

**DEVELOPMENT OF A DUST EXPOSURE LEVEL INDEX (DELI)
FOR SOUTH AFRICAN UNDERGROUND COAL MINE WORKERS**

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DECLARATION

I declare that this thesis is my own, unaided work. It is being submitted for the degree of Doctor of Philosophy in the University of Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

Signed _____

Dated this.....day of.....2004

Abstract

Inhaling excessive amounts of respirable coal dust will lead to work-related lung disease commonly known as Coal Worker's Pneumoconiosis (CWP) or black lung. Prevention and control of CWP requires accurate knowledge of the dose-response relationship to set-up and review occupational exposure limits (OELs), which do not exist in SA. Due to historical reasons, poor emphasis of occupational health on the mines resulted in inadequate exposure data in SA. The new Mine Health and Safety Act (1996) overcame the deficiencies of the past and require quantifying the dust exposure and efficiency of dust control measures, and continuous risk assessments for dust exposure.

The current method of exposure assessment is expressed using an Air Quality Index (AQI) which is the ratio of the measured dust level and OEL of coal dust. The difficulties with the usage of AQI are poor descriptions of dust problem areas and its magnitude, poor quality of the data leading to "no dust problem situation" and failure to extract information on 'dose in milligram' to relate them to the disease rate. Gravimetric size-selective dust sampling was introduced for the first time in 1990 in SA. Due to the lack of critically important coal dust exposure data available, this thesis has set out to examine several critical exposure related parameters and determine dust levels underground.

This research study had the objective of the development of a pragmatic diagnostic tool (method) called the Dust Exposure Level Index (DELI) to evaluate the exposure of workers. The DELI incorporates a set of controllable parameters and influential areas and prioritises them to manage and reduce the worker exposure. The DELI model was to provide critical information as an index, i.e., to show whether the environment is dusty, border line or relatively free of dust and effectiveness of administrative and engineering dust control measures. The research work in this thesis has led to very explicit conclusions, which were based on extensive dust measurements in various coal mines over a five year period. Conclusions obtained for the various sets of controllable parameters used in the DELI model are as follows:

- ✓ A previous analysis of the dust data during 1990 indicated that the dust levels have increased with mechanisation. The contamination of coal dust samples due to stone dusting can result in high dust levels giving a "false" indication of the efficiencies of the dust-control systems.
- ✓ The dust exposure levels during coal cutting indicated that a worker positioned inside the cabin of a CM during the cutting of a 24 m coal block is at a higher dust exposure risk than the worker when cutting a 12 m coal block. Also, the miner who is operating in a heading is exposed to higher dust exposure risk than in a split.
- ✓ The analyses of measured real-time dust data showed a clear relationship between the average dust levels and the frequency of occurrence of "peak" dust levels. The study demonstrated a clear method of using real-time dust data for assessing exposure.
- ✓ The average measured section intake dust level was 0.80 mg/m^3 and 60 % of the collected data exceeded the 0.5 mg/m^3 limit indicating that this is a *base* dust level to

- which the worker is exposed without carrying out any additional work in the section.
- ✓ The average measured section return dust level was greater than 2.0 mg/m^3 indicating the high exposure levels of workers, and ineffectiveness of the ventilation and dust-control systems.
 - ✓ The results of this research study indicated that there is no conclusive relationship between the rate of coal production and respirable dust levels. Also, the type of dust control system used has pronounced effect on dust levels in the sections. The capture efficiency of any dust control system is not one hundred percent at any given time. During any cutting process for a given time and dust control type, part of the escaped respirable dust is added to the coal face atmosphere through air re-circulation. Therefore, respirable dust levels can be expected to increase with time during the shift, even at constant production levels.
 - ✓ A limited number of particle size analyses have indicated that there is no clear relationship between the dust concentration in mg/m^3 and total surface area (m^2) of the respirable dust sample.
 - ✓ For the first time, a clear delineation of coal types (semi-bituminous and semi-anthracite) that possess the most inherent respirable dust generation potential (IRDGP) was possible ($p = 0.000$). Also, there was no conclusive relationship ($p = 0.373$) between different semi-bituminous coal seams (1, 2, 4 and 5) and IRDGP.
 - ✓ The laboratory roll-crusher test results of South African coal types indicated that average inherent silica for the test coals was 3.54 %.

The DELI model took into account, the merits of personal exposure data in exposure assessment, but the limitations and quality of data one obtains in the South African situation overweighed use of the fixed-point sampling. The “limits of acceptability” used in DELI are based upon acceptable guidelines prescribed by the authorities such as National Institute of Occupational Safety and Health (NIOSH), Mine Safety and Health Administration (MSHA), South African Department of Minerals and Energy Affairs (DME) and latest information on epidemiological studies. The DELI model gives the visual “colour” coding and descriptive categories for easy interpretation and understanding of exposed dust level to uneducated workforce. This type of DELI index representation gives a clear and concise picture of the mine or various section dust conditions. The DELI model exposure assessment technique gives accurate feedback because it was based on latest recommended size-selective sampling methods and instrument and vast amount of measured data, which was not previously available. The application of the developed DELI model for exposure assessment and its comparison with AQI were evaluated for coal mine dust data. The study demonstrated that the DELI model is a practical diagnostic tool that gives a fair reflection and information on dust levels and is an exposure assessment tool for the coal mining industry that will assist in reduction of CWP in South Africa.

Glossary of abbreviations, symbols and terms

Abbreviations

ACGIH	American Conference of Governmental Industrial Hygienists
ARD	Airborne Respirable Dust
ANOVA	Analyses Of Variance
BMRC	British Medical Research Council
CB	Cutting Block
CD	Cutting Distance
CM	Continuous Miner
COM	Chamber OF Mines
CMRS	Central Mining Research Station
CWP	Coal Workers Pneumoconiosis
CWSP	Coal Workers Simple Pneumoconiosis
DELI	Dust Exposure Level Index
DME	Department of Minerals and Energy
DGMS	Director General of Mine Safety (India)
DISA	Diffraction Size-Frequency Analyser
ESM	Estonian Standard Method
ECSC	European Community Steel and Community
ER	Exposure Response
FEV	Forced Expiratory Volume
FRG	Federal Republic of Germany
FSA	Fritsch Size Analyser
GM	Geometric Mean
H	Heading
IARC	International Agency for Research on Cancer
IRDGP	Inherent Respirable Dust generation Potential
ILO	International Labour Organization

IOM	Institute of Occupational Medicine
OEL	Occupational Exposure Limit
OSHA	Occupational Safety and Health Administration
OHS	Occupational Health and Safety
MBOD	Medical Bureau of Occupational Diseases
MRC	Medical Research Council
MRE	Mine Research Establishment
MSA	Mine Safety Appliances
MSHA	Mine Safety and Health Administration
MWU	Metal Workers Union
NAS	National Academy of Sciences
NCB	National Coal Board
NSCWP	National Study of Coal Workers' Pneumoconiosis
NIOSH	National Institute of Occupational Safety and Health
NUM	National Union of Mineworkers
PEL	Permissible Exposure Levels
PMF	Pulmonary Massive Fibrosis
PFRU	Pneumoconiosis Field Research Unit
RH	Road Header
RSA	Republic of South Africa
S	Split
SA	South Africa
SC	Sample Concentration
SADC	Southern African Development Community
SAMOHP	South African Mine Occupational Hygiene Programme
SIMRAC	Safety in Mines Research Advisory Committee
SSM	Swedish Standard Method
TLV	Threshold Limit Value
TWA	Time-Weighted Average
UK	United Kingdom
USA	United States of America

USBM	United States Bureau of Mines
VLC	Very Low Concentration
VM	Volatile Matter
WHO	World health Organization

Symbols

%	percentage
μm	micrometers/microns
L/min	litres per minute
m	metre
m/s	metres per second
m^2	square metre
m^3/s	cubic metres per second
mg/m^3	milligrams per cubic metre
mm	millimetre

DEDICATED TO

**To the South African Coal Mining Industry and Coal Mine Workers from
the Southern African Development Community (SADC)**

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Chapter 1 Introduction

1.1 Introduction

The mining industry continues to be the foundation for the economic growth and development of South Africa. The mining industry's contribution to gross domestic product (GDP) was 7.5 % in 2001 and the overall contribution of mining to GDP is estimated to be about 10 % (COM, 2001). South Africa is the world's third largest steam coal exporting country and the fourth largest producer. Power generation dominates domestic coal consumption using 58 % of the coal consumed, followed by the production of synthetic fuels at 32 %, metallurgical use at 2 % and others at 8 %. Figure 1.1 shows the South African coal production and the workforce over the years. From the plot it is noticed that the coal production has increased while the number of workers in the coal mining industry has decreased. When compared with countries like Australia and Canada, the number of South African work force is in an order of magnitude higher.

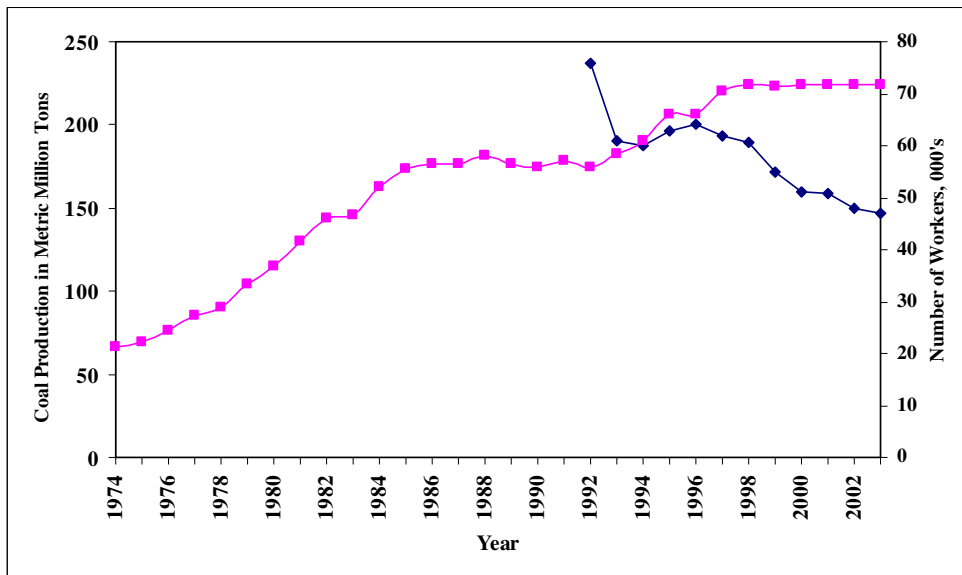


Figure 1.1: South African coal mining workforce

Like in any industrial operation, coal mining is also affected by both safety and health hazards. The safety hazards such as fall of grounds, moving machinery, explosions result in loss of life. Similarly, inhaling various types of dusts would result in health hazard such as debilitating lung related respiratory diseases. Figure 1.2 shows the underground and surface coal mine fatalities. The plot shows the decrease in the fatalities in the coal mining industry in the last decade.

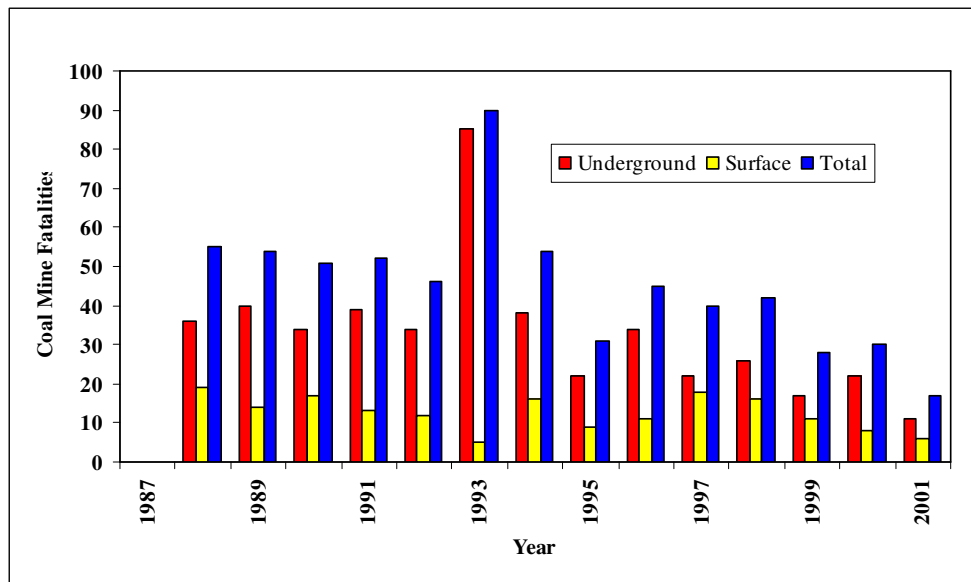


Figure 1.2: South African coal mine fatalities

Pneumoconiosis among coal miners (known commonly as black lung) is caused by inhaling excessive amounts of respirable coal mine dust. It can be prevented by reducing exposure to this dust, and to this end, coal mine operators are required to monitor dust exposure of workers. In South Africa, the Mine Health and Safety Act was enacted in 1996 after the Leon Commission of Enquiry into the health and safety of workers. According to the act, inspectors from the Department of Minerals and Energy Affairs (DME) inspect, issue notices, report and inquire on the dust related matters. In the United States, dust monitoring and other measures designed to prevent black lung (medical surveillance, development of dust control methods, and epidemiological research) were implemented following passage of the Federal Coal Mine Health and Safety Act of 1969, and continued unchanged

when that act was amended in 1977.

For public policy to be rational and effective, it is axiomatic that the objective of the standards and the information for its foundation must be accurate (Weeks, 1995). When operators provide data for enforcement purposes, they have both an incentive and an opportunity to make dust exposure appear as low as possible. In the USA, it was noted that sometimes mine operators achieved this through legal means through loopholes in the regulations and some through illegal means (Weeks, 2003). The incentive arises from a desire to avoid punitive actions; the opportunity arises because operators can submit the dust values without the direct oversight of enforcement authorities.

Opportunity based submission of the dust data may sometimes result in the inclusion of very low dust values ($< 0.1 \text{ mg/m}^3$) in the submitted dust data to the enforcement authorities or management. Inclusion of such very low dust values knowingly or unknowingly due to measurement faults can significantly underestimate the worker exposure to dust. Therefore, data provided to the enforcement authorities for the purpose for estimating worker dose requires careful analysis and large human resources. The luxury of such resources is not available in South Africa, where the DME is severely short of the mine inspectors.

‘Healthy work’ and ‘healthy workplaces’, as a basis for ‘occupational health’ and ‘occupational hygiene’, with their medical associations, and ‘occupational safety’, with the implied emphasis on regulation, have become mainstream political and economic issues in both industrialized and developing countries (Ennals, 2002). In Southern Africa, this was seen as central to sustainable development during a SADC ministerial meeting (SADC, 2002). Workplace health in the mining industry is acquiring both political and economic dimension in the Southern African region. With globalization, the mining companies are outsourcing the mining activities to contract labour resulting in ambiguous responsibilities. In South Africa the burden of diseases from working in mines was unacceptably

high, peaking at about 25,000 applications for compensation for occupational lung diseases (Anon, 2002). Further a tripartite committee, consisting of the National Union of Mineworkers (NUM) and the Mine Workers Union (MWU), and the Chamber of Mines and the Department of Minerals and Energy Affairs (DME), was formed in 1997 to consider sections of the Occupational Diseases in Mines Act (1973). Against this background the issue of workplace dust and workers exposure to dust is recognized as being central to employer, employee and governmental policies. In South Africa, there are two compensation Acts, which makes provision for compensation for those workers with occupational diseases resulting from occupational exposure to dust such as coal dust and silica or quartz dust.

The Occupational Diseases in Mines and Works Act (Act 78 of 1973) (ODMWA Amendment Act 1993) provides for compensation for cardiorespiratory diseases, arising from occupational exposure in mines and scheduled works. Compensation for employees is guaranteed without regard to apportionment of blame. The amendment of 1993 has authorised owners of mines and works to issue certificates of fitness to employees. The Certification Committee, based at the Medical Bureau for Occupational Diseases (MBOD), remains responsible for certifying people as being first or second degree disabled. Payment remains a lump sum payment, influenced by the job category of the miner or ex-miner. A spouse is eligible for lump sum payment for disease proven on post mortem irrespective of the cause of death.

Compensation for Occupational Injuries and Diseases Act (Act 130 of 1993)(COIDA) provides for compensation for disablement caused by occupational diseases contracted by employees in the course of their employment, or for death resulting from such injuries or diseases; and to provide for matters connected with the above. According to Schedule 3 of the Act, pneumoconiosis-fibrosis of the parenchyma of the lung resulting from exposure to organic or inorganic fibrogenic dust, e.g. silicosis and CWP, is compensable. Compensation is paid to successful

claimants from a Compensation Fund that is financed by a levy paid by industry. The worker is compensated for the injury or disease, not for the loss of the job or the inability to continue a particular job.

The MBOD renders medical examination benefits to active and former mine workers and provides its service delivery to all its clients. Mine workers certified as suffering from occupational respiratory diseases are then compensated. The surveillance is ongoing. The major difference between the two compensation systems is outlined in the following Table 1.1.

Table 1.1: Major differences between ODMWA (1973) and COIDA (1993)

ODMWA (1973)	COIDA (1993)
<ul style="list-style-type: none"> • Treatment for a period of 24 months from the date of diagnosis. Medical aid payment may be extended where the treatment may reduce the disease or improve clinical symptoms. • Payment of 75% of any wages lost up to a period of 6 months. • Lump sum payment for first or second degree occupational diseases. • Miners, including ex-miners, have a life long right to benefit medical examinations to exclude occupational lung diseases. • This compensation system is a no-fault system. 	<ul style="list-style-type: none"> • Payment for medical expenses for 24 months. If treatment is more than 24 months, permanent disability (PD) is assessed. Further treatment will be considered only if it will reduce disability. • Payment for total temporary disablement (TTD) is for 12 months and may be extended to 24 months at the discretion of the CC. This is equivalent to 75 % of the employee's total earnings. • Payment for PD is for loss of function or loss of any body part. If PD is less than 30 %, a lump sum is paid and if more than 30 %, a monthly pension is provided. • Death benefits to the dependants if the death is due to injury or occupational disease. • This compensation system is a no-fault system where the employer is protected against a civil claim from the employee and the employee has the right to compensation. The employee can however claim for extra compensation where negligence on the part of the employer can be proven.

A decision has been made to integrate the two compensation systems (COIDA and ODMWA) and to amend all the relevant legislations to effect the creation of a

single compensation system. This integration (which is currently being discussed) is required to standardise procedures, unify and equalise benefits, while at the same time ensuring that all those entitled to these benefits have access to them.

In order to reduce the number of CWP cases, the South African coal mining industry requires a well-established strategy in dust measurement, dust control, exposure assessment and dedicated dust research. Currently, such a strategy in the mining industry does not exist and dust control strategies have been well established overseas, for example, USA. According to the National Academy of Sciences (NAS) Committee on the Measurement and Control of Respirable Dust (NRC, 1980) "...the bureau's (earlier U.S. Bureau of Mines) past and future research has been, and is intended to be, directed mainly at the development of improved measuring instruments, mining machines that produce less respirable coal mine dust, suppression of respirable dust primarily by water sprays, and control of respirable dust principally by ventilation..." The conditions in coal mines have been improved, principally through the adoption of existing technology--but continuation along these lines will yield diminishing returns.

Very effective methods of controlling dust by applying water to deal with the dust at source were developed by the U.S. Bureau of Mines (USBM) following the studies on the interactions between water droplets and dust particles (King, 1980). With existing technology, Jayaraman, Schroeder, and Kissell (1984), Jayaraman and Jankowski (1988) Jayaraman et al. (1989), Jayaraman et al. (1991), Alaboyun (1989) and Hu (1992), Belle (1996) and Ramani and Belle (1997) have shown the improvements that could be achieved in dust control techniques. In South Africa, after the promulgation of the Mine Health and Safety Act (1996), significant dust control measures have been carried out in the continuous miner (CM) and road header (RH) and longwall faces through the Safety In Mines Research Advisory Committee (SIMRAC). The recent South African research on various dust control technologies (Du Plessis, Belle and Vassard, 1998; Belle and Du Plessis, 1998a and 1998b; Belle, Van Zyl, and Du Plessis, 2001; Belle et al., 2002; Belle and

Clapham, 2002, Belle, 2002) have indicated that the dust concentration at the operator's position in an underground mining environment can comply with the limits as prescribed by the DME directive of 1997.

Measurement of dust is an important aspect in determining the exposure levels. The current standards on dust exposure levels were derived by using size-selective dust sampling instruments and methods of medical examination. Apparently, these standards are blindly accepted (at least in South Africa) for use when the sampling and examination are done by quite different methods and conditions. An International Labour Organization (ILO, 1967) publication clearly concluded "...No evaluation or comparison of dust contents ... has any significance unless the type of equipment, method of sampling and the nature of the dust are precisely known ... Except in case of homogeneous dust clouds with a constant particle size distribution, the correction factors will always vary with the particle size distribution or the nature, or both, of the dust examined."

The major objective of this proposed study is the development of a Dust Exposure Level Index (DELI) for the South African underground coal mines for dust exposure assessment. The literature review work of the study will look into the mine dust standards of various countries, the limits of dust exposure and the reasons behind the set levels. A second objective is to evaluate the existing method of determining the exposure levels and compare it with the DELI.

1.2 Problem Statement

The dust hazard to miners in South Africa was first specifically recognized and brought under intensive study, during the early years of this century. Despite the South African mining industry's early achievement, it has not kept pace with the rest of the world. The problem is, however, being addressed by research programs and this current study forms part of this research. The history of dust measurement and type of instruments used are discussed in detail in Section 2.5.11.

In well-ventilated coal mines, the dust becomes well mixed over the cross-section, and the point-to-point differences in concentration tend to be less than those occurring in surface industries. Nevertheless, concentrations differ significantly in the intake air, downwind of the workings, and in the immediate vicinity of coal cutting machines. Also, the workers move from place to place, into different dust concentrations, during the shift.

In the early 1960's, the measure of hazard was provided by average dust levels rather than peaks of dust exposure. Also, peak levels were not used as it was thought that the peak levels would misdirect the study of dust suppression through collection efficiency. It was also argued at that time that it could not be stated with certainty whether the average value is correct (Wright, 1953; Wright 1957). Studies on animals did not show any difference between amount of dust accumulated at high and average concentrations. The study did not focus on influence of variation in exposure periods on dust accumulation at peak dust concentrations.

In the 1950's and 1960's, experiments on animals revealed that pathological changes were closely related to the surface or mass of the dust rather than to the number of particles. This led to the conclusions that dust mass would prove to be the best parameter. It was also recognized that in mixed dusts the hazard will dependent on composition. Analyses of epidemiological data indicate that the higher the rank of coal mined, the greater is the prevalence of Coal Workers Pneumoconiosis (CWP) amongst miners. The physical characteristics of the coal mined may be partly responsible for the regional differences in the incidence and prevalence of CWP. Therefore, this study will be focusing on developing an index which is based on various parameters, viz., the coal cutting methods, working areas, frequency of peak dust concentration levels, Inherent Respirable Dust Generation Potential (IRDGP), etc.

Research by the United Mine Workers of America (Weeks, 1995) has shown that mines with one section were far more likely to have frequent very low concentration (VLC) samples, and mines with five or more sections were very unlikely to have frequent VLC samples. The exact reasons for these observations are difficult to conclude. There is considerable evidence that exposure level is influenced by mining method and individual mine effects. Mine effects could result from practices and conditions peculiar to each mine and have to do with geological and other conditions, the condition of coal cutting machines, and the use and effectiveness of dust control methods. Dust exposure control methods vary from mine to mine and section to section. In South Africa, during many instances the non-random occurrence of VLC samples below 0.1 mg/m^3 were observed (Belle, 2002). In any event, the detection limit for the dust measuring instruments currently available is 0.1 mg/m^3 and at mass loadings of less than 0.5 mg , the precision of respirable dust measurements is less (Kogut et al., 1997). The question of exposure limits set by the regulatory authorities in respective countries, and the need for careful analysis of submitted operator dust concentration data is clearly important from an exposure assessment and control point of view.

Personal exposure data in the mines under similar working conditions show a greater variability and the differences in exposure levels due to spatial variation. Therefore, it would be useful to have an investigative or diagnostic tool called DELI (Dust Exposure Level Index) that will incorporate a set of parameters, which greatly influence the exposure levels. It is predicted to be a very useful tool to the mine operators to check on their process, mine workers to identify their exposure levels and the enforcement authorities to develop their judgement on the values supplied by mines.

1.3 Scope of Work

In the coal mining world, South Africa has some of the best mining conditions

resulting in long development headings and increased production. This requires innovative dust control technologies specifically for South African coal mines, which are operating at seam heights of greater than 3.5 m unlike the mines in USA. With enticement for coal production and resulting financial rewards, the focus on working environments are often neglected or take a back seat. The Leon Commission of Inquiry (1994) looked into the Occupational Health and Safety (OHS) in the South African mining industry for the past 30 years or more. The Commission found that over 69,000 mine workers had died in the first 93 years of this century, and more than a million were seriously injured.

In previous years, the main emphasis and focus of occupational health activity on the mines has been on regulating the compensation for occupational diseases rather than the prevention thereof. The Minerals Act focused predominantly on safety issues in the mining industry with little or no emphasis on promoting the occupational health status of workers. The deficiencies were overcome by the new Mine Health and Safety Act (MHSA, 1996) to provide the comprehensive legal framework for creating a healthy and safe working environment. The Mine Health and Safety Act of 1996 entrenches the right of workers to refuse to do dangerous work, thereby paving the way for improved health and safety conditions in the mining industry.

According to the World Health Organization (WHO) report (2002), development of work-related lung diseases is influenced by the amount of exposure and the toxicity of the dust, and the diseases are characterized by long latency periods. Therefore, even in countries in which exposures have been recognized and controlled, the disease rates are only gradually declining (NIOSH, 1999). However rate trends in developing countries like South Africa are mostly unknown but the magnitude of the problem is substantial (Chen et al., 2001). In 1980, the National Academy of Sciences (NAS) Committee on the Measurement and Control of Respirable Dust in Mines of USA, recommended that the spatial and temporal characteristics (of fragments produced in coal mining) need to be understood so

that the exposure of workers to the dust can be controlled. The WHO report (2002) suggests that these diseases are entirely preventable through elimination of exposure through wet methods of excavation and ventilation at work places.

The research proposed in this study has the objective of the development of a unique index to evaluate the dust exposure of a mine worker at the workplace. The index is called the Dust Exposure Level Index (DELI). This index will be unique as it depends on many parameters, which were not used heretofore. With the evolvement of effective dust control techniques, better understanding of size-selective sampling, newly developed real-time monitoring instruments and monitoring of respirable dust is now a practical possibility, and focusing attention on quantitatively measuring the exposure levels through a qualitative index is appropriate.

The scope of work for this study has included conducting a series of laboratory experiments to obtain the basic information (e.g., determine the inherent respirable dust generation potential of coal), which was not currently available in South Africa. This was followed by collecting additional field data by studies underground to reinforce the existing data for analyses where applicable. Lastly this was followed by the statistical analyses of the data. These will ultimately result in the development of the DELI. This is further compared with the existing means of evaluation of dust exposure levels.

1.4 Importance of Work

The results from the proposed work are important as they are expected to achieve the following:

1. DELI will be an administrative tool incorporating the set of controllable parameters that greatly influence the assessment of worker dust exposure

levels. It will be useful to mine operators to check on their process, mineworkers to identify their estimated qualitative exposure levels and the enforcement authorities to have their views influenced by the index.

2. It will identify the major operational factors affecting the exposure level of workers to coal dust.
3. As the development of a comprehensive index of exposure has not been done anywhere in the world, thus will be unique to the South African coal mining industry.
4. Clarifies the current disagreement, where mines, which are under non-compliance due to the uncontrollable natural circumstances that differ from, mine to mine. This would enable the non-compliance mine operator to search for innovative production techniques in order to reduce the dust levels.

Chapter 2 Literature Review

2.1 Historical Background

Dust is an immediate by product of any type of mining operation, both underground and surface (metal and non-metal). Preparation plants, processing plants and materials-handling sites such as harbours are also operations that present a wide variety of dust problems. Dust is defined as a solid particle (excluding the fiber) aerosol formed by the mechanical disintegration of a parent material by various processes such as crushing and grinding.

Pneumoconiosis is the general term used for diseases of the lungs caused by inhaling dusts. The dust becomes embedded in the lungs, causing them to harden and making breathing very difficult by reducing the lung's ability to extract oxygen from air (NIOSH, 1995). Pneumoconiosis is defined as "a diagnosable disease of the lungs produced by the inhalation of dust, the term being understood to refer to particulate matter in the solid phase, but excluding living organisms," (3rd International Conference of Experts on Pneumoconiosis, 1950). When very fine dust particles are inhaled, they can accumulate in the lungs, resulting in lung diseases. Tissue reactions such as fibrosis or scarring of lung tissue can result from the inhalation of certain dusts.

There are many types of pneumoconiosis such as silicosis, siderosis and fibrosis. Silicosis is an incurable lung disease resulting in death or disability. The presence of crystalline free silica, commonly called quartz, can cause silicosis, which is a disabling, irreversible form of pneumoconiosis. The hazard of breathing dust depends greatly on the composition of the dust, the concentration, particle size and duration of exposure. The disease of coal miners, known as "black lung or Coal Worker's Pneumoconiosis (CWP)" was recognized in Britain over 300 years ago (Evelyn, 1661). In the 1800s the disease was referred to as *spurious melanosis*,

miners' asthma, anthracosis, black phthisis and silicosis (Gregory, 1831; Laennec, 1819; Pearson, 1813; Gibson, 1833, Makellor, 1845). Up until the 1920s it was thought that lung disease associated with coal mining was caused by silica dust rather than the coal dust itself.

