-winning face. The occupations selected for the study were CM operators, RB operators, SC operators, section miners and GL's.

Respirable coal dust sampling and respirable EED coal dust sampling has been well entrenched in the coal mining industry for many years and a well established database is available through CECS who has been providing a respirable coal dust sampling service to the Mpumalanga coal fields.

Retrospective data from 2005 was used in the study due to some of the mines not having adapted their sampling methodologies to suit the ISO/CEN/ACGIH respirable dust curve prior to 2005. The number of samples from the occupations that were included in the study is detailed in Table 2-3.

2.5.2 EED sampling strategy

EED sampling was required in terms of Directive B7 which stipulated a maximum of 5mg/m^3 for EED sampling (8). This sampling was done by sampling each CM on a daily basis on the main production shift. The sampling pump was positioned on the CM at the CM operator's position. CM operators collected sampling instruments from the lamproom at the start of their shift and returned them to the lamproom at the end of the shift. Sampling was carried out in accordance with NIOSH 7602 method and sampling results were calculated for the full shift (shift TWA).

2.5.2.1 Selection of CM used in the study

CM samples included in the study were taken from coal-winning operations during the main shift (Day shift).

Table 2-3 Sample numbers per mine, per occupation, total sample numbers included in the study and average shift durations per mine

Mine	Continuous Miners	Shuttle Cars	Roof Bolters	Miners	General Labourers	Number of Personal Samples (initial)	Number of Personal Samples (filtered)	Number of EED Samples (initial)	Number of EED Samples (filtered)	Average shift length (minutes)
1	0	27	19	10	5	66	61	1539	61	585
2	32	51	59	18	46	270	206	4000	206	600
3	0	8	12	6	9	47	35	1011	35	600
4	17	32	26	12	0	100	87	1407	87	540
5	14	32	6	8	1	70	61	1888	61	600
Total	63	150	122	54	61	553	450	9845	450	

2.6 Data analysis

Data presented was analysed with the statistical package MINITAB 13.3 (Eberly Statistical Canter, PA, USA, 1997). The data used in the study was filtered to ensure that the results obtained from personal and EED sampling were on corresponding dates in order to ensure that the actual environmental conditions and the status of dust control measures applied on the sampling days were comparable. The actual results compared can be seen in Appendix A for each mine.

Data analysed for each objective is described below:

2.6.1 Personal sampling data

An analysis was carried out to determine whether the data distribution is normal or lognormal. The Anderson Darling Normality Test was used to compare the cumulative data distribution to an expected distribution, expected if the data were normal. When the p-value for the Anderson-Darling test is lower than the chosen significance level (usually 0.05 or 0.10), it can be concluded that the data does not follow a normal distribution.

Data was evaluated considering the mean, median, standard deviation, variance, skewness and 95% confidence intervals (CI) around the mean and median.

Occupations within the data set were considered separately and were compared to establish if data is truly homogenous for the occupations in the HEG.

Box and whisker plots were used to depict data distributions. These plots indicate outliers which are results that are unusually large or small, whiskers that extend outwards having plus 1.5 from the third quartile and minus 1.5 from the first quartile, the top of the box is the third quartile being 75%, the bottom of the box is the first quartile being 25% and the middle of the box is the median.

A probability plot was used to determine whether data distribution fell within the 95% CI. Data integrity was assessed by utilising the Geometric Standard Deviation (GSD) of the sample distribution. The GSD of a distribution is a measure of the variability of the individual measurements in that distribution. The smaller the variability between each measurement in the distribution, the more likely it is that potential exposures are controlled and that everyone in the group is encountering the same level of atmospheric contaminants in their work environment. If this is the case, the group of individuals is considered to be a HEG for the purposes of statistically analysing exposure profiles.

While there is no fixed value of GSD which describes a similar exposure group, a GSD of around 3.0 can be used as the criterion for determining a similar exposure group. If the GSD is greater than 3.0, then there is a need to investigate the reasons for the variability in the exposures within the group (22).

2.6.2 EED sampling

Results in this data set were corrected from a full shift time weighted average to an eight hour time weighted average to allow for comparison with personal sampling results. The actual results compared can be seen in Appendix A.

An analysis was carried out to determine whether the data distribution is normal or lognormal. The Anderson Darling Normality Test was used to compare the cumulative data distribution to an expected distribution, expected if the data were normal.

Data was evaluated considering the mean, median, standard deviation, variance, skewness and 95% CI's around the mean and median.

2.6.3 Comparison of personal to EED sampling results

Box and whisker plots were used to depict data distributions, the properties for these plots were the same as previously mentioned.

An analysis was carried out to determine whether the data distribution is normal or lognormal. The Anderson Darling Normality Test was used to compare the cumulative data distribution to an expected distribution, expected if the data were normal.

Data was evaluated considering the mean, median, standard deviation, variance, skewness and 95% CI's around the mean and median.

Polynomial regression with a single predictor and a regression through the data were used. Personal sampling results were set as the response variable while the CM was selected as the predictor variable because the CM is the main dust generation source in the coal cutting process. The R^2 was used to indicate how much the CM results account for the variation of the personal sampling results.

The Pearson Test was also applied to quantify correlation with a single number which describes both the strength and direction of the relationship. The correlation coefficient ranges from -1 to 1 where**:**

-1: Describes a relationship where an increase in one variable is accompanied by a predictable and consistent decrease in the other,

0: Describes a random or non-existent relationship,

1: Describes a relationship where an increase in one variable is accompanied by a predictable and consistent increase in the other.

2.7 Quality control

Quality control was carried out in the following manner:

- The samplers were calibrated as detailed in the guidelines for the gravimetric sampling of airborne particulates for risk assessment in terms of the Occupational Diseases in Mines and Works Act No. 78 of 1973, that is with regard to the calibration of the sampling pumps and balance (23).
- Sampling results were analysed by CECS who are South African National Accreditation System (SANAS) in terms of SANS 17025 accredited.
- NIOSH 7602 analytical method was followed.
- CM samplers were placed in the CM operators' positions as detailed in Directive B7 (8).
- Sampling requirements were included in induction training and awareness programmes.
- Calibration checks were done on the pumps at the beginning and end of each shift.

- Sample train integrity throughout the day was ensured through the appointment of a partial supervisor who checked the instrument during the shift and documented deviations, abnormal conditions, sampler run status etc.
- Random audits of the sampling data, data management systems and instrument calibration by Inspectors from the local Inspector of Mines' office.
- Random inspections were carried out in-field to verify sampling position and status.
- Air sampling pumps were equipped with lock plates covering the on/off switch to avoid tampering.
- Sampling pumps were started and stopped by lamproom personnel who recorded the instrument run times.

2.8 Ethics

Ethics clearance was obtained from the Human Research Ethics Committee (Medical) at Witwatersrand University, Reference Number R 16/49 Ferreira.

The following applied:

- Written consent was obtained prior to use of data,
- No colliery names were mentioned as they were not provided by CECS,
- Personal information was not made available as it was not provided by CECS,
- Reference to unique information that could lead to the identification of any mine or manufacturing company was not utilised,
- A copy of the final report is to be made available to CECS who provided the data for the study.

CHAPTER 3 - RESULTS

In this chapter respirable dust sampling results from both personal and CM sampling were analysed, evaluated and compared to provide a clear interpretation and understanding of these results. This chapter follows the study objectives starting with the analysis of personal dust exposure concentrations for the occupations within the CM HEG, followed by the analysis of EED concentrations at the CM operator position. The aforementioned analyses are then compared to each other to show the correlation between the two sampling methodologies. Each section starts with a brief description of the applicable objective mentioned in this studies objectives followed by the results pertaining to the objective.

Data from five underground coal mines was used. This data was accumulated from actual sampling results over a two year period in Mpumalanga from January 2005 to December 2006.

3.1 Objective addressed in this section

In this section the first objective of the study is addressed by describing personal respirable coal dust concentrations of the occupations within the CM HEG.

Data is presented as follows:

- A graphical summary per mine,
- Box and whisker plot per mine showing occupations included in the study,
- Probability plot including all mines data,
- Box and whisker plot for all mines showing all occupations included in the study, and
- Box and whisker plot comparing personal samples from CM operators to environmental engineering samples, grouping mines who sampled CM operators separately.

3.1.1 Personal respirable coal dust distribution patterns per mine

Personal dust sampling results are represented by means of graphical summaries. These graphical summaries include four graphs: histogram of data with an overlaid normal curve, box plot, 95% CI's for the mean and 95% CI's for the median. Also included in the Figures is the Anderson Darling Normality Test which was used to compare the cumulative data distribution to an expected distribution, expected if the data were normal. If the p-value for the Anderson-Darling test was lower than the chosen significance level (usually 0.05 or 0.10), it was concluded that the data does not follow a normal distribution.

As can be observed from the Figures that follow, the P-Values are lower than the significance level of 0.05 selected, therefore, the data does not follow a normal distribution curve.

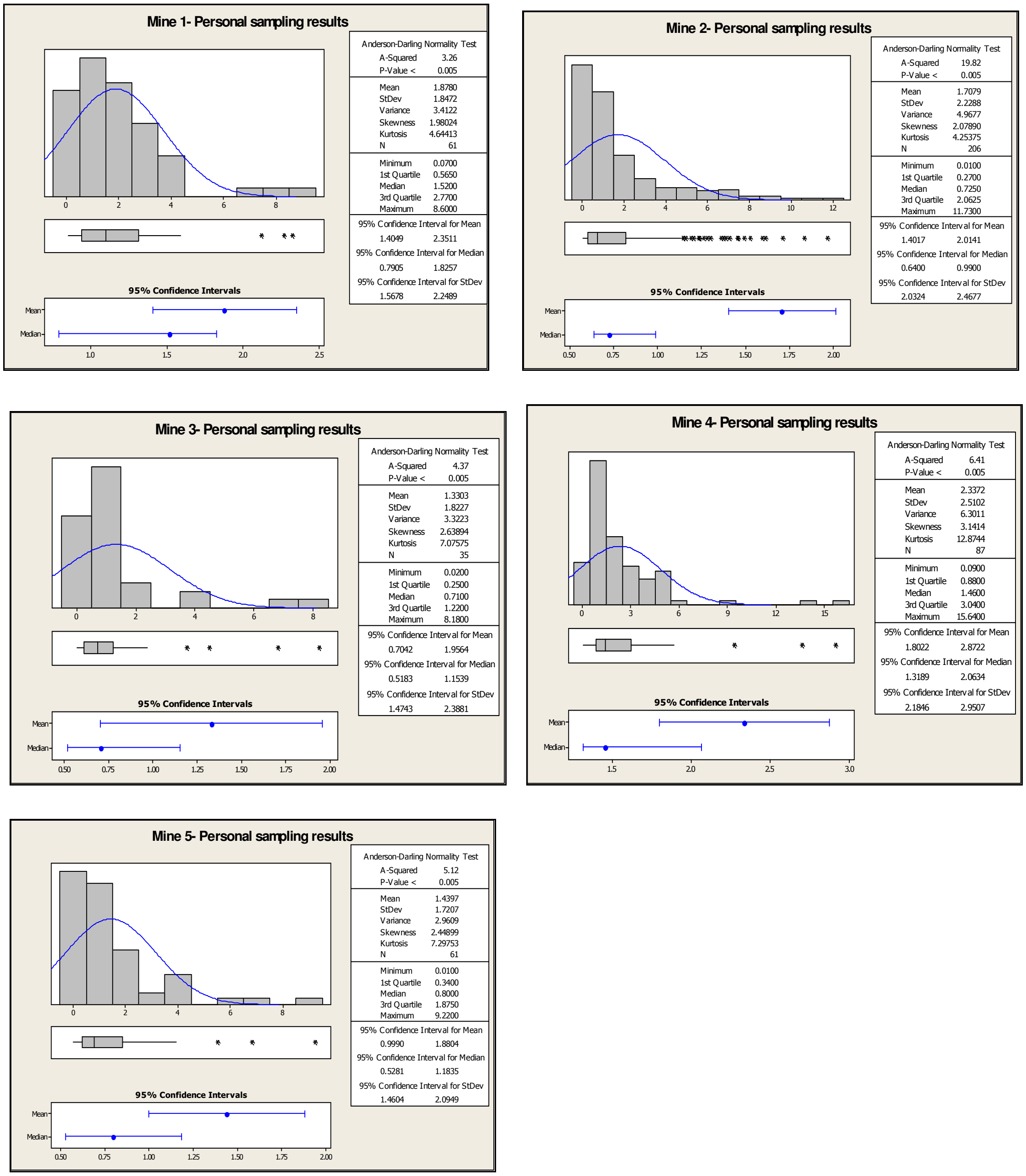

Figure 3-1 Graphical summary for Mines 1, 2, 3, 4 and 5 representing all personal coal dust sampling results in mg/m^3 from the CM HEG.

3.1.2 Personal respirable coal dust result comparison per mine

Personal dust sampling results are represented for each occupation by means of box and whisker plots. Box and whisker plots were used to compare sample distributions and also to indicate the distribution for the various occupations sampled for each mine.

From the Figures that follow it can be observed that there were variations in some mines, these are discussed in turn.