CWP is the condition caused when mixed coal dust from the working environment is inhaled and accumulates in the lungs. Initially, Coal Workers' Simple Pneumoconiosis (CWSP) occurs when sufficient coal dust has accumulated in the lungs to form small macules. The macules are formed when macrophages engulf the particles and engulf together; subsequently reticulin fibers proliferate to consolidate the lesion. In general the severity of CWP can be simply related to the progressive deposition and retention of respirable coal dust generated during mining operations. The development of Pulmonary Massive Fibrosis (PMF) is associated with a further high rate of coal dust accumulation in the lungs (Davis, 1979). PMF lesions are large dust lesions over one centimeter in diameter, located mainly in the upper and posterior regions of the lungs. PMF leads to greatly impaired respiratory function and has a high mortality rate for affected patients.

Coal Workers' Pneumoconiosis (CWP), as distinct from classical silicosis, had first been recognized as a compensable industrial disease in 1943, after the investigations in the UK between 1936 and 1941 by the Medical Research Council (MRC) (Hart and Aslett, 1942). In 1945 the Pneumoconiosis Field Research Unit (PFRU) was established in South Wales, UK. The National Insurance Act (1946) came into force in 1948 and permitted miners in receipt of disability benefit to continue working in the mines under '*approved*' dust conditions based on a report by the MRC (Bedford et al., 1943).

Coal mining in South Africa employed in excess of 57 000 people in 1998 (SIMRAC Handbook, 2001). The output is predominantly bituminous coal although a small amount of anthracite coal is also mined. The silica content of

South African coal is generally fairly low. Mpumalanga, Gauteng and Free State coal has a quartz content of about 2 %, whereas that of Natal contains 3% (White, 2001).

2.2 Epidemiological Research

Human health studies provide the greatest relevance when assessing effects of exposure to dust. Yet they suffer from a difficulty in eliminating the effects of confounding exposures (e.g., the effects of smoking and exposure to other environmental carcinogens). In epidemiological studies historical exposure data have often not been well characterized or documented with great accuracy. These limitations result in a wide range of estimates of the effects of exposure to dust on the health of the exposed mine workers (Jurinski, 1997). Medical prevalence data show the number of miners known to have radiographic changes of pneumoconiosis at a stated point in time. Prevalence can be influenced by movements in populations, particularly of older miners, inaccurate data gathering due to early retirement or job losses.

Post-mortem studies of miners' lungs have shown a relationship between the average weight of dust in the lungs and the radiological category of pneumoconiosis (Rivers, et al., 1960; Rossiter, 1972). Experimental studies carried out on animals when injected with quartz dusts of different particle sizes produced pathological changes that were more closely related to the mass or surface of the dust than to the total number of particles (King et al., 1953; Zaidi et al., 1956).

Since the early research, cumulative exposure has been identified as one of the most critical factors in the development of pneumoconiosis. Duration of exposure and the amount of airborne respirable dust present in the mining environment have a significant influence upon the prevalence of the disease. In 1971, Reisner concluded that the development of CWP was '*largely due*' to the frequency and

severity of exposure. Further, Reisner (1971) suggested that individual large exposures to mixed dust could be important in certain cases. The findings indicated the distinct correlation between a worker's estimated exposure and the risk of developing CWSP (Jacobsen et al., 1980; Attfield et al., 1995).

Inhaled respirable dust particles will reach the alveoli of the lungs and cause health effects. Experiments on animals have revealed that with the dust present in inhaled air as suspensions of solid particles, the potential hazard depends on both the particle size and the mass concentration because of:

- *the effects of particle size on the deposition site within the respiratory tract*
- *the tendency for many occupational diseases to be associated with material deposited in particular regions of the respiratory tract.*

Studies have shown that the risk of progression to a higher category of pneumoconiosis increases with increasing intensity of exposure (mean dust concentration) (Jacobsen *et al.*, 1970, 1971) and increasing cumulative exposure (i.e. intensity × duration) (Jacobsen, 1973, 1979).

The dust exposure of any individual miner is a function of the dust concentrations in the mine areas in which he has worked and the number of years he has been employed. The diagnosis of CWP is based on a history of occupational exposure, X-ray findings, and in some instances, direct examination of lung tissue by biopsy or autopsy. CWP can be classified according to radiographic appearance into simple and complicated disease categories. Each of these categories can be sub classified into three stages. Simple CWP is a condition, which does not cause disability or decrease life expectancy. Category 1, simple CWP, is a relatively benign condition. On the other hand, complicated CWP can cause significant lung damage and result in excessive shortness of breath, pulmonary hypertension, and congestive heart failure (ILO, 1980).

Epidemiological research regarding the development of CWP has been carried out in Germany, Great Britain, USA, and other countries (CNR, 1976; Morgan et al., 1973; Attfield and Hudak, 1981; Reisner, 1973; Hurley et al., 1979). Based on these studies, exposure-response (E-R) relationships have been derived between cumulative exposure and respirable dust levels and the risk of developing pneumoconiosis. The first phase of German epidemiological studies began in 1960 relating over 18,000 miners from 13 different mines to disease. Figure 2.1 shows the exposure-response curves, which represented the probability of developing category 2 or higher pneumoconiosis with 35 years of dust exposure.

In Great Britain, the Institute of Occupational Medicine (IOM) coordinated two epidemiological studies in 1970 (Jacobsen et al., 1970; Jacobsen et al., 1971) and in 1979 (Hurley et al., 1979). The model from the 1970 report is shown in Figure 2.2.

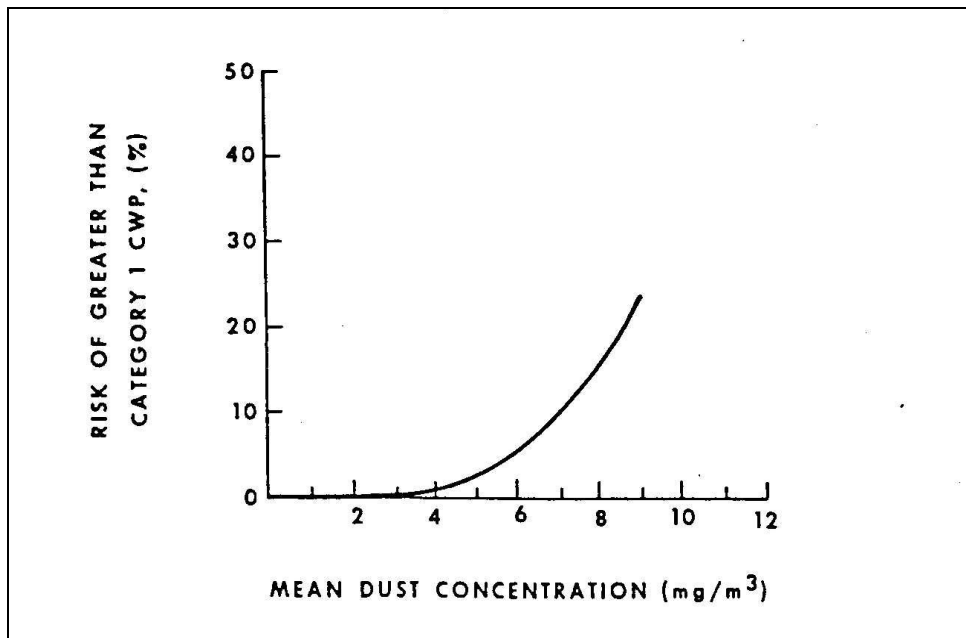


Figure 2.1: German CWP exposure-response curve (Reisner, 1973)

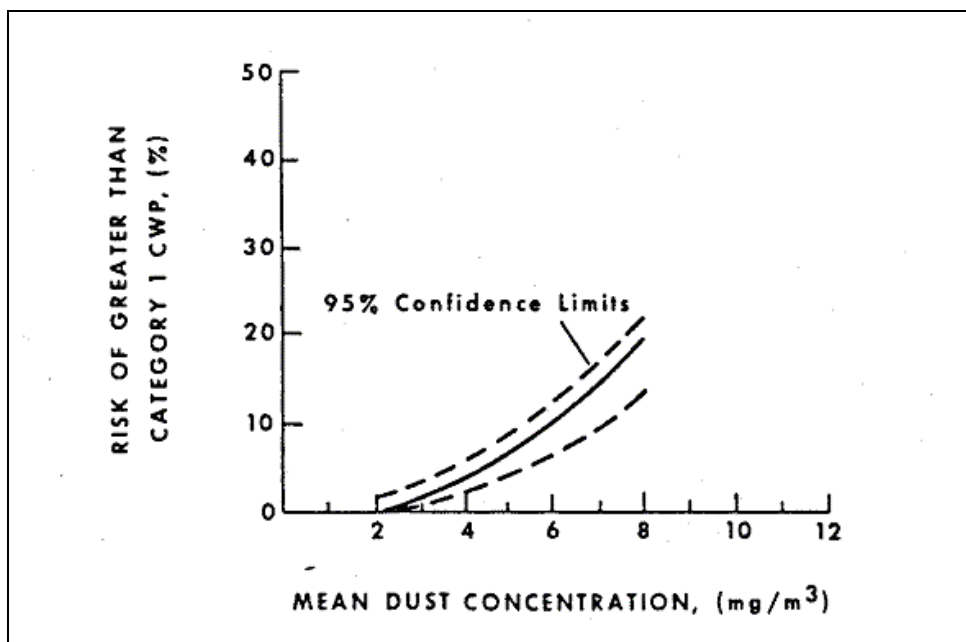


Figure 2.2: British CWP exposure-response curve (Jacobsen et al., 1970)

The exposure-response model shown in Figure 2.2 is widely known as the Jacobsen model and was used as the basis to set the US respirable coal dust standards. In general, the British curve indicates slightly higher risks of CWP than does the German curve. Dust level of 2.0 mg/m³ appears to be the threshold for the development of higher than category 1, simple pneumoconiosis. The 1979 exposure-response model is shown in Figure 2.3. No significant difference exists between the 1970 and 1979 models as the 1979 curve falls within 95 % confidence levels as shown in Figure 2.2. Moreover, it is known that the 1979 curve has prompted a re-evaluation of the US standard (MSHA) for coal dust. Figure 2.3 shows the comparison of two British CWP dose-response curves.

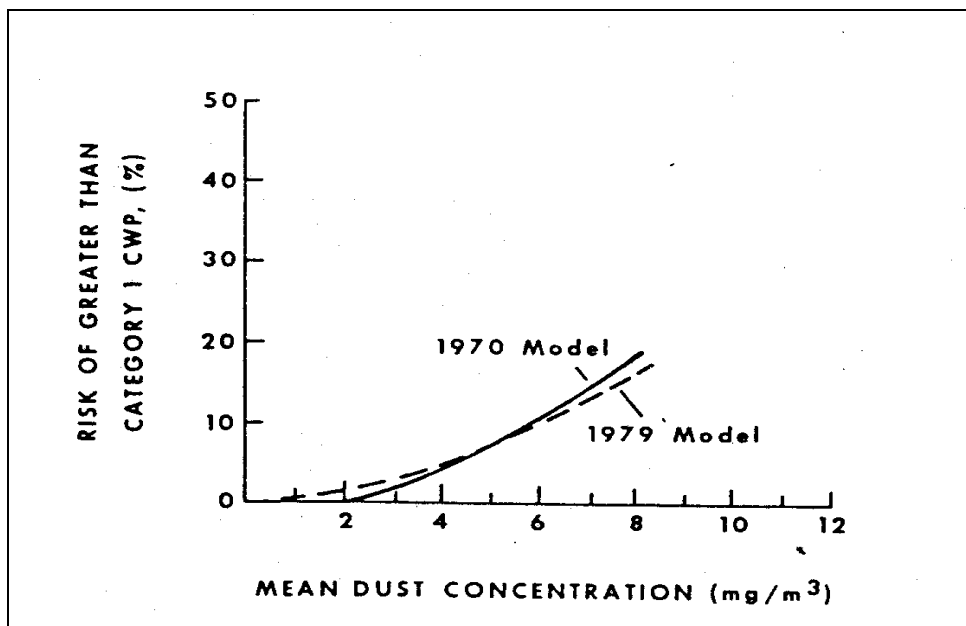


Figure 2.3: Comparison of two British CWP exposure-response curves (Jacobsen et al., 1970; Hurley et al., 1979)

From these models legislated standards in Europe and America were formulated. From the existing standards at the time, one notices American legislators were implementing the no-effect portion of the exposure-response curve, while UK and Germany implemented dust standards at a higher exposure level. From the plot we notice that over 90 % of the miners are protected by maintaining a standard of 6.5 mg/m^3 . However, the American approach is expected to result in zero-simple CWP.

Another exposure-response study by Hurley and Maclaren (1987) is shown in Figure 2.4. From the plot we observe, for eight of the 10 collieries, an E-R function similar to that of the Jacobsen model, although the two studies had different subjects, different data and very different designs (Hurley, Kenny and Miller, 2002).

In a recent commentary on pneumoconiosis, coal mine dust and PFR (Pneumoconiosis Field Research) by Attfield and Kuempel (2003), the following points were made on the historic exposure-response study of Jacobsen et al.:

- Control of CWP lay primarily in the simple reduction of levels of respirable coal dust. Moreover, the various components of the dust (e.g., silica and carbon content) were found to be of secondary importance compared to respirable mixed coalmine dust.
- The sine-squared model employed predicted a zero probability that a miner would develop CWP category 2 or greater after 35 years of exposure of 2 mg/m^3 . A 3.4 % probability was expected at approximately 4.3 mg/m^3 . This concentration as adopted as a long-term mean value (represented by a daily limit of 8 mg/m^3 in the return roadway) as the dust exposure limit for underground coal mines in the UK. Based on these data, compliance limits in both Britain and the US were set (e.g., the basis for the current 2 mg/m^3 (MRE equivalent) exposure limit over each full shift in US coal mines).
- To a large degree, these limits have succeeded in dramatically reducing the prevalence of CWP in both countries and elsewhere.

Some of the lessons learned from the exposure-response modelling by Jacobsen et al., was the strong influence of the chosen mathematical model to predict the disease probability. Therefore, the Jacobsen model predicted essentially zero risk of category 2 or greater at the 2 mg/m^3 exposure limit. However, subsequent analyses by Hurley et al. (1982) using a logistic mathematical model, which does not assume a threshold; indicate higher disease probabilities at low concentration. This indicates the choice of model in predicting the lung diseases at the low end of exposure limits. This had an influence on current US dust limit as it was not as protective as originally desired prompting the review of the current limits (minor implications to British standard at 4.3 mg/m^3 limit). Overall, the fundamental importance of reducing dust exposure to reduce disease remains valid, as do the

steps that were taken to implement dust control plans as a result of this research (Attfield and Kuempel, 2003).

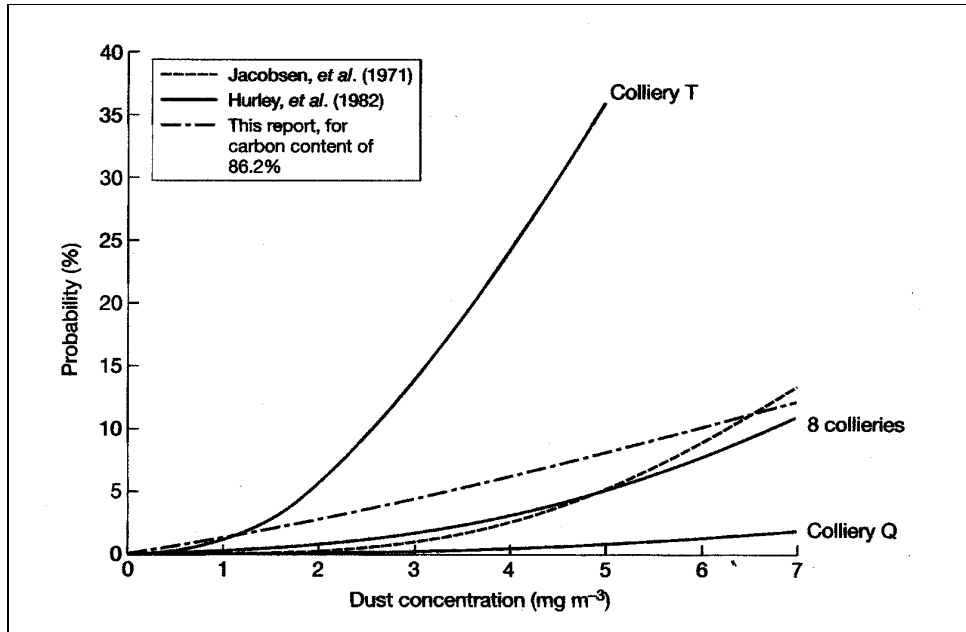


Figure 2.4: Estimates from various studies of the concentration-specific risks showing Category 2 or higher CWP after 35 years of work (Hurley and Maclaren, 1987)

A recent complete inception cohort study on German miners followed up for CWP indicated no miner contracting a higher degree of CWP (Morfeld et al., 2002). The study pointed out the unexpectedly low risk estimates in comparison with the findings of Attfield and Moring (1992) and Attfield and Seixas (1995) in US coal miners. The authors attributed the discrepancies to exposure assessment procedure (personal sampling in the USA and stationary sampling in Germany). However, comparison measurements of respirable coal mine dust between personal sampling and stationary sampling in German coal mining revealed rather similar results with a mean ratio of 1.2 (Bauer et al., 1990).

Until now, medical research has been unable to identify in advance those people who are more likely than others to develop pneumoconiosis in response to exposure to dust (Annon, 2002). Typically pulmonary function of an individual is measured at the pre-employment medical examination (e.g., South Africa) and these tests are not predictive of future experience.

With the introduction of automation and remote control, fewer people will be exposed to the higher dust levels due to the nature of mining operations. Although this may hopefully reduce the number of pneumoconiosis cases, the risk will not thereby be lessened for the few individuals left. Automation and remote control allows the operator to stand in a better location, e.g., the ultimate would be control from an office on surface, with zero risk.

With the number of cases of pneumoconiosis showing an optimistic picture, in recent years, a note of caution was identified (US federal Register, 1995). Recent studies by British scientists and by NIOSH indicated that the risk of developing the most serious form of CWP at the present exposure level standard (2.0 mg/m^3) is higher than had been previously believed. However, the Australians have reported that they have no evidences of CWP at levels greater than the 2.0 mg/m^3 standard. Additionally, the evidences of tampering with respirable dust samples in the USA, raises questions about the dust exposure levels in US coal mines especially those reported as being below 2.0 mg/m^3 (US Federal Register, 1995, Weeks, 2003).

Given the importance of coal mining in South Africa, there is surprisingly little information available on CWP. Some information relating to certification of CWP among coal miners is available from Medical Bureau of Occupational Diseases (MBOD) reports. According to the SIMRAC handbook (2001), prior to 1980, certifications of pneumoconiosis (when expressed as a proxy rate of living cases certified per 1,000 miners currently employed) tended to be higher in coal mines than in gold mines (approximately 6 per 1,000 in 1980 versus 2 per 1,000 in gold

mining). CWP certification rates declined in the years 1980 to 1989. In 1989, the CWP rate was over 4 per 1,000, a similar rate to the silicosis in gold mines. The 1998/99 MBOD report suggests 0.6 % of all first degree pneumoconiosis certifications among miners (25 cases or 0.5 per 1,000 currently employed miners) were CWP among coal miners (White, N., 2001).

An unpublished study (White, 2001) documented radiological abnormalities among Kwa Zulu-Natal anthracite miners. A total of 187 employees with more than five years exposure at a mine were included. 15.8 % were thought to have CWP ILO grade 1/0 or higher, including 7.6 % of grade 1/1 or greater and 1.1 % (2 cases) grade 2/1 or greater. There was a positive association between presence of pneumoconiosis and length of service in a relatively young workforce (mean age 40.3 years).

A SIMRAC research study by Naidoo et al., (2002) reported low prevalence (1.8 % to 4.2 % depending on the chest X-ray reader) of CWP among active and ex-coalminers from three South African mines. The prevalence of CWP increased with cumulative exposure to coal dust. CWP prevalence among former miners who had had only coal exposure (no smoking) was 7.3 %. Also, the study reported an average decline in FEV1 (Forced Expiratory Volume in one second) attributable to coal dust exposure was 17 ml per mg/m³ per year of coal dust exposure among active miners. Low CWP prevalence may be speculative in the absence of trend data on coal dust exposures in South Africa. In recent years coal mining has become highly mechanized with fewer miners in the workplace but with the potential for high dust exposures if the dust control measures are poor.

The results of Trapido (1999) show a high prevalence of pneumoconiosis in a random sample of ex-mineworkers in South Africa. It has also been demonstrated that there is a statistically significant association between total length of service and pneumoconiosis with a probability of developing pneumoconiosis after ten and twenty years of service is 30 % and 44 % respectively. An important

methodological issue regarding the ILO codes was also shown up by reader variation found in the study of Trapido (1998). The reader variation relates to the problems of diagnosing pneumoconiosis in the presence of tuberculosis. This indicates, from a perspective of medical studies, a clear problem associated with radiological reading in communities with high levels of chest diseases.

Finally, although various dose-response curves have been developed in Germany, Great Britain and USA, their direct adoption to South African conditions may not be appropriate. Therefore, meticulous medical surveillance and collection of exposure data specific to South African coal mines which mine bituminous or low rank coal may contribute in developing South African worker exposure –response curves for coal dust.

2.3 Major Pathogenic Characteristics of Respirable Dust

The major factors implicated in the pathogenic characteristics of respirable dust (pertaining to coal dust) in this century (ECSC, 1997) are discussed below:

2.3.1 Dust Type

Coal is classified into rank, which is roughly associated with the relative geological age of the coal and the degree to which the coalification process has progressed (Larson, 1981; Page and Organiscak, 2001). Coal rank is defined by the percentage of fixed carbon (the proportion of carbon that remains when coal is heated and the volatile material (VM) is removed), by the percentage of volatile material, and by the heat content of the coal (Mutmansky, 1984). The general classification of coal include anthracite, semi-anthracite, bituminous, semi-bituminous, and lignite. Anthracite, or “hard coal,” contains between 91 % and 95 % fixed carbon; and lignite, or “brown coal,” between 65 % and 70 % fixed

carbon (Parkes, 1982). High rank coals are of the greatest geological age and consequently have a high percentage of carbon but a low proportion of volatile matter (VM). Conversely, low rank coals have lower carbon content but higher levels of volatile matter (VM). In the past few decades, several health studies have indicated the role the dust type (e.g., coal) plays is crucial to the miner's health. High coal rank mines have been generally found to produce a coal dust with a lower ash, including quartz content (Casswell et al., 1971; Douglas, 1986). High rank coal dust is characterized by coarse dust particles enriched with high mineral content with an average density greater than low rank coal and explains the apparently greater hazard of breathing high rank coals (Lippman et al., 1973).

Workers exposed to coal mine dust are at risk of developing simple Coal Workers' Pneumoconiosis (CWP), Pulmonary Massive Fibrosis (PMF), silicosis, and chronic obstructive pulmonary disease (Parks, 1982). A British study by Hart and Aslett (1942) related coal rank and CWP and noted that the descending order of prevalence of radiological abnormalities in relation to coal rank are viz., anthracite coal, steam coal and bituminous coal. Hicks et al., (1961) studied 20 collieries in Britain and concluded that the average period of work at the coal face required to produce a 20 % prevalence of CWP in high, medium and low rank coals are 8 years, 16 years and 36 years respectively. A positive association of the incidence of CWP with the rank of coal has been reported by Nagelschmidt (1965).

Efforts to study the prevalence of pneumoconiosis in the United States were initiated in the 1960s. In 1969, the U.S. Public Health Service and the U.S. Bureau of Mines initiated a special study of 31 mines widely scattered throughout the USA. This study, referred to as the National Study of Coal Workers' Pneumoconiosis (NSCWP), included medical examinations and exposure measurements. In 1972, Morgan et al., using data from that study, reported on the prevalence of CWP and PMF found in the bituminous and anthracite coal miners of Pennsylvania. For anthracite miners, the data showed that the prevalence was

60 % as a whole for pneumoconiosis and 14 % for PMF; for bituminous miners, it was 47 % and 2.4 %, respectively. In addition, the prevalence of bronchitis was found to be higher in the anthracite miners.

Toxicity studies have confirmed that there are pronounced differences in specific risk from different fine coal dusts. Reisner's (1971) study to investigate the cytotoxic effect of different fine coal dusts showed increased cytotoxicity related to higher rank coals. Reisner (1971) and Jacobsen's (1980) observations in coal miner's data showed that very strong variations existed in the prevalence and progression of CWP between different regions and individual mines, despite similar cumulative exposures and quartz contents of the coal dusts. However, these studies were unable to identify specific factors causing the variation, suggesting that some mines produce coal dust that is more pathogenic than others.

A radiographical study (Jacobsen, et al., 1980) indicated that South Wales (UK) mines producing high rank coals were more hazardous than others. It was found that in high rank coal mines, the mean exposure period for the development of Pulmonary Massive Fibrosis (PMF) was 34 years, while in low rank coal mines the mean was between 41 and 44 years (Douglas, 1986). This differential mean age for developing PMF indicated that high rank coals might cause more rapid and severe pathogenic effects for a given degree of exposure than low rank coals. Serological testing on a series of healthy miners and miners suffering from CWP revealed the possibility that certain ranks of coal produce a more inflammogenic dust (Lippman, et al., 1973). However, the study concluded that more research in the area was necessary to elucidate the results and examine other types of immunological activity associated with CWP.

Attfield and Moring (1992) investigated the relationship between pneumoconiosis and respirable dust in U.S. coal miners. Their results showed that the exposure-response relationship was a function of coal rank and age. The relationship between decrease in lung function and coal type has been studied by

Morgan et al., (1972) and Attfield and Hodous (1992). The later study showed a greater decline in FEV1 (amount of air exhaled in one second) among miners exposed to high rank coal. The results of Attfield and Hodous study were similar to those found in the British Pneumoconiosis Field Research (PFR) studies (McLintock, 1972; Jacobsen et al., 1970; Hurley and Maclaren, 1984; Maclaren et al., 1989) which estimated prevalence of CWP among miners at high rank coal mines was approximately two times higher than miners at low rank coal mines. The authors (Attfield and Moring, 1992) noted that the results from the British research should be interpreted with caution because of the lack of knowledge of occupational exposures prior to 1969, the lack of being able to reliably adjust the data for mine-specific factors, and uncertainties associated with the model at dust levels below 2.0 mg/m³. Finally, epidemiological studies both in the USA and in Great Britain have demonstrated that the prevalence of category 1 and greater CWP and PMF are dependent on the rank of the coal dust to which miners are exposed.

Prior coal mine worker health studies have shown an increased prevalence of CWP for higher rank coals (Attfield and Seixas, 1995; Attfield and Moring, 1992, Hurley and Maclaren, 1987). A European study (ECSC, 1997) compared the pathology with the mineral content of the lungs from coal workers exposed to different rank coals in South Wales, UK. This study concluded that the biological potential of dust produced from the various ranks of coal in South Wales was identical. Results have shown that their inorganic mineralogical composition was very similar and they do not contain components, which could enhance their disease potential. The predominant proportion of pneumoconiosis cases occurring in South Wales (UK) some years ago appeared to indicate a special hazard attached to the dust in high rank mines as compared with that from low rank coal mines, but distinction was less marked. From this we can conclude that higher confidence and attention are required in accurate personal dust sampling and dust measurement strategies.

Experiments by Skidmore et al., (1965), using rats, to determine whether high rank coal dust when inhaled is retained in the lungs to a greater extent than low rank coal gave negative results. Therefore it can be concluded that the retention of dust particles in lungs of rats is independent of coal type or rank. Coarse dust is enriched with high mineral content and hence their mass is found to be greater than low rank coal. This may in part explain the apparently greater hazard of the high rank coals. Suggestions of introducing concentration levels for specific seams, known to be of a higher risk to the work force were made but this was found not to be practicable (Walton, 1966). Interestingly enough, pneumoconiosis not suspected during life was occasionally found at post-mortem.

No literature relating South African mine workers with various pneumoconiosis levels to coal rank has been found. Several studies were carried out in the USA relating the dust generation potential to the coal rank and these are discussed in Chapter 11. No study has yet been done in South Africa, to determine the inherent respirable dust generation potential (IRDGP) of various coals. Thus determination of the propensity of various coal seams for dust generation would enable the understanding of the relationship between the exposure levels, dust types and the disease rate among South African miners.

2.3.2 Particle Charges

Previous research has shown that lung deposition of aerosol particles increases directly with the aerosol's charge properties (Melandri, et al., 1983). In the research study by Organiscak and Page (1998), coal rank and CWP relationship was reported to be in part related to the increase in dust cloud charging properties of higher rank bituminous coals. However, determining particle charges is a complex analytical procedure, and use of particle charges as a parameter was not included in the study.

2.3.3 Silica Content

Silica is the common name for silicon dioxide (SiO_2). In the crystalline forms of silica the silicon and oxygen atoms are arranged in a highly ordered lattice, which extends infinitely in all directions. The most common crystalline form of silica is quartz, which occurs as solid crystals from several centimetres in size down to microscopic dimensions (Ratney, 1997). Other forms of crystalline silica are cristobalite and tridymite. Inhaling crystalline silica dust results in silicosis.

In the United States, studies by the US Public Health Service in 1913 to 1915 found 60 % of 720 lead and zinc miners in Missouri to have silicosis. New studies of miner's phthisis in 1911 in the South African gold mines found a silicosis incidence of 50 % in the first five years of employment, accounting for one-sixth of the deaths among rock drillers on the Witwatersrand (Glenn, 1998). In Western Australia in the early 30s, the Perth Chest Clinic in Paris reported an incidence of new cases of silicosis of 200 per 10,000 examinations (Glenn, 1998).