It should be noted that there were no CM operator results for Mines 1 and 3. This was due to the mines sampling strategy which accepts the current EED sampling result as being representative of a personal sample for the HEG. In Mine 1 the SC operator results had a higher median value than the other occupations in the absence of CM operators.

Mine 2, results indicated a large number of outlying results when compared to other mines. This was mainly due to the larger number of sampling results available. Mine 4, indicated no results for GL's, there were no sampling results for this occupation within the data set. The median for Mine 4 CM operators was above the OEL for respirable coal dust and this was the only mine which exhibited a personal exposure profile above the 2mg/m^3 limit.

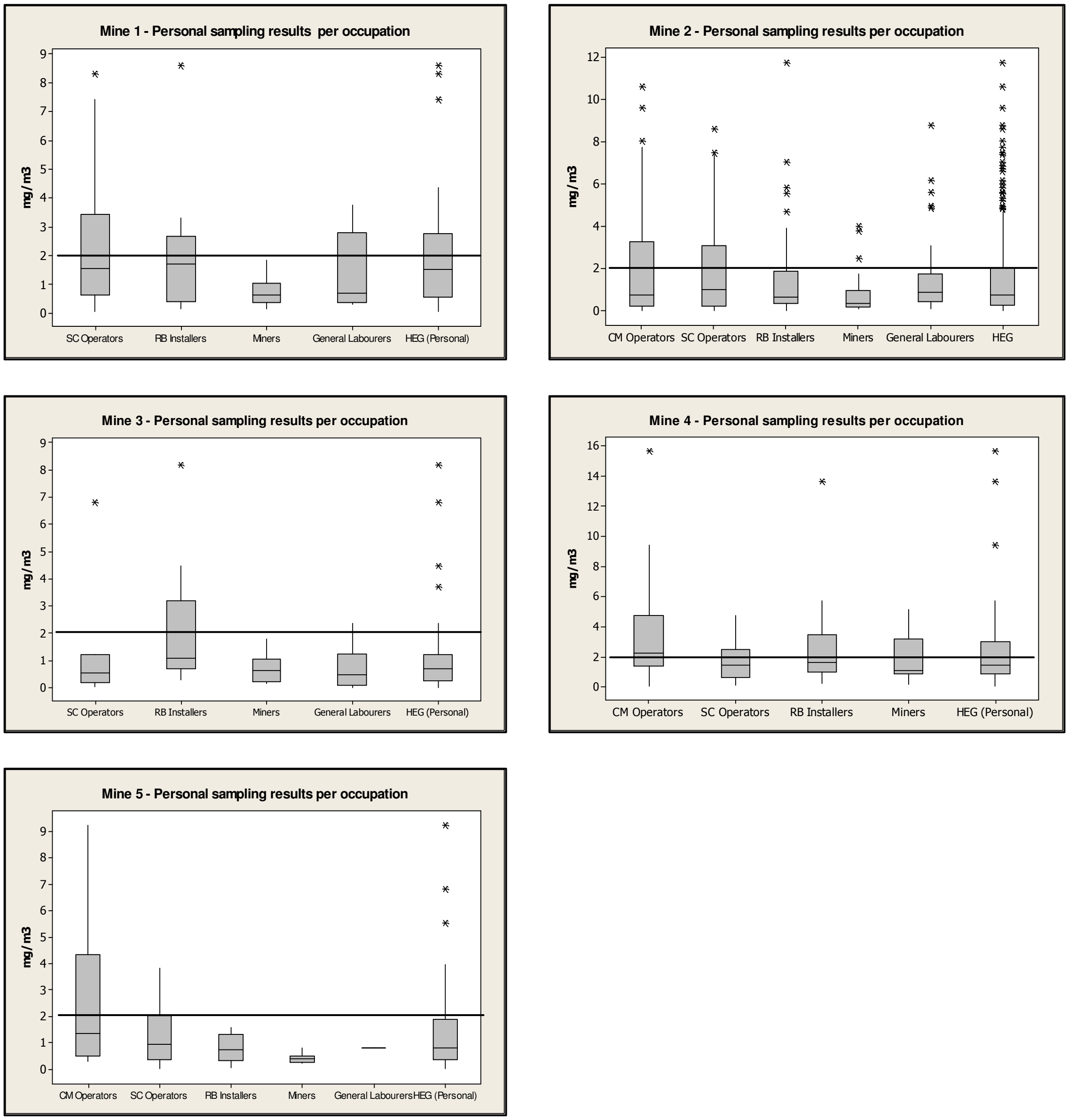

Figure 3-2 Box and whisker plots for Mines 1, 2, 3, 4 representing personal coal dust sampling results per occupation in mg/m³ from the CM HEG.

3.1.3 Personal respirable coal dust results combined for all mines in study

Figure 3-3 shows a probability plot which was used to determine whether the data distribution fell within the 95% CI. From the results it was observed that the data does not fit within the CI on both the upper and lower ranges (indicated on graph).

When assessing the integrity of the data a review of the GSD of the sample distribution was carried out. A GSD of around 3.0 was used as the criterion for determining a similar exposure group. If the GSD was greater than 3.0 then this would indicate a need to investigate the reasons for the variability in the exposures within the group (22).

The GSD for the personal exposure group was calculated as 3.69 mg/m^3 based on an OEL of 2mg/m^3 and a CI of 95%. Therefore, one can assume that the exposure group is not homogenous based on the aforementioned classification.

Figure 3-2 shows a box and whisker plot comparing all the occupations in the study within the CM HEG.

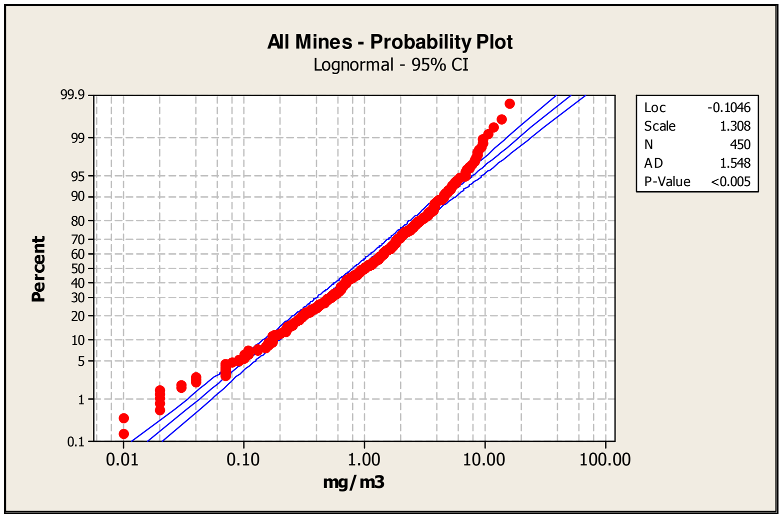

Figure 3-3 Probability plot for all mines representing personal coal dust sampling results in mg/m³ from the CM HEG.

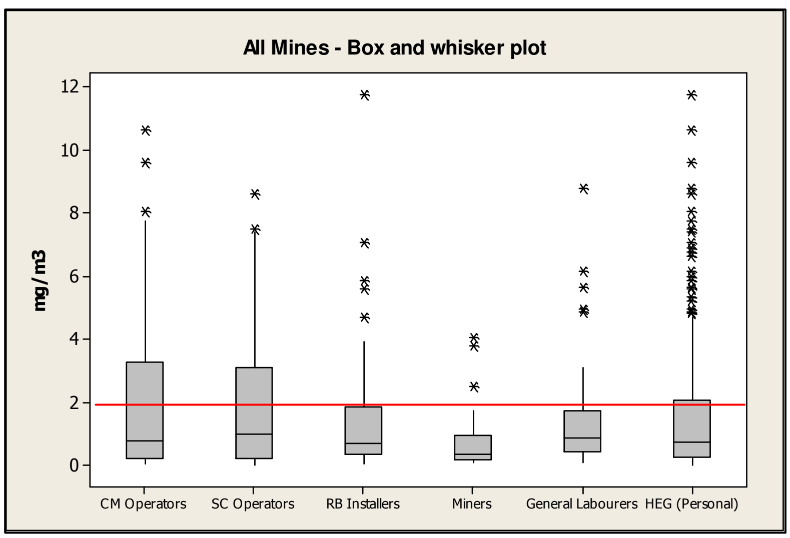

Figure 3-4 Box and whisker plot for all mines representing personal coal dust sampling results per occupation in mg/m³ from the CM HEG.

3.1.4 Exclusion of occupations from study

It should be noted at this point that information pertaining to the actual CM results was considered for exclusion due to some mines that were including EED results from CM’s in their personal sampling programmes. In addition, the data made available for the study did not distinguish between CM operators who operate the CM from a position in the last through road via a remote control and those who physically operate the CM from an on-board position. EED sampling result and the personal CM operator results were compared. These results indicated that there was a relatively large variation in the results which would indicate that the results are dissimilar and for this reason it was decided not to exclude the CM operator results from the study.

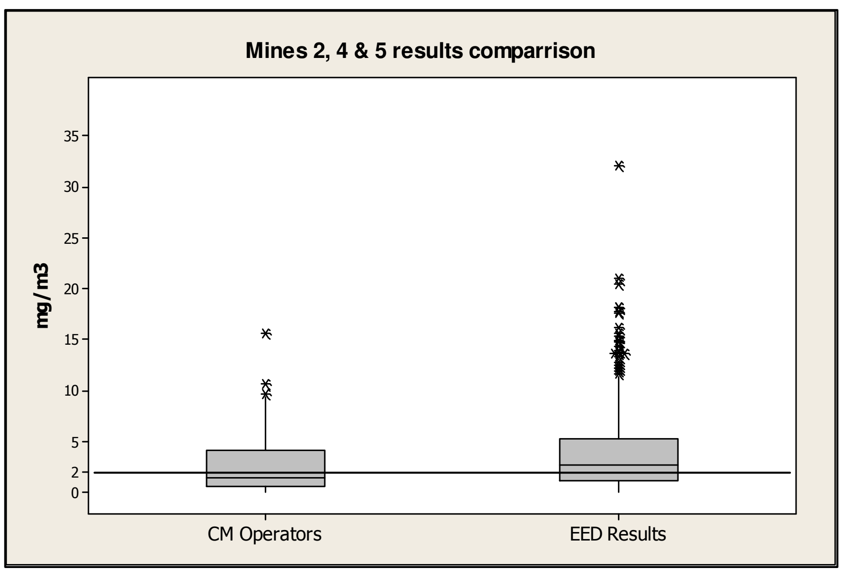

Figure 3-5 Box and whisker plot for Mines 2, 4 & 5 comparing CM operator results to EED results.

3.2 Objective addressed in this section

In this section the second objective of the study is addressed by describing EED respirable coal dust concentrations from the CM operator position.

Data is represented by means of a graphical summary per mine.

3.2.1 Correcting results from full shift sampling to an eight hour TWA

EDD results were back calculated from a full shift to an eight hour TWA to allow for comparison with occupational exposure results.

Table 2-3 includes shift lengths per mine while actual results are available in Appendix A.

3.2.2 Alignment of sampling results

EED and personal sampling results were aligned to ensure that sampling results compared were taken on corresponding dates. This approach was used to ensure that the actual environmental conditions and the status of dust controls applied on the sampling days were comparable. The actual results compared for each mine can be seen in Appendix B.

3.2.3 Environmental engineering respirable coal dust result distribution patterns per mine

EED sampling results are also represented by means of graphical summaries. These graphical summaries include four graphs: histogram of data with an overlaid normal curve, box plot, 95% CI for the mean, and 95% CI for the median. Also included in the graphical summaries is the Anderson Darling Normality Test which was used to compare the cumulative data distribution to an expected distribution, expected if the data were normal. As can be observed from the Figures the P-Values were lower then the significance level of 0.05 selected, therefore, the data did not follow a normal distribution curve.

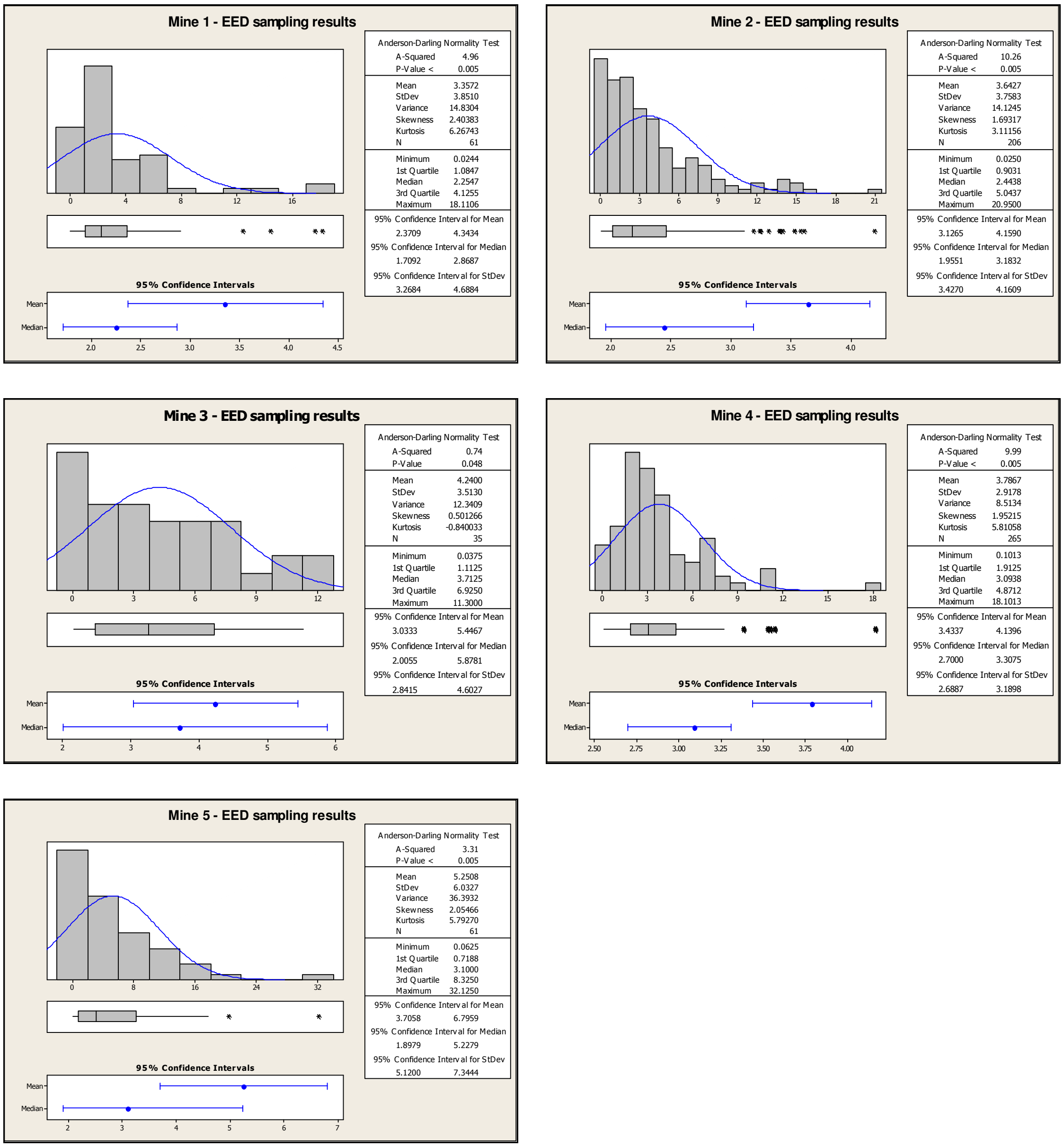

Figure 3-6 Graphical summaries for Mines 1, 2, 3, 4 and 5 representing EED coal dust sampling results in mg/m^3.

3.3 Objective addressed in this section

In this section the third and final objective of the study is addressed by comparing personal respirable and EED results from the first and second objectives.

Personal and EED sampling results were compared to establish if there is a consistent trend between the two data sets, compare variations within the various mines with regard to both personal and environmental engineering sampling results, provide a graphical summary for personal and environmental engineering sampling results for the study, and to group together and compare all the mines results in terms of personal and environmental engineering results.

Data is presented as follows:

- Box and whisker plots per mine showing personal results for the homogenous study group compared to EED results per mine,
- Box and whisker plot comparing personal sampling results among individual mines,
- Box and whisker plot comparing EED results among individual mines,
- Graphical summary including all personal sampling results for all mines included in the study,
- Graphical summary including all EED sampling results for all mines included in the study,
- A box and whisker plot for all mines comparing the personal sampling results of the homogenous study group to EED results.
- A tabulation of analysis results comparing the personal sampling results of the homogenous study group to EED results per mine and as a whole (See Appendix B),
- Marginal plot comparing personal sampling results of the homogenous study group to EED results,
- Matrix plot comparing personal sampling results of the homogenous study group to EED results,
- Fitted line plot establishing correlation between personal sampling results and EED results.

3.3.1 Comparison between personal and EED sampling results.

Box and whisker plots are presented per mine showing personal sampling results for the homogenous study group compared to EED results per mine.

From the results it is evident that a definite trend was established which indicated that EED results tend to be higher than personal results for each mine individually.

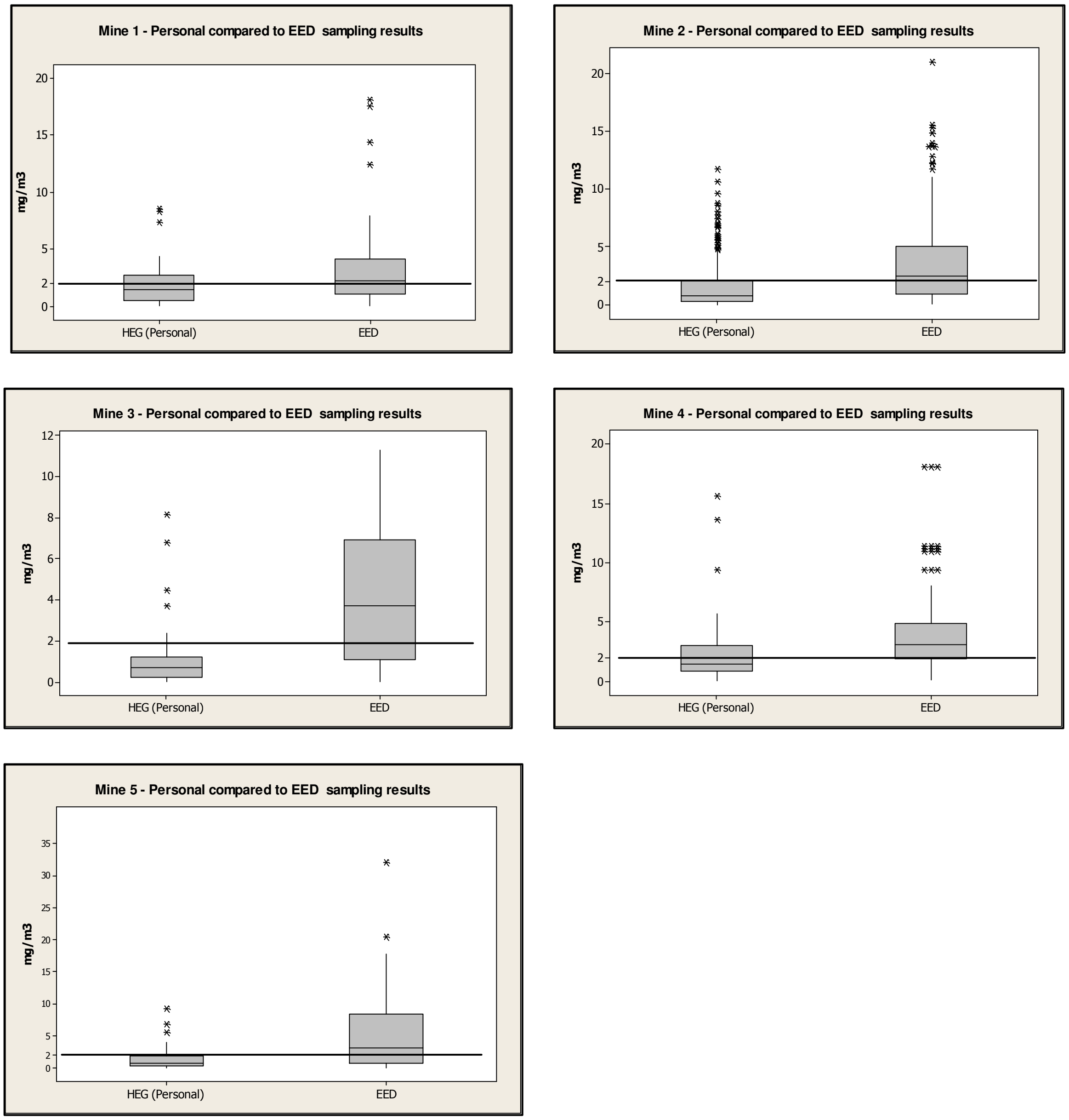

Figure 3-7 Box and whisker plots for Mine 1, 2, 3, 4 and 5 comparing personal and EED coal dust sampling results in mg/m^3.

3.3.2 Comparison between mines for personal and EED sampling results.

The following Figures indicate box and whisker plots comparing first personal then EED coal dust sampling results within mines. As can be seen the personal exposure results for all the mines had medians below the respirable coal dust OEL of 2 mg/m^3, while all the medians for EED sampling were above the OEL.

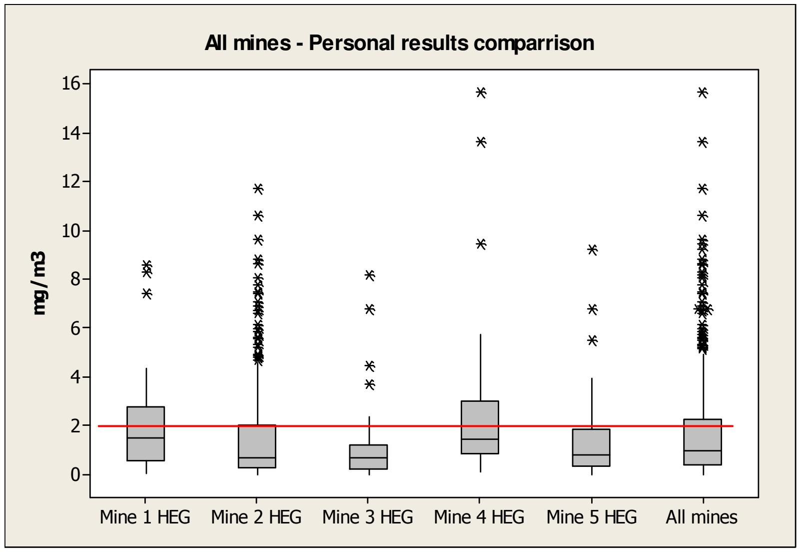

Figure 3-8 Box and whisker plot for All mines comparing personal coal dust sampling results per mine in mg/m^3.

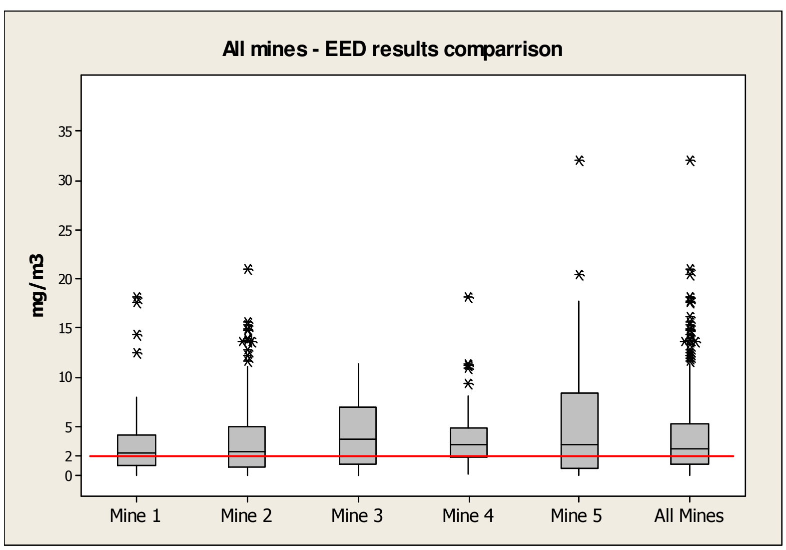

Figure 3-9 Box and whisker plot for All mines comparing EED coal dust sampling results per mine in mg/m^3.

The following Figures indicate graphical summaries of first personal then EED coal dust sampling results including all mines.

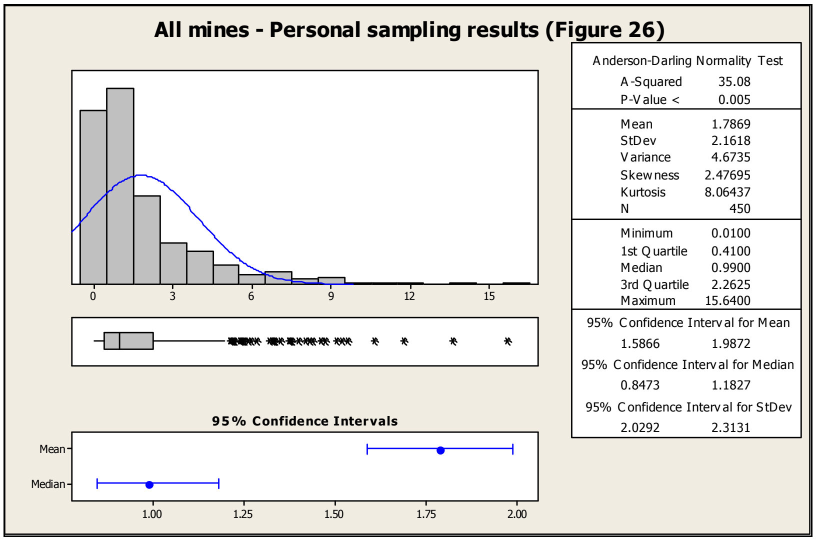

Figure 3-10 Graphical summary for All mines representing personal coal dust sampling results in mg/m3.