Quartz was originally believed to be the primary agent in the pathogenesis of CWP. However, it was subsequently found that workers such as dock labourers, who had contact only with the pure coal product, were also susceptible to the disease (ECSC, 1997). On the contrary, the high rank coal mines, with the highest incidence rate of CWP produce airborne dust that tends to have lower quartz content (Casswell et al., 1971; Douglas, 1986). Experimental work (Reisner, 1971) has shown that increased quartz content of dust leads to an enhanced pathological effect.

A pathological study by Davis (1979) suggested that PMF in miners who previously worked in coal mines exploiting low rank seams may be induced primarily by the quartz and mineral particles in the dust. Hurley et al., (1982) rejected the idea that CWP in the general mine population is caused by quartz in coal dust. Also, a specific study on miners who showed unusual radiographic

changes indicated that some individuals are more at risk from quartz levels set for the general mining population (Hurley et al., 1982). In the UK and RSA, high rank coals are generally found in thinner seams and hence more of the rock surrounding is excavated in the mining process hence a higher silica content is present.

Study on smokers and silica dust exposure indicated that the synergistic action both causing chronic obstructive lung disease (Hnizdo and Sluis-Cremer, 1991; Hnizdo, 1990 and Malmberg et al., 1993). There was also reported association of silica exposure with other lung diseases, such as tuberculosis (Chen et al., 1997; Althouse and Bang, 1995) and lung cancer (Cherry et al., 1998; Costello et al., 1995; Koskela et al., 1994). In 1996, the International Agency for Research on Cancer (IARC) reviewed additional literature and studies published in the intervening decade and recommended that quartz and cristobalite, two polymorphs of crystalline silica, be listed as Group 1, carcinogenic to humans (Miles, 1999). The findings of this IARC report (1997) are:

- There is sufficient evidence in humans for the carcinogenicity of inhaled crystalline silica in the forms of quartz or cristobalite from occupational sources
- There is sufficient evidence in experimental animals for the carcinogenicity of quartz and cristobalite
- There is limited evidence in experimental animals for the carcinogenicity of tridymite
- There is inadequate evidence in humans for the carcinogenicity for amorphous silica
- There is inadequate evidence in experimental animals for the carcinogenicity of synthetic amorphous silica.

In the USA, to determine the quartz content of a dust sample, MSHA utilizes an infrared spectrophotometer to measure the absorbance of infrared energy by quartz

in a dust sample. This analysis is conducted following the destruction of the combined sample and filter matrix by a low temperature ashing process and subsequent filter redeposition of the ash containing the quartz (Parobeck, Ainsworth and Tomb, 1997). In South Africa, the quartz content of a coal mine dust sample is determined using the X-ray diffraction technique.

In an Australian sampling study of various metalliferous mine sites by Bell and Lynch (1997) for quartz dust indicated that approximately 20 % of occupations surveyed failed the respirable quartz TLV of 0.2 mg/m^3 while over 60 % failed when the level is lowered to 0.1 mg/m^3 . The situation with quarries and gold mines was generally worse with the values being 40 % to 90 % and 30 % to 50 % respectively. However, epidemiological evidence in the Australian context had not been established at the time of the study. In the UK, maximum occupational exposure limit for respirable crystalline silica is 0.3 mg/m^3 (Biffi and Belle, 1999). In the UK quarrying industry, 64 % of 474 dust samples exceeded 0.1 mg/m^3 , with 10 % in excess of 0.5 mg/m^3 (Tickner, 1997).

2.3.4 Clay Minerals

Clay minerals such as phyllosilicates are present in significant quantities in some mine dust; individual samples have been found to contain up to 60 % illite, muscovite and kaolin (Sabastien, 1989). Some research has suggested that phyllosilicate clay minerals may be able to inhibit the toxic effects of quartz dust in airborne dust sampled from different mines. An inhalation study (Le Bouffant et al., 1977) on rats suggested the diverse range of natural phyllosilicates found in mixed coal dust may have some protective effect. However, to extrapolate the experimental results on rats to human exposure is difficult as is an understanding of the protective effect itself. Further, it is hard to assess the protective effect of clay minerals because their variability and diverse geological distribution make gathering accurate data a complex task even with sophisticated mineral sampling equipment (ECSC, 1997).

2.3.5 Particle Size

Particle size is an important parameter for characterizing the behaviour of dust. One of the important measurable factors with regard to health effects on human beings is the particle size as many properties of dust depend on it. In most situations where dusts are found, there is a very wide range of particle sizes in the air. The "size" of particles deposited in the respiratory region of the lungs has been investigated by two methods:

- by inhalation experiments in which the particle concentration is measured on entering and leaving the lungs, and
- by examination of the dust found in lungs at post-mortem.

In the mine atmosphere, where the dusts are found, there is a very wide range of particle sizes in the air. There have been a number of experimental studies comparing the lung's response to fine low toxic dusts, some of which are discussed by Soutar and his co-workers (Soutar, et al., 1997). All of the ultra-fine dusts were found to produce more damage to the lungs than the same mass of the identical material of fine particles around 250 nm diameter. It is important to consider carefully the possible effects of fine particles on health when we make exposure risk assessment/measurement strategy. In view of the emerging evidence about the importance of particle size in toxicity, it is used as one of the parameters in the development of DELI, i.e., exposure effect of workers to high concentrations of very fine particles.

The MRC selection curve corresponded approximately to lung deposition measured by the inhalation method (Davies, 1952). Post-mortem studies (Cartwright, 1961, 1966; Leiteritz et al., 1966), have subsequently indicated that the dust found in the lungs of coal miners at death is appreciably finer than would be collected according to this curve, and it has thus been questioned (MRC, 1966)

and amended to a new international standard. Rossiter (1972) has compared the amounts and composition of dust found in lungs at post-mortem with the pneumoconiosis category. The differences among the categories were identified due to the composition of dust and large differences in the response of individuals.

2.3.5.1 Particle Penetration and Human Respiratory System

The aerodynamic behaviour of airborne particles is very important in all areas of measurement and control of dust exposure. Detailed information, including the relevant physics, can be found in the specialized aerosol science literature (Green and Lane, 1964; Fuchs, 1964; Hinds, 1982; Vincent, 1989 and 1995; Willeke and Baron, 1993). The human respiratory system is broadly classified into different regions, namely, nasopharyngeal (or extra thoracic region), tracheobronchial region and alveolar region. Particles small enough to stay airborne may be inhaled through the nose (nasal route) or the mouth (oral route).

The probability of inhalation depends on particle aerodynamic diameter, air movement round the body, and breathing rate. The inhaled particles may then either be deposited or exhaled again, depending on a whole range of physiological and particle-related factors. The five deposition mechanisms are sedimentation, inertial impaction, diffusion, interception, and electrostatic deposition (Vincent, 2001). Sedimentation and impaction are the most important mechanisms in relation to inhaled airborne dust, and these processes are governed by particle aerodynamic diameter. There are huge differences between individuals in the amount deposited in different regions of the lungs (Lippman, 1977).

The largest inhaled particles, with an aerodynamic diameter greater than about 30 μm , are deposited in the airways of the head, which are the air passages between the point of entry at the lips or nose and the larynx. During nasal breathing, particles are deposited in the nose by filtration by the nasal hairs and impaction where the airflow changes direction. Retention after deposition is

helped by mucus, which lines the nose. In most cases, the nasal route is a more efficient particle filter than the oral, especially at low and moderate flow rates. Thus, people who normally breathe part or all of the time through the mouth may be expected to have more particles reaching the lung and depositing there than those who breathe entirely through the nose. During exertion, the flow resistance of the nasal passages causes a shift to mouth breathing in almost all people. Other factors influencing the deposition and retention of particles include cigarette smoking and lung disease (WHO, 1999).

Studies were carried out on the magnitude of the difference between nasal and oral breathing, and the role of physical activity on the amount of dust inhaled and deposited in different regions of the respiratory airways (Fabriès, 1993). The research presented the mass of particles that would be inhaled and deposited in workers exposed continuously, during 8 hours, to an aerosol with a concentration of 1.0 mg/m^3 , a mass median aerodynamic diameter equal to $5.5 \mu\text{m}$ and a geometric standard deviation equal to 2.3. The calculations were performed using software developed by INRS (Fabriès, 1993), based on the model developed by a German team (Heyder et al., 1986; Rudolf et al., 1988). The results showed very clearly that oral breathing increases dust deposit in the alveolar (gas-exchange) region when compared to nasal breathing, indicating the protective function of the nasal airways. A higher physical activity such as experienced by face workers in a coal mine can significantly increase dust deposit in all parts of their respiratory airways.

Of the particles, which fail to deposit in the head, the larger ones will deposit in the tracheobronchial airway region and may later be eliminated by mucociliary clearance or if soluble may enter the body by dissolution. The smaller particles may penetrate to the alveolar region, the region where inhaled gases can be absorbed by the blood. In aerodynamic diameter terms, only about 1 % of $10 \mu\text{m}$ particles gets as far as the alveolar region, so $10 \mu\text{m}$ is usually considered the practical upper size limit for penetration to this region. Maximum deposition in

the alveolar region occurs for particles of approximately 2.0 μm aerodynamic diameter. Most particles larger than this are deposited further up the lung. For smaller particles, most deposition mechanisms become less efficient, so deposition is less for particles smaller than 2 μm until it is only about 10 % to 15 % at about 0.5 μm . Most of these particles are exhaled again without being deposited. For still smaller particles, diffusion becomes an effective mechanism and deposition probability is higher. Deposition is therefore a minimum at about 0.5 μm (WHO, 1999).

2.3.5.2 Particle Size and Health Effects

Recent studies (Cherrie, 1998) show that the retention times of dust in the lungs play, amongst others, an important part in the pathogenic effect of the exposure. In both categories, the inability of the lung scavenger cells or alveolar macrophages to clear the dust, results in the migration of the contaminant particle from the lungs' epithelium to the interstitium (the underlying cellular layer surrounding the blood vessels). Here the dust particle may produce inflammation that may lead to fibrosis and, for some dusts (silica), even cancer.

The production of fibrogenic tissue resulting from the irritation of the alveolar tissue is a known effect which leads to the irreversible damage of the elastic lung tissue and reduces the oxygen absorption capacity of the lung (Seaton, 1995). In addition, observations have shown that the presence of irritating material in the interstitium may alter the blood's ability to coagulate and lead to the triggering of heart failure as documented by Seaton (1995).

Coal dust and silica dust are the predominant dust types historically presenting health effects to the worker's in the coal and gold mining industry respectively. The particle size, concentration, and exposure time have been studied extensively throughout the world. As early as 1912 the first dust legislation for mine dusts were formulated when the Union of South Africa introduced laws governing

working conditions in gold mines. In 1950 both Europe and the United States proved that workers in bituminous coal mines could contract CWP. In 1959 at the International Pneumoconiosis Conference held in Johannesburg, South Africa, it was recognised that particles of equivalent diameter of less than 5 μm were most likely to be retained in the lungs.

Particle size and shape determine whether such particles will reach the lung or upper respiratory tract and, together with the toxicity and the period of exposure, will determine the effect on a worker's health (WHO, 1999). Medical researchers found that the mean size of dust recovered from the lungs of deceased coal miners is about 1 μm . They concluded that it is mostly the less than 5 μm fraction of the respirable dust that is harmful to health and in particular particles smaller than 3 μm , which tends to accumulate in the lungs. Investigations carried out by the Central Mining Research Station (CMRS) of India show that 75 % of dust found in lungs are of 1 μm size (Table 2.1).

Table 2.1: Size distribution of dust collected from CWP lung of Indian coal miners (CMRS, 1986)

Mean size, μm	Cumulative % of particles	Cumulative % of surface area
0.20	48.1	-
0.28	60.1	1.8
0.39	65.8	-
0.55	71.5	4.6
1.10	85.5	-
1.55	91.5	21.40
2.20	97.2	-
3.10	100*	100

The dusts typically liberated in the environment during mining operations display a very wide range of particle sizes. There have been a number of experimental

studies comparing the lung's response to fine low toxic dusts (unlike coal dust), some of which are discussed by Soutar and others (Soutar, et al., 1997). All of the ultra-fine dusts (particles less than 0.2 microns) were found to produce more damage to the lungs than the same mass of the identical material of fine particles around 250 nm diameter. It is important to consider carefully the possible effects of fine particles on health when the exposure risk assessment or measurement strategies are developed. In view of the emerging evidence about the importance of particle size on toxicity, sampling should also focus on the exposure of workers to high concentrations of very fine particles. High concentrations of ultra-fine particles ($d_p = 25$ to 250 nm) are characterized by relatively large surface areas that interfere with the dust-clearing mechanisms. Furthermore, toxic dust may react in a different manner.

The MRC selection curve corresponded approximately to lung deposition measured by the inhalation method (Davies, 1952). Post-mortem studies (Cartwright, 1961, 1966; Leiteritz, 1966), have subsequently indicated that the dust found in the lungs of coal miners at death is appreciably finer than would be collected according to this curve. This finding has been questioned and has led to the creation of an amended new international standard. Rossiter (1972) has compared the amounts and composition of dust found in lungs at post-mortem with the pneumoconiosis category. The differences among the categories were identified due to the composition of dust and large differences in the response of individuals.

In the area of ambient air-pollution research, recent epidemiological studies have indicated that an association exists between fine particulate and acute mortality and morbidity at concentrations below 100 microgram/m³ (Schwartz et al., 1991; Schwartz and Dockery, 1992a, 1992b; Dockery et al., 1993; Pope et al., 1991). Measurements of ambient aerosol distributions showed a tri-modal pattern as pointed by Wilson et al. (1977) in their road studies. Oberdorster et al., (1995) have suggested that even at low mass concentrations, inhaled single ultra fine

particles (< 50 nm) have a high pulmonary toxicity because of the large numbers of particles involved. This hypothesis was based on the results with ultra fine fume particles and the resultant fume fever (Drinker et al., 1927; Makulova, 1965; Rosenstock and Cullen, 1986; Goldstein et al., 1987; Gordon et al., 1992; Blanc et al., 1991, 1993; Ferin et al., 1992; Oberdorster et al., 1992, 1994).

For ultra fine particles, some have suggested that the total surface area of inhaled particles may be an appropriate measure while others consider the particle number more suitable. In any case it is clear that the mass concentration is not the “only” best way of describing the exposure to insoluble dusts over such a wide size range. In view of the emerging evidence about the importance of particle size in toxicity we must take care not to expose workers to the fine dust particles. Materials such as dusts of low toxicity may become more harmful when delivered to our lungs in the form of fumes or ultra fine dusts. In such cases it may be wise to attempt to control exposure to levels lower than the current gravimetric limits.

2.3.6 Particle Shape

Since the beginning of particle research, scientists have assumed the particle shape to be spherical. Shape of a particle in the majority of cases is assessed by SEM (Scanning Electron Microscopy), which provides two-dimensional views of the particle. A SEM analysis of a particle two-dimensional shape is ambiguous (i.e., particle looking like a sphere could in actually be a particle shaped like a disk or spear). Most of the recent studies have been carried out at the Particle Technology Laboratory in Minnesota in the USA (Marple, Rubow and Zhang, 1997). Breakthrough and development in accurate particle shape recognition would assist the mining industry in a "quantum-leap" with regard to health research if the shape of the particle has an effect on health. It could also be argued that the aerodynamics of sphere and cone type of particles could be much different in terms of its intensity to dust exposure and health impact.

2.3.7 Individual Susceptibility

Although individual susceptibility is not a pathogenic characteristic of a dust particle, the factor plays an important role in the disease. A study by Maclaren et al., (1989) indicated that there was an increased prevalence of PMF amongst men of aesthetic build than any other group. It was suggested that the increased rate of disease reflect the greater respiratory effort exerted by a tall man working in a restricted environment. Increased respiratory effort could lead to increased dust deposition in the worker's lungs. One remarkable response to coal dust pathogens occurred in individuals who have a distinct rheumatoid factor. Caplan's (1960) syndrome, a form of CWP characterized by multiple small lesions, 0.5 to 5 cm in diameter, usually originating in the periphery of the lung, highlighted the importance of immunological responses in the development of CWP.

2.4 Principles Underlying Sampling Procedures for Routine Dust Measurement

2.4.1 Dust Measurement

The measurement of dust in mines worldwide is usually carried out through various air sampling instruments. The collected sample amount is expressed as mass of dust (mg) per cubic meter (m^3) of air or number of particles per cubic meter of air (m^3) and generally referred to as “dust concentration or dust count” in the air. The standard sampling instrument used in the 1950's for dust measurement was the thermal precipitator, and collected dust samples were evaluated by counting the particles under a microscope which was time consuming and was prone to errors. Roach (1958) showed that the chances of deposition of particles on top of one another in thermal precipitator samples can seriously reduce the count by up to 50 % or even more, depending on the number of particles sampled

and their size; thus discrediting the exposure assessment using microscope particle size counting.

The primary purpose of dust sampling is therefore to characterize (with regard to mass and size) the environment of individual workers to evaluate their dust exposure. Other reasons include evaluating the effectiveness of engineering controls and changes in dust levels as a result of process changes, and as a measure of dose in epidemiological studies. The mass of respirable dust inhaled can be determined by sampling.

Airborne respirable dust sampling in mines for personal monitoring is performed using a sampling train consisting of:

- A size-selective device – A two-stage, size-selective sampler which separates the larger particles in the dust and allows respirable particles to pass through the cyclone, where they are collected on the filter to determine concentration levels
- Filters and filter holders - The cyclone assembly is connected to a two-piece 37-millimetre cassette containing a collecting medium which consists of a filter with a 0.5 μm pore size
- A sampling pump - A portable battery-operated pump that will draw air at a specified rate (L/min) for at least eight hours is used as a vacuum source and equipped with flow-compensating features to automatically maintain the desired flow rate as dust loading on the filter increases
- Tubing to connect the cyclone and pump.

To measure the *total or non-respirable dust*, the above sampling train is used without the cyclone.

Using the mass of dust collected on the filters, the sample dust concentration (SC) in mg/m^3 is obtained as follows:

$$SC = \frac{(C_f - C_i)}{(FI) \times (T)} \quad (2.1)$$

Where,

- C_i = corrected initial filter mass (mg)
- C_f = corrected final filter mass (mg)
- FI = sample flow rate (m^3/min)
- T = sampling time (min)

The eight-hour time-weighted average (TWA) concentration of an airborne dust to which an individual is exposed is that average concentration of dust, which a worker would receive if he were exposed to this concentration for 8 h/day or 40 h/week. Therefore, the time-weighted average dust concentration (TWA-8hr) in mg/m^3 is obtained as follows:

$$TWA - 8h = \frac{(SC \times T)}{480} \quad (2.2)$$

Where,

- SC = sample dust concentration (mg/m^3)
- T = sampling time (min)

From the dust measurements at a workplace, exposure of a miner can be determined. Dust exposure can be defined as "the presence of dust in the air within the breathing area of a worker". It is described in terms of concentration of dust in mg/m^3 as derived from exposure measurements and referred to the same reference time period as that used for the limit value."

Worker exposures in terms of the concentration levels of respirable dust obtained from personal sampling must be compared with the Threshold Limit Values (TLVs) to determine whether the amount of dust the worker breathes in during the workday exceeds the limit. This is done by using a single full-shift sample collected with a sampling device that operates in accordance with the NIOSH accuracy criteria (Busch and Taylor 1981) and the international definition of respirable dust (ACGIH, 1998; CEN, 1993; ISO, 1993; Soderholm, 1991a,b; 1989).

2.4.2 Dust Exposure Limits

In order to reduce or completely eliminate the health effects of exposure to dust, several studies have been carried out in the USA, the UK and other European countries on dust exposure limits. These exposure limits provide the necessary guidance for planning, engineering monitoring and controlling the systems and work practices for effective dust control. There are wide variations in the dust exposure limits of major countries and regulatory authorities such as the OSHA, MSHA, NIOSH, WHO and ACGIH. The exposure limits of various countries cannot be compared directly because of differences in each country's measurement strategies. TLVs refer to airborne concentrations of substances and represent conditions to which it is believed that nearly all workers may be repeatedly exposed day after day without adverse health effects. "TLV" is a copyrighted trademark of the ACGIH (American Conference of Governmental Industrial Hygienists) and TLVs are not mandatory Federal or State employee exposure standards. They are updated annually and generally reflect the most current professional recommendations on worker exposures to specific substances. Table 2.2a and 2.2b lists the exposure limits for respirable *coal* dust and crystalline silica (quartz) in various countries.

Table 2.2a: OELs for coal dust in various countries (Source: NIOSH, 1995)

Country	Recommended Value
Australia*	3 mg/m ³
Belgium	10 mg/m ³ / (% quartz + 2)
Brazil	8 mg/m ³ / (% quartz + 2)
Finland*	2.0 mg/m ³
Germany*	4 mg/m ³
Italy**	3.33 mg/m ³
Netherlands*	2.0 mg/m ³
South Africa*	2.0 mg/m ³
UK*	3.8 mg/m ³
USA (MSHA)*	2.0 mg/m ³
USA (OSHA)*	2.4 mg/m ³
USA (NIOSH)*	1.0 mg/m ³
USA (ACGIH)*	0.9 mg/m ³ (Bituminous coal dust)
	0.4 mg/m ³ (Anthracite coal dust)
Yugoslavia***	4.0 mg/m ³

*For coal dust < 5 % quartz; ** For coal dust < 1 % quartz; *** For < 2 % quartz

Table 2.2b: OELs for Quartz dust in various countries (Source: IMA, 2003)

Country	Recommended Value
Australia	0.2 mg/m ³
Austria	0.15 mg/m ³
Belgium	0.1 mg/m ³
Brazil	0.1 mg/m ³
Denmark	0.1 mg/m ³
Finland	0.2 mg/m ³
France	0.1 mg/m ³
Germany	0.15 mg/m ³

Greece	0.1 mg/m ³
Ireland	0.05 mg/m ³
Italy	0.05 mg/m ³
Netherlands	0.075 mg/m ³
Norway	0.1 mg/m ³
Portugal	0.1 mg/m ³
South Africa	0.1 mg/m ³
Spain	0.1 mg/m ³
Sweden	0.1 mg/m ³
Switzerland	0.1 mg/m ³
UK (Maximum Exposure Limit)	0.3 mg/m ³
UK	0.1 mg/m ³
USA (MSHA)	0.1 mg/m ³
USA (OSHA)	10/ (% SiO ₂ +2)
USA (NIOSH)	0.05 mg/m ³
USA (ACGIH)	0.05 mg/m ³

2.4.3 Dust Concentration

In 1956, the NCB (UK) adopted the convention of sampling throughout periods of mining activity but not when production was interrupted. In the light of the problems of dust counting and of measuring fluctuating concentrations, Bedford and Warner (1943), from whose work the 1949 limits for approved NCB conditions were mainly derived, considered that the hazard of exposure would be best represented by the mass concentration of dust particles less than 5 µm. Moreover, they made no reference to peaks of dust production and it appears that their proposals were intended to relate to the average concentration.

The Dust Panel of the MRC, in 1957, expressed the view that mass might prove to be the best parameter for inert dusts and urged the development of suitable

measuring instruments; the 1959 Johannesburg Conference recommended the use of mass for coal and surface area for quartz. Later research indicated that mass may be the more appropriate measure for quartz as well (Goldstein and Webster, 1966).

The Johannesburg curve and the British Medical Research Council (BMRC) curve accept no particles with falling speeds greater than that of a unit density sphere 7.1 microns in diameter, 50 % of 5 micron unit density spheres and 100 percent at very small sizes (Hamilton, 1966). There is no simple relationship between gravimetric concentrations and number counts; indeed, the results reported by Hamilton (1961) show variations in the mass-number index (defined as mass concentrations in mg/m^3 per 1,000 particles (1-5 μm range)/ cm^3 from about 6 to 33. The variations are reasoned to be due to the particle density, shape and state of aggregation of the particles as well as in their size distribution.

In the UK, the MRC's Dust Panel in 1956 and the Johannesburg International Conference on Pneumoconiosis in 1959 put forward the view that the *average concentration levels* to which miners were exposed provide the most important measure of dustiness in relation to pneumoconiosis, but should be supplemented by a measure of variability if possible.

The development of methods of measurement of airborne dust in British mines and the associated problems up to 1966 have been well documented by Walton (1966). The size selective sampling led to the introduction of a number of instruments. For the past twenty years, the introduction of gravimetric dust standards was based on what is seen as being reasonably practicable. The airborne dust standard was based on a standard working week of 40 hours. There is also the possibility of effects of increased exposure time and excessive overtime working as in the case of South African mines (45 hours/week) on health. European studies are largely based on experience in UK mines. However, the reduced dust standard

has undoubtedly contributed greatly to the continuing decline in prevalence of pneumoconiosis.

The significance of peak compared with average dust exposures over longer periods than the shift has been examined by Reisner (1977) who showed that pulmonary changes over 7 to 10 years were only slightly more frequent among miners who had experienced high monthly peaks of dust compared with miners exposed to the same average levels more evenly distributed in time. It was concluded that the differences were too small for definite conclusions to be drawn, but that any peak effect could not be high.

The question whether peaks of dust exposure or the average level provide the best measure of the hazard has been discussed by Wright (1953, 1957). He concluded that the "peak hypothesis" is not supported by any evidence. Walton (1966) concluded of Wright's study that "...*Although it could not be stated with certainty that the "average" hypothesis is perfectly correct, it was simple and reasonable and did not conflict with anything known about the mechanism of dust inhalation and retention..*".

Later, in experimental studies using rats, one group of which was exposed to dust for 20 hours per day and the other to a concentration 10 times greater for only 2 hours, Wright (1953, 1957) found little difference between the amounts of dust accumulated in the lungs. In fact, the amount was slightly but perhaps not significantly greater in the animals receiving the 20 hours exposures. Interestingly it could not be ascertain if exposure to high dust concentrations for more than 2 hours will result in the similar effect.

Based on the studies of Trapido (1999), it can be concluded that face workers are apparently showing high levels of pneumoconiosis compared to the workers with the supervisory roles in South African mines. The most probable explanation given was that the face mineworkers are intermittently exposed to very high dust

levels that overwhelm the lungs' dust clearing mechanisms (Trapido et al., 1998). One possibility to be considered in this connection was that periods of high dust concentration might coincide with periods of high work rate and consequently with larger volumes of air breathed. It can also be reasoned that workers in a supervisory role are often away from the face area and obviously are not exposed to frequent peak dust exposure levels. This has been studied by Hadden et al., (1966), whose results indicate that exposures obtained by summing the products of concentration and respired volume for successive short periods throughout the shift may sometimes exceed the product of mean concentration and total respired volume by as much as 20 %. Hadden et al., (1966) showed that a man doing heavy work at the face area may breathe up to 5 times more air in a shift than a man doing light work at the pit bottom. The effect of these differences on the amount of dust retained in the lungs is not fully known; a diminution in the time of residence of air in the lungs may, in part, compensate for increased volume breathed.

After the research in the 1960's, it was accepted that dangerous particles are those with particle sizes smaller than 5 μm diameter. However, the lower limit for such conclusions was not defined. It can be easily hypothesized that dusts may become more harmful when delivered to our lungs in the form fine dusts. In such cases it may be prudent to attempt to measure the fine particle concentration and control exposure to levels lower than the current limits for size specific criteria. Some of the recent scientific evidence concerning the hazard from very small particles argues that it may not be appropriate to ignore a specific effect of these on worker's health. The size distribution of lung dust samples from cases originating from the western area of South Wales coalfield were observed to be slightly finer than those from the eastern South Wales coalfield area. The difference can be explained on the basis of the higher specific gravity of coals from the western area resulting in a decrease in the respirable size range of particles produced (Walton, 1966).

2.4.4 Sampling (Measurement) Methods

Several sampling strategies have evolved over the years and the sampling methods (viz., personal, occupational, area or environmental and engineering) are defined as follows:

Personal Sample: A personal sample is the dust sample collected in the breathing zone of a worker while performing occupational duties during a work shift. In this sampling method, the worker wears the sampling train (cyclone, pump, tube, sample filter) for the entire shift.

Area or Environmental Sample: An area or environmental sample is the dust sample taken at a fixed location at the workplace in an environment or area of interest. The dust sample reflects the concentration in the area of interest and does not necessarily reflect the exposure of any worker in that area.

Occupational Sample: An occupational sample is the dust sample taken during a work shift on individual workers who perform duties in a designated occupation. This method of sampling measures the dust exposure for defined occupations as if one person performed the duties in that occupation for the working shift.

Engineering Sample: An engineering sample is the dust sample taken at a fixed point in the working area. The engineering sampler is switched on at the face area at the beginning of the shift where the cutting machine is standing and is switched off before leaving the face area at the end of the shift. The engineering sample will determine the effectiveness of the dust control and ventilation systems in the section as well as the management of the overall dust control and ventilation systems.

A study has indicated that personal sampling provides the best estimate of worker exposure and the temporal and spatial variability in those exposures (Vincent,

1994). In nearly all the studies where personal and area sampling were compared with clinical measures of occupation-related adverse effects, the personal exposure measurements provided the best correlations (Stopford et al., 1978; Linch et al., 1970; Linch and Pfaff 1971). Also, the personal exposures are frequently higher than the exposures measured by area sampling (Niven et al., 1992; Cinkotai et al., 1984; Yoshida et al., 1980; Tomb and Ondrey 1976). Spot dust measurements using a real-time measurement instrument are insufficient to determine whether the TLVs have been exceeded (Vincent, 1994). The variabilities associated with the dust samples collected by various methods are discussed in the next section:

2.4.5 Inferences from Global Dust Measurement Variability Studies

Extensive work has been done to identify the factors associated with the variability of measured dust concentrations obtained by various methods. The following studies reflect the extent and the possible reasons identified for the variability:

- A Government Accounting Office (1975) report to US Congress indicated that under certain conditions the error associated with the respirable mine dust samples could be as great as 50 %.
- US National Bureau of Standards (1975) submitted an investigation report to the Senate Committee on Labor and Public Welfare studying respirable mine dust sampling and analysis. The study focused specifically on gravimetric sampling and analysis and examining each step of the sampling process, such as dust weighing, pump flow variation and others. It was concluded that under tightly controlled conditions with a “well-trained” technician, the average standard deviation associated with the process was $\pm 0.39 \text{ mg/m}^3$, or 19 % (at 2 mg/m^3 standard dust concentration).
- NIOSH (1976) found that in high-risk mine sections, which failed to

comply with the 2.0 mg/m^3 standard, the coefficient of variation in dust measurements was 91.6 %.