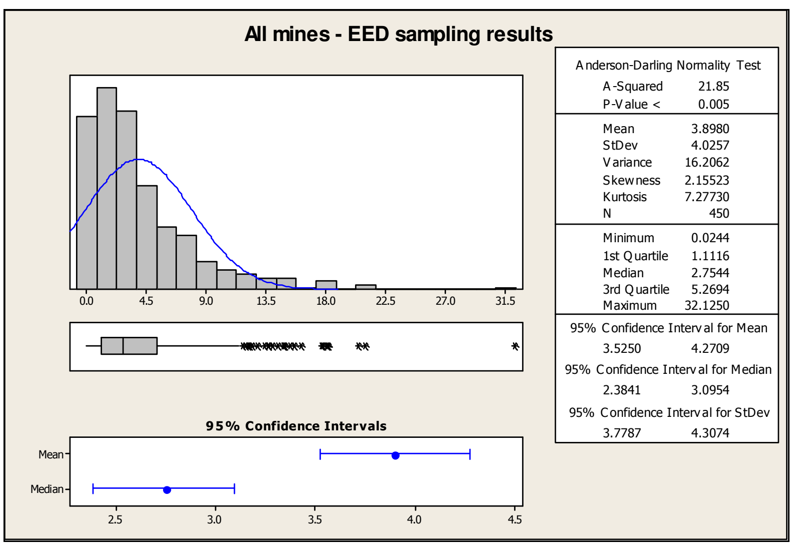

Figure 3-11 Graphical summary for All mines representing EED coal dust sampling results in mg/m3.

The following Figure indicates a comparison of all the mines personal sampling and EED sampling results and again it was evident that EED results were higher than personal results.

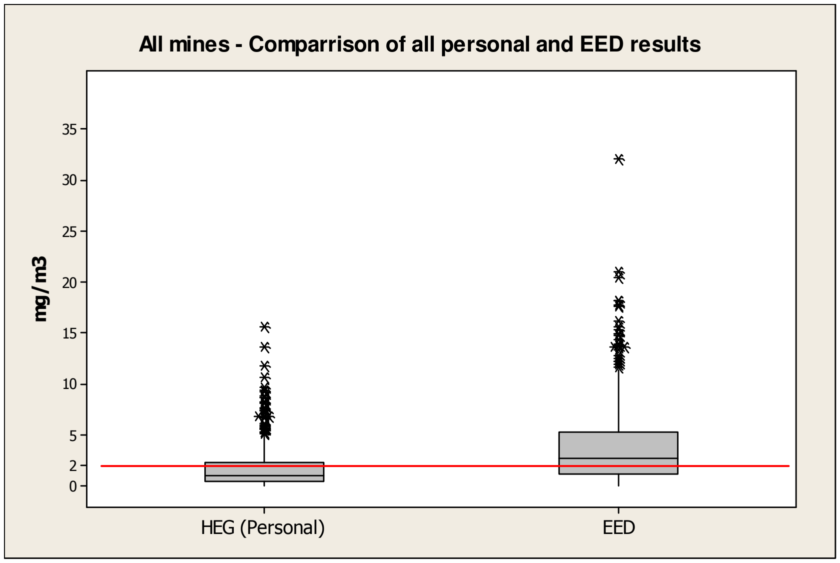

Figure 3-12 Box and whisker plot for coal dust results grouped together for All mines comparing personal and EED sampling results in mg/m^3.

3.3.3 Comparison by means of scatter plots

The following Figures indicate scatter plots showing the data distribution for personal and EED coal dust sampling results.

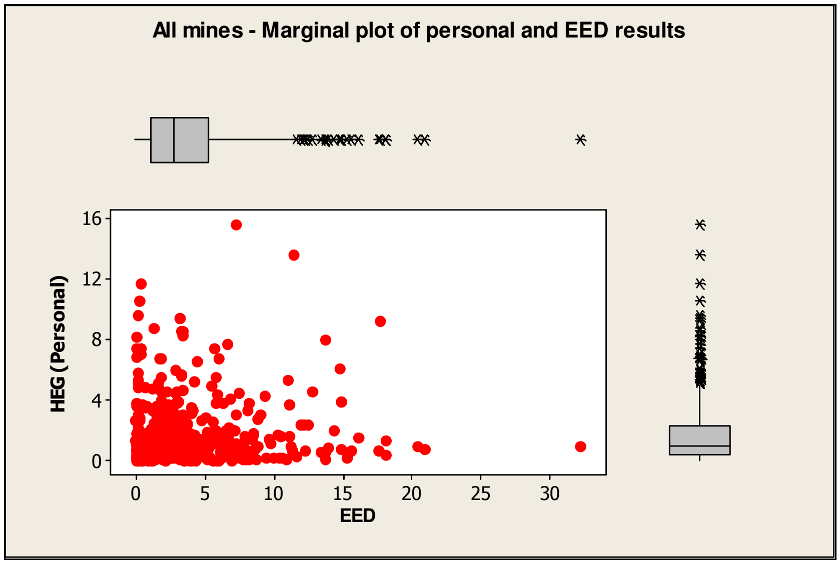

Figure 3-13 Marginal plot for All mines indicating personal and EED coal dust sampling results in mg/m³.

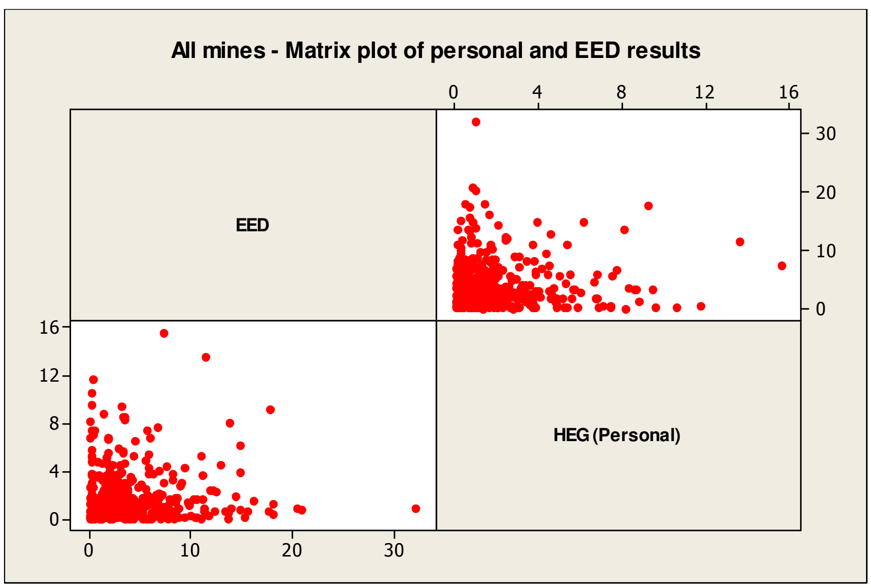

Figure 3-14 Matrix plot for All mines indicating personal and EED coal dust sampling results in mg/m³.

3.3.4 Correlation of results

The following Figure indicates a fitted line plot showing polynomial regression with a single predictor plotting a regression line through the data. In this case the personal sampling results were set as the response variable while the EED results were selected as the predictor variable because the CM was the main dust generation source in the coal cutting process. The results indicated that the quadratic model (p-value = 0.924 or actually p-value > 0.0005) provided a poor fit to the data. The R^2 value indicated that EED sampling results accounted for 0.1% of the variation of the personal sampling results.

In addition the Pearson Test was also applied to quantify correlation with a single number which describes both the strength and direction of the relationship.

When analysing the linear association between the two variables, the coefficient result obtained was equal to 0.029 with a P-Value equal to 0.537, therefore, the relationship could best be described as almost non-existent.

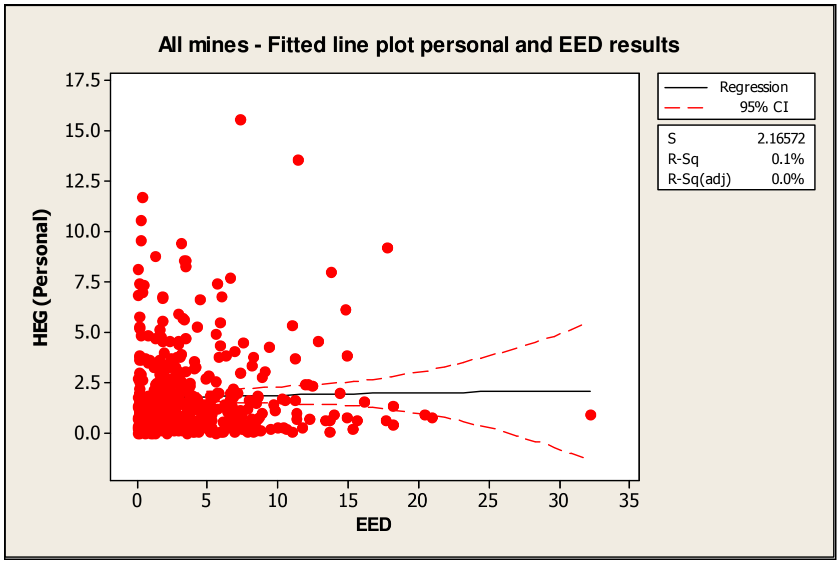

Figure 3-15 Fitted line plot showing data distribution around the regression line with 95 % confidence intervals.

CHAPTER 4 - DISCUSSION

4.1 General

The DME, through the introduction of Directive B7 (8), initiated a programme to evaluate the efficiency of the dust suppression systems at CM's. The specified position for the respirable dust sampler has since been a cause for debate among mine occupational hygienists and is seen by many to be a crude method of measuring dust exposure.

This study examined respirable coal dust monitoring results taken at the coal face from five underground coal mines in Mpumalanga from January 2005 to December 2006. Consideration was given to personal results collected from workers and machine operators BZ and results obtained from the CM at the operator's cab position. The appropriateness of the approach used at CM's for dust management, and the applicability of the assigned $5mg/m^3$ as an indication of exposure when compared to the personal occupational exposure limit of $2mg/m^3$, was evaluated. Findings from this study indicate that the exposure from respirable coal dust for occupations in the CM HEG is significantly lower than the results obtained from EED sampling and, findings also indicate that there is almost no correlation between personal and EED sampling results.

4.2 Study limitations

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

- EED sampling is carried out on the main production shift while personal sampling is carried out over all working shifts. Management and services department personnel worked primarily during day shifts, therefore, the visibility of management is increased over these periods and dust control methods may be applied more stringently by employees and line supervisors. On the other hand there is less visibility of management and service department personnel on the remaining shifts, and this could lead to less stringent application of dust control methods. Variation in control application over the different shifts could lead to variation in results.

- Mining parameters may vary between coal mines, for example, deeper coal seams generally have to apply more stringent pillar stability safety factors to ensure that there is sufficient support for the overlying strata to prevent roof collapse. When safety factors increase in bord-and-pillar mining the pillar centres also increase thereby increasing the length of the heading being cut during the cutting cycle. Deeper headings are generally more difficult to ventilate than shorter ones.
- Coal-winning heading ventilation methods may vary from mine to mine in terms of placement of auxiliary fans, volumes supplied by fans and the auxiliary ventilation method applied. The positioning of these fans contributes to the amount laminar or turbulent flow patterns inside the heading which in turn has an effect on the dust suppression system.
- Cutting sequences applied at the mines are not all the same, some may compliment the section ventilation system more than others. The cutting sequence applied in bord-and-pillar operations plays a vital role as this has a direct influence on the amount of dust that personnel are exposed to.
- Although most on-board dust suppression systems follow the COL 518 Research Report recommendations they may not all be similar in terms of the number of sprays, water pressures, water filter placement and availability, scrubber fan type and volume etc. System maintenance is also an area to consider as the various mines may not apply the same maintenance regime and this will lead to a variation in exposure results.
- This study focused on the dust readings obtained from sampling in the underground coal mining sections only and did not account for the variables outside of the section such as dust generated

in the intake air to the section on the sampling days, for example, high air velocities and dry travelling ways.

4.3 Study findings

4.3.1 Personal sampling

Personal sampling results were considered in turn per mine and then as a whole. All the mines' data upon analysis reflected that the data followed a lognormal distribution pattern when applying the Anderson-Darling normality test. For this reason the median was considered as it is a more informative measure of the centre of skewed data. The median for all the mines together was 0.99 mg/m^3, this indicates that the OEL of 2mg/m^3 was most likely achieved for the data set as a whole. The mines ranged from 0.72 to 1.71 mg/m^3 which also indicated that no mines were above the OEL on an individual basis establishing a definite pattern. The 95% CI for the median was 0.14 to 1.18. It is worth noting that the inter quartile range of three of the five mines exhibited third quartile results above 2 mg/m^3 indicating that 25 % of the results were above the OEL.

Upon analysis of the occupations within the HEG results reflected a wide variation results both in-between occupations per mine and between the various mines. Mine 1 and 3 did not include CM operators in their personal sampling strategy while Mine 4 did not include GL's. These variations could be as a result of variations in dust control practices such as heading ventilation, cutting sequence etc.

In order to determine if the HEG is truly homogeneous it was decided to use the GSD as a measure of variability for the individual readings in the distribution. A GSD of 3.0 was used as a criterion to determine a similar exposure group (this is discussed in detail in Chapter 2 - Methods). The GSD for the data set is 3.69 based on an OEL of 2mg/m^3 and a CI of 95%, indicating that the results obtained most likely do not support a homogenous profile. Upon combining all the mines per occupation results indicate that the highest exposed occupation were in the following sequence: CM operators, SC operators, RB operators, GL's and lastly miners. Of note is that the medians per occupation do not vary largely with the first quartile values showing small variation, however, the range between the first and third quartile of the box and whisker plots for the CM and SC operators are substantially broader than the other occupations, this would, therefore, indicate that these occupations are exposed to more coal dust concentrations on the higher end of the scale.

Consideration was given to exclude CM results from the study due to some of the mines utilising the EED result as a personal exposure for the CM operator by including these results in their sampling programme. To clarify this situation a comparison was done between CM operator results and EED results used in the study, these results were largely dissimilar, therefore, it was decided to keep the CM operator results in the study. The reason for the variation could be as a result of some of the CM operators not being on-board the CM, operating the CM by means of remote control devices. In addition, the sampling pump used for EED sampling is positioned on the CM for the entire shift while CM operators who operate CM's on-board could take rest breaks and are relieved of their duties for that period and are thus not exposed for the full shift. Due to the large variation in sampling results in the study no other occupations were considered for exclusion.

4.3.2 EED sampling

Corrected EED sampling results were aligned with personal sampling results to ensure that sampling was done on corresponding dates. This was done to ensure that the actual environmental conditions and status of controls inside the section were similar in order to allow for a more accurate analysis between the two data sets. The full shift TWA was corrected to an 8 hour TWA to allow for comparison of results. This also allows the results to be compared to the personal exposure OEL of 2 mg/m^3.

All the mines data upon analysis reflected that the data followed a lognormal distribution pattern when applying the Anderson-Darling normality test as is the case for personal sampling results. The median for all the mines data together was 2.75 mg/m^3. This indicates that the personal exposure OEL of 2mg/m^3 was most likely not achieved for the data set as a whole, the mines ranged from 2.25 to 3.71 mg/m^3 which also indicated that all the mines were above the OEL on an individual basis establishing a definite pattern. The 95% CI for the median was 2.38 to 3.09. Worth noting is that the inter quartile range of all five mines exhibited third quartile results more than twice the respirable coal dust OEL, this indicates that 25% of the results were more than twice the OEL.

4.3.3 Comparison of personal and EED sampling

When comparing personal sampling results to EED sampling results it is evident that all the mines had lower personal sampling results than EED results, thus establishing a definite trend. Mines 1, 2 & 4 indicated similar variations between the two data sets. Mine 3 while having similar personal results to Mine 1, 2 & 4 indicated significantly higher EED results, this could be as a result of different control methodologies applied at coal-winning operations. Mine 5 indicated lower results for personal exposures than Mines 1, 2, 3 & 4. The reason for variations in these results is unclear as it is not included in the scope of this study.

When combining all the mines in the two data sets it is also evident that EED sampling results are significantly higher than personal sampling results confirming the trend observed on individual mines.

Correlation tests carried out between the two data sets indicated that there is no correlation between the results. Correlation was tested utilising two different methods, the first was by utilising a quadratic model having the personal sampling data as the response variable and the EED results as the predictor variable because the CM is the main dust generation source in the coal cutting process. The results indicate that the quadratic model provides a poor fit to the data. This test showed that EED sampling results account for 0.1% of the variation of the personal sampling results. The second test for correlation was the Pearson Test which also indicated that the relation is most likely non-existent.

Due to the CM being the main coal dust generation source in the section it would be expected that a strong correlation between the two data sets exists that is an increase in EED results should be accompanied by an increase in personal sampling results. The fact that the correlation between the two data sets is poor could indicate that the EED sampling position is not ideal and is not taking account of the actual contaminant levels leaving the coal-winning heading.

Comparison between the medians of the two data sets as a whole when extrapolated directly, considering the OEL of 2.0 mg/m^3, is roughly two-fold in this case.

Sampling position	Median (mg/m^3)	Extrapolated value (mg/m^3)
Personal sampling	0,99	2.0 (OEL)
EED sampling	2,75	5,5

Table 4-1 Extrapolation of medians

This simple extrapolation indicates that the OEL is exceeded more than two-fold and thus the EED limit of 5 mg/m^3 as set by Directive B7 cannot be compared to the personal respirable coal dust OEL of 2 mg/m^3. In addition, the basis of the initial calculation used to derive the 5 mg/m^3 limit assumed that the shift lengths were in the region of 8 hours and cutting times around 40% of the shift, however, the actual sampling results are calculated for a full shift. Another important aspect to be considered is the fact that most coal mines have shift lengths ranging from 9 to 10 hours. This would imply that the 2 mg/m^3 OEL for personal exposures should be lower in real terms to compensate for the extended shift.

4.4 Conclusions and recommendations

In conclusion it is evident that the required limit of 5 mg/m^3 as set out by Directive B7 cannot be related to the personal exposures limit of 2 mg/m^3. Poor correlation results observed indicate that the EED sampling position does not account for the respirable dust concentrations leaving coal-winning headings and is affected by the recirculation of contaminated air over the sampling position. In addition the EED sampling position does not give an indication of the respirable dust capture efficiency of the scrubber fan, and therefore it is recommended that the Directive B7 approach be revised to take the efficiency of controls into account.

While Directive B7 led to a revolutionary change in dust control methods applied at the coal-winning face and a reduction in exposure levels to which the section crew is exposed, the approach can be considered as crude when used to manage personal respirable dust exposures.

It is recommended that the current personal sampling strategy is further refined with the aim of including a more accurate representation of occupations HEG's. It is further recommended that the practice of utilising the EED result as a CM operator result be discontinued and that the sampling strategy as set out in the SAMOHP Codebook and Guideline for Airborne Pollutants for personal sampling be followed.
A final recommendation is that further evaluation be carried out to pinpoint and quantify respirable dust monitoring positions at coal-winning operations which are representative of respirable dust concentrations to which section personnel may be exposed. It is further recommended that this strategy is inclusive of a method to monitor the respirable dust capture efficiency of the on-board scrubber fan system.

It is hoped that this study will lead to future studies that will further refine coal dust monitoring and control methodologies used to reduce personal exposures and the occurrence of related occupational illnesses.

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APPENDIX A – Respirable coal dust data used in the study

Table A1, Mine 1 - Personal sampling results for occupations aligned with EED sampling results								
Personal sampling results						EED sampling results		
Area	Activity number	HEG	Sample date	Occupation	TWA	Section number	Full shift dust result mg/m³	Corrected eight hour result (TWA 8) mg/m³
01	02	A	07-Jan-05	RB Operator	2,01	2	11,81	14,39
01	02	B	13-Jan-05	Miner	1,69	2	2,17	2,64
01	02	A	25-Feb-05	RB Operator	1,39	1	5,51	6,72
01	02	A	15-Mar-05	RB Operator	2,01	1	5,55	6,76
01	02	A	01-Apr-05	SC Operator	8,31	4	2,84	3,46
01	02	A	16-May-05	SC Operator	4,37	1	4,81	5,86
01	02	A	18-Aug-05	RB Operator	0,42	2	1,00	1,22
01	02	A	24-Aug-05	SC Operator	1,79	1	2,37	2,89
01	02	A	08-Sep-05	RB Operator	2,67	2	1,56	1,90
01	02	A	14-Sep-05	SC Operator	1,56	4	0,11	0,13
01	02	A	04-Oct-05	SC Operator	0,58	2	2,55	3,11
01	02	A	07-Oct-05	SC Operator	3,82	2	2,33	2,84
01	02	B	13-Oct-05	Miner	1,85	4	0,59	0,72
01	02	A	16-Nov-05	SC Operator	2,96	4	1,27	1,55
01	02	A	07-Dec-05	SC Operator	0,93	1	0,91	1,11
10	02	A	05-Jan-06	SC Operator	1,43	2	0,25	0,30
11	02	A	09-Jan-06	Gen Worker	1,85	4	1,24	1,51
11	02	A	11-Jan-06	SC Operator	1,52	1	4,21	5,13
13	02	A	19-Jan-06	Miner	0,41	2	14,86	18,11
10	02	A	08-Feb-06	RB Operator	1,9	4	1,09	1,33
11	02	A	14-Feb-06	RB Operator	2,36	1	10,21	12,44
12	02	A	16-Feb-06	Miner	0,66	2	14,44	17,60
14	02	A	02-Mar-06	RB Operator	8,6	4	2,70	3,29
10	02	A	16-Mar-06	SC Operator	0,29	1	3,15	3,84
11	02	A	22-Mar-06	RB Operator	0,22	2	0,09	0,11

Table A1, Mine 1 - Personal sampling results for occupations aligned with EED sampling results								
Personal sampling results						EED sampling results		
Area	Activity number	HEG	Sample date	Occupation	TWA	Section number	Full shift dust result mg/m³	Corrected eight hour result (TWA 8) mg/m³
12	02	A	24-Mar-06	Gen Worker	0,44	6	2,41	2,94
12	02	A	28-Mar-06	Miner	0,17	1	0,33	0,40
10	02	A	05-Apr-06	Miner	0,62	2	4,28	5,22
14	02	A	10-Apr-06	SC Operator	3,85	6	5,17	6,30
13	02	A	21-Apr-06	Miner	0,53	1	0,87	1,06
14	02	A	25-Apr-06	RB Operator	2,82	6	1,65	2,01
11	02	A	08-May-06	RB Operator	2,72	1	0,02	0,02
12	02	A	12-May-06	Miner	0,33	2	0,08	0,10
13	02	A	16-May-06	SC Operator	0,55	4	2,16	2,63
14	02	A	22-May-06	RB Operator	1,72	6	5,37	6,54
10	02	A	30-May-06	SC Operator	0,07	1	0,17	0,21
14	02	A	02-Jun-06	SC Operator	3,67	2	0,19	0,23
11	02	A	15-Jun-06	Miner	0,75	4	2,03	2,47
11	02	A	19-Jun-06	SC Operator	1,55	6	0,63	0,77
10	02	A	03-Jul-06	Gen Worker	3,75	1	0,43	0,52
10	02	A	05-Jul-06	SC Operator	0,26	2	1,81	2,21
11	02	A	11-Jul-06	Gen Worker	0,32	4	2,39	2,91
13	02	A	17-Jul-06	SC Operator	3,25	6	1,46	1,78
14	02	A	25-Jul-06	SC Operator	1,61	1	3,47	4,23
10	02	A	15-Aug-06	SC Operator	7,43	2	0,09	0,11
11	02	A	17-Aug-06	RB Operator	3,31	4	1,85	2,25
10	02	A	07-Sep-06	SC Operator	3,15	6	1,53	1,86
14	02	A	08-Sep-06	RB Operator	0,63	1	1,31	1,60
11	02	A	11-Sep-06	Miner	0,85	2	0,80	0,98
11	02	A	13-Sep-06	SC Operator	0,59	4	2,03	2,47
12	02	A	15-Sep-06	SC Operator	1,36	6	3,69	4,50
10	02	A	05-Oct-06	SC Operator	3,21	1	3,30	4,02

Table A1, Mine 1 - Personal sampling results for occupations aligned with EED sampling results								
Personal sampling results						EED sampling results		
Area	Activity number	HEG	Sample date	Occupation	TWA	Section number	Full shift dust result mg/m³	Corrected eight hour result (TWA 8) mg/m³
11	02	A	11-Oct-06	Gen Worker	0,71	1	2,24	2,73
13	02	A	17-Oct-06	SC Operator	1,31	2	0,06	0,07
14	02	A	25-Oct-06	RB Operator	1,67	4	6,50	7,92
10	02	A	13-Nov-06	RB Operator	0,89	6	1,37	1,67
10	02	A	15-Nov-06	SC Operator	3,45	1	1,45	1,77
11	02	A	17-Nov-06	RB Operator	0,33	2	4,13	5,03
12	02	A	21-Nov-06	RB Operator	0,17	6	1,49	1,82
13	02	A	27-Nov-06	SC Operator	0,63	4	1,35	1,65
14	02	A	13-Dec-06	RB Operator	0,29	2	2,30	2,80

Table A2, Mine 2 - Personal sampling results for occupations aligned with corrected EED sampling results								
Personal sampling results						EED sampling results		
Area	Activity number	HEG	Sample date	Occupation	TWA	Section number	Full shift dust result mg/m³	Corrected eight hour result (TWA 8) mg/m³
01	02	A	03-Jan-05	CM Operator	3,52	19	0,58	0,73
03	02	A	07-Jan-05	Gen Worker	0,87	56	0,33	0,41
04	02	A	10-Jan-05	Gen Worker	0,56	68	0,73	0,91
04	02	A	11-Jan-05	RB Operator	1,78	68	1,69	2,11
05	02	A	13-Jan-05	Gen Worker	2,03	40	4,53	5,66
06	02	A	14-Jan-05	Gen Worker	0,07	45	0,38	0,48
07	02	A	17-Jan-05	SC Operator	0,08	55	6,23	7,79
08	02	A	19-Jan-05	Gen Worker	0,35	58	1,89	2,36
08	02	A	20-Jan-05	RB Operator	7,05	58	0,28	0,35
09	02	A	21-Jan-05	Gen Worker	1,45	59	2,06	2,58
10	02	A	25-Jan-05	CM Operator	0,16	91	2,59	3,24