- The National Research Council in USA (1980) concluded that uncertainties associated with spatial and temporal variations in dust estimates from machine-mounted samplers precluded this method for estimating personal exposures.
- A study by Page and Jankowski (1984) comparing dust measurements of paired RAM-gravimetric sampler results in longwall mining operations expressed as dust concentration ratios of 0.41 to 1.63. The authors attributed this variation to differences in the aerosol cloud being sampled, air flow velocity at the face and cyclone orientation.
- A comparative study of personal and fixed-point (area) samplers by Breslin, Page and Jankowski (1983) reported the coefficient of variation of measured mine dust concentrations to be typically less than 20 %.
- In 1986, a study by Kissell, Ruggier and Jankowski reviewed several factors contributing to the measured dust concentration variability. They concluded that sampler position, geological variation in composition of coal (for variability in measured free silica), production factors such as deep or continuous cutting and failure to control known sources such as shuttle car loading, play an crucial role in dust concentration sample results.
- Sampling and laboratory variability for respirable mine dust concentration measurements was studied using 23 and 20 pairs of dust samples from coal and non-coal mines (Hall, Corn and Zeger, 1997). In coalmines, mine dust concentration ratios (larger to smaller values) exceeded 1.5 in half of the paired samples and 2.5 in 10 % of the pairs. The variability of dust concentration was somewhat less in non coal mines with 50 % of the samples having ratios greater than 1.13. Ten percent of the samples demonstrated ratios of 6.19. Discussions indicated that in coalmines, sampler location was an important contributor to the variability. Machine mounted samples showed an improvement in variability for all measured

parameters. The improvement in variability for machine-mounted samples when compared with personal samples was 40%.

- Parallel measurements taken at a cement plant with Estonian Standard Method (ESM) and Swedish Standard Method (SSM) indicated the differences between two methods. The study illustrated the importance of comparing and evaluating different sampling and analytical methods (Berg, Jaakmees and Bodin, 1999).

From the above studies, it can be concluded that the method of sampling (personal or engineering), sampling location, dust concentration levels (low, medium or high), type of sample dust, can contribute to the variability in measured dust concentrations. This requires thorough understanding of dust sampling, analyses and interpretation of the dust results for exposure assessment as well as for exposure control and prevention purposes.

2.5 Dust Sampling Protocols and Procedures in South Africa and Globally

The instruments currently available and used in South Africa can give the details of respirable and total dust fractions through mass dust concentrations. However, the mineralogical composition, physical properties such as size and shape of particle could be achieved at a later stage in the laboratory. The existing sampler flow rate worldwide ranges from 0.4 L/min to 50 L/min.

Several dust samplers have evolved through the years, viz., cyclones and spectrometers. In the dust spectrometers, the determination of the dust concentration in each fraction was carried out by first determining the particle aerodynamic size distribution for the sampled dust, and then numerically calculating the size (frequency) distribution of the fraction of interest. The area

under this curve gives the mass sampled in the fraction of interest, and hence its airborne concentration. Spectrometers need more skill on the part of the operator.

The methods used for mineralogical assessment were usually carried out by infrared spectrophotometry and X-ray diffractometry, which necessitates a greater amount of dust for better assessment. The minimum amount of dust required to carry out a satisfactory analysis depends on the analytical instrumentation (X-Ray Diffraction or Infra Red based) available. For assessing quartz content, current rule-of-thumb, is a minimum of 0.1 mg of mixed mine dust (Vincent, 1997).

The dust measurement strategies in various countries are discussed in the following subsections.

2.5.1 Measuring Strategy in Federal Republic of Germany (FRG)

Earlier information on German dust measurement can be found in an epidemiological study by Reisner (1971). In that study, Reisener (1971) calculated the dose of worker as the summation of the monthly products of average workplace tyndallometric fine dust concentration and number of shifts worked. According to the measuring strategy effective in the FRG since 1954, the respirable dust concentration has to be measured at the location of a working area at which the maximum dust concentrations is expected (Prinz, Stolz and Essen, 1998). The sampling location was generally set up in the tailgate, 50 m from the longwall coal face. Measurements are taken once a month under normal operating conditions.

The measuring strategy in the FRG is based on the following considerations (Prinz, Stolz and Essen, 1988):

- For the people employed in the environment of the measuring point, the measuring result is sufficiently accurate.

- The impact of dust on people employed on the intake side upstream the measuring point is overrated by the “high risk method”
- By overrating higher urgency is attributed to the measures for a prevention of dust impact on the employees.
- One monthly measurement over a five year period is sufficient as the dust load of each miner is determined with sufficient accuracy by 60 measurements in five years.

Control and assessment of dust concentrations by gravimetric measurements was introduced in Germany in 1974 (Morfeld et al., 2002). German regulations, made effective October 1, 1979, call for fixed-point measurements to be made at coal faces, intake airways, auxiliary ventilated roadways, and other places. Measurements were made during the presence of miners in the workplace, during coal mining, and in stone drivings. A measurement point is installed at the point of maximum dust concentration within each working area, and samples are collected when both geological and mining operations are normal.

Samples are collected once every seven days in areas of very high concentrations, greater than 9.5 mg/m^3 , and up to every six months in areas with very low concentrations. The new regulations are administered by determining measurement and classification areas. The new regulations have established five dust categories and a weighing factor for each category. The coal dust and quartz dust provisions and weighing factors are summarised in Table 2.3.

The enforced (Morfeld et al., 2002) maximum dust level using stationary sampling was lowered from 13 mg/m^3 in 1974 to 8 mg/m^3 in 1992 and the personal long-term dust limit was lowered from 10 mg/m^3 to 4 mg/m^3 (assuming 220 shifts worked underground per year).

Table 2.3: Dust and quartz limits under German regulations (Source: Saltsman and Costantino)

Category	Quartz concentration, < 5 %		Quartz concentration, > 5 %		Factor*
	Dust limits, mg/m ³		Quartz limits, mg/m ³		
0	< 2.5		< 0.125		0.8
1	2.5	5.0	0.125	0.25	1
2	5.0	7.5	0.25	0.375	2
3	7.5	9.5	0.375	0.475	4
4	9.5	12.0	0.475	0.60	5
Forbidden	> 12.0		> 0.60		-

* The factor is multiplied by the number of shifts for the cumulative dust index.

If quartz is less than 5 %, then the dust concentration is the controlling factor of the category; if quartz is greater than five percent, then the quartz concentration defines the category. The factor obtained from the above table and the number of shifts is used to compute the cumulative dust exposure value. Maximum levels for different medical classes are shown in Table 2.4.

Table 2.4: German Dust Exposure Value by Medical Class (Source: Saltsman and Costantino)

Medical Class	Description	Dust exposure value for 5 years (Factor*shifts)
1	No pneumoconiosis	2500
2	Some pulmonary changes	1500 (group includes all people less than 21 years old)
3	Severe pulmonary changes	Forbidden underground
4	Other health problems	2500

The enforced maximum face value (stationary) was lowered from 13 mg/m³ in 1974 to 8 mg/m³ in 1992 and the personal long-term dust limit was lowered from 10 mg/m³ to 4 mg/m³. The 1992 values are still in force (Morfeld et al., 2002).

2.5.2 Measuring Strategy in Great Britain

In the 1930s, the average measured dust levels in the Welsh coal mines were generally between 200 and 400 mg/m³ and about five percent of the measurements exceeded 1000 mg/m³ of air (Croner's, 1999). The developments in coal breakage techniques, the principle of deep cutting, improvements in design, effective methods of applying water to deal with dust at source and ventilation methods have led to reductions in dust concentrations. In the UK by the 1960s, more than 55,000 miners were receiving disablement benefit for their lung diseases. Since then there have been a steady decline in the prevalence of these diseases so that in 1997, there were just 362 new cases of pneumoconiosis and silicosis (Dyer, 1998). The average concentration for all coal faces in 1970-71 was approximately 6 mg/m³ and it has fallen over the following years to approximately 3 mg/m³ in 1990-91.

The British respirable dust regulations were revised several times in the 1970's. In the late 1960's, the National Coal Board (NCB) agreed on an 8 mg/m³ standard at a point in the return 70 meters from the face. This is equivalent to 4.3 mg/m³ average on the coal face. In 1971, this standard was reviewed and continued without change. In 1975, mandatory standards were promulgated, with dust levels set at 8 mg/m³ at the longwall faces and 6 mg/m³ for headings based on measured dust concentrations and progression of CWSP (Jacobsen et al., 1971).

In 1976, the standards were reviewed; and, on a policy basis (non-mandatory), the standard was lowered to 7 mg/m³ on a longwall face. In 1978, the standards were again reviewed, and the permissible dust levels were lowered to 7 mg/m³ at a point 70 meters from the face, equivalent to 3.5 mg/m³ on the longwall coal face,

and 5 mg/m^3 for heading machines. Under current regulations, if the samples collected at the mine in roadways are between 3 mg/m^3 and 5 mg/m^3 , five samples will be collected the following month. For longwall faces, five samples are required the following month if the samples are between 5 mg/m^3 and 6 mg/m^3 . For any samples over 7 mg/m^3 , continuous sampling is required until the samples are below 7 mg/m^3 . In the 1980s, results derived from extended research confirmed the earlier dose-response curve with a small underestimate of risk at lower concentrations (Hurley et al., 1982).

Most of the coal mines in UK are longwall mines. To assess the dust conditions at the workplaces in the face, measurements were carried out using fixed-point sampling located in the return airways approximately 70 m behind the face. The reason for selection of the location was that the results are no longer influenced by the coarse dust or the unequal distribution of the respirable dust in the air. Measurements are taken at monthly intervals for a sampling period corresponding to the time the miners stay at the workplace. At values less than 5 mg/m^3 one measurement per month is sufficient. At values greater than 8 mg/m^3 , the average value has to be calculated from up to five subsequent measurements in one week. The partial deposition of dust between the face and the measuring point is considered by correction factors. Application of the same correction factors worldwide and in South Africa can be questionable due to operating parameters. The development of similar correction factors in South Africa requires different (e.g., multiple or single return airways, velocity etc.,) sets of factors for bord and pillar and longwall mines. Currently, UK dust measurement strategy is under review (Hurley et al., 2002).

2.5.3 Measuring Strategy in Canada

Levels of Respirable Dust Underground: The concentration of respirable dust in the air shall be measured from respirable dust samples taken by a MRDE Cassella 113A respirable dust sampling instrument or an instrument that has been calibrated to duplicate the results of the MRDE Cassella 113A. The concentration of respirable dust in the air underground shall not exceed the following levels:

(a) in a longwall section:

- (i) 3.0 mg/m^3 , measured at any location 70 m from the longwall face in the intake airway, and
- (ii) 6.0 mg/m^3 , measured at any location 70 m from the longwall face in the return airway; and

(b) in a development roadway:

- (i) 5.0 mg/m^3 , where the coal extracted is greater than 70% of the total material extracted, measured at any location at the face of the roadway, and
- (ii) 3.0 mg/m^3 , where the non-coal material extracted is greater than 30% of the total material extracted, measured at any location at the face of the roadway.

A qualified person shall measure and record the concentration of respirable dust in the air at the referred locations at least once every month. The employer shall, once every month, send a copy of these records to a safety officer at the district office.

2.5.4 Measuring Strategy in USSR

The main point in the measuring strategy in USSR mines is the monitoring of dust suppression in the face. When cutting the coal with shearers, the airborne dust

concentrations with sizes of up to 74 μm without pre-separator is sampled directly behind the shearer while coal is cut. The strategy for these dust measurements has the main objective to improve the efficiency of dust suppression measures. The measuring time per measurement equals to a few minutes during the coal cutting process. The measurements are repeated in monthly intervals when concentration values are less than or equal to 10 mg/m^3 . At higher concentration values the measurement is repeated directly after improving dust suppression.

2.5.5 Measuring Strategy in USA

Most of the US respirable dust standard was based on the experience of British and German regulations. In the USA, the federally mandated respirable coal dust standard since 1969 have been 2.0 mg/m^3 (Tomb, 1988) as measured by a sampler following the BMRC respirable size-selective curve. For this purpose, respirable dust is defined as the fraction of dust recommended by BMRC and adopted by the Johannesburg Pneumoconiosis conference in 1959. MSHA data shows that average dust levels for an 8-hr period in most mines have been reduced from 8.0 mg/m^3 (prior to 1969) to below the current standard of 2.0 mg/m^3 (Black Lung Benefits Annual Report to Congress, 2003).

In the USA, measurement of the respirable dust concentration is by means of “personal dust samplers,” attached to the miners. There are two types of sampling methods, namely personal (breathing zone) sampling and area sampling. The dust samples collected through these processes are called personal samples and area samples respectively. A *personal or breathing zone* sample is collected within a few centimetres of the worker's face for the purpose of determining the concentration of respirable dust in the miner's breathing zone during the workday. *Area sampling* is conducted by placing samplers at strategic locations in the workplace to measure the concentrations of airborne respirable dust in the general work area.

For a better understanding of the exposure levels, the *designated occupation* and *designated area* are also determined (NIOSH, 1995). A *designated occupation* sample is obtained in 'the environment' of the mechanized operation that is exposed to the greatest concentration of respirable dust. A worker in the designated occupation wears a sampler, thus yielding a personal exposure sample. *Designated area* samples are required to be collected at locations appropriate to the dust-generating sources in the active workings. A "designated occupation sampling" is collected by the person wearing the sampler, whereas, "area sampling" is collected by the sampler positioned in a fixed position.

The sampling flow rate for all the sampling devices is 2.0 L/min (± 0.1 L/min), as the sampling cyclone used is a Dorr-Oliver type cyclone. The sampling train is normally mounted on the miners (referred to as personal sampling) prior to the start of the shift and removed after the shift is finished, which is usually 8 hours. Because the 2.0 mg/m³ dust standard is based on measurement data obtained with an instrument that sampled with respect to the BMRC selectivity curve, respirable dust concentrations determined from measurement obtained with the personal coal mine dust sampler must be multiplied by a factor of 1.38 before the measurements are used for determining compliance.

In the USA, there are two programs to enforce the mandatory respirable dust standard, a program conducted by the mine operators in accordance with mandatory regulatory requirements and a program conducted by the Federal government (Tomb, 1997). Under the "operator's program" each operator is required to collect five respirable dust samples from a "designated occupation" bi-monthly i.e., from the occupation in the cutting operation that previous sampling has shown to have the highest dust exposure. For each designated occupation, cutting on consecutive production shifts or on production shifts on consecutive calendar days must be carried out. The dust concentrations of the five samples were averaged to establish the case of compliance or non-compliance for regulatory requirements.

According to the "Federal government's program" to enforce the legislated standard in a bord and pillar section or a longwall , an MSHA inspector will collect a personal sample on at least five miners, viz., one sample from the environment of the CM operator (shearer operators and jack setters for longwall mines), one sample from the environment of the roof bolter operator and three samples from other occupations working in the area such as shuttle car operator helpers and labourers.

If the average concentration determined from the five samples is below 2.0 mg/m^3 but one of the five collected samples is greater than 2.0 mg/m^3 , then sampling continues on all five occupations on subsequent production shifts. Sampling is continued until the average of five samples are less than 2.0 mg/m^3 . No more than five production shifts are sampled. Typical samples selected for quartz analysis are the designated occupation sample, all roof bolter samples and any other sample that may be suspected of having a high quartz percentage.

The "designated locations" are strategically selected so that the environment where miners normally work or travel is monitored for compliance with the respirable dust standard. If at any time it is determined from any of these samples that the respirable dust standard is exceeded, five additional samples are collected either on consecutive days or consecutive production shifts at the site where it was determined that the applicable standard may be exceeded. The dust concentrations determined from these samples are averaged and compliance is determined. The measuring time of each individual measurement corresponds to the shift length, i.e. working time plus travelling time (8 hrs). Currently in the USA, recommendations made on the sampling instrument, coal and silica dust exposure limits and number of samples are being reviewed.

2.5.6 Measuring Strategy in France

According to French regulations, the level of coal dust exposure in each underground working must be measured by static sampling, i.e., positioning the samplers in the return air. The concentrations measured by CIP-10 in a national survey through more than 5000 measurements in 194 job categories showed a TWA of 0.64 mg/m^3 respirable dust. Strategy for sampling is based on five successive days of measurements, eventually repeated following the results dispersion and their extreme values (Zitter, et al., 1998).

For the CIP-10, selectivity matches the BMRC-definition quite well except at small particle sizes where the finest particles are not collected by the porous foam in the final collection stage of the instrument and are lost. Therefore, this instrument would under sample by the amount equivalent to the lost fine particles. In view of disproportionate influence of fine particles, this instrument may be seriously underestimating the true exposure (Vincent, 1997). A similar result has been encountered in South African mines (Unsted 1998). It may be argued that the samples used by Unsted for comparison may have contained ultra-fine particles that would have escaped the sponge-type rotating filter thus giving rise to the discrepancies and under-estimation of dust concentrations. Recently, the CIP-10 dust monitor has been recommended (Kenny, 2002) by the HSE in the UK for “potential underground usage for personal sampling.” However, a study conducted by the Mine Safety and Health Administration (MSHA) in the 1980s indicated that sample collection by the CIP-10 was found to differ from both the ACGIH and BMRC respirable size-selective criteria and as much as 40 % (by weight) of particles smaller than 1.5 microns may pass through the instrument without being captured (Gero and Tomb, 1988). Further analyses of the CIP-10 data from the UK study indicated that it fails to meet the accuracy criteria (Belle, 2002). Similarly, a recent HSE study indicated that CIP-10 failed during the underground

trials because of the transfer of large non-respirable particles to the respirable dust deposit (Mark et al., 2003).

An abstract of the French Regulation concerning coal dust sampling is entitled "Arrêté du 11 Juillet 1995 autorisant l'utilisation d'appareils de prélèvements de poussières" (Arrêté of 11th July 1995 about the use of dust sampler). It describes the dust samplers, which are agreed for determination of dust content.

For an individual use (which is the main requirement and the basis of the regulation) the dust sampler to be used is "CIP-10" developed by CERCHAR (cyclone type, 10 L/min, 280 g weight), which is a portable sampler. For a collective use, measurement is done through a "CPM 3" placed in a fixed position, as this apparatus is too heavy to be handled. This type of apparatus is also a cyclone with a flow rate of 50.0 L/min. It weights 3 kg. It was also developed by CERCHAR around 30 years ago and was manufactured by MSA.

2.5.7 Measuring Strategy in Sweden

The Swedish Standard Method (SSM), which meets criteria for the method 0500 described in the NIOSH manual of analytical methods (NIOSH, 1993) is commonly used in Sweden today. With this method, air samples are collected during a full shift (5-8 hours) on Millipore AAWP cellulose-acetate filters with a pore size of 0.8 microns. The filter is mounted on open-face cassettes (SKC) with a diameter of 25 mm. The sampling rate is 2.0 L/min, which gives a sampling velocity of 0.07 m/sec for the filter. The Swedish method is designed to give one sample during a full shift.

2.5.8 Measuring Strategy in Estonian Countries

The Estonian Standard Method (ESM), a method developed in Russia, has been a practice in Estonia and other former East Block countries since the early 1950's

(Kask and Uibo, 1963; SUSC, 1988). With this method, dust samples are taken for 10 minutes every hour over a full shift of 8 hours. The sampling pump used, Migunov model 822, is a pump developed and manufactured in Russia. The sampling filters used are PVC-fibre filters AFA 201 in a 45 mm diameter cassette. The sampling flow rate is 20 L/min, which gives a sampling velocity of 0.21 m/sec. As described, ESM requires approximately five to eight samples during a full shift.

2.5.9 Measuring Strategy in Australia

Coal mines across Australia are sampled on a regular basis for respirable dust and quartz by officers attached to the Coal Mines Inspectorate. However, no regular systematic respirable dust sampling has ever been carried out at metalliferous mines. The reasons identified were diversity of mining types and geographical separation of mine sites (Bell and Lynch, 1997). Usually collection and processing of the samples were taken by a five-member group. The sampling technique, adapted followed from the Australian Standard 2985-1987 (Workplace Atmospheres-method for Sampling and Gravimetric Determination of Respirable Dust), which itself is based on the MDHS 14 of the UK Health and Safety Executive.

The concentrations of airborne respirable dust that persons may breathe must not exceed the following: (1) A concentration of coal dust of 3.0 mg/m³ of air, and (2) Dust containing free silica exceeding an average concentration of 0.1 mg/m³ of air. If the atmosphere where a person works contains respirable dust concentrations higher than those specified, and it is essential that work takes place, a person working in that place must be provided with a respiratory protection device.

Monitoring of respirable dust concentrations: A mine must have a system to monitor and record the concentration of respirable dust and the concentration of

free silica in the atmosphere of the working environment. The records are to be readily available. Where shift lengths are greater than 8 hours a mine must ensure that the physiological effect of dust on a person is no more adverse than if an 8 hour shift was worked.

Standard operating procedure-Respirable Dust: A mine must have a standard operating procedure to maintain where possible the concentration of respirable dust in the atmosphere of the working environment to within prescribed levels.

Standard operating procedure-Airborne Dust: A mine must have a standard operating procedure for the suppression of excessive airborne dust so that safety is not jeopardized because of reduced visibility or otherwise.

2.5.10 Measurement in Republic of India

The dust measurement strategies and methods followed in the Indian mines (Sharan, 2000) are as follows:

- Every work place within the premises of a mine, which generates or is likely to generate respirable dust, needs to be sampled and the respirable dust concentration must be determined.
- All respirable dust concentrations are measured by MRE Dust Sampler Type 113A or its approved equivalent and this is not cyclone type. The sampling flow rate is 2.0 L/min.
- The frequency of sampling is guided by the Coal Mines Regulation of India. It is stipulated that all work places where respirable dust is generated will be sampled and respirable dust concentration determined every 6 months.
- If any measurement at any workplace shows the concentration in excess of 50 % or 75 % of the permissible exposure limit ($3 \text{ mg/m}^3 - 8 \text{ hr TWA}$ – where the respirable silica is less than 5 %), the sampling interval shall

not exceed 3 months or 1 month, respectively.

- The basic objective of sampling and determination of concentration is to limit the exposure of the persons to respirable dust to an extent that is not harmful to the health. There is a guideline also for the sampling strategy under the CMR which states that the sampler shall be positioned on the return side of the point of dust generation and within 1.0 m of the normal working position of, but not behind, the operator or other worker whose exposure is deemed to be maximum in his working group.
- Based on the results of fixed-point sampling the representative dust exposure profiles for different categories of workers are estimated and as a measure of cross-checking the “Static monitoring” is duly supplemented by “portal to portal personal monitoring” of selected workers whose exposure is deemed to be the representative of their working groups.

2.5.11 Measurement in South Africa

With the worker exposure limits becoming stringent in South Africa, it is increasingly necessary to measure the dust concentrations precisely and accurately to assess the dust exposure, by using personal or engineering sampling techniques. Currently, South African mines are assessing worker’s dust exposure using various air samplers such as the Casella 10 mm cyclone, Gillian cyclones, MSA cyclones, and CIP-10 samplers as designed for monitoring dust and approved by the Department of Minerals and Energy (DME). These operate at a conventional flow rates of 1.9 L/min, except for the CIP-10 in which the flow rate is 10 L/min. The mines are also obliged to submit “engineering samples” to the DME, where the samples were collected at the continuous miner. Until 2002, the DME collected “personal sample data” from each coal mining section every six months for assessing personal dust exposure. It must be noted that these samples were collected and measured by the mines and the data was submitted to the DME.

In most of the South African underground mines, dust samples were required to be collected in accordance with the BMRC respirable convention (BMRC, 1952). However, according to the new ISO/CEN/ACGIH respirable dust curve with a 50 % cut point (d_{50}) of 4 μm (previous 5.0 μm) the recommended flow rate should be 2.2 L/min (Kenny, and Maynard, 1995). The new flow rate confers an immediate advantage in sensitivity since existing South African cyclones sample 16 % less air per minute. At present, no change is being recommended by the ACGIH for measuring respirable dust using a 10-mm nylon cyclone at a flow rate of 1.7 L/min. As a matter of interest, measurement of the size-selection characteristics of the South African cyclones confirmed that they are similar to the Higgins-Dewell designs commonly used in the UK and Europe, and hence for sampling according to the new ISO/CEN/ACGIH respirable convention with a 50 % cut-point (d_{50}) of 4 μm). Figure 2.5 shows the different size-selective curves for dust sampling in mines.

System of Dust Measurements

According to the South African regulation 9.2(2), the employer must establish and maintain a system of occupational hygiene measurements, as contemplated in Section 12, of all working areas where respirable coal dust levels are $\geq 1/10$ of the Occupational Exposure Limit (OEL).

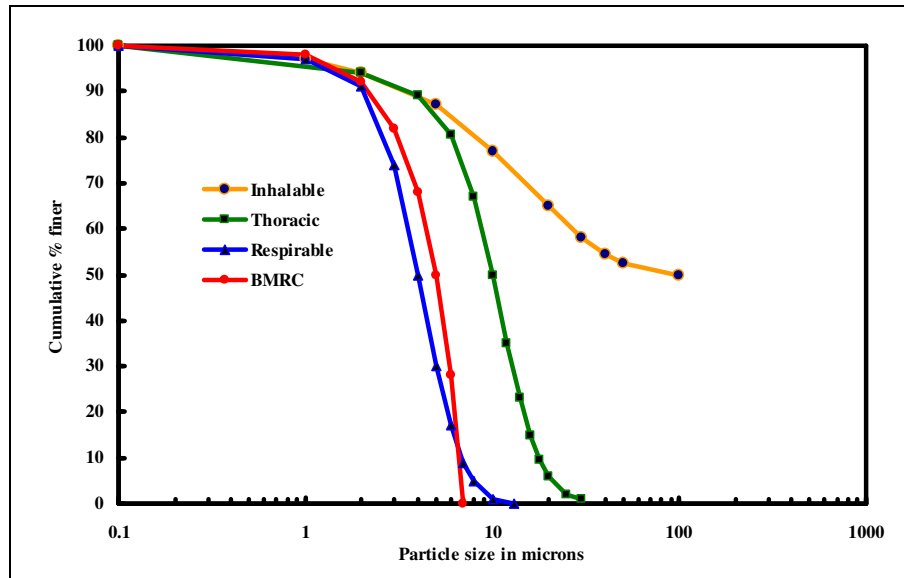


Figure 2.5: Various size-selective curves for dust sampling

Table 2.5 shows the classification band for particulates based on personal exposure level used for assessment. Similarly, the mandatory sampling frequency is dependent on the category rating as classified in Table 2.5. Table 2.6 depicts the relevant frequency per category classification.

Table 2.5: Classification Band Table (DME Codebook, 2002)

	Classification Bands
Category	Personal Exposure Level
A	Exposures \geq the OEL or mixtures of exposures ≥ 1
B	Exposures $\geq 50\%$ of the OEL and $< OEL$ or mixtures of exposures ≥ 0.5 and < 1
C	Exposures $\geq 10\%$ of the OEL and $< 50\%$ of the OEL or mixtures of exposures ≥ 0.1 and < 0.5

Table 2.6: Frequency of monitoring (DME Codebook, 2002)

Category	Minimum Frequency
A	Sample 5% of employees within a Homogenous Exposure Group (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 Homogenous Exposure Group (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 Homogenous Exposure Group (HEG) on an annual basis with a minimum of 5 samples per HEG, whichever is the greater

Air Quality Index (AQI) for a single pollutant such as coal dust is defined as the ratio of the average TWA concentration (mg/m^3) and the threshold limit (OEL) for coal dust (mg/m^3). In order for a specific working area to be within compliance the AQI should be ≤ 1 .

South African Mine Occupational Hygiene Programme (SAMOHP), which includes a system of dust measurements came into effect in the South African mines on September 1, 2002 (DME 16/3/2/1-A3).

2.6 Health Cost

Human health effect studies provide the greatest relevance when assessing effects of exposure to dust; yet they suffer from difficulty in eliminating the effects of confounding exposures (e.g., the effects of smoking and exposure to other environmental carcinogens). In epidemiological studies historical exposure data have often not been well characterized or documented for many substances. These

limitations result in a wide range of estimates of the effects of exposure to dust on the health of the exposed mine workers (Jurinski, 1997).

Recent studies by British scientists and by NIOSH indicate that the risk of developing the most serious form of CWP in US coal mine workers at the present exposure level standard of 2 mg/m³ is higher than had been previously believed. However, the Australians have reported that they have no evidence of CWP at exposure levels greater than the 2.0 mg/m³ standard. While attempts to bring in stringent dust standards in the hope of reduced level of CWP among coal miners is valid, it is important to ascertain the quality of the historic 'dose' in the developed dose-response curves. For example, as noted in the US Federal Register (1995), evidence of tampering with respirable dust samples raises questions about dust exposure levels in US coal mines below 2.0 mg/m³ (Weeks, 2003). The validity of Weeks allegations will be self-evident only with time and with the number of future CWP cases.