Table A2, Mine 2 - Personal sampling results for occupations aligned with corrected EED sampling results								
Personal sampling results						EED sampling results		
Area	Activity number	HEG	Sample date	Occupation	TWA	Section number	Full shift dust result mg/m³	Corrected eight hour result (TWA 8) mg/m³
06	02	A	03-Feb-05	Miner	0,17	45	4,28	5,35
07	02	A	04-Feb-05	RB Operator	0,3	55	0,59	0,74
08	02	A	08-Feb-05	Gen Worker	0,53	58	3,17	3,96
09	02	A	10-Feb-05	Miner	0,16	59	7,01	8,76
10	02	A	14-Feb-05	CM Operator	4,09	91	5,51	6,89
01	02	A	21-Feb-05	RB Operator	0,99	19	5,44	6,80
01	02	A	22-Feb-05	SC Operator	0,11	19	1,55	1,94
02	02	A	23-Feb-05	SC Operator	2,01	25	2,89	3,61
05	02	A	28-Feb-05	Gen Worker	0,19	40	0,36	0,45
04	02	A	28-Feb-05	RB Operator	0,09	68	10,95	13,69
04	02	A	28-Feb-05	SC Operator	0,62	68	10,95	13,69
08	02	A	07-Mar-05	Gen Worker	0,91	58	11,17	13,96
08	02	A	08-Mar-05	Gen Worker	0,38	58	1,29	1,61
01	02	A	09-Mar-05	RB Operator	0,64	19	2,82	3,53
09	02	A	10-Mar-05	CM Operator	0,22	59	1,23	1,54
02	02	A	10-Mar-05	Gen Worker	0,72	25	0,07	0,09
02	02	A	11-Mar-05	SC Operator	0,15	25	0,11	0,14
03	02	A	15-Mar-05	CM Operator	1,09	56	1,43	1,79
05	02	A	17-Mar-05	CM Operator	0,17	40	1,22	1,53
07	02	A	24-Mar-05	SC Operator	0,21	55	4,11	5,14
05	02	A	13-Apr-05	Miner	0,51	40	0,83	1,04
04	02	A	13-Apr-05	CM Operator	10,62	68	0,19	0,24
06	02	A	14-Apr-05	RB Operator	0,23	45	0,49	0,61
07	02	A	15-Apr-05	SC Operator	0,18	55	2,06	2,58
07	02	A	18-Apr-05	Miner	0,32	55	2,93	3,66
08	02	A	20-Apr-05	RB Operator	0,49	58	3,49	4,36
09	02	A	21-Apr-05	CM Operator	0,04	59	3,44	4,30

Table A2, Mine 2 - Personal sampling results for occupations aligned with corrected EED sampling results								
Personal sampling results						EED sampling results		
Area	Activity number	HEG	Sample date	Occupation	TWA	Section number	Full shift dust result mg/m³	Corrected eight hour result (TWA 8) mg/m³
10	02	A	22-Apr-05	RB Operator	0,13	91	2,76	3,45
06	02	A	12-May-05	SC Operator	0,22	45	3,14	3,93
08	02	A	17-May-05	Gen Worker	0,34	58	3,17	3,96
10	02	A	20-May-05	RB Operator	0,43	91	2,57	3,21
01	02	A	24-May-05	SC Operator	3,32	19	0,96	1,20
03	02	A	27-May-05	Miner	0,17	56	2,07	2,59
05	02	A	03-Jun-05	Miner	0,1	40	6,59	8,24
05	02	A	03-Jun-05	SC Operator	0,25	40	6,59	8,24
07	02	A	07-Jun-05	SC Operator	0,73	55	2,61	3,26
08	02	A	09-Jun-05	Gen Worker	0,55	58	0,55	0,69
10	02	A	14-Jun-05	SC Operator	1,8	91	4,39	5,49
01	02	A	20-Jun-05	RB Operator	0,42	19	6,67	8,34
02	02	A	21-Jun-05	SC Operator	2,43	25	9,73	12,16
03	02	A	23-Jun-05	SC Operator	0,42	56	6,23	7,79
05	02	A	28-Jun-05	Miner	4,02	40	1,52	1,90
06	02	A	30-Jun-05	RB Operator	0,76	45	0,07	0,09
01	02	A	01-Jul-05	RB Operator	5,58	19	1,45	1,81
02	02	A	06-Jul-05	CM Operator	9,61	25	0,17	0,21
04	02	A	08-Jul-05	RB Operator	0,67	68	0,16	0,20
05	02	A	12-Jul-05	RB Operator	0,37	40	2,52	3,15
06	02	A	14-Jul-05	CM Operator	0,72	45	0,48	0,60
07	02	A	15-Jul-05	Gen Worker	0,7	55	1,27	1,59
07	02	A	18-Jul-05	SC Operator	0,47	55	2,33	2,91
08	02	A	20-Jul-05	Gen Worker	1,72	58	1,82	2,28
06	02	A	04-Aug-05	Miner	0,71	45	2,47	3,09
07	02	A	05-Aug-05	RB Operator	3,9	55	11,87	14,84
01	02	A	08-Aug-05	RB Operator	2,17	19	2,49	3,11

Table A2, Mine 2 - Personal sampling results for occupations aligned with corrected EED sampling results								
Personal sampling results						EED sampling results		
Area	Activity number	HEG	Sample date	Occupation	TWA	Section number	Full shift dust result mg/m³	Corrected eight hour result (TWA 8) mg/m³
07	02	A	08-Aug-05	SC Operator	1,95	55	0,86	1,08
08	02	A	10-Aug-05	Gen Worker	3,1	58	2,74	3,43
09	02	A	11-Aug-05	Gen Worker	0,07	59	4,73	5,91
09	02	A	12-Aug-05	RB Operator	0,54	59	3,40	4,25
01	02	A	22-Aug-05	RB Operator	1,72	19	3,40	4,25
03	02	A	25-Aug-05	RB Operator	0,4	56	0,85	1,06
04	02	A	29-Aug-05	RB Operator	1,86	68	6,84	8,55
05	02	A	31-Aug-05	SC Operator	1,06	40	3,80	4,75
08	02	A	05-Sep-05	RB Operator	1,43	58	7,76	9,70
09	02	A	06-Sep-05	Gen Worker	0,15	59	3,17	3,96
09	02	A	07-Sep-05	RB Operator	0,24	59	4,95	6,19
10	02	A	08-Sep-05	SC Operator	3,1	91	2,33	2,91
01	02	A	16-Sep-05	SC Operator	3,79	19	6,57	8,21
02	02	A	20-Sep-05	CM Operator	1,25	25	0,70	0,88
03	02	A	21-Sep-05	SC Operator	1,19	56	4,57	5,71
04	02	A	23-Sep-05	SC Operator	1,48	68	6,72	8,40
05	02	A	27-Sep-05	Miner	0,34	40	0,70	0,88
06	02	A	29-Sep-05	CM Operator	0,7	45	5,25	6,56
02	02	A	05-Oct-05	Gen Worker	4,85	25	0,60	0,75
02	02	A	06-Oct-05	SC Operator	6,74	25	1,41	1,76
04	02	A	11-Oct-05	Gen Worker	0,27	68	1,46	1,83
05	02	A	12-Oct-05	RB Operator	0,75	40	0,15	0,19
07	02	A	18-Oct-05	SC Operator	1,82	55	5,43	6,79
08	02	A	19-Oct-05	CM Operator	0,31	58	1,80	2,25
08	02	A	20-Oct-05	RB Operator	0,66	58	2,05	2,56
09	02	A	21-Oct-05	RB Operator	0,57	59	0,08	0,10
10	02	A	25-Oct-05	Miner	3,79	91	0,09	0,11

Table A2, Mine 2 - Personal sampling results for occupations aligned with corrected EED sampling results								
Personal sampling results						EED sampling results		
Area	Activity number	HEG	Sample date	Occupation	TWA	Section number	Full shift dust result mg/m³	Corrected eight hour result (TWA 8) mg/m³
03	02	A	08-Nov-05	Miner	0,23	56	1,73	2,16
05	02	A	11-Nov-05	RB Operator	0,35	40	1,53	1,91
06	02	A	15-Nov-05	Miner	1,72	45	0,75	0,94
07	02	A	16-Nov-05	RB Operator	0,43	55	1,51	1,89
08	02	A	18-Nov-05	Gen Worker	0,79	58	2,90	3,63
09	02	A	22-Nov-05	CM Operator	0,78	59	16,76	20,95
10	02	A	24-Nov-05	CM Operator	0,48	91	0,33	0,41
02	02	A	30-Nov-05	Gen Worker	1,43	25	2,96	3,70
07	02	A	07-Dec-05	SC Operator	0,27	55	9,35	11,69
08	02	A	08-Dec-05	Miner	2,49	58	1,62	2,03
09	02	A	13-Dec-05	Gen Worker	8,79	59	1,05	1,31
10	02	A	14-Dec-05	RB Operator	2,92	91	0,19	0,24
01	02	A	19-Dec-05	SC Operator	4,83	19	1,35	1,69
02	02	A	20-Dec-05	CM Operator	1,33	25	0,02	0,03
02	02	A	21-Dec-05	RB Operator	0,79	25	0,18	0,23
03	02	A	23-Dec-05	Miner	0,63	56	5,74	7,18
04	02	A	09-Jan-06	RB Operator	0,65	68	1,31	1,64
05	02	A	11-Jan-06	Gen Worker	0,64	40	0,45	0,56
07	02	A	16-Jan-06	Miner	0,09	55	4,35	5,44
07	02	A	17-Jan-06	RB Operator	1,04	55	0,33	0,41
08	02	A	18-Jan-06	SC Operator	5,98	58	2,29	2,86
09	02	A	20-Jan-06	Gen Worker	2,03	59	5,25	6,56
10	02	A	23-Jan-06	RB Operator	0,35	91	1,43	1,79
07	02	A	03-Feb-06	RB Operator	0,07	55	3,19	3,99
08	02	A	06-Feb-06	SC Operator	0,17	58	0,87	1,09
09	02	A	07-Feb-06	Gen Worker	0,15	59	0,94	1,18
09	02	A	08-Feb-06	RB Operator	1,44	59	4,05	5,06

Table A2, Mine 2 - Personal sampling results for occupations aligned with corrected EED sampling results								
Personal sampling results						EED sampling results		
Area	Activity number	HEG	Sample date	Occupation	TWA	Section number	Full shift dust result mg/m³	Corrected eight hour result (TWA 8) mg/m³
10	02	A	09-Feb-06	SC Operator	6,87	91	0,05	0,06
01	02	A	20-Feb-06	SC Operator	2,7	19	3,85	4,81
02	02	A	22-Feb-06	Gen Worker	4,95	25	4,42	5,53
03	02	A	23-Feb-06	RB Operator	3,32	56	3,34	4,18
04	02	A	27-Feb-06	SC Operator	0,1	68	0,20	0,25
05	02	A	28-Feb-06	RB Operator	0,17	40	6,71	8,39
06	02	A	28-Feb-06	SC Operator	2,89	45	4,03	5,04
02	02	A	08-Mar-06	Miner	0,41	25	2,03	2,54
02	02	A	09-Mar-06	Gen Worker	1,65	25	1,91	2,39
03	02	A	10-Mar-06	SC Operator	0,99	56	7,04	8,80
04	02	A	14-Mar-06	SC Operator	5,34	68	8,83	11,04
05	02	A	15-Mar-06	SC Operator	8,62	40	2,72	3,40
06	02	A	17-Mar-06	SC Operator	2	45	0,15	0,19
08	02	A	22-Mar-06	SC Operator	0,1	58	4,13	5,16
09	02	A	24-Mar-06	Gen Worker	0,46	59	3,64	4,55
09	02	A	27-Mar-06	SC Operator	0,32	59	3,85	4,81
01	02	A	04-Apr-06	CM Operator	1,18	19	0,90	1,13
03	02	A	07-Apr-06	RB Operator	11,73	56	0,31	0,39
04	02	A	10-Apr-06	Gen Worker	2,54	68	3,01	3,76
04	02	A	11-Apr-06	RB Operator	0,46	68	0,43	0,54
06	02	A	18-Apr-06	CM Operator	0,2	45	5,96	7,45
07	02	A	20-Apr-06	Miner	0,36	55	0,06	0,08
08	02	A	21-Apr-06	RB Operator	0,67	58	12,45	15,56
09	02	A	25-Apr-06	Gen Worker	0,85	59	5,89	7,36
03	02	A	05-May-06	CM Operator	4,46	56	2,34	2,93
04	02	A	10-May-06	RB Operator	5,83	68	0,12	0,15
05	02	A	11-May-06	Gen Worker	0,93	40	0,83	1,04