2.6.1 United Kingdom

In 1974 British Coal introduced a no fault scheme for pneumoconiosis, which has paid out £165m up to the year 2002. The British government is currently facing an estimated £1bn (\$16 billion Rands) bill to compensate more than 100000 former miners who contracted respiratory diseases (Dyer, 1998). The blame for respiratory illnesses was attributed to the failure by British Coal and its predecessor, the NCB, to control the levels of coal dust in mines. The "abundant evidence" showed that 'officials' interpreted their duties as "requiring the production of coal first and the taking of precautions in respect of health second." The court ruling said that British Coal had failed to take all reasonable steps to minimize the effects of dust by using known and available dust suppression techniques "from about 1949 to 1970 and to a lesser extent thereafter."

2.6.2 United States of America

In the USA, since 1969, there has been a significant reduction in coal mine respirable dust levels. MSHA data shows that average dust levels for an 8-hr period in most mines have been reduced from 8.0 mg/m³ to below the current standard of 2.0 mg/m³. In the last 25 years since passage of legislation to compensate miners and their dependents for black lung, the Department of Labour and Health and Human Services have paid benefits totalling over \$30 billion. The annual cost to the federal government in "Black Lung" disability benefits exceeded \$ 1.7 billion in 1995 (US Federal Register, 1995). Figure 2.6 shows the CWP benefits between 1980-1999 (Black Lung Benefits Annual Report to Congress, 2003).

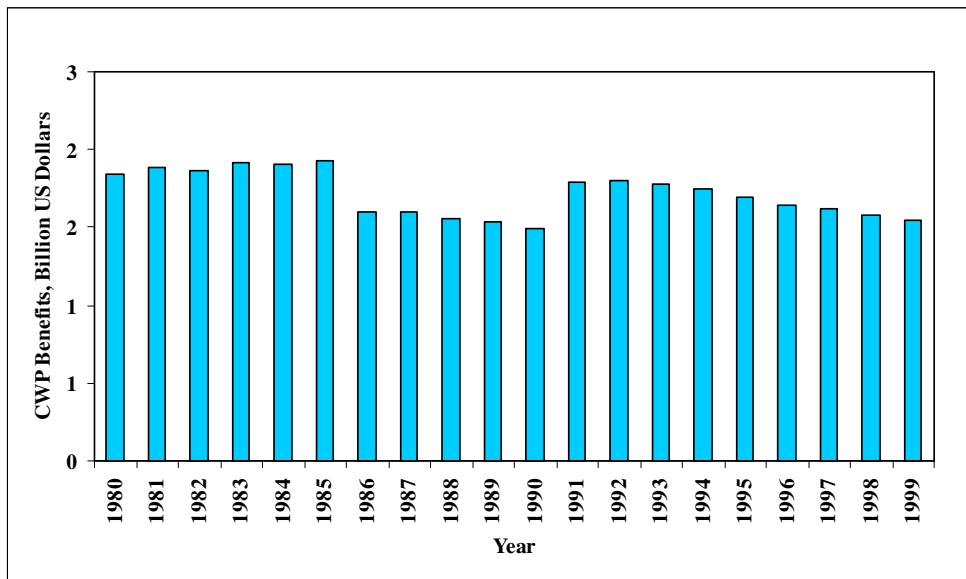


Figure 2.6: US Black Lung Benefits between 1980 to 1999

2.6.3 South Africa

In South Africa, National Council for Occupational Health (NCOH) is responsible for the pathological analysis of a deceased miner's lungs to determine the possibility of the presence of an occupational related disease. The analysis was done at the expense of the State and in accordance with the Mine Health and Safety Act (1996). However, the validity of the analysis is questionable as the historic information relating to any previous medical examinations for occupational related disease and the dust exposures is incomplete. However, the results of the analysis by the pathologist and the information relating to the presence of an occupational disease and the possible grade of the disease can be obtained from the database.

With the advent of the Mine Health and Safety Act, to determine worker exposure, mines are still required to continue with the gravimetric dust sampling program. The following tables (2.7 and 2.8) depict employee exposure levels to airborne particles as well as total compensation paid per mineral category for the respective years.

Table 2.7: Over exposed persons to airborne pollutants during the years 1998-2002

Mineral	No of Mines (2002)	Number of Occupationally exposed Persons Employed (2002)	Number of Occupationally Exposed Persons (2002) Exposed to An AQI \geq 1.0	% Persons Exposed to an AQI \geq 1.0				
				2002	2001	2000	1999	1998
Gold	52	109843	5213	4.75	6.65	6.62	4.92	7.37
Platinum	15	80221	134	0.17	0	1.03	1.09	0.80
Coal	73	37178	7374	19.83	28.92	30.94	25.1	34.3
Asbestos	0	No operating mines – All mines closed -						
Other Mines	140	18523	1196	6.46	4.40	4.23	5.65	13.9
TOTAL	280	245765	13917	5.66	6.94	8.52	6.14	9.01

**Table 2.8: Total compensation paid for pneumoconiosis during the years
1997-2001**

Mineral	Year and Total Compensation Paid in Rand (in millions)				
	1997	1998	1999	2000	2001
Gold	27.52	30.011	49.118	82.689	104.504
Platinum	1.241	-	0.758	2.678	2.504
Coal	1.407	-	1.563	1.933	3.291
Asbestos	10.09	-	9.916	25.537	24.182
Other mines	2.817	14.604	3.841	9.070	8.115
Total	43.08	44.615	65.196	121.907	142.596

2.7 Underground Visibility and Dust Levels

With the already poor visibility conditions underground, high dust concentration levels at the face further adds a further risk factor. Poor visibility conditions further reduce machine operator's judgment in cutting the roof bands, which may result in ignitions causing methane and coal dust explosions. Decreased visibility interferes with safe operation of the mechanical miner and is also a problem for operators of all mobile machines.

Reduced visibility in an underground face area is one of the immediate effects of fine dust generation, and the scattering of light by coal dust particulate matter, which is responsible for that reduction. Particles in the range of visible light (0.38 to 0.76 microns) are the most effective in visibility reduction (Peavy, Rowe and Tchobanoglous, 98).

Assuming coal dust particles in the underground face atmosphere are of uniform size (which is not true) and that scattering alone accounts for light attenuation, the following mathematical formula was derived to relate visibility with particulate matter concentration (NAPCA, 1970):

$$V = \frac{5.2 \times \rho \times r}{K \times M} \quad (2.3)$$

Where,

- V = visibility in m
- ρ = density of particle, mg/m³
- r = particle radius, micrometer
- K = scattering area ratio, dimensionless (not available for coal mining conditions)
- M = face area dust concentration in mg/m³

No information is available on the scattering ratio of fine particles for an underground coal mine face operation and therefore visibility as a parameter was not used in this study. However, the parameter can be indirectly used for effective inference of exposure levels based on the face area concentration levels. However, the use of the above equation and its application were not attempted but merely identified that the visibility can be used as a parameter to assess the worker exposure.

2.8 Summary

This chapter summarizes the literature on the historical background to the Coal Workers Pneumoconiosis (CWP), epidemiological research, major pathogenic characteristics of the respirable dust, principles underlying sampling procedures for routine dust measurement, dust sampling protocols and procedure in South Africa and globally, and the health cost of the CWP worldwide. This Chapter

attempts to give the South African coal mining community a global perspective of complex issues on dust sampling, exposure assessment, origin of dust standards, epidemiological studies and cost of CWP. In comparison with the USA, the cost of CWP benefits in South Africa is insignificant. Use of visibility as an indicator in exposure assessment is mentioned. However, this require a detailed research study in developing the scattering ratio of the particles.

Chapter 3 Research Methodology

3.1 Introduction to Dust Exposure Level Index (DELI)

Causal relationship between respiratory diseases and long-term exposure to coal dust particles is well established (e.g., Jacobsen, 1970). The integrated dose of coal dust at time t since the start of the exposure can be expressed in general form (Vincent et al., 1990) as:

$$\text{Dose} = \int_0^T f\{E(t), R(t), G(t)\} dt \quad (3.1)$$

Where,

$E(t)$ is the coal dust exposure history from measured dust concentration

$R(t)$ is a function describing the retention of inhaled coal dust particles in the lung tissue that is documented in lung deposition models.

$G(t)$ is a function describing the time-dependent potency of the coal dust particle to cause harm to the tissue.

Most of the exposure-based epidemiological studies assume that cumulative exposure is a good measure. The drawback of such types of studies is that it requires an accurate knowledge of past exposures of individuals or populations as functions of time over the periods of interest.

However, in the South African case, the historical data are not readily available, so one requires reconstruction of the exposure assessment through various mathematical and probabilistic reasoning. Therefore, the development of a systematic framework of a dust exposure level index, using the currently available data and the probable exposure, would be of great benefit to all the parties

involved. This study is based on engineering, and static dust measurement data in the South African mines and deduces the possible health effects on the worker. This is based on retention of coal dust in the lung tissue of the worker and its known time-dependent effect to cause harm to the tissue.

Practical experiences and various historical methods highlight the convenience of easily interpreting the critical scientific data in a simple and understandable way. The introduction of such indices into the mining industry is not strange to mining people. However, from the pollution and exposure point of view there is no such tool available to-date in South Africa.

In order for DELI to be meaningful to all the affected parties identified in Chapter 1, the following attributes of the collected dust exposure data are important:

- Dust sampling and sampling strategy should be scientifically designed and consistent
- Include the major parameters of coal dust exposure and environment
- Allow to sample different locations for comparison of concentration levels
- Incorporate and communicate the exposure risks
- Represent the section or face air quality in an underground coal mine

3.2 DELI Parameters

Figure 3.1 outlines the parameters that are considered important for inclusion in the DELI. The data for developing an index (DELI) should be based on analysing extensive underground sampling data collected according to the new ACGIH/ISO/CEN size-selective respirable curve and measured in underground production sections.

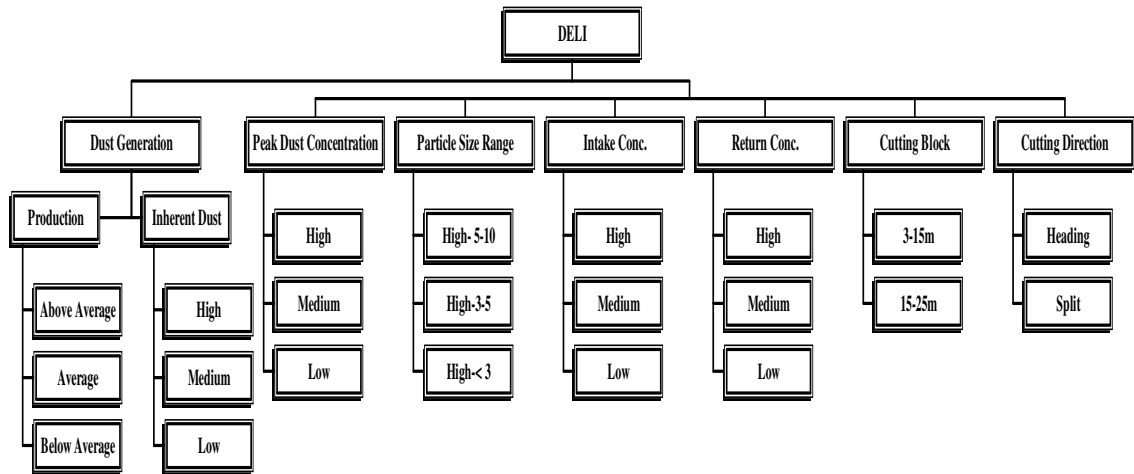


Figure 3.1: Parameters of DELI

Most of the parameters, which will be used in the DELI, are controllable in order to minimize the worker’s exposure to dust. A brief discussion of the identified parameters of DELI is presented below:

Cutting Block (CB): In South Africa, coal mines follow the 12 m rule in bord and pillar CM production sections. Figure 3.2 shows the coal headings and splits divided into various 12 m cutting blocks. In an ideal situation, the CM follows the cutting sequence in the ascending order of cutting block numbers (designated 1 to 14) as shown in Figure 3.2. We can observe that the total length of the split was 21 m, while that of the heading was 30 m. For this study, data on cutting distance block (CB) either in the heading or the split (12 m or 24 m) was analysed for dust levels during coal production.

Cutting Direction: As shown in Figure 3.2, cutting direction is defined as the direction in which continuous mining machine is operating in a bord and pillar production shift, i.e., heading [H] or split [S]. In practice, the length of heading [H] is longer than split [S]. For this study, dust concentration data on cutting direction, i.e., heading or the split was noted and analysed for dust levels during different cutting directions.

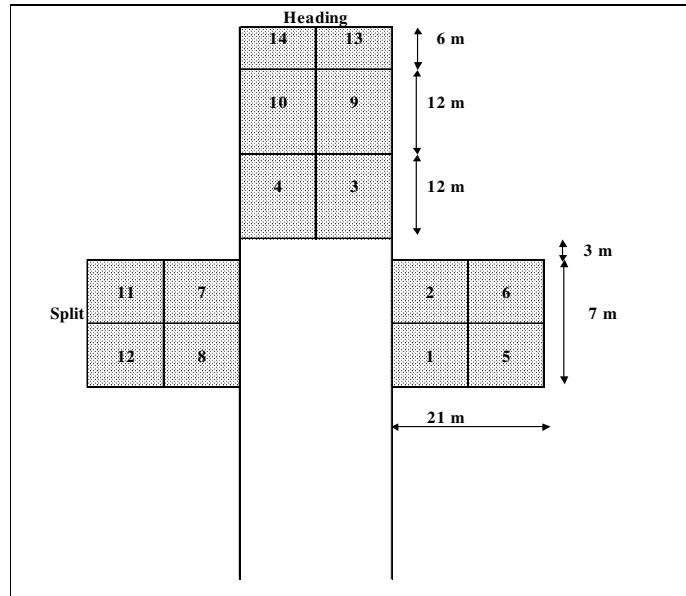


Figure 3.2: Cutting block and cutting direction in a bord and pillar section

Intake Concentrations: The intake dust samples for this study were collected in the section intake roadway of coal mines during the actual production conditions. Figure 3.3 shows the position of dust samplers in the fresh air intake (40 m outbye of the face) of the section. Similarly, the intake dust level in a longwall section was measured upwind of the feeder breaker and samplers were placed in the fresh air roadway to the longwall panel. The levels of dust in the fresh air intake to the coal section can be classified into different levels based on the quality of the air. Intake dust level in a shift is a reflection of minimum exposure to dust for the coal workers in the section with 'zero' coal production. Therefore, the intake dust levels can be an important indicator of exposure to dust.

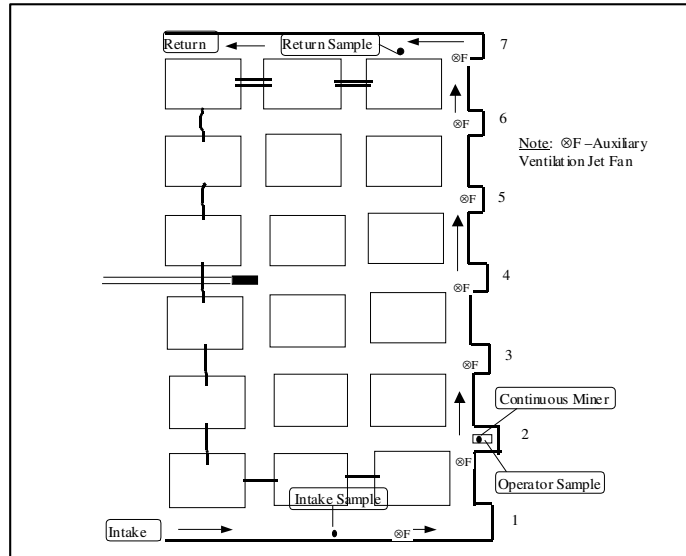


Figure 3.3: General layout of a bord and pillar coal mine

Return Concentrations: The return dust samples for this study were collected in the return (main return) roadway (40 m outbye of the face) of the bord and pillar section of coal mines (See Figure 3.3). Similarly, the return dust level in a longwall section was measured at the main return of the longwall panel. The return dust levels will be later classified into various groups as an indication of efficiency of dust control systems on the machine or amount of possible section worker exposure to dust.

Particle Size Range: Particle size characteristic of the respirable dust was analysed to describe its effect on worker health. The effect of particle size of dust on the human beings exposed to it can be addressed using this parameter. With the advances in the particle characterization technology, the use of particle size as a parameter in assessing the severity of the exposure is becoming a reality. Therefore, particle size is used as a parameter in the DELI assessment tool and is described Chapter 9. For this study, the respirable dust samples were collected from an underground CM section. The particle size analysis on the sample dust collected was carried out using a Fritsch Size Analyser (FSA) at the CSIR Miningtek laboratory. This was a laser-particle-sizer "analysette 22" for fast

automatic measurement of particle size distributions of solids in suspension and emulsions by laser light scattering with a patented convergent laser beam. The technology applied in the FSA laser particle sizer is based on the principle of the analysis of a Fraunhofer diffraction pattern with significantly improved optical components. Size distribution computations were done using Fraunhofer theory and Mie theory (Fritsch GmbH, 1994). The drawback of the existing size analyser is that it requires a relatively large (at least 1 mg of dust) dust sample for size analysis. Therefore it precluded sample concentrations below the 2.0 mg/m³ limit. However, only a few (four) dust samples were attempted for size analysis. The size analyses results were further classified into three different levels based on the size range and its well-documented effects on health. The dust sample size characteristic results are predicted to give an importance of particle size (surface area of particle) and their use as a parameter in DELI exposure assessment tool.

Peak dust concentrations: Peak dust concentration for this study is defined as the real-time dust concentration measured at the CM operator position where the concentration level is a factor of the compliance limit value of 2 mg/m³. Peak dust concentration levels during a working shift are an aspect of environmental health hazard not considered in coal mines due to the limitations in real-time monitoring instruments until a few years ago. The valuable information and knowledge regarding the influence of peak dust levels and their frequency may lead to a better understanding of developing CWP, and its use as both an engineering and an administrative control method.

In order to analyse the effect of peak dust levels on worker exposure in a working shift a real-time full-shift dust exposure survey is necessary. This could be obtained with real-time dust monitoring instruments such as the Hund tyndallometer. The best location to obtain good exposure dust data is the location of the highest dust concentration levels, which in fact is the continuous mining machine operator cabin position. Therefore real-time dust concentration data was

collected for analysis of peak concentrations from various underground mines for the production shift.

In order to analyse the influence of peak dust concentration level and their frequency during a continuous mining operation, each underground shift concentration data obtained from real-time dust monitoring instruments was extracted to incorporate only the period when the continuous mining extraction unit was in operation or cutting. This was carried out using the time-study data collected during each of the cutting shifts. The real-time data recorded the dust concentration levels for every 8 seconds. Furthermore, each of the individual processed real-time shift concentration data was classified according to the various concentration levels in the bin range of 0.0 to 2.0 mg/m³, 2.0 to 5.0 mg/m³, 5.0 to 10.0 mg/m³, 10.0 to 50.0 mg/m³, 50.0 to 100.0 mg/m³, 100.0 to 150.0 mg/m³, 150.0 to 300.0 mg/m³, and 300.0 to 400.0 mg/m³. The frequency-dust concentration data was plotted for dust concentrations, which are below and above the DME directive of 5 mg/m³. From the combined frequency-dust level plot of collected data, trend of peak concentrations and its influence on shift dust concentrations were made.

Dust Generation Rates: Coal dust is a by-product of the coal cutting operation. As the cutting rate increases, the fine dust produced also increases. However, the rate at which the fine dust produced depends on inherent coal characteristics (i.e., inherent dust generation potential) and the method of cutting and cutting tools used during the process, from hand tools to semi-mechanized coal cutting to total mechanization or broadly as 'coal production.' Therefore, mine management must be able to plan the dust control system and continuously maintain the dust control system and the operation of the auxiliary ventilation parameters. However, such planning is expected to cover the maximum production expected during a shift and taking into consideration the inherent respirable dust generation potential of coal.

Coal Production: In recent years, production of coal appears to have been the utmost priority due to the changing expectations of the shareholders. This expectation has resulted in increased production and greater demand in maintaining a better working environment in individual mines. Therefore, coal 'production' can be used as a parameter in estimating the exposure assessment of coal workers to airborne dust. Therefore, production is considered as an important parameter in the exposure assessment of the workers in an underground coal mine. In order to evaluate the relationship between the dust levels and production during the shift, several coal sections operating with different dust control systems were monitored. Also, data gathered from various sections of an operating coal mine was analysed to determine the relationship between dust levels and coal production. Based on the analysis production was classified accordingly as an indicator of exposure level.

Inherent Respirable Dust Generation Potential (IRDGP): Coals are classified into rank in relation to their calorific values and carbon content. High rank coals are of the greatest geological age and consequently have a high percentage of carbon but a low proportion of volatile matter (VM). Conversely, low rank coals have lower carbon content but higher levels of volatile matter (VM). Correlation between the rank of the coal seam in which miners worked and disease incidence and severity is acknowledged world-wide.

Therefore, it is possible to use coal type as an administrative parameter for determining exposure in a coal mining environment by operators to effectively manage the exposure of workers to coal dust. Extensive work has been carried out in the USA by Organiscak and Page (1998) and Srikanth (1997) on the primary dust generation potential of various coal seams. No literature relating South African mine workers with various pneumoconiosis levels to coal rank has been found. Similarly, no study has yet been done in South Africa, to determine the inherent respirable dust generation potential (IRDGP) of various coal seams. Therefore, any correlation found by such a study could be used subsequently to

investigate relationships between the exposure levels and the disease (or risk) rate among various sectors of South African coal miners from a long-time perspective.

The objective of this part of the research study is to contribute to the understanding of the inherent respirable dust generation potential (IRDGP) or dustiness of various South African coal seams operating in different geographical regions. Further, quantification of the amount of inherent respirable dust that becomes airborne, rather than the coal product size in the respirable range is the focus of this study.

Therefore, the inherent respirable dust generation potential test facility was built at the Kloppersbos research facility. Coals from five classified coal seams (1,2, 4 and 5) and region were targeted for sample collection. South African coal seams were numbered according to geological formation (bottom-up). The run of mine (ROM) samples with approximate sizes of 120 mm in thickness were collected from various operating coalmines producing in different provinces representing five different coal seams (where possible). The inherent respirable dust generation potential data was classified into different levels (low, medium and high) and used as an indicator of exposure level in DELI. The details of the test facility, test procedure and the results are discussed in Chapter 11.

3.2.1 DELI Development Method

DELI will be designed and developed as an administrative tool for dust exposure assessment according to a distinctive approach based on the known effects of health on inhalation of respirable coal dust, the dust management principles and latest control technology available to comply with the existing standards. Qualitative limits will be set based on the latest engineering control technologies and the perceived adequate health protection it may provide.

The DELI will be composed of sub-indices of the identified parameters that correspond to the qualitative exposure levels. Appropriate use of this tool is expected to result in achieving the ultimate objective of a clean and healthy underground mine environment for workers. The index has been designed as a flexible tool incorporating a number of identified parameters. However, the flexibility is such that additional parameter can be added in future. The DELI will be providing or directing for some action, based on the level of exposure for a particular parameter and will ultimately be a guide for a better underground environment for the workers. The calculation of the index is envisaged to be relatively simple in that a shift-dust concentration level is transformed into its corresponding sub-index using the DELI calculation procedure through the charts or the formulas using an Excel sheet.

3.2.2 DELI Colour Coding

Due to historic circumstances, the level of literacy standards among the South African mining population is very low. Furthermore, comprehension of statistics, level of understanding, meaning and interpretation of OELs is virtually unknown. Therefore, in order to enable the transfer of the knowledge and the findings from this study a mechanism was developed through appropriate and easily understandable media, i.e., colour coding. DELI colour coding designations to enable the uneducated workforce to understand the situation. The colour reference gradient for acceptable dust exposure levels is started with colour 'Green' and unacceptable dust exposure levels is ended with 'Red.' Obviously only 'Green' is acceptable to work underground.

3.3 Underground Sample Collection

Sampling definitions currently used in South Africa in the field of occupational hygiene and mine environmental control vary widely and therefore the following definitions have been adopted for this study:

Personal Sampling: A personal sample is the dust sample collected in the breathing zone of a worker performing occupational duties during a work shift. With this sampling method, the worker wears the sampling train (cyclone, pump, tube, and sample filter) for the entire shift (bank to bank).

Area or Environmental Sampling: An area or environmental sample is the dust sample taken at a fixed location in the workplace in an environment or area of interest. The dust sample reflects the average concentration in an area of interest and does not reflect the exposure of any worker in that area. The sampling is usually carried out at a fixed location such as at the intake position and section return.

Engineering Sampling: An engineering sample is the dust sample taken at a “pre-determined” CM operator’s position consistently. An engineering sample is the dust sample taken to determine the dust concentration near machinery, tipping points, air filters, etc. to characterize the emission source or suppression effectiveness of dust suppression or control measures. The engineering sampler is switched on at the face area at the beginning of the shift at its pre-determined position and is switched off before leaving the face area at the end of the shift. The engineering sample is therefore not collected for the entire 8-h period since travel time is excluded.

The engineering sample enables determination of the effectiveness of dust control and ventilation systems in the section. Further, this sample is aimed at evaluating both the management (administrative effectiveness) of the dust control measures

as well as the effectiveness of the dust control system (engineering). The South African DME directive of 1997 requires the engineering dust concentration at the CM operator position to be less than 5 mg/m^3 . In this study, the engineering sample was always collected at the CM Operator's position in the cabin.

3.5 Dust Sampling Instrumentation

For this study, the dust measurements were carried out using gravimetric size-selective samplers commonly known as cyclones or gravimetric samplers. The gravimetric samplers consist of an air pump that draws 2.2 L/min of air through a mini-cyclone, which separates the airborne dust and collects only the fraction of respirable dust ($< 10 \text{ }\mu\text{m}$) on a pre-weighed filter disc. At the stipulated flow rate of 2.2 L/min, the instrument conforms to the new USA, UK and European respirable dust curve with a D_{50} of $4 \text{ }\mu\text{m}$. D_{50} is commonly used to describe the performance of cyclones and other particle-size selective devices. The letter 'D' describes the 'diameter' of the sampled particle and the subscript '50' describes the size cut-point of dust that the device collects with 50% efficiency. Particles smaller than the 50% cut-point will be collected with an efficiency greater than 50%. Particles larger than the 50% cut-point will be collected with an efficiency less than 50%. To reach worldwide consensus on the definition of respirable dust in the workplace, a compromise respirable curve between defined BMRC (D_{50} of 5 microns) and ACGIH (D_{50} of 3.5 microns) curves was developed with a 50% cut-point of 4 microns.

The cyclones used in the study were locally manufactured and DME approved (GME 008) and were of the Higgins-Dewell type commonly used in European mines. The samples for the study were collected at section intake (Figure 3.4), section return (Figure 3.5) and CM operator's cabin position (Figure 3.6).

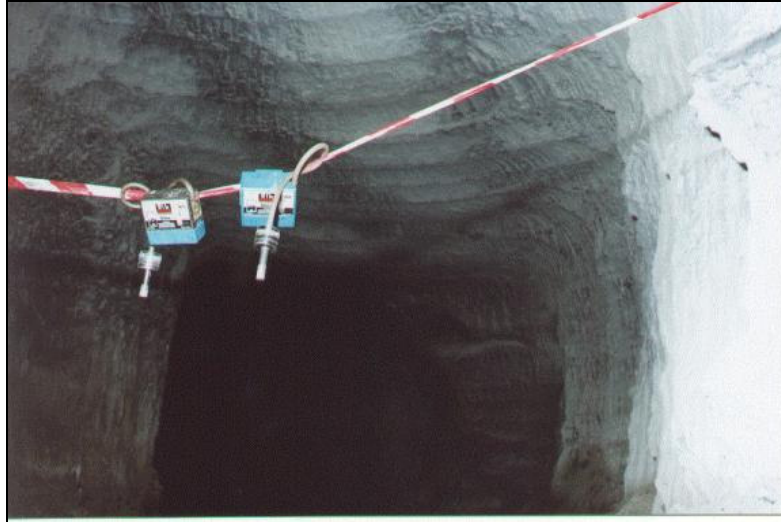
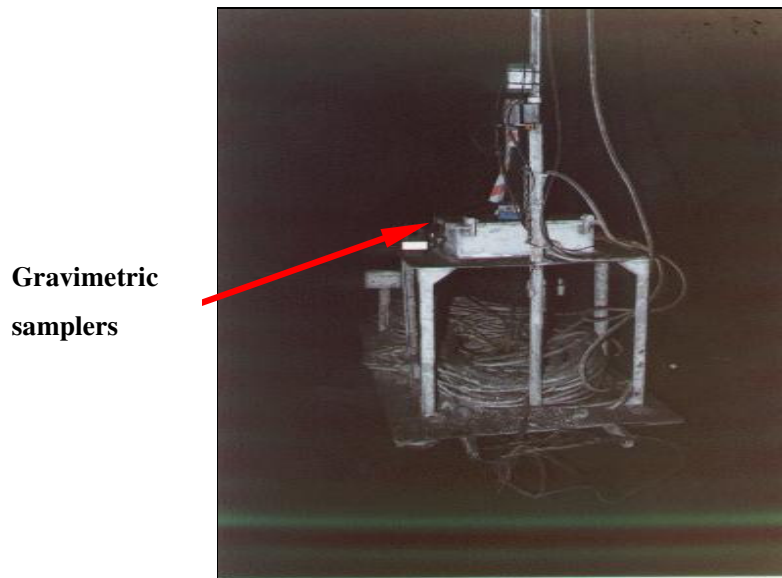


Figure 3.4: View of samplers at the section intake



**Gravimetric
samplers**

Figure 3.5: View of samplers at the section return

For the purpose of this study, the CM operator's cabin sampling set-up contained a pair of gravimetric samplers and a Hund tyndallometer. The dust sample collected at the continuous mining machine operator's position is commonly termed an engineering sample.

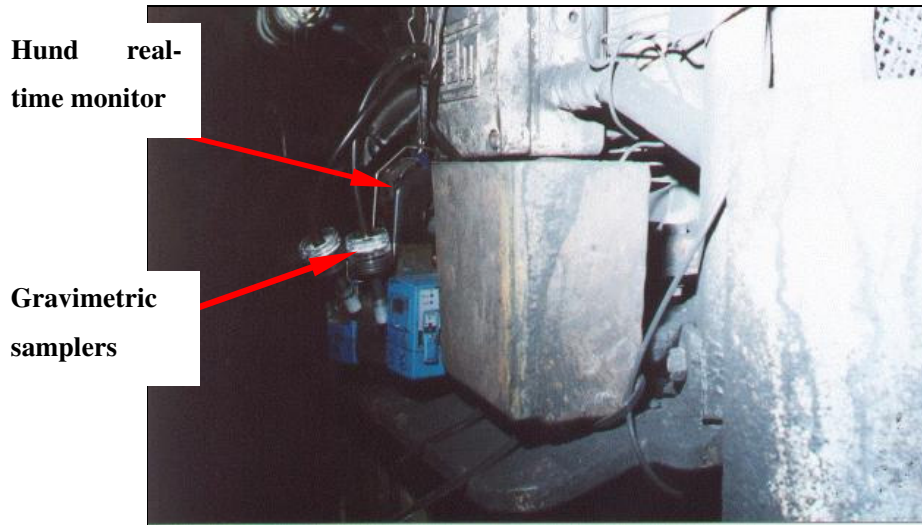


Figure 3.6: View of samplers at the continuous miner (CM) operator position

The average gravimetric respirable dust concentration determined at the operator's position for the sampling period was used to convert the Hund readings to mass concentrations (mg/m^3) to obtain dust concentration peaks (time based dust levels). The dust samples collected underground were weighed and the procedure for determining the particulate mass was followed according to DME guidelines (1994).

3.6 Sampling Procedure

In order for effective underground sampling of dust levels, the following procedure was followed:

1. Before the start of the shift, identified monitoring instruments and sampling pumps were calibrated.
2. All the sampling devices were positioned in the respective areas such as operator cabin, face area, intake and return.
3. Throughout the underground shift, the air pumps and the condition of the sampling train and the activities in the section (humidity and stone dusting,

sprays and mists, presence of diesel operating machinery) were monitored and recorded.

4. The air velocity and the section quantity in the return were monitored.
5. After sampling, the air pumps and real-time monitors were turned off and the time noted down.
6. Finally, the gravimetric dust samples were removed from the samplers for gravimetric analyses. The data loggers from the real-time monitors were processed to download the data onto a personal computer and a software package was used to calculate average dust concentrations during the test periods.
7. After each sampling shift, the dust monitors were cleaned thoroughly.

3.6.1 Data Acquisition

From each of the underground experiments, the following data were collected:

- (a). Air velocity in the section, section details, production rate and operator or personnel position.
- (b). The gravimetric dust samples at specified locations.
- (c). Instantaneous dust concentrations recorded by real-time monitors at the CM operator position.

3.7 Data Analysis Procedure

The dust concentrations presented throughout the study reflect respirable gravimetric dust measurements representing a full production period (from the beginning of the shift to the end of the shift). This production period was never greater than or equal to an 8-h period during any of the test shifts. Approximately an hour of the time was spent on travelling to and from the section to the surface. Real-time dust-sampling results allow the comparison of face-area dust

concentrations under different ventilation and mining conditions. Using the mass of dust collected on the filters, the sample dust concentration is obtained as follows:

$$\text{Sample Dust Concentration (SC)} = \frac{(C_f - C_i)}{Fl \times T_s} \quad (3.2)$$

Where,

- SC = sample dust concentration measured in mg/m³
- C_i = corrected initial filter mass in mg
- C_f = corrected final filter mass containing dust in mg
- Fl = sample flow rate in m³/min
- T_s = sampling time in min

Since the dust sampling was carried out for the entire production period of the shift (excluding travel time), an 8-h time-weighted average dust concentration (TWA-8 h) is obtained as follows:

$$\text{TWA} - 8\text{h} = \frac{(\text{SC} \times T_s)}{480} \quad (3.3)$$

Where,

- SC = sample dust concentration measured in mg/m³
- T_s = sampling time in min

Environmental officers in the mines use the above equation (3.3) to determine the average shift dust concentration levels in South Africa. It is, however, recognised that if the intake air concentrations are greater than zero, the result will change. Since travelling time in dusty conditions is being ignored.

The gravimetric samples collected during various stages of the studies were analysed to determine the airborne dust concentration at specified locations and for parameter of interest. Appropriate descriptions of individual DELI parameters are discussed along with the data analysis of individual parameter in the respective chapters hereafter.

3.7.1 Analysis of Dust Sampling Data

Dust data with respect to the DELI parameters were used to perform an analysis of variance (ANOVA). The discussion of the ANOVA models and their underlying assumptions can be found in Scheffe (1961); Davies (1956); Miller and Freund, 1965. The statistical package MINITAB 13.0 was used for analysis purposes. A full description of the test of the hypothesis method is given in respective DELI parameter chapters of this thesis.

3.8 Summary

This chapter summarizes the various parameters used in the development of Dust Exposure Index Level (DELI). The DELI development method, collection of dust samples underground, dust sampling instrumentation, sampling procedure and analysis of sampling data are also outlined. Details of the data analysis can be found in the individual chapters describing the parameters in this Thesis.

Chapter 4 Historic Dust Concentration Profiles in Underground Coal Mining

4.1 Introduction

Several studies have been carried out in the past decade with regard to total and respirable dust levels in mines. The subject is complex and it is extremely difficult to predict the respirable and total dust levels in the mines. Landman (1992) has reported on the total dust measurements (pot sampling method) in South African mines close to the face i.e., around cutting drums and within 0.2 m of the cutting picks. The sampling flow rate for the measurement was reported to be 5.0 L/min. The particle size analysis reported that particles up to 600 microns in size were captured. Table 4.1 summarizes the results of 14 tests carried out in five collieries for various sampling periods in South Africa.

As a part of the present study total dust levels were measured in an underground CM section at a sampling flow rate of 2.2 L/min. Table 4.2 shows the total dust levels measured 2 m and 4 m respectively from the CM operator cabin. The CM operator cabin is approximately 7 m from the coal face. As we see from the Table 4.2, there exists a steep gradient around the continuous mining machine operator cabin and closer to the face area. The results re-affirm the past USBM study that if you move closer to the dust source, the dust concentration goes way up (Kissell and Jankowski, 1993).

Table 4.1: Total dust levels measured in South African Collieries (Landman, 1992)

Mine	Sampling time, min	Concentration in g/m³
Eastern Transvaal	10	64.38
	20	124.00
Eastern Transvaal	5	2.08
	5	2.08
	3	3.46
Highveld Coalfield-CM	4	1.70
	4	30.39
Klipriver Coalfield-CM	4	2.17
	32	160.00
South Rand Coalfield-CM	5	4.26
	5	7.68
	5	8.98
	5	44.22
	3	61.53

Table 4.2: Total dust levels measured around the CM cutting drums

Sampling Time	2.0 m from CM cabin towards coal face	Sampling Time	4.0 m from CM cabin towards coal face
Minutes	mg/m ³	Minutes	mg/m ³
394	17.12	394	1573.07
241	36.60	395	1929.37
242	39.92	242	91.81
292	10.59	243	2991.21
292	9.37	295	40.45
361	53.26	296	60.50
362	36.17	362	1489.07
424	12.52	364	1733.39
426	11.56	426	1201.66
426	12.22	423	2471.38
424	11.89	422	1156.67

In an effort to determine dust profiles for various operations underground during a working shift several dust measurements were carried out. This was an attempt to understand typical average dust levels as well as the peak dust exposures possible for various job categories underground. Little or no information is available in public on real-time dust profiles for various job categories. The measurements were carried out in different bord and pillar mines. The typical real-time dust concentration levels in an underground coal production shift for various job titles are shown in Figures 4.1 to 4.9 and discussed hereafter.

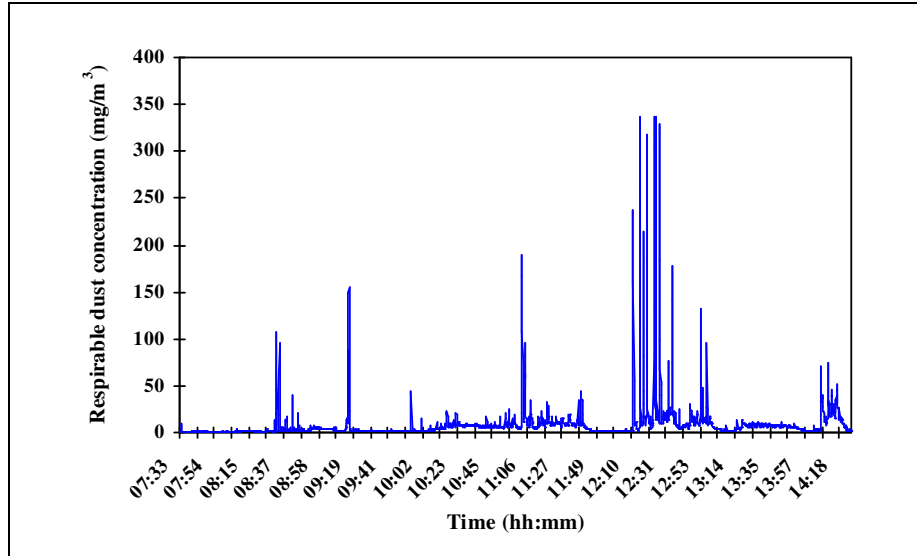


Figure 4.1: The real-time dust levels at the CM operator position

Figures 4.1 to 4.3 show the real-time dust profile measured at the CM operator cabin, section intake and section return in a bord and pillar section in the same shift. The average measured dust level at the CM operator, section intake and section return for the shift was 9.01 mg/m^3 , 1.82 mg/m^3 and 3.26 mg/m^3 respectively.

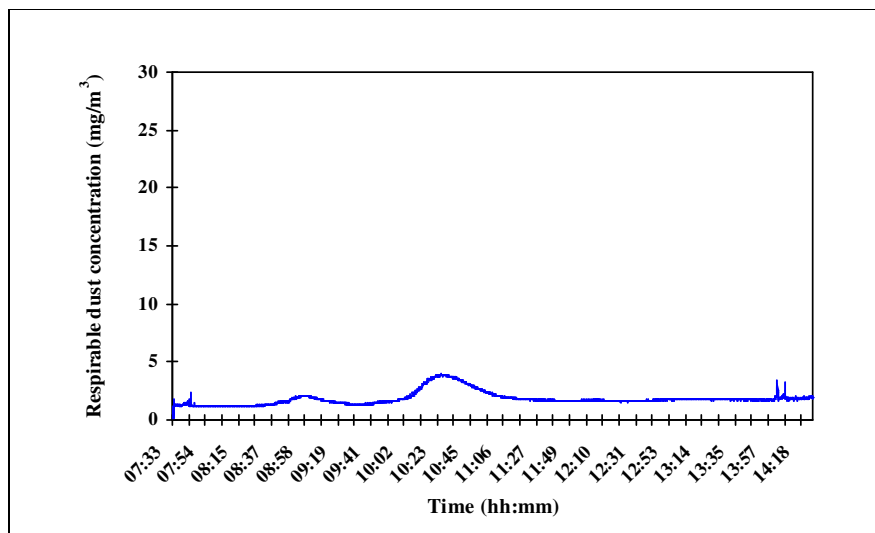


Figure 4.2: The real-time dust concentration levels at the section intake

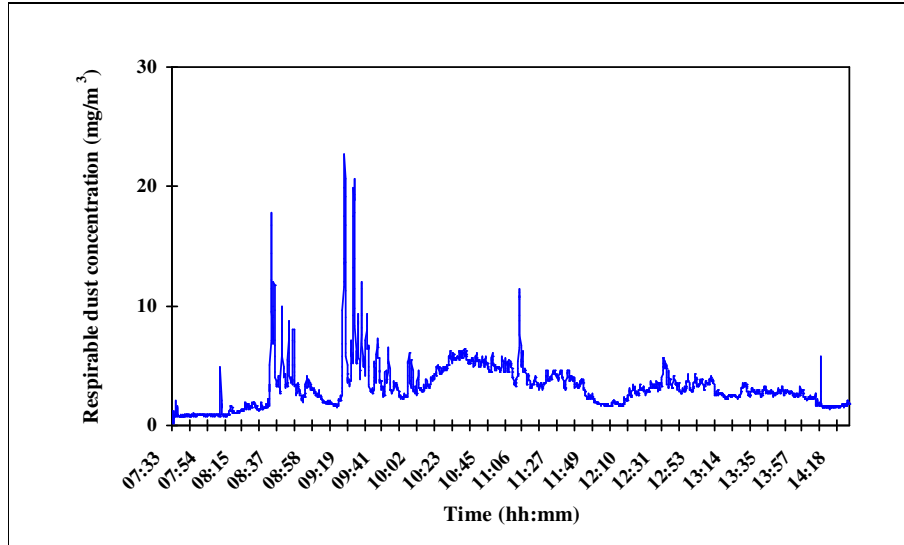


Figure 4.3: The real-time dust concentration levels at the section return

Figure 4.4 show the real-time dust profile measured at the feeder breaker position in a coal mine section for the sampling period. The average measured dust level at the feeder breaker for the sampling period was 5.20 mg/m³.

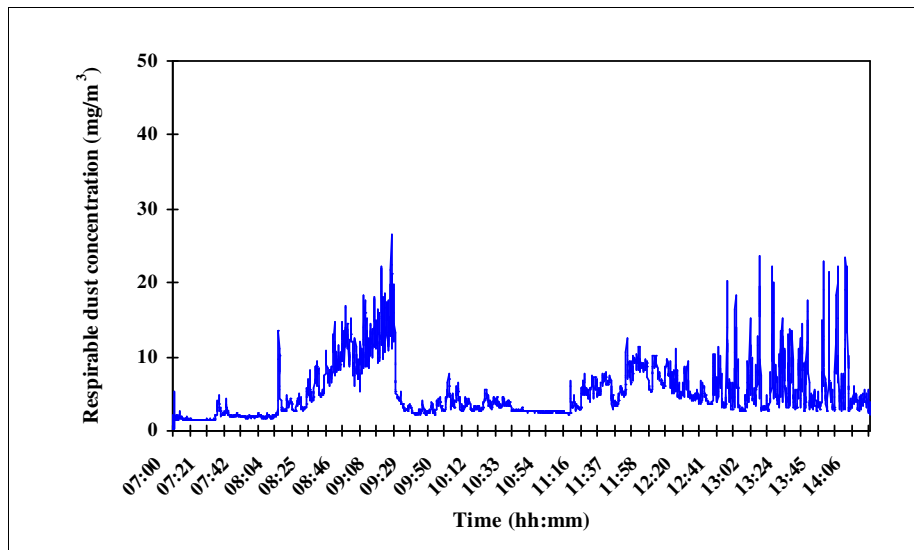


Figure 4.4: The real-time dust-concentration levels at the feeder breaker

Figures 4.5 and 4.6 show the real-time dust profile measured at the shuttle car operator cabin and roof bolt operator cabin position in a coal mine section for the

sampling period. The average measured dust level at the shuttle car operator and roof bolt operator for the sampling period was 0.63 mg/m^3 and 1.08 mg/m^3 respectively.

From the plots of real-time dust levels, we can identify high exposure areas in a section, major dust source identification and quantify the improvements due to newly implemented technologies. It is noted from the above plots that the face worker exposure to dust is the highest of all the occupations in a coal section.

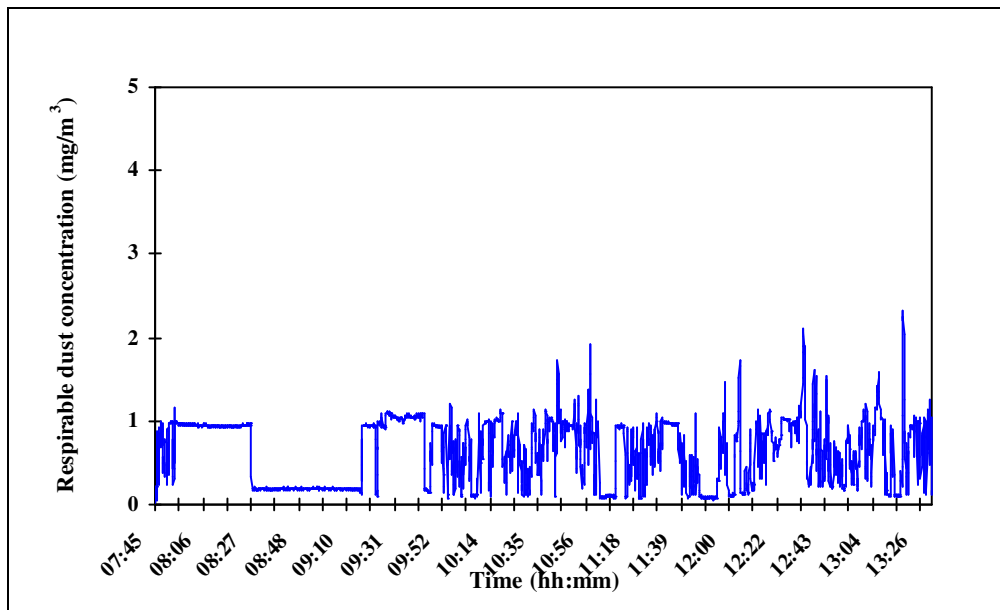


Figure 4.5: The real-time dust concentration levels at the shuttle car operator

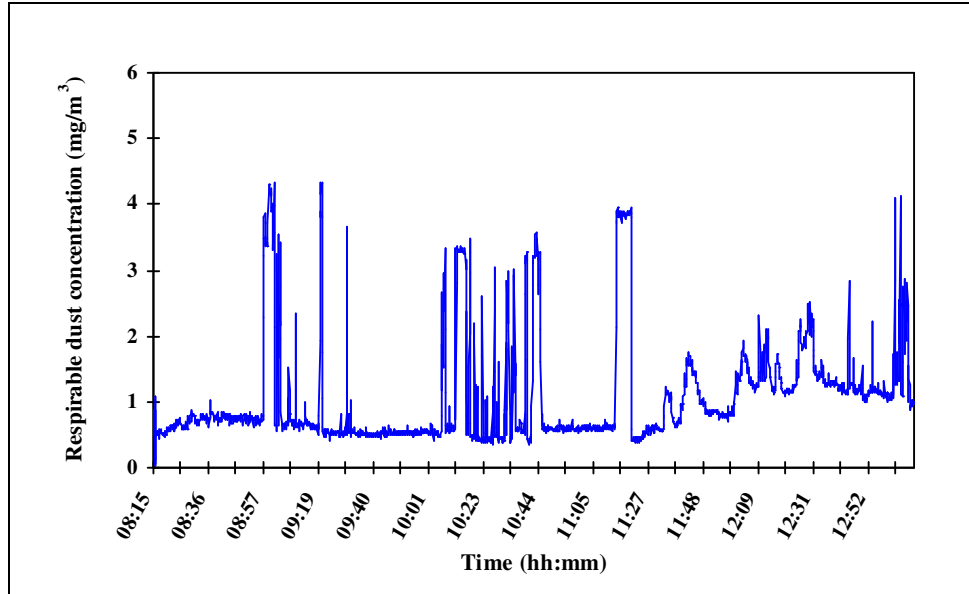


Figure 4.6: The real-time dust concentration levels at the roof bolt operator

Little information is available on dust exposure levels during pillar extraction operations in South African coal mines. Table 4.3 summarises the personal dust levels measured in the pillar extraction panel using a Voest Alpine road header in a coal mine in Kwa Zulu-Natal (Maharaj, 1998). Figure 4.7 shows the measured dust levels at the positions of various occupations. From the results we notice that respirable dust is a serious problem during pillar extraction. The average cutting time for all the measured shifts was 58 minutes with a maximum and minimum cutting time of 135 and 23 minutes respectively. It was assumed that the measured dust levels were for the cutting period. From the plot we note that of all the workers, the Voest operator is exposed to the highest coal dust concentration.

Table 4.3: Measured dust levels in a pillar extraction section (Maharaj, 1998)

Test number	Sampling position, mg/m ³				Cutting time, min.
	Voest operator	Voest cabin	Cable attendant	Shuttle car driver	
1	32.25	30.38	9.82	1.95	112
2	38.54	37.28	11.38	2.48	135
3	23.86	22.19	1.78	1.06	80
4	31.79	31.86	1.46	1.06	98
5	11.41	11.69	12.22	4.01	49
6	19.49	18.36	11.59	1.69	45
7	12.32	11.85	7.65	2.10	33
8	6.26	6.25	5.81	1.74	31
9	11.48	11.49	6.00	2.40	45
10	4.31	4.40	0.72	0.67	37
11	4.20	4.22	2.03	1.34	23
12	3.32	3.32	1.93	1.22	42
13	5.01	4.95	1.87	0.32	40
14	4.91	4.98	3.33	1.01	31

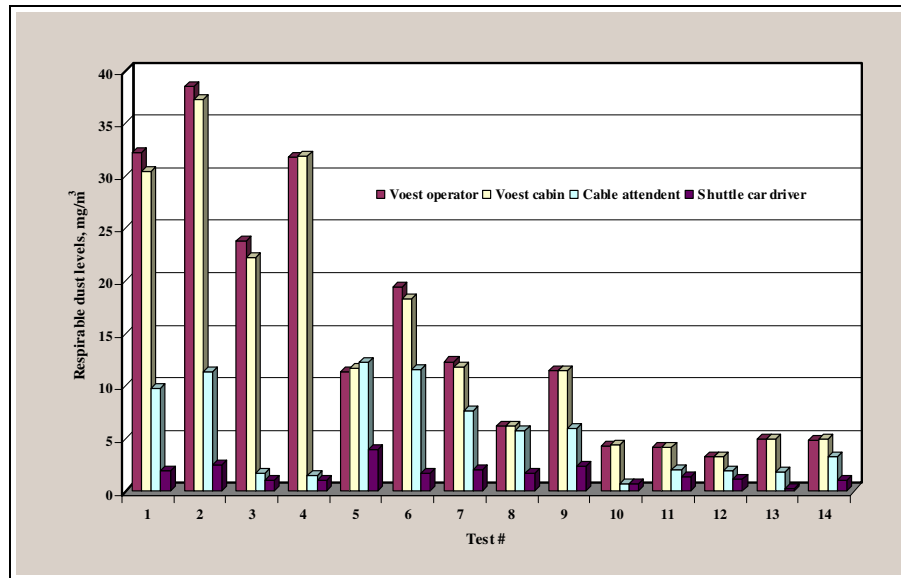


Figure 4.7: Measured dust levels in a pillar extraction section of a coal mine.

4.2 Historic Dust Levels in the South African Coal Mines

Little or no published historical information on dust levels in South African coal mines is available. An attempt was made to determine the dust trends in various types of mining operation and the trends in dust levels from various collieries across South Africa. The dust measurement data from various coal mining occupations were gathered after researching documents available from the Chamber of Mines (COM) of South Africa (Anon., 1990). It was assumed that the dust data were personal exposure values, since engineering sampling was only introduced in 1997. Figures 4.8 to 4.10 show the measured dust levels during conventional, continuous and longwall mining operations respectively, from various collieries across South Africa in 1990. The calculated average of the dust levels of all the dust samples collected during 1990 in conventional, continuous mining and longwall mining operations were 4.42 mg/m^3 , 5.92 mg/m^3 and 3.71 mg/m^3 , respectively. This to be expected as production per shift increase considerably during this changeover. From the data it is noted that the CM

operations made higher dust levels than the longwall operations, probably due to the lack of auxiliary ventilation control devices available at the time. Similarly, during the longwall operations, the measured dust levels were lower than the conventional mining. This can be attributed to effective dust control systems on the shearers and ease of ventilation at longwall faces.

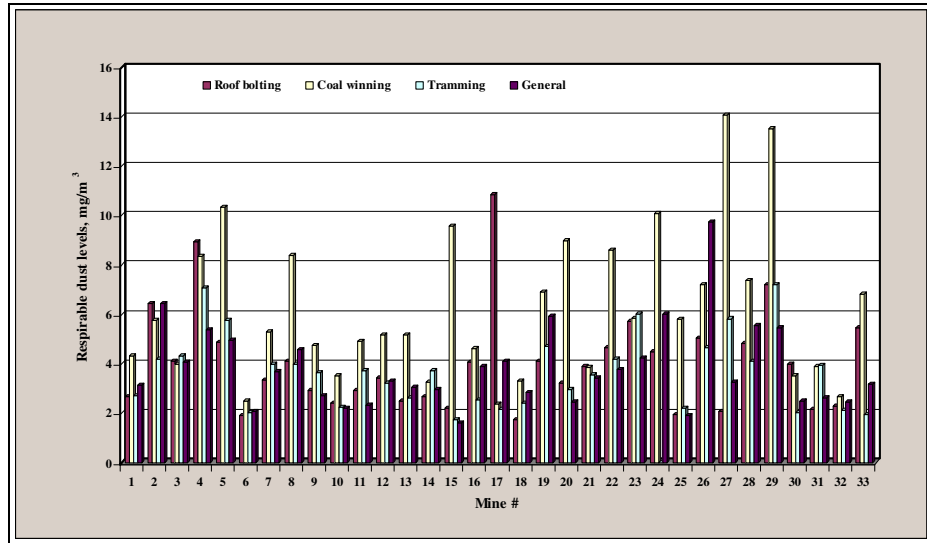


Figure 4.8: Dust levels measured during conventional mining operations

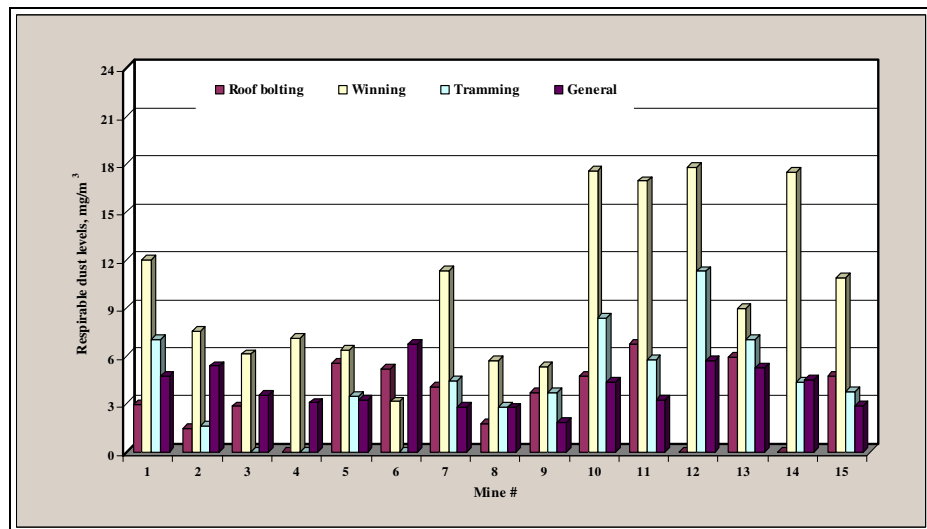


Figure 4.9: Dust levels measured during continuous mining operations

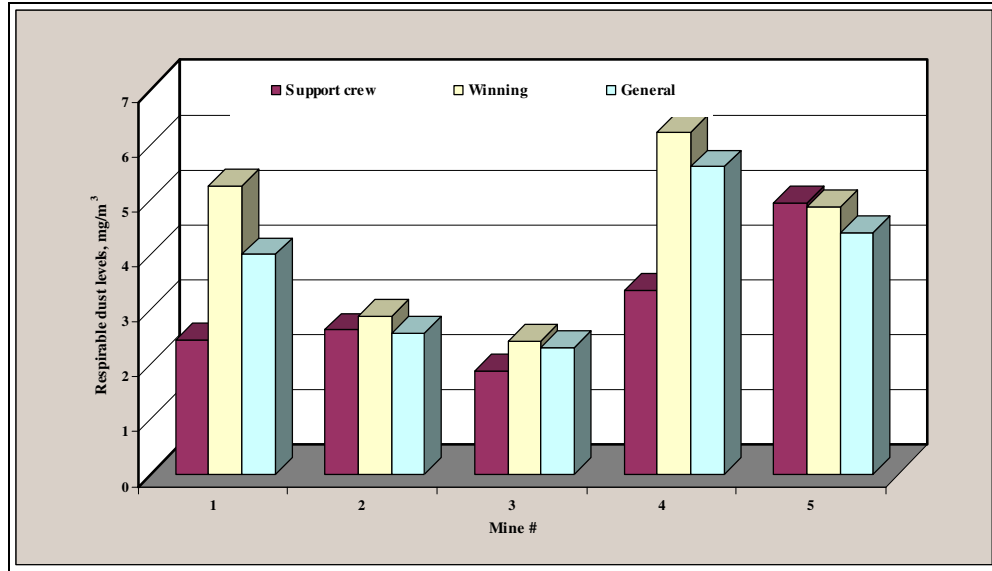


Figure 4.10: Dust levels measured during longwall mining operations

Historic personal exposure data could not be found in the literature and it was reported in 1996 that South African coal mines showed gravimetric dust readings far exceeding the acceptable range- often as high as 120 mg/m^3 (Safety Management, 1996).