Table A2, Mine 2 - Personal sampling results for occupations aligned with corrected EED sampling results								
Personal sampling results						EED sampling results		
Area	Activity number	HEG	Sample date	Occupation	TWA	Section number	Full shift dust result mg/m³	Corrected eight hour result (TWA 8) mg/m³
06	02	A	15-May-06	CM Operator	0,7	45	9,80	12,25
07	02	A	16-May-06	RB Operator	2,79	55	7,10	8,88
08	02	A	18-May-06	SC Operator	0,46	58	2,77	3,46
09	02	A	19-May-06	CM Operator	0,1	59	4,83	6,04
10	02	A	24-May-06	RB Operator	0,11	91	1,84	2,30
01	02	A	30-May-06	Gen Worker	6,16	19	11,85	14,81
04	02	A	05-Jun-06	Gen Worker	1,79	68	0,07	0,09
05	02	A	06-Jun-06	CM Operator	0,11	40	0,84	1,05
05	02	A	07-Jun-06	RB Operator	1,81	40	1,71	2,14
07	02	A	12-Jun-06	SC Operator	7,47	55	4,54	5,68
08	02	A	13-Jun-06	Gen Worker	0,8	58	0,09	0,11
08	02	A	14-Jun-06	SC Operator	0,07	58	0,32	0,40
09	02	A	19-Jun-06	CM Operator	0,26	59	8,00	10,00
01	02	A	26-Jun-06	Gen Worker	1,36	19	1,21	1,51
02	02	A	28-Jun-06	CM Operator	6,63	25	3,55	4,44
03	02	A	29-Jun-06	RB Operator	0,13	56	0,15	0,19
03	02	A	30-Jun-06	SC Operator	5,2	56	0,15	0,19
01	02	A	03-Jul-06	CM Operator	7,74	19	5,31	6,64
01	02	A	04-Jul-06	SC Operator	7,41	19	0,32	0,40
02	02	A	06-Jul-06	Gen Worker	0,11	25	0,90	1,13
03	02	A	07-Jul-06	RB Operator	2,16	56	0,91	1,14
04	02	A	10-Jul-06	CM Operator	2,57	68	0,12	0,15
06	02	A	14-Jul-06	Gen Worker	1,72	45	1,08	1,35
07	02	A	18-Jul-06	CM Operator	8,05	55	10,97	13,71
08	02	A	19-Jul-06	Miner	0,27	58	0,58	0,73
08	02	A	20-Jul-06	Gen Worker	1,03	58	0,10	0,13
09	02	A	21-Jul-06	SC Operator	0,92	59	3,90	4,88

Table A2, Mine 2 - Personal sampling results for occupations aligned with corrected EED sampling results								
Personal sampling results						EED sampling results		
Area	Activity number	HEG	Sample date	Occupation	TWA	Section number	Full shift dust result mg/m³	Corrected eight hour result (TWA 8) mg/m³
10	02	A	24-Jul-06	SC Operator	0,18	91	1,77	2,21
03	02	A	07-Aug-06	SC Operator	0,07	56	0,12	0,15
04	02	A	08-Aug-06	Gen Worker	5,63	68	2,68	3,35
04	02	A	10-Aug-06	RB Operator	1,13	68	1,53	1,91
05	02	A	11-Aug-06	Gen Worker	0,23	40	12,22	15,28
06	02	A	14-Aug-06	CM Operator	2,34	45	1,43	1,79
06	02	A	15-Aug-06	RB Operator	4,7	45	2,73	3,41
07	02	A	17-Aug-06	CM Operator	0,58	55	0,80	1,00
08	02	A	18-Aug-06	CM Operator	0,53	58	0,33	0,41
09	02	A	22-Aug-06	SC Operator	4,56	59	10,27	12,84
10	02	A	23-Aug-06	SC Operator	0,03	91	0,99	1,24
01	02	A	29-Aug-06	Gen Worker	1,02	19	2,99	3,74
04	02	A	11-Sep-06	Gen Worker	1,97	68	0,11	0,14
01	02	A	03-Oct-06	SC Operator	0,01	19	1,71	2,14
04	02	A	10-Oct-06	RB Operator	0,07	68	3,12	3,90
05	02	A	12-Oct-06	Gen Worker	0,65	40	0,37	0,46
06	02	A	13-Oct-06	SC Operator	0,72	45	3,80	4,75
07	02	A	16-Oct-06	RB Operator	0,9	55	5,78	7,23
08	02	A	18-Oct-06	RB Operator	2,24	58	0,14	0,18
09	02	A	20-Oct-06	SC Operator	2,5	59	2,00	2,50
09	02	A	10-Nov-06	RB Operator	0,57	59	3,42	4,28
10	02	A	15-Nov-06	RB Operator	0,04	91	2,84	3,55
01	02	A	17-Nov-06	RB Operator	2,3	19	1,81	2,26
04	02	A	24-Nov-06	Gen Worker	0,5	68	1,27	1,59
04	02	A	27-Nov-06	RB Operator	2,62	68	2,44	3,05
05	02	A	28-Nov-06	RB Operator	1	40	1,77	2,21
07	02	A	30-Nov-06	RB Operator	1,16	55	1,58	1,98

Table A2, Mine 2 - Personal sampling results for occupations aligned with corrected EED sampling results								
Personal sampling results						EED sampling results		
Area	Activity number	HEG	Sample date	Occupation	TWA	Section number	Full shift dust result mg/m³	Corrected eight hour result (TWA 8) mg/m³
05	02	A	07-Dec-06	RB Operator	0,03	40	2,79	3,49
06	02	A	08-Dec-06	SC Operator	0,67	45	0,44	0,55
02	02	A	18-Dec-06	CM Operator	1,72	25	0,63	0,79
10	02	A	19-Dec-06	RB Operator	0,02	91	0,87	1,09
04	02	A	21-Dec-06	Gen Worker	1,32	68	0,86	1,08
05	02	A	22-Dec-06	CM Operator	0,02	40	0,14	0,18

Table A3, Mine 3 - Personal sampling results for occupations aligned with corrected EED sampling results								
Personal sampling results						EED sampling results		
Area	Activity number	HEG	Sample date	Occupation	TWA	Section number	Full shift dust result mg/m³	Corrected eight hour result (TWA 8) mg/m³
01	17	B	05-Jan-05	Gen Worker	1,34	1	0,14	0,18
01	02	A	13-Jan-05	RB Operator	3,71	2	1,90	2,38
01	17	B	16-Feb-05	Gen Worker	1,01	3	9,01	11,26
01	02	A	21-Feb-05	RB Operator	1,16	4	3,49	4,36
01	02	A	07-Mar-05	RB Operator	1,06	3	0,09	0,11
01	02	A	11-Mar-05	SC Operator	6,81	4	1,45	1,81
01	02	A	01-Apr-05	RB Operator	0,93	1	0,08	0,10
01	02	A	05-Apr-05	SC Operator	0,39	4	2,97	3,71
01	02	A	12-May-05	RB Operator	0,71	1	1,66	2,08
01	02	A	16-May-05	SC Operator	1,22	2	4,00	5,00
01	17	B	15-Jun-05	Gen Worker	0,5	4	3,00	3,75
01	02	A	22-Jun-05	RB Operator	0,3	2	0,89	1,11
01	02	A	30-Jun-05	SC Operator	0,23	4	1,58	1,98

Table A3, Mine 3 - Personal sampling results for occupations aligned with corrected EED sampling results								
Personal sampling results						EED sampling results		
Area	Activity number	HEG	Sample date	Occupation	TWA	Section number	Full shift dust result mg/m³	Corrected eight hour result (TWA 8) mg/m³
01	02	A	01-Jul-05	SC Operator	0,17	1	2,35	2,94
01	02	A	05-Jul-05	Miner	0,25	4	0,06	0,08
01	17	B	21-Jul-05	Gen Worker	0,16	1	1,11	1,39
01	02	A	08-Dec-05	SC Operator	0,71	4	6,81	8,51
01	02	A	09-Jan-06	RB Operator	0,58	2	4,89	6,11
01	17	B	25-Jan-06	Gen Worker	0,15	1	6,40	8,00
01	02	A	14-Feb-06	Miner	0,56	1	5,01	6,26
01	02	A	22-Feb-06	RB Operator	1,14	3	0,08	0,10
01	02	A	05-Apr-06	SC Operator	1,21	4	6,22	7,78
01	02	A	13-Apr-06	Miner	1,81	4	1,83	2,29
01	17	B	30-Jun-06	Gen Worker	2,38	3	2,95	3,69
01	02	A	05-Jul-06	Miner	0,17	6	0,58	0,73
01	17	B	21-Jul-06	Gen Worker	1,17	3	7,83	9,79
01	02	A	07-Aug-06	RB Operator	4,49	6	6,01	7,51
01	17	B	23-Aug-06	Gen Worker	0,07	1	4,80	6,00
01	02	A	28-Aug-06	Miner	0,71	3	9,04	11,30
01	02	A	06-Sep-06	Miner	0,8	6	4,15	5,19
01	02	A	14-Sep-06	RB Operator	1,72	3	8,24	10,30
01	02	A	24-Nov-06	RB Operator	0,7	1	0,05	0,06
01	02	A	28-Nov-06	RB Operator	8,18	4	0,03	0,04
01	17	B	06-Dec-06	Gen Worker	0,02	3	4,48	5,60
01	02	A	08-Dec-06	SC Operator	0,04	6	5,54	6,93

Table A4, Mine 4 - Personal sampling results per occupation aligned with corrected EED sampling results								
Personal sampling results						EED sampling results		
Area	Activity number	HEG	Sample date	Occupation	TWA	Section number	Full shift dust result mg/m³	Corrected eight hour result (TWA 8) mg/m³
01	02	A	18-Dec-06	SC Operator	0,38	41	1,70	1,91
03	02	A	06-Dec-06	SC Operator	0,46	43	6,28	7,07
02	02	A	04-Dec-06	CM Operator	4,86	42	0,19	0,21
02	02	B	30-Nov-06	SC Operator	1,46	42	3,27	3,68
03	02	A	13-Oct-06	SC Operator	2,75	43	0,14	0,16
03	02	A	11-Oct-06	RB Operator	1,32	43	3,54	3,98
01	02	A	05-Oct-06	Miner	1,18	41	3,16	3,56
03	02	A	18-Sep-06	RB Operator	1,38	43	16,09	18,10
02	02	A	08-Sep-06	RB Operator	0,49	42	3,76	4,23
03	02	A	25-Aug-06	CM Operator	5,28	43	3,80	4,28
02	02	A	21-Aug-06	RB Operator	0,63	42	2,10	2,36
02	02	A	17-Aug-06	CM Operator	3,38	42	7,19	8,09
01	02	A	11-Aug-06	SC Operator	1,85	41	3,46	3,89
02	02	B	03-Aug-06	SC Operator	0,88	42	1,82	2,05
03	02	B	27-Jul-06	Miner	4,56	43	1,62	1,82
03	02	A	11-Jul-06	SC Operator	3,33	43	2,36	2,66
02	02	A	07-Jul-06	RB Operator	0,28	42	4,66	5,24
03	02	A	19-Jun-06	RB Operator	5,31	43	0,12	0,14
03	02	A	15-Jun-06	CM Operator	4,61	43	2,05	2,31
02	02	A	09-Jun-06	RB Operator	2,49	42	1,20	1,35
01	02	A	07-Jun-06	CM Operator	1,5	41	1,88	2,12
03	02	B	26-May-06	Miner	0,84	43	2,87	3,23
01	02	A	25-May-06	Miner	0,98	41	2,16	2,43
01	02	A	23-May-06	SC Operator	0,25	41	2,38	2,68

Table A4, Mine 4 - Personal sampling results per occupation aligned with corrected EED sampling results								
Personal sampling results						EED sampling results		
Area	Activity number	HEG	Sample date	Occupation	TWA	Section number	Full shift dust result mg/m³	Corrected eight hour result (TWA 8) mg/m³
03	02	A	10-May-06	RB Operator	0,64	43	1,19	1,34
03	02	A	13-Apr-06	CM Operator	1,38	43	3,52	3,96
02	02	A	07-Apr-06	RB Operator	2,79	42	2,34	2,63
01	02	A	03-Apr-06	SC Operator	1,58	41	3,10	3,49
03	02	A	30-Mar-06	RB Operator	1,24	43	1,30	1,46
02	02	A	28-Mar-06	CM Operator	1,8	42	2,47	2,78
02	02	B	27-Mar-06	SC Operator	2,4	42	1,17	1,32
01	02	A	24-Mar-06	SC Operator	0,64	41	1,18	1,33
01	02	A	22-Mar-06	RB Operator	1,08	41	5,68	6,39
03	02	A	27-Feb-06	CM Operator	0,55	43	3,52	3,96
02	02	A	17-Feb-06	CM Operator	0,63	42	1,56	1,76
01	02	A	15-Feb-06	SC Operator	1,25	41	1,77	1,99
03	02	B	25-Jan-06	Miner	0,17	43	6,87	7,73
03	02	A	11-Jan-06	SC Operator	0,58	43	3,92	4,41
02	02	A	05-Jan-06	RB Operator	13,62	42	10,16	11,43
02	02	A	22-Dec-05	RB Operator	0,87	42	2,75	3,09
01	02	A	20-Dec-05	SC Operator	0,63	41	3,17	3,57
02	02	B	30-Nov-05	SC Operator	2,57	42	4,94	5,56
03	02	A	21-Nov-05	SC Operator	3,66	43	2,21	2,49
03	02	A	17-Nov-05	RB Operator	4,32	43	8,34	9,38
02	02	A	15-Nov-05	Miner	1,05	42	1,58	1,78
01	02	A	09-Nov-05	CM Operator	0,09	41	9,74	10,96
03	02	A	13-Oct-05	SC Operator	0,28	43	1,73	1,95
01	02	A	07-Oct-05	CM Operator	9,43	41	2,81	3,16
01	02	A	03-Oct-05	SC Operator	0,92	41	2,51	2,82