4.2.1 Contribution of stone dust in the collected personal samples

The application of stone dust was introduced in the early 1990s in order to reduce the coal dust explosion risks in South African coal mines. Regulations on the application of stone dust to freshly exposed coal face areas came into effect in 1998. However, the implications of stone dusting in terms of personal dust sampling for dust exposure assessment or the effect on sampled data were not studied intensely as stone dust did not appear to pose any significant health hazard, apart from skin irritation. The adopted TWA (8-h) value for stone dust, as published by ACGIH (2002) is 10 mg/m^3 of air provided it contains no asbestos and less than 1% crystalline silica.

As a part of this study, the influence of stone dust on the personal exposure levels to coal dust was determined using personal exposure data. This influence was determined purely on the basis of the real-time dust data and the time study in the section. Currently, there is no accredited procedure for quantifying the presence of stone dust in the personal dust samples collected in the coal mines. The real-time dust level plot of a shift provides markers of high exposure areas in a section, source identification and quantification. Similarly, it is possible from the time study to locate the peak dust levels created by stone dusting during a shift. In many instances, stone dusting is done at the beginning of the shift, thereby contaminating the personal and area dust samples meant for exposure assessment in mines. Figure 4.11 shows the real-time personal dust levels measured in the breathing zone of a research team who were monitoring the dust in a coal mine section.

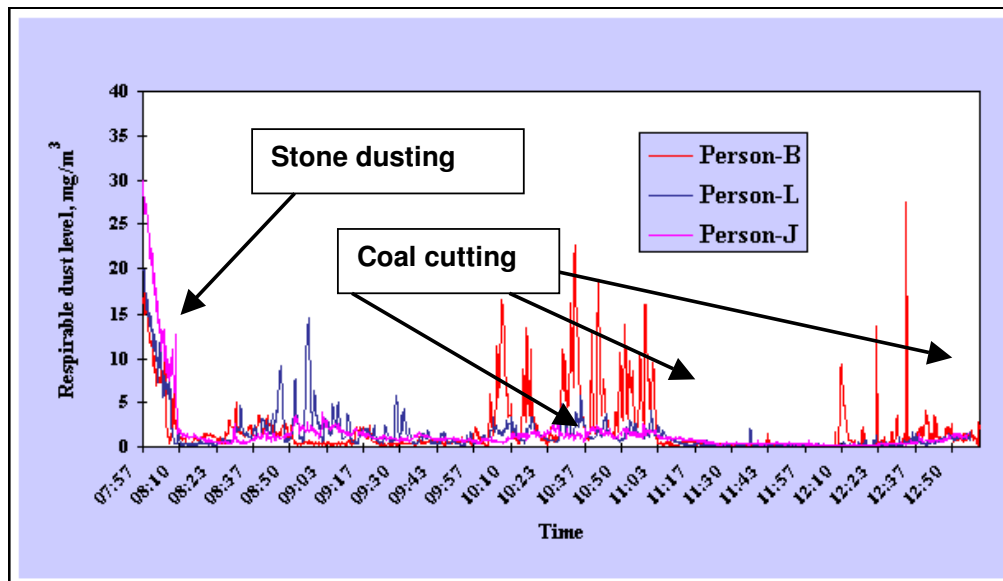


Figure 4.11: Influence of stone dusting on personal dust exposure samples

When the research team entered the workplace (morning shift), the section was stone dusted and the levels were monitored in the waiting place along with those of the section personnel. We can clearly note that the peak stone dust levels (see

Figure 4.11) were close to or higher than the peak coal dust levels monitored during the shift over a longer duration at positions such as waiting places.

The stone dust and coal dust levels derived from personal real-time dust data are summarised in Table 4.4. From the analysis we note that longer exposure to stone dust or contamination due to stone dusting can result in significantly higher non-compliance dust samples. Further, this also may give a “false” indication of the efficiencies of the dust-control systems in the sections.

Table 4.4: Estimated stone dust levels in the personal coal dust samples

Sample type	Parameter	Person B	Person L	Person J
Total sample (coal + stone)	Sampling time, min	303	300	300
	Dust level, mg/m ³	2.05	1.48	1.57
	Dust mass, mg	1.36	0.97	1.03
Stone dust in the sample	Sampling time, min	9	11	12
	Dust level, mg/m ³	10.23	10.56	15.22
	Dust mass, mg	0.20	0.25	0.40
Coal dust in the sample	Sampling time, min	294	289	287
	Dust level, mg/m ³	1.8	1.15	0.96
	Dust mass, mg	1.16	0.73	0.606

From the above analysis of the three personal dust samples, we notice that, on average, 26.43% of the dust samples were contaminated with stone dust (mass basis), with an average exposure level of 12 mg/m³ for a period of just 12 minutes. The amount of stone dust in the dust sample appears to be small, but it must be borne in mind that the actual exposure to stone dust at the waiting place is a *significant underestimation* of the exposure closer to the stone dust source.

4.3 Summary

This chapter briefly summarizes the dust concentration profiles and historic measured gravimetric dust levels in underground coal mining sections at various dust sources. The intention of the dust profiles is to give an idea of peak dust concentration levels, their frequency of occurrence during an operating shift and average dust levels for the shift.

It has been noted that there is little or no historic information available on published dust level data in South African coal mines. An attempt has been made to reflect the dust trends in various types of mining operations and the trends in dust levels from various collieries across South Africa. The data presented may assist in future on developing a CWP dose-response curve specifically for South African coal mines. This chapter summarized the influence of stone dusting in measured dust levels in coal mines. Further investigations are necessary to quantify the amount of stone dust in the personal samples obtained from the mines and their frequency occurrence. In the mean time, any times at which stone dusting is done should also be noted in the dust sample results.

Chapter 5 Cutting Direction and Cutting Block

5.1 Introduction

A Directive (1997) of the South African Department of Minerals and Energy (DME) was sent to all coalmines in South Africa instructing them to reduce the dust-concentration level to below 5 mg/m^3 for the sampling period at the operator's cab position on continuous mining machines. The rationale for 5 mg/m^3 is not established or documented in any of the DME documents. Although no explanations on the arbitrary choice of a 12 m rule, after discussions with industry personnel, it was noted that the rule would also give more safety for roof bolters. Furthermore, the rule was inherited with the intention of reducing personal dust exposures of workers. Further, the directive also specified a 12 m rule to assist effective dust control and minimize the dust exposure of workers. The 12 m rule required the following aspects to be considered (DME Directive, 1997). The directive stated as follows:

1. “No continuous miner (CM) heading must be developed further than 12 m from the last row of permanent support or from the point of auxiliary ventilation; and
2. Only ventilation systems that can ensure, at all times, a maximum dust reading of 5.0 mg/m^3 , measured at the drivers position on the continuous miner (CM), must be employed.”

5.2 Background

The interpretation of the DME directive of 1997 suggested that the continuous miner (CM) cannot advance for a distance further than 12 m before the necessary support is installed and the auxiliary ventilation devices such as jet fan or force

fan are advanced to the required distance behind the CM. Therefore, in a production section, if there is a lag distance between the face and the most forward point of auxiliary ventilation devices such as jet fan or force fan, that exceeds 12 m, then the operation must be stopped in order to comply with the directive. In the event of a CM being operated by a remote control device the limit of the unsupported roof is then the length of the CM. From the perspective of roof hazard prevention, the rule is also favourable to the worker and prevents him from travelling under unsupported roof.

The mining industry's initial reaction was that the 12 m rule would negatively impact on the operation of a CM section, because the CM would be prevented from advancing uninterruptedly for more than 12 m in the same heading. However, a research study conducted by Oberholzer (1998) concluded that the introduction of the 12 m rule, although detrimental to production, would not have a significant enough effect to exclude its use based on productivity constraint considerations. Aspects like the perceived increase of effort to do the necessary support and installation of secondary ventilation are seen as being necessary and part of the work required for extracting coal safely.

The focus of this chapter of the thesis is to carry out a detailed analysis from the perspective of dust control after following the 12 m rule and also to address the question of whether the mere restriction of not mining beyond a distance of 12 m will on its own solve dust problems. The 12 m rule would undoubtedly enhance roof support practice, but its efficacy in keeping dust levels down on its own is less certain. Since the introduction of the 12 m rule directive, it has drawn the attention of the industry's environmental officers to the problem of achieving the required dust concentration results. This chapter describes the measurement and analysis of results for the dust concentration levels in 30 m development headings in CM sections that comply with the 12 m cutting sequence rule and its use in developing the dust exposure level index.

5.3 Test Systems, Data Collection and Analysis

For the analysis of the 12 m rule with regard to its role in reducing dust levels, data was gathered from two bord and pillar CM production sections. For the purpose of this analysis individual headings and splits were divided into various 12 m cutting blocks as shown in Figure 5.1. The CM followed the cutting sequence in the ascending order of cutting block numbers (designated 1 to 14) as shown in Figure 5.1. We can observe that the total length of the split was 21 m, while the heading was 30 m.

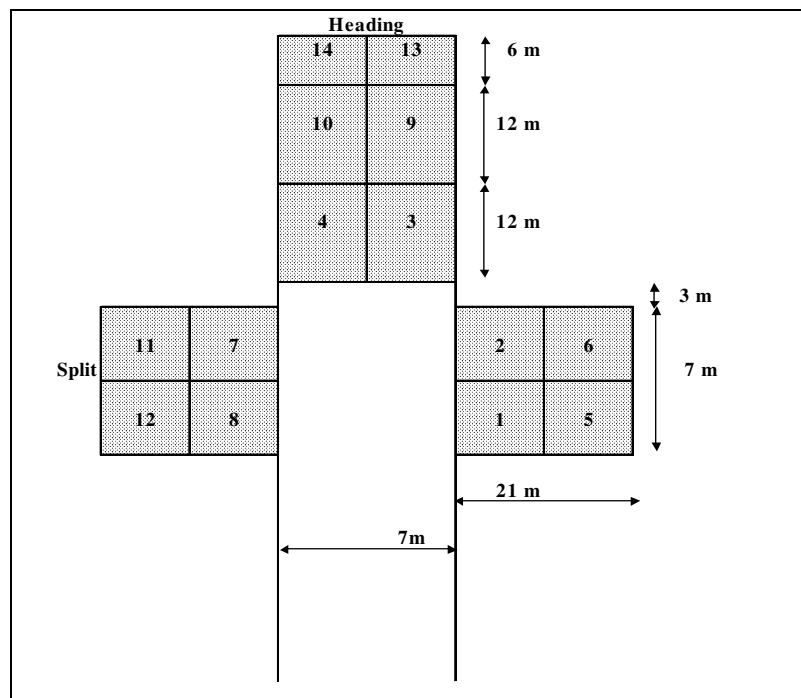


Figure 5.1: 12 m cutting sequence rule in a development underground bord and pillar section

During the underground trials four different dust control systems were evaluated under the 12 m cutting sequence rule. The four different dust control systems were:-half-curtain system, retrofitted hood system, double scrubber system and

integrated hood system (See Appendix-A). Hereafter these systems will be referred to as System 1, System 2, System 3 and System 4 respectively. The four different dust control systems were analysed using the results obtained from over 60 underground sampling shifts, for which the real-time dust concentration data was available.

5.3.1 Dust Monitoring

The dust-monitoring instruments were deployed at the CM operator's cabin position. The respirable dust concentration levels were determined by two gravimetric respirable dust samplers along with Hund tyndallometers. The gravimetric samplers consisted of an air pump that draws 2.2 L/min of air through a mini-cyclone, which separates the airborne dust and collects only the respirable dust (< 10 µm) fraction. In each underground shift, data on cutting block distance (CB) either in the heading or the split (12 m or 24 m), cutting direction (heading [H] or split [S]), and dust control system type were collected.

5.3.2 Data Analysis

The dust samples collected underground were weighed and the procedure for determining the particulate mass was followed according to DME guidelines (DME, 1995). Using the mass of dust collected on the filters, the dust concentration in mg/m³ was obtained at the operator's location. It must be noted that these dust concentration levels are not personal exposure levels but measured at the CM operator's position (cabin). In order to analyse the dust concentration level at the operator during each cutting block (CB) use was made of real-time dust concentration data. From the dust concentration data for the sampling period, the real-time dust concentration data was adjusted using a correction factor. Also, from the time-study data of individual cutting block (CB) during each shift, the dust concentration levels for each CB scenario were determined. The results of the dust concentration levels during individual cutting blocks (1 to 14) were classified

into cutting block (12 m and 24 m) data and cutting direction (H and S) data for four different dust control systems.

5.4 Results and Discussions

5.4.1 Sampling Results

Tables 5.1 and 5.2 provide a summary of the experimental results and show the dust concentration levels for the four dust control systems tested underground. The results were tabulated according to cutting block (12 m and 24 m) and cutting direction (heading [H] and split [S]) respectively. The influence of the test parameters (cutting block and cutting direction) on the dust concentration levels at the operator's position was examined by drawing scatter diagrams for the four different dust control systems.

Figures 5.2 to 5.9 show the relationship between cutting blocks (12 m or 24 m) and cutting direction (H or S) on dust concentration levels for four different dust control systems.

Table 5.1: Summary statistic of cutting block (CB) dust concentration levels (both H and S)

Statistic	System 1		System 2		System 3		System 4		Overall	
	12 m	24 m	12 m	24 m	12 m	24 m	12 m	24 m	12 m	24 m
Mean	4.199	6.371	1.022	1.457	5.464	7.446	8.560	12.632	4.970	6.829
Median	3.420	4.240	0.820	1.110	3.210	6.150	6.320	11.400	3.380	4.680
Variance	7.704	5.566	0.661	0.548	24.608	23.068	50.136	56.299	27.407	40.333
Minimum	0.970	1.240	0.460	0.670	1.390	3.060	2.430	2.070	0.460	0.670
Maximum	12.230	23.450	3.760	3.340	16.510	20.990	31.440	24.240	31.440	24.240
Sample Size	24	27	15	13	12	11	20	13	71	64

Table 5.2: Summary statistic of cutting direction (H and S) dust concentration levels (both 12 m and 24 m)

Statistic	System 1		System 2		System 3		System 4		Overall	
	H	S	H	S	H	S	H	S	H	S
Mean	5.869	4.849	1.400	1.072	7.204	5.685	11.065	8.587	6.807	4.822
Median	3.460	4.340	1.110	0.880	5.410	4.230	9.320	6.660	4.205	3.740
Variance	38.227	4.474	0.800	0.487	26.074	22.722	71.417	25.779	49.280	16.280
Minimum	0.970	2.520	0.460	0.460	3.060	1.390	2.070	3.890	0.460	0.460
Maximum	23.450	10.300	3.760	3.340	20.990	16.510	31.440	17.970	31.440	17.970
Sample Size	25	26	13	15	11	12	21	12	70	65

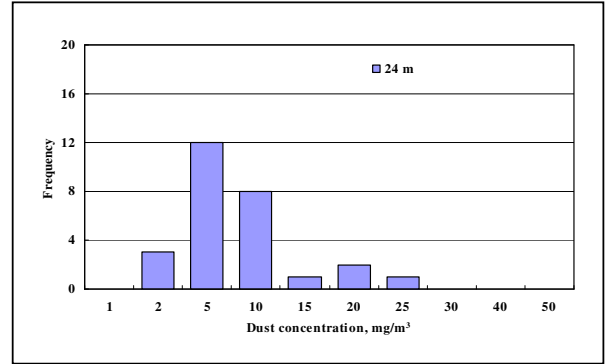
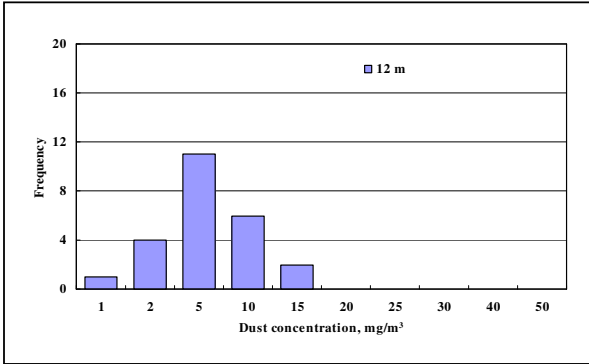


Figure 5.2: Influence of cutting block (both H and S) on dust levels for dust control System 1

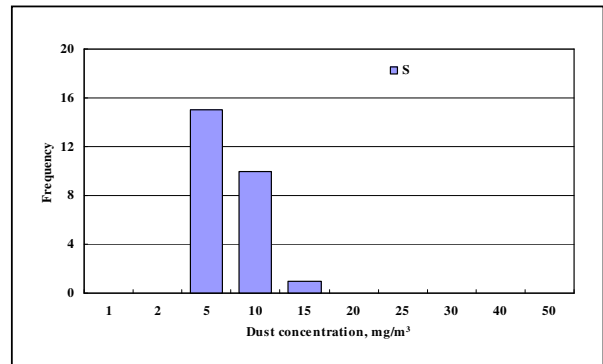
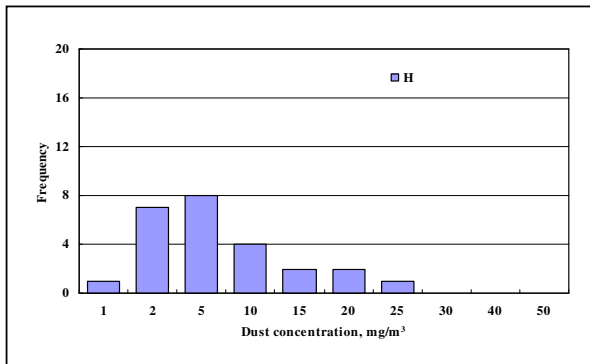


Figure 5.3: Influence of cutting direction (both 12 m and 24 m) on dust levels for dust control System 1

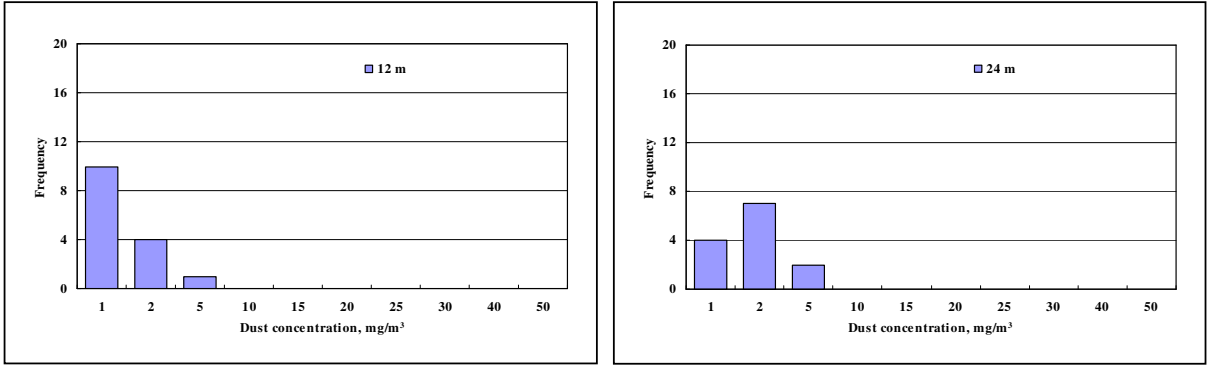


Figure 5.4: Influence of cutting block (both H and S) on dust levels for dust control System 2

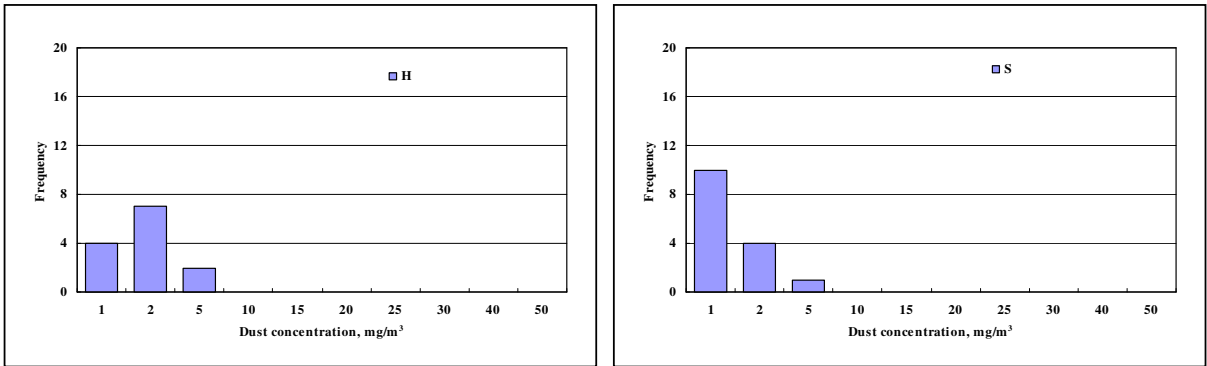


Figure 5.5: Influence of cutting direction (both 12 m and 24 m) on dust levels for dust control System 2

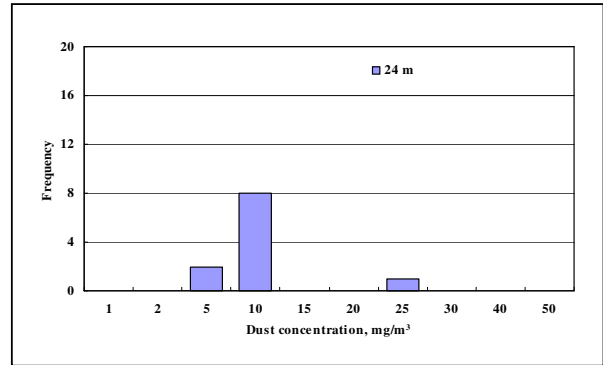
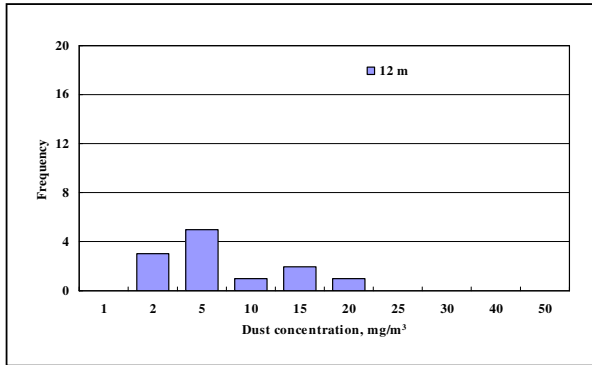


Figure 5.6: Influence of cutting block (both H and S) on dust levels for dust control System 3

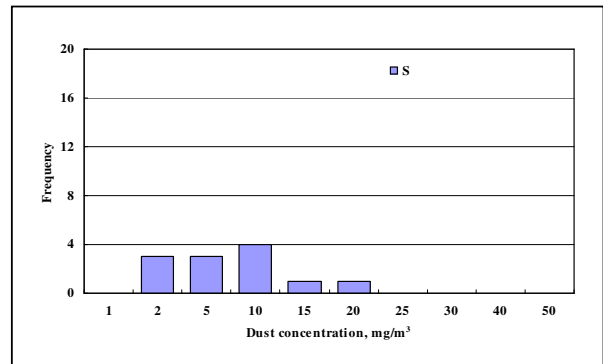
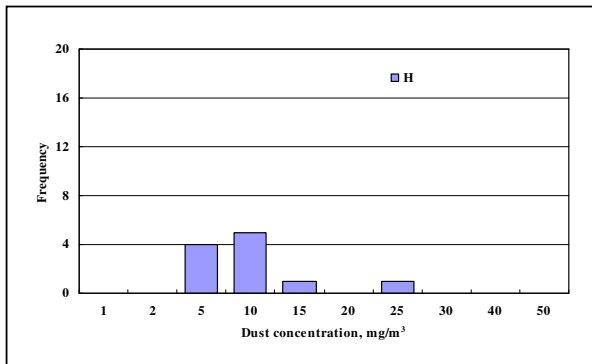


Figure 5.7: Influence of cutting direction (both 12 m and 24 m) on dust levels for dust control System 3

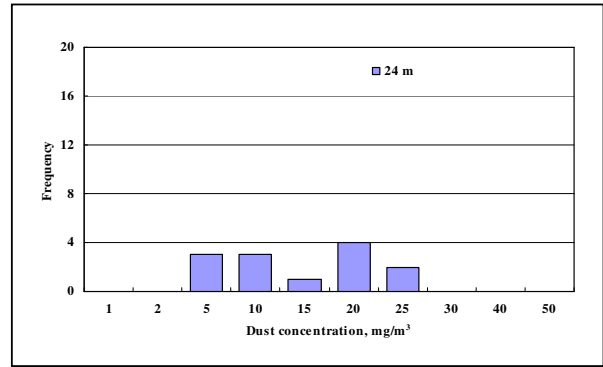
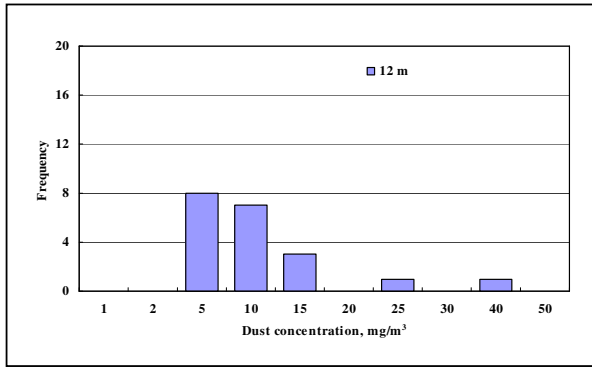


Figure 5.8: Influence of cutting block (both H and S) on dust levels for dust control System 4

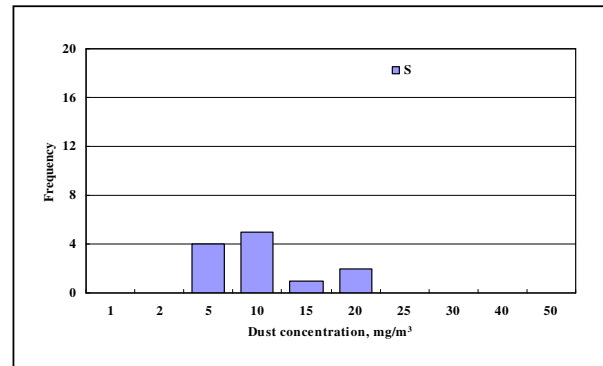
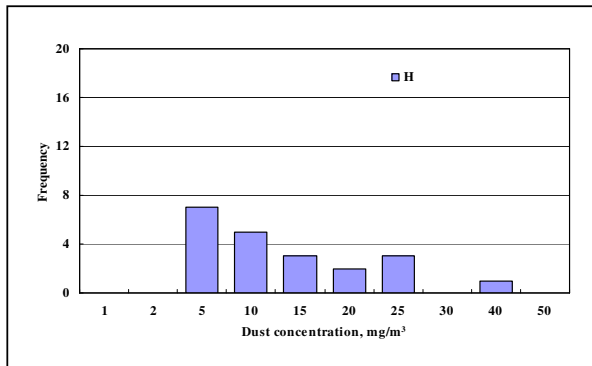


Figure 5.9: Influence of cutting direction (both 12 m and 24 m) on dust levels for dust control System 4

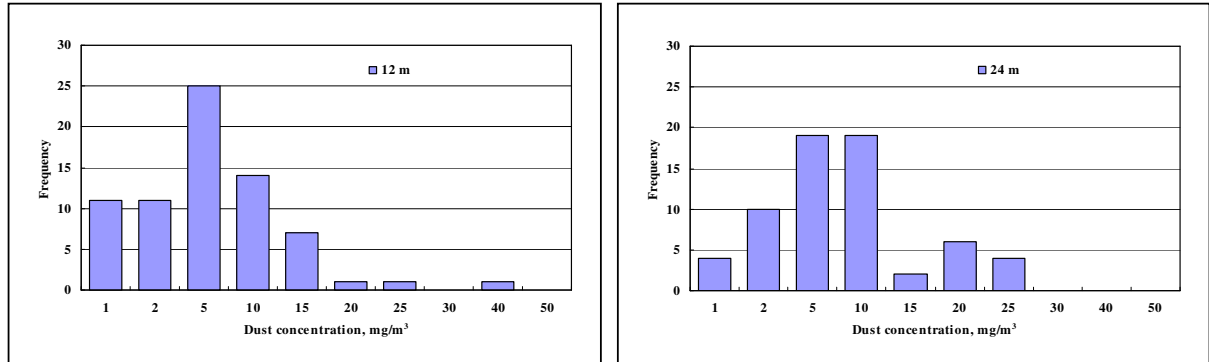


Figure 5.10: Combined plot of the influence of cutting block (both H and S) on dust levels

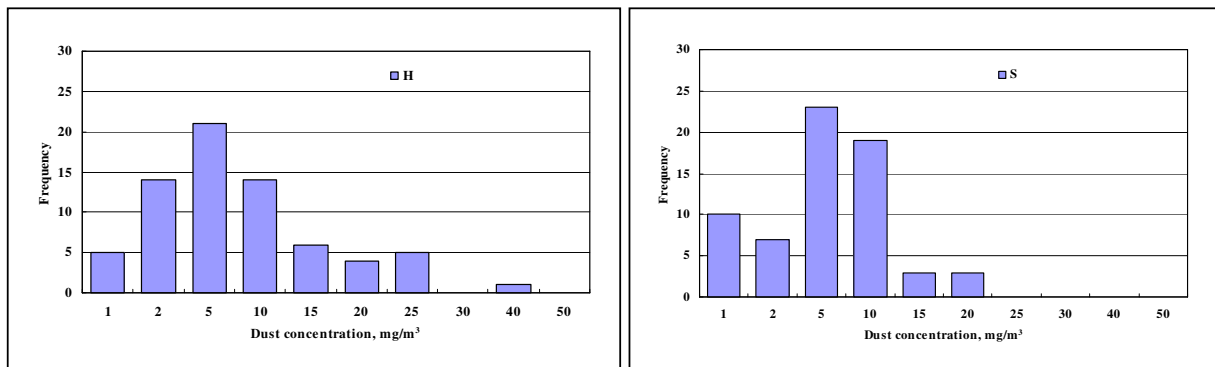


Figure 5.11: Combined plot of the influence of cutting direction (both 12 m and 24 m) on dust levels

The combined plot of the influence of cutting block and cutting direction on dust concentration levels from four different dust control systems is shown in Figures 5.10 and 5.11 above. From the plots the following conclusions may be deduced:

- For each of the dust control system types, the mean dust concentration levels in the 24 m cutting blocks was higher than the 12 m cutting block
- Similarly, for the various dust control system types, the mean dust

concentration levels in the headings were greater than the split

- However, for dust control System 2, the scatter was narrow and the mean dust concentration levels were comparatively lower than the other system types.
- As can be expected (See above statements) the overall plots show that there is a difference between the mean dust concentration levels when the CM was cutting either headings or splits and 12 m or 24 m cutting blocks.

In order to come to a conclusive relationship and rank the significant factors that reduce the dust levels in an underground section, statistical analysis (two-sample t-test and ANOVA) was subsequently carried out

5.4.2 Statistical Analyses

An analysis of frequency distribution of the dust concentration values for the four different dust control systems resulted in a set of histograms. The sample distributions of the histograms were not normally distributed. The histogram plots of the \log_e -transform of the dust concentration data lead to the conclusion that the dust levels were \log_e -normally distributed.

Since there was an uneven number of concentration values for pair-wise statistical comparison, a two-sample t-test was performed on the set of all the sample data combinations to determine if there was a statistical difference in the \log_e -transformed (normally distributed) concentration levels. A two-sample t-test of hypotheses was developed to compare the mean concentration level measured between the test parameters (μ_A and μ_B). The null and alternative hypothesis for the tested sample pairs were:

$$H_0: \mu_A = \mu_B$$

$$H_1: \mu_A \neq \mu_B$$

In the two-sample t-test, hypothesis H_0 states that the mean dust concentration levels between test parameters (μ_A and μ_B) are equal. On the other hand, the alternative hypothesis states that the test parameters in fact have different mean concentration levels. It is therefore necessary to use hypothesis testing to accept or reject H_0 . For the analysis, a standard 95% confidence level was chosen. As the hypothesis stated were $\mu_A = \mu_B$ and $\mu_A \neq \mu_B$, all analyses were two tailed to account for both conditions $\mu_A < \mu_B$ and $\mu_A > \mu_B$. Hypothesis tests were carried out on each of the test parameters in terms of cutting block (12 m and 24 m) and cutting direction (heading and split) for individual dust control systems as well as the overall system (average of Systems 1, 2 3 and 4).

Results of the two-sample t-test statistical analyses are given in Tables 5.3 and 5.4. The p -value represents the probability of making a Type 1 error, which is rejecting the null hypothesis when it is true. In this study a cut-off p-value of 0.05 was used (95% confidence level).

From the analysis table, we observe that with various degrees of freedom, the large p-value (> 0.05) suggesting that the measured mean concentration levels are consistent with the null hypothesis, $H_0: \mu_A = \mu_B$, that is, the dust concentration levels between the test parameters are not affected at 95% level of confidence.

Table 5.3: Results of two-sample t-test hypothesis (on transformed values)

	System 1		System 2		System 3		System 4		Overall	
	12 m	24 m	12 m	24 m	12 m	24 m	12 m	24 m	12 m	24 m
Mean	1.241	1.570	-0.149	0.275	1.364	1.882	1.916	2.313	1.158	1.512
Standard Deviation	0.646	0.743	0.546	0.455	0.830	0.484	0.657	0.766	0.981	0.943
Sample Size	24	27	15	13	12	11	20	13	71	64
P - Value	0.100		0.036		0.085		0.120		0.035	
t - statistic	-1.680		-2.220		-1.810		-1.590		-2.130	
Hypothesis	Accept H_0		Reject H_0		Accept H_0		Accept H_0		Reject H_0	

Table 5.4: Results of two-sample t-test hypothesis (on transformed values)

	System 1		System 2		System 3		System 4		Overall	
	H	S	H	S	H	S	H	S	H	S
Mean	1.325	1.501	0.173	-0.061	1.816	1.425	2.112	2.003	1.420	1.219
Standard Deviation	0.939	0.390	0.588	0.491	0.549	0.830	0.806	0.556	1.030	0.907
Sample Size	25	26	13	15	11	12	21	12	70	65
P - Value	0.380		0.260		0.200		0.680		0.220	
t - statistic	-0.880		1.150		1.320		0.420		1.220	
Hypothesis	Accept H_0		Accept H_0		Accept H_0		Accept H_0		Accept H_0	

From Table 5.3, it can be observed that, for individual dust control systems as well as for the overall dust control system, the t-statistic $C_{12}-C_{24}$ (concentration C at 12 m – concentration C at 24 m) was negative confirming that the mean dust concentration levels during 24 m cutting block were generally greater than the mean dust concentration level from the 12 m cutting block. However, the null hypothesis was rejected (small p- value, < 0.05) for system 2, where there was significant difference between the concentration values obtained for the 12 m and 24 m cutting blocks at the 95% confidence level. However, at the 85 % confidence level, there was significant difference between the concentration values obtained for the 12 m and 24 m cutting blocks.

A two-sample t-test was performed on all the data to determine if there was a statistical difference in the concentration levels between two parameters (cutting direction and cutting blocks) for the overall dust control system. The result of the two-sample t-test was a test statistic with 133 degrees of freedom, and $p = 0.035$ confirming that there is a significant difference between measured dust concentration levels when the CM was cutting the 12 m and 24 m cutting blocks.

From Table 5.4, it can be observed that except for System 1 (half-curtain system), the t-statistic C_H-C_S (concentration C in heading [H] – concentration C in split [S]) was positive indicating that the mean dust concentration levels in the heading (H) were generally greater than the mean dust concentration levels in a split (S). Further, the null hypothesis was accepted (large p-value, > 0.05) for the individual dust control systems as well as for the overall system confirming that there was no significant difference between the mean concentration levels in a heading (H) or a split (S) at 95% confidence level. This could be attributed to the distance cut in the direction of a heading was always greater than the split direction which is dependent on the mine planning. Furthermore, cutting in the direction was half-the-time in the direction of fresh air and half-the-time against the fresh air direction.

5.4.3 Analysis Of Variance (ANOVA)

The dust concentration data were also used to perform an analysis of variance (ANOVA). The discussion of the ANOVA models and their underlying assumptions can be found in any of the standard statistics books (e.g., Scheffe (1961); Davies (1956); Miller, 1965). In order to statistically quantify the influence of cutting blocks (CB), cutting direction and type of dust control systems on the dust concentration levels in the section, a factorial analysis was carried out. Essentially the airborne dust concentration at the operator's data that was used was in the form of C_{ijk} (mg/m^3). The subscripts have the following definitions:

i = cutting block (CB), $i = 1$ is a 12 m cutting block, $i = 2$ is a 24 m cutting block

j = cutting direction, $j = 1$ is a heading (H), $j = 2$ is a split (S)

k = dust control system, $k = 1, 2, 3,$ and 4 respectively indicate the half-curtain dust control system, retrofitted hood system, double scrubber and integrated hood system respectively.

The results of analyses of variance (ANOVA) on the data are summarized in Table 5.5. The main factors of the statistical analysis were: dust control system type; cutting direction; and cutting block (CB). The ANOVA table gives, for each term in the model, the degrees of freedom (Df), the sums of squares (SS), the adjusted means squares (MS), the F-statistic from the adjusted means squares, and its p-value. In the ANOVA table, p-values for two factors (cutting distance and dust control system type) was less than 0.05, indicating that these factors are significant and important.

Table 5.5: Results of Analysis of Variance (ANOVA)

Sources of Variation	Df	SS	MS	F value	Pr > F
A (Cutting Distance: 12 m or 24 m)	1	147.78	147.78	5.82	0.017
B (Cutting Direction: Heading or Split)	1	35.97	35.97	1.42	0.236
C (Dust Control System Type)	3	407.43	407.43	16.04	0.000
A*B	1	15.78	15.78	0.62	0.432
A*C	3	63.53	21.18	0.83	0.478
B*C	3	23.83	7.94	0.31	0.816
A*B*C	3	15.50	5.17	0.20	0.894
Error	119	3022.67	25.40		
Total	134				

From the results of ANOVA, the following conclusions can be deduced:

- Effect of dust control system type on the dust concentration levels is highly significant with a mean square (MS) value of 407.43.
- There is a significant evidence (p – value of 0.017) of the effect of cutting block (12 m and 24 m) on dust levels recorded at the operator’s position during the coal cutting operation for various dust control systems (the MS value for the cutting distance is 147.78).
- The effect of cutting direction (heading or split) on the results of dust concentration levels at the operator’s position is insignificant with a p - value of 0.236.
- From the magnitude of each test parameter the dust control system and cutting distance can be placed in a descending order of importance. As we note from the table, the dust control system has a pronounced effect on the dust concentration levels (p-value of 0.000 and highest MS value of 407.13) followed by cutting distance with a p-value of less than 0.05.

The following two-factor interactions viz., cutting distance × cutting direction, cutting distance × dust control system type, cutting direction × dust control system type in the analysis are statistically insignificant. Also, three-factor interaction effect, dust control system type × cutting direction × cutting distance do not have a significant effect on concentration levels at the operator’s position. Finally, the

main factors, such as dust control system type and cutting distance influencing the dust concentration levels at the operator's position are well demonstrated.

5.5 Conclusions

Although recent international analyses of the incidence of pneumoconiosis show favourable trends, the latest studies by British scientists and by NIOSH indicate that the risk of developing the most serious form of CWP at the current exposure level standard (2.0 mg/m^3) is higher than had been previously believed. However, Australian researchers have reported that they have no evidence of CWP at levels greater than the 2.0 mg/m^3 standard (US Federal Register, 1995).

Previous studies have shown that the risk of progression to a higher category of pneumoconiosis due to coal dust exposure increases with increasing intensity of the exposure, represented by the mean dust concentration (Jacobsen et al., 1970, 1971), and with increasing cumulative exposure, represented by the product of intensity and duration (Jacobsen, 1973, 1979). Therefore, from this study we can deduce that a worker positioned inside the cabin of a CM during the cutting of a 24 m block is usually at higher exposure risk than the worker when cutting a 12 m block. Based on the mean dust concentration results and statistical analyses, the miner who is operating in a heading is exposed to more dust than when operating in a split position.

Finally, from the analysis of the dust concentration results at the operator's position, it can be inferred that the mere application of the 12 m rule on its own does not solve the dust problems, but that meticulous and regular maintenance, together with the application of best available dust control technologies, effective dust control strategies and best practices, ensures reduced worker exposure. The introduction of remotely controlled cutting operations in the section may effectively lower the duration, severity and intensity of workers' exposure to coal dust. It is strongly believed that the use of the cutting block (CB) distance is one

of the most important and easily controlled parameters in assessing the worker exposure to coal dust. As an administrative control measure for effective dust exposure control, mine environment officers, occupational hygienists and mine management can effectively use this information by rotating the CM operators during the working shift so that a particular CM operator is not constantly exposed to the higher levels of coal dust.

From this study, a Dust Exposure Level Index (DELI) based on dust levels during coal cutting operations in a section can be shown pictorially (Figure 5.12) and an index of approximate exposure of workers present in the working face is summarized in Table 5.6.

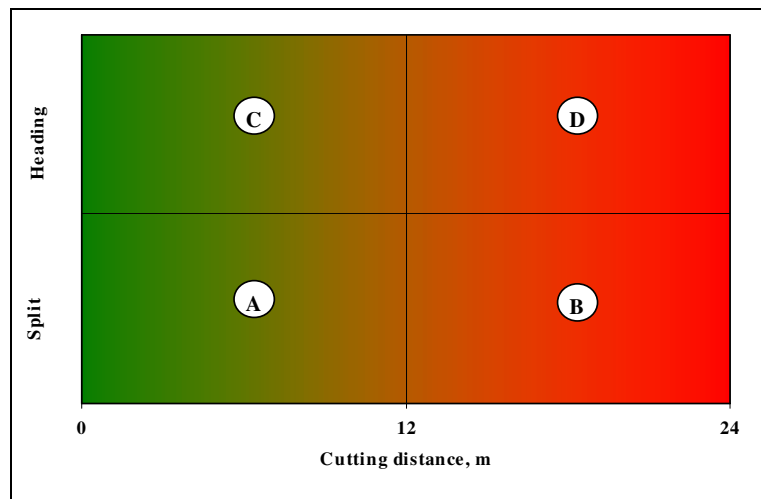


Figure 5.12: Dust exposure level index chart based on cutting direction and cutting distance

The plot shows in the x-axis cutting distance for a length up to 24 m and y-axis representing cutting direction (split or heading). The cutting distance was limited to 24 m as face ventilation becomes totally ineffective beyond 24 m hence dust level will be very high.

The intention of colour coding is two fold. viz., literacy standards in the South African mining population is very low and comprehension of statistics, OELs and their meaning is virtually unknown. DELI colour coding designations enables the uneducated workforce who can understand the meaning of different colours to visualise the severity of dust problems under different conditions. Obviously only ‘Green’ is acceptable for work underground and ‘Red’ is unacceptable.

Table 5.6: Dust exposure level index (DELI) based on cutting distance and cutting direction

DELI Parameter	Code	Colour	Descriptor
Split-12 m	A	Green	Good
Split –24 m	B	Red	Unhealthy to Hazardous
Heading –12 m	C	Green	Good
Heading –24 m	D	Red	Unhealthy to Hazardous

5.6 Summary

The focus of this chapter was to understand exposure in the various working areas during coal cutting in a bord and pillar coal mine. The task was carried out indirectly through a detailed analysis of the efficacy of the 12 m rule from the perspective of dust control and also to address the question of whether the mere restriction of not mining beyond a distance of 12 m will on its own solve dust problems.

Analysis of the data indicated that the application of a 12 m rule on its own does not solve the dust problems, but that meticulous application of available state-of-the-art dust control technologies, best work practices, and the regular maintenance of the installed system can have a significant effect. It is strongly believed that the use of a cutting block (CB) distance is one of the most important parameter

affecting worker exposure to coal dust. As an administrative control measure for effective dust exposure control, the mine environment officers, occupational hygienists and mine management can effectively use this information in order to rotate CM operators during the working shift to ensure that a particular CM operator is not exposed continuously to high levels of coal dust. Finally, an approximate exposure chart and index has been developed that could assist all the interested parties to understand the dust exposure level when an individual is present during the identified scenarios in a coal mine section.

Chapter 6 Peak Dust Concentration and Exposure

6.1 Introduction

In order to reduce or eliminate the health risk of exposure to dust, several studies have been carried out in the USA, the UK and other European countries on coal dust exposure limits. These exposure limits provide the necessary guidance for planning, engineering, monitoring and controlling the coal extraction systems and work practices for effective control of dust. There are wide variations in the dust exposure limits as defined by regulatory and research authorities such as the Occupational Safety and Health Administration (OSHA), Mine Safety and Health Administration (MSHA), National Institute of Occupational Safety and Health (NIOSH), World Health Organization (WHO) and American Conference for Governmental Industrial Hygienists (ACGIH). The exposure limits of countries worldwide are also different and must not be compared directly with each other because of differences in each country's dust measurement strategies.

6.2 Threshold Limit Values (TLVs) or Occupational Exposure Limits (OELs)

Occupational Exposure Levels (OELs) were first proposed by Emhurst Duckering in the UK, as a way of limiting exposure to dust, in 1910 (Piney, 2001). But, in practice, OELs were developed, applied and promulgated by industrial hygienists in the USA, the ACGIH TLVs being the most famous and influential standards. According to Duckering (1910) "...The most scientific way of regulating a dusty trade would be to impose a limit on the amount of dust which may be allowed to contaminate the air breathed by the workpeople and to leave the manufacturer a

completely free choice of methods by which this result may be attained...” Threshold Limit Values (TLVs) refer to airborne concentrations of substances and represent conditions to which it is believed that nearly all workers may be repeatedly exposed day after day without adverse health effects. The establishment of a TLV is essentially an exercise in dose-response relationships. “TLV” is a copyrighted trademark of the ACGIH and TLVs are not mandatory Federal or State employee exposure standards in any countries but can be used as a guideline. These limits are updated annually and reflect generally the current professional recommendations on workers’ exposures to specific substances. In principle, the incidence of adverse health effects in people or animals is observed at different exposure levels. The level at which no adverse health effects occur is then determined, alternatively, the level where some effect is observed but at a rate that is somehow considered to be “acceptable” in terms of health effects. The definition of TLVs as levels that protect “nearly all workers” gives the clear impression that these limits are based primarily on health considerations. For coal dust there is no short-term exposure limits like for some airborne pollutants, due to the fact that no serious toxic effects have been reported from short-term exposures in humans or animals.

In studying the effects of toxic substances in humans, experimental exposures are becoming less and less common. Most commonly, the health status is determined for persons who are exposed to hazardous materials in their normal work situations. Dose can be measured indirectly through sampling but they are not an accurate reflection of the “true dose.” Workers breathing rate depends on body size, race, gender; and the fraction of an inhaled dose deposited in the lungs of the worker depends on breathing rate, particle size, solubility and mouth versus nose breathing. This indicates that the dose received by different groups of workers may not be completely characterized by their airborne exposures.

The major causes of inaccuracy in characterizing exposure, and thus dose, are the lack of exposure measurements. The past and continuing airborne exposures have

not been measured with a view toward supporting the development of an accurate and informative OEL. Measurements are frequently taken to assess compliance with existing standards. In South Africa measurements were taken for the calculation of levies bi-annually. Measuring exposures in a systematic way can be expensive and unless employers can see benefits for themselves, they will be reluctant to do it. Therefore this study will attempt to disseminate the measured dust levels that can be easily used in estimating the exposure level of workers with the existing control strategies.

It has been accepted for several years that the time periods over which dust exposures are measured should be similar to the biological time periods over which adverse health effects develop. Hence, for primary irritants, which act almost instantaneously, very short sampling times or direct-reading instruments are needed. Where the health effect is the result of the cumulative dose during a single work shift an 8-hour time weighted average could be considered. However, this technique would ignore any high or peak exposures during the shift and, since the role of these short duration- high exposures in the development or advancement of pneumoconiosis is not fully understood, average full shift exposures should be used with caution and perhaps used with additional measurements.

Exposures in the past are frequently examined using records from the past but more often using present records. The dangers of using these methods are that past records may not be available, especially if a mine has closed down and, secondly, present exposure levels may not be anywhere near what past levels used to be. Estimations may be not only non-representative but also far off the mark. (Ratney, 1997).

6.3 Time Weighted Average (8-hour)

Time Weighted Average (TWA) underpins many occupational exposure limits. Its limitations are recognized but its use and elements have received little attention in South Africa. The assessment of compliance is based on the exposure of the individual worker, usually expressed as the 8-hr Time Weighted Average (TWA) concentration. On a day-by-day basis, this exposure has to remain below a compliance dust standard; irrespective of the different tasks the worker performs using normal work procedures. Such OELs for coal dust are different for different countries. Also monitoring for a compliance dust standard is practically difficult for countries with scarce competent human resources like South Africa.

In 1976 MacFarland emphasized the difference between *exposure* and *true dose*. Exposure corresponds to milligram-minutes per cubic metre of atmospheric air. True dose corresponds to grams per kilogram of body weight. Exposure is often measured in epidemiological studies: true dose, seldom. Exposure is specified in occupational exposure limits and true dose is vital for toxicological research.

It is very important to note that true dose differs from exposure because, for example (Vincent, 2001) there may be inconsistencies in respiration caused by exposure conditions such as changes in air temperature that affects body metabolism. Furthermore, not all the inhaled substance is absorbed; some of the inhaled substance absorbed is re-excreted through the lungs; some of the absorbed substance is metabolised to other substances which may be more or less active than the substances to which the exposure occurred. Particles may have to be portioned according to size; other biochemical variables may interfere; and there may be large individual biological differences and responses.

Use of single values (example, AQI or dust standard of 2.0 mg/m^3) as an exposure index should be treated with due care because (Kielblock, et al., 1997):

- Simple averages or integration with time and concentration of exposure may be a practical expedient, but they may produce erroneous results because toxicological response cannot be expected to be a linear function of time and concentration and,
- The amplitude and frequency of variation from a defined mean, currently ignored may be very important.

A warning on the use of TWA states, “it is certain that with some chemicals a given Time Weighted Average concentration including major peaks during the day is more likely to injure than is the same average concentration during substantially constant exposure.” This is true in coal (Unsted, 1996).

Since the effect (or response) of an airborne contaminant on a worker who is being exposed thereto is dependent on the dose (or mass) of the substance inhaled by the worker, it depends on two variables, viz., time of exposure (T) and concentration of the contaminant in the air (C). That is the product of concentration of contaminant in the air and time of exposure is defined as dose (Schroder, 1980). A SIMRAC study summarizing various past scientific studies indicated the following (Kielblock et al., 1997):

- Concentration-time (CT) *is not* directly proportional to the severity of toxic effect for *all* values of CT i.e. CT is *not* a constant
- The total amount of the substance absorbed is assumed decisive, irrespective of extent of fluctuation in concentrations and time distribution. The justification for this assumption has not been fully proven.
- Estimation of whole shift average concentrations - even in the breathing zone by personal sampling - will not define the magnitude of the hazard. The monitoring of the fluctuations of concentration should complement such estimations exposure to high concentration peaks produced larger burdens and neuro-chemical effects than comparable exposure to stable concentrations of a (specific) contaminant. Constant TWA produced inconsistent effects.

- Concentration and duration are *not* equally weighted as presupposed by TWA.

The study concluded that eight-hour TWA exposure limits may not be appropriate for controlling pneumoconiosis because lung impairment may be induced by transient peak exposures rather than by sustained exposure levels (Unsted, 1996).

6.4 Peak Dust Concentrations

The MRC's Dust Panels in the UK in 1956 and the Johannesburg International Conference on Pneumoconiosis in 1959 put forward the view that the average concentration levels to which men were exposed provides the most important measure of dustiness in relation to pneumoconiosis, but should be supplemented by a measure of variability if possible. In 1956, the NCB (UK) adopted the convention of sampling throughout periods of mining activity but not when production was interrupted. In the light of the problems of dust counting and of measuring fluctuating concentrations, Bedford and Warner (1943), considered that the hazard of exposure would be best represented by the mass concentration of dust particles less than 5 μm . Moreover, they did not refer to peaks of dust production and it appears that their proposals were intended to relate to the average concentration.

The Dust Panels of the MRC, in 1957, expressed the view that mass might prove to be the best parameter for inert dusts and urged the development of suitable measuring instruments; the 1959 Johannesburg Conference recommended the use of mass for coal and surface area for quartz. Later research indicated that mass might be the more appropriate measure for quartz as well (Goldstein and Webster, 1966).

The development of methods of measurement of airborne dust in British mines and the associated problems up to 1966 have been well documented by Walton

(1966). The size selective sampling led to the introduction of a number of instruments for dust measurement. For the past twenty years, the introduction of gravimetric dust standards was based on what is seen as being reasonably practicable. The airborne dust standard was based on a standard working week of 40 hours. There is, however, also the possibility of effects of increased exposure time and excessive overtime working as in the case of South African mines (45 hours/week or 48 hours/week).

The significance of peaks compared with average dust exposures over longer periods than the shift has been examined by Reisner (1977) who showed that pulmonary changes over 7 to 10 years were only slightly more frequent among miners who had experienced high monthly peaks of dust compared with men exposed to the same average levels more evenly distributed in time. It was concluded that the differences were too small for definite conclusions to be drawn, but that any peak effect could not be high. It was reported that for the purpose of risk assessment, it is desirable to estimate long-term cumulative or average exposures. However, peak exposures or sustained periods of high exposures may be important in the cause or origin of many occupational chronic diseases (Hewett, 1996).

It is common theory that high concentrations (i.e., peaks) for short periods are more dangerous than lower concentrations over longer periods. The question whether peaks of dust exposure or the average level provide the best measure of the hazard has been discussed by Wright (1953). He concluded that the "peak hypothesis" is not supported by any evidence and further "*Although it could not be stated with certainty that the "average" hypothesis is perfectly correct, it was simple and reasonable and did not conflict with anything known about the mechanism of dust inhalation and retention.*" The inadequate health study in this regard and monitoring and collection of such data would be helpful for surveillance of pneumoconiosis.

In later experimental studies involving rats, one group was exposed to dust for 20 hours per day and the other to a concentration 10 times greater for only 2 hours, Wright (1953) found little difference between the amounts of dust accumulated in the lungs. Indeed, the amount was slightly but perhaps not significantly greater in the animals receiving the 20-hour exposures. The questions that remain unanswered are whether exposure to peaks longer than two hours would have yielded similar results and whether deposition in human lungs will follow a similar characteristic.

One of the biggest problems to emerge with regards to gravimetric dust sampling has been the attempt to describe exposures in terms of average dust concentrations. It is well known that a low average concentration for a shift cannot accurately indicate any extreme conditions encountered during the shift. There is a growing awareness of the importance of peak concentrations and their effects on the human body. The concept of Threshold Limit Values (TLV) does not take into account exposure to a high concentration of material for only a short period of time (Rekus, 1988). This is an acknowledged limitation of 8-hour averaging. Even though the 8-hour time weighted average is below the TLV, frequent high-level short-term exposure could in itself result in adverse health effects in the long run.

In the absence of non-linear effects, individual risk would be related to the cumulative history of exposure. If non-linear effects are involved, then isolated peak exposures might contribute disproportionately to chronic damage or might trigger the first stage in a multi-stage progression of disease. The frequency with which a particular threshold is exceeded could be an appropriate index of exposure (Roach and Rappaport, 1990). Although there are no medical studies specifically related to peak coal dust exposure in a working shift either on animals or human beings, this study is expected to give a picture of peak dust exposure and non-compliance to average engineering dust levels at the continuous mining machine. Any information on peak dust levels and their frequency in relation to average dust levels is envisaged to assist in quicker reactive measures on fixing

the dust control systems and their effectiveness in ultimately reducing the worker exposure.

The studies of Trapido (1999) in gold mine workers in South Africa, it was concluded that face workers are apparently showing high levels of silicosis compared to the workers with supervisory roles in South African mines. The authors attributed this due to face workers being intermittently exposed to very high dust levels that overwhelm the lungs' dust clearing mechanisms (Trapido 1999, Williams, 1999). It can also be reasoned that workers on the supervisory role are always away from the face area and obviously are not exposed to frequent peak dust exposure levels. Further explanations are explained in Section 2.4.3. Based on the above discussions, the peak dust levels observed during coal cutting operation is considered as a parameter of DELI and discussed hereafter.

6.5 Data Collection and Analysis

Peak dust concentration levels during a working shift are an aspect of environmental health and is a safety hazard not currently considered in coal mines. The implications are that research is warranted in the quest to address missing information and knowledge regarding the influence of peak dust levels and their frequency in the effective understanding of pneumoconiosis, its formation and control from both engineering and administrative control means.

In order to analyse the effect of peak dust concentration levels on worker exposure in a working shift, a real-time full-shift dust exposure survey is necessary. This was obtained with the real-time dust monitoring instruments. The best location to obtain the exposure data is the highest dust concentration levels, which in fact is the continuous mining machine operator cabin position. Therefore real-time dust concentration data was collected for analysis of peak concentrations from various underground mines for the production shift. *The peak dust level for the study is defined as the respirable dust level recorded by the real-time dust monitor at the*

CM operator's position during an underground working shift which is a multiple of the statutory compliance level of 2.0 mg/m³.

Table 6.1 shows the summary of real-time concentration shift data obtained from 6 different underground mines for the purpose of peak dust level analysis. Three types of underground mining machine data were used for the analysis purposes. At mines A, B, C and D continuous miners (CM) were used for the bord and pillar development section. Similarly, at Mine E, a road heading (RH) machine was used for the bord and pillar development section. Real-time data obtained at Mine F was at an operational longwall. Also, at Mine A, real-time shift data for various types of dust control systems (See Appendix-A) were separated for analysis purposes as Mine A1, Mine A2, Mine A3 and Mine A4. It must be borne in mind that the real-time data collected for this study was not measured in the breathing zone of the worker and therefore it is not a real-time personal dust exposure.

Table 6.1: Summary of real-time concentration shift data

Mining type	Mine Name	Number of sample shifts	Avg. sample concentration, mg/m³	Avg. production, tons
Continuous Miner	Mine A	48	3.76	620
	Mine A1	26	3.66	590
	Mine A2	8	2.33	770
	Mine A3	10	4.44	550
	Mine A4	4	5.87	630
	Mine B	15	5.69	570
	Mine C	8	4.28	750
	Mine D	4	6.12	1060
Road Header	Mine E	25	4.52	760
Longwall	Mine F	4	8.19	3355

6.5.1 Data Analysis

In order to analyse the influence of peak dust levels and their frequency during a continuous mining operation, each underground shift concentration data set obtained from a real-time dust monitoring instrument (Hund tyndallometer) was analysed to incorporate only the data when the continuous mining extraction unit was in operation or cutting. This was carried out using the time-study data collected during each of the cutting shifts. The real-time dust monitoring instrument recorded the dust concentration levels for every 8 seconds. Further each of the individually processed real-time shift concentration data sets was classified according to the various concentration levels between the range of 0.0 to 2.0 mg/m³, 2.0 to 5.0 mg/m³, 5.0 to 10.0 mg/m³, 10.0 to 50.0 mg/m³, 50.0 to 100.0 mg/m³, 100.0 to 150.0 mg/m³, 150.0 to 300.0 mg/m³, and 300.0 to 400.0 mg/m³. Further, frequency of dust levels in the respective dust range was quantified.

For the analysis of peak dust levels during an underground shift, individually