Table A4, Mine 4 - Personal sampling results per occupation aligned with corrected EED sampling results								
Personal sampling results						EED sampling results		
Area	Activity number	HEG	Sample date	Occupation	TWA	Section number	Full shift dust result mg/m³	Corrected eight hour result (TWA 8) mg/m³
02	02	A	29-Sep-05	RB Operator	1,38	42	1,32	1,49
02	02	B	22-Sep-05	SC Operator	2,13	42	1,90	2,14
03	02	A	08-Sep-05	RB Operator	3,56	43	3,60	4,05
03	02	A	22-Aug-05	SC Operator	1,65	43	9,92	11,16
03	02	B	17-Aug-05	Miner	1,23	43	2,40	2,70
02	02	A	16-Aug-05	RB Operator	5,71	42	2,90	3,26
02	02	B	15-Aug-05	SC Operator	4,75	42	1,10	1,24
01	02	A	12-Aug-05	SC Operator	1,31	41	1,28	1,44
03	02	A	11-Jul-05	SC Operator	2,6	43	2,78	3,13
01	02	A	01-Jul-05	SC Operator	1,46	41	5,45	6,13
03	02	A	24-Jun-05	RB Operator	3,45	43	2,20	2,48
02	02	B	23-Jun-05	SC Operator	0,94	42	3,01	3,39
02	02	A	20-Jun-05	RB Operator	2,1	42	1,69	1,90
01	02	A	14-Jun-05	CM Operator	4,56	41	2,62	2,95
01	02	A	26-May-05	RB Operator	2,1	41	1,84	2,07
01	02	A	24-May-05	Miner	5,15	41	1,44	1,62
03	02	B	19-May-05	Miner	0,92	43	4,66	5,24
03	02	A	05-May-05	SC Operator	0,16	43	0,42	0,47
02	02	A	03-May-05	Miner	1,33	42	5,88	6,62
03	02	A	11-Apr-05	SC Operator	3,67	43	0,76	0,86
02	02	A	07-Apr-05	RB Operator	0,61	42	3,48	3,92
02	02	B	06-Apr-05	SC Operator	1,13	42	6,46	7,27
01	02	A	05-Apr-05	CM Operator	3,04	41	0,13	0,15
01	02	A	01-Apr-05	Miner	3,85	41	0,09	0,10
03	02	A	24-Mar-05	SC Operator	0,81	43	2,31	2,60

Table A4, Mine 4 - Personal sampling results per occupation aligned with corrected EED sampling results								
Personal sampling results						EED sampling results		
Area	Activity number	HEG	Sample date	Occupation	TWA	Section number	Full shift dust result mg/m³	Corrected eight hour result (TWA 8) mg/m³
03	02	A	22-Mar-05	CM Operator	15,64	43	6,49	7,30
02	02	A	16-Mar-05	RB Operator	1,88	42	4,62	5,20
04	02	A	02-Mar-05	RB Operator	3,82	44	5,15	5,79
03	02	B	28-Feb-05	Miner	0,4	43	6,31	7,10
02	02	A	28-Feb-05	CM Operator	1,45	42	4,15	4,67
01	02	A	24-Feb-05	SC Operator	3,04	41	6,47	7,28
02	02	B	24-Feb-05	SC Operator	1,78	42	3,66	4,12
01	02	A	22-Feb-05	RB Operator	1,82	41	1,67	1,88
04	02	A	14-Feb-05	CM Operator	2,25	44	6,01	6,76
03	02	A	08-Feb-05	RB Operator	1,43	43	4,33	4,87
04	02	A	19-Jan-05	SC Operator	2,09	44	2,11	2,37
04	02	A	17-Jan-05	CM Operator	2,06	44	2,63	2,96
03	02	A	13-Jan-05	RB Operator	1,46	43	2,94	3,31

Table A5, Mine 5 - Personal sampling results per occupation aligned with corrected EED sampling results								
Personal sampling results						EED sampling results		
Area	Activity number	HEG	Sample date	Occupation	TWA	Section number	Full shift dust result mg/m³	Corrected eight hour result (TWA 8) mg/m³
04	02	A	05-Jan-05	SC Operators	1,3	1	1,56	1,95
04	02	A	07-Jan-05	Gen Worker	5,51	2	4,66	5,83
03	02	B	19-Jan-05	Miner	0,41	4	1,33	1,66
03	02	B	21-Jan-05	RB Operator	0,52	1	2,90	3,63
03	02	A	14-Feb-05	SC Operators	1,98	2	4,64	5,80
04	02	A	15-Feb-05	CM Operator	0,29	2	2,79	3,49
03	02	A	16-Feb-05	CM Operator	3,69	3	8,92	11,15
04	02	A	18-Feb-05	SC Operators	2,25	5	2,87	3,59
03	02	A	22-Feb-05	SC Operators	0,2	1	3,45	4,31
04	02	A	22-Feb-05	SC Operators	3,65	3	0,09	0,11
03	02	A	07-Mar-05	CM Operator	6,81	4	4,78	5,98
04	02	A	09-Mar-05	SC Operators	3,82	3	2,41	3,01
04	02	B	10-Mar-05	Miner	0,22	5	0,05	0,06
03	02	A	01-Apr-05	SC Operators	0,96	1	25,70	32,13
04	02	A	05-Apr-05	SC Operators	1,68	3	8,37	10,46
03	02	B	15-Apr-05	RB Operator	1,58	2	12,92	16,15
03	02	B	19-Apr-05	Miner	0,48	1	5,34	6,68
04	02	B	10-May-05	RB Operator	0,94	2	16,31	20,39
03	02	A	13-May-05	SC Operators	2,45	3	2,43	3,04
03	02	A	17-May-05	CM Operator	0,54	5	0,26	0,33
04	02	A	19-May-05	SC Operators	3,68	4	1,27	1,59
04	02	A	06-Jun-05	SC Operators	0,45	4	5,17	6,46
04	02	A	08-Jun-05	SC Operators	1,13	1	0,85	1,06

Table A5, Mine 5 - Personal sampling results per occupation aligned with corrected EED sampling results								
Personal sampling results						EED sampling results		
Area	Activity number	HEG	Sample date	Occupation	TWA	Section number	Full shift dust result mg/m³	Corrected eight hour result (TWA 8) mg/m³
04	02	B	22-Jun-05	Miner	0,24	2	7,53	9,41
03	02	A	28-Jun-05	SC Operators	2,02	3	5,71	7,14
03	02	A	30-Jun-05	CM Operator	0,67	4	3,51	4,39
04	02	A	01-Jul-05	CM Operator	1,26	5	1,12	1,40
04	02	B	19-Jul-05	Miner	0,8	1	6,88	8,60
04	02	A	11-Aug-05	SC Operators	3,06	2	7,25	9,06
04	02	A	17-Aug-05	CM Operator	3,95	3	2,48	3,10
04	02	A	04-Oct-05	SC Operators	2,64	4	0,25	0,31
04	02	A	07-Oct-05	SC Operators	0,43	1	1,49	1,86
04	02	B	19-Oct-05	Miner	0,49	2	0,74	0,93
04	02	A	09-Nov-05	SC Operators	1,62	4	1,59	1,99
4	02	A	15-Nov-05	CM Operator	0,35	5	0,12	0,15
04	02	B	22-Dec-05	RB Operator	1,22	5	0,23	0,29
04	02	A	04-Jan-06	SC Operators	1,07	3	0,47	0,59
04	02	A	10-Jan-06	CM Operator	1,42	3	2,33	2,91
04	02	A	09-Feb-06	SC Operators	0,63	4	3,44	4,30
04	02	A	16-Mar-06	SC Operators	0,3	5	5,11	6,39
04	02	A	22-Mar-06	SC Operators	0,87	1	2,44	3,05
04	02	A	04-Apr-06	SC Operators	0,62	2	0,26	0,33
04	02	A	07-Apr-06	CM Operator	9,22	3	14,19	17,74
04	02	A	15-May-06	SC Operators	0,75	4	0,45	0,56
04	02	A	18-May-06	CM Operator	0,3	2	0,08	0,10
04	02	A	20-Jun-06	CM Operator	2,42	3	9,53	11,91
04	02	C	20-Jun-06	Gen Worker	0,8	5	11,89	14,86

Table A5, Mine 5 - Personal sampling results per occupation aligned with corrected EED sampling results								
Personal sampling results						EED sampling results		
Area	Activity number	HEG	Sample date	Occupation	TWA	Section number	Full shift dust result mg/m³	Corrected eight hour result (TWA 8) mg/m³
04	02	A	21-Jun-06	SC Operators	0,72	1	6,50	8,13
04	02	A	04-Jul-06	SC Operators	0,01	1	0,73	0,91
04	02	A	07-Jul-06	SC Operators	1,77	2	6,82	8,53
04	02	B	25-Jul-06	Miner	0,33	3	0,56	0,70
04	02	A	10-Aug-06	SC Operators	0,25	4	8,31	10,39
04	02	A	16-Aug-06	SC Operators	0,3	1	0,06	0,08
04	02	B	07-Sep-06	RB Operator	0,41	2	2,78	3,48
04	02	A	04-Oct-06	SC Operators	0,22	3	8,47	10,59
04	02	A	10-Oct-06	SC Operators	0,91	4	0,59	0,74
04	02	B	19-Oct-06	Miner	0,24	5	0,08	0,10
04	02	A	13-Nov-06	SC Operators	0,02	1	0,07	0,09
04	02	A	16-Nov-06	CM Operator	0,64	2	10,70	13,38
04	02	A	07-Dec-06	SC Operators	0,29	4	1,98	2,48
04	02	B	19-Dec-06	RB Operator	0,02	5	0,43	0,54

APPENDIX B – Tabulation of personal and EED sampling results

Measure	Mine 1		Mine 2		Mine 3		Mine 4		Mine 5		All mines	
	Personal sampling	EED sampling	Personal sampling	EED sampling	Personal sampling	EED sampling	Personal sampling	EED sampling	Personal sampling	EED sampling	Personal sampling	EED sampling
Mean (mg/m^3)	1,85	3,35	1,70	3,64	1,33	4,24	2,33	3,78	1,43	5,25	1,78	3,89
Median (mg/m^3)	1,52	2,25	0,72	2,44	1,71	3,71	1,46	3,09	0,80	3,10	0,99	2,75
Standard deviation (mg/m^3)	1,84	3,85	2,22	3,75	1,82	3,51	2,51	2,91	1,72	6,03	2,16	4,02
Variance (mg/m^3)	3,41	14,83	4,96	14,12	3,32	12,34	6,30	8,51	2,96	36,39	4,67	16,20
95 % CI – mean (mg/m^3)	1,40 – 2,35	2,37 – 4,34	1,40 – 2,01	3,12 – 4,15	0,70 – 1,95	3,03 – 5,44	1,80 – 2,87	3,43 – 4,13	0,99 – 1,88	3,70 – 6,79	1,58 – 1,98	3,52 – 4,27
95 % CI – median (mg/m^3)	0,79 – 1,82	1,70 – 2,85	0,64 – 0,99	1,95 – 3,18	0,51 – 1,15	2,00 – 5,87	1,31 – 2,06	2,70 – 3,30	0,52 – 1,18	1,89 – 5,22	0,14 – 1,18	2,38 – 3,09
95 % CI – St Dev (mg/m^3)	1,56 – 2,24	3,26 – 4,68	2,03 – 2,46	3,42 – 4,16	1,47 – 2,38	2,84 – 4,60	2,18 – 2,95	2,68 – 3,18	1,46 – 2,09	5,12 – 7,34	2,02 – 2,31	3,77 – 4,30
Number of samples (N)	61	61	206	206	35	35	87	87	61	61	450	450

APPENDIX C – Ethics clearance certificate

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

Division of the Deputy Registrar (Research)

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)
R14/49 Ferreira

CLEARANCE CERTIFICATE	**PROTOCOL NUMBER M071151**
PROJECT	Evaluating Respirable Coal Dust Concentrations at the Face of South African Coal Mines
INVESTIGATORS	Mr EF Ferreira
DEPARTMENT	School of Public Health
DATE CONSIDERED	07.11.30
DECISION OF THE COMMITTEE*	APPROVED SUBJECT TO: stating for what degree & completing 6.1 on ethics form

Unless otherwise specified this ethical clearance is valid for 5 years and may be renewed upon application.

DATE 07.12.07 **CHAIRPERSON** ....
(Professors PE Cleaton-Jones, A Dhai, M Vorster, C Feldman, A Woodiwiss)

*Guidelines for written 'informed consent' attached where applicable

cc: Supervisor : A Swanepoel

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10005, 10th Floor, Senate House, University.
I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee. **I agree to a completion of a yearly progress report.**

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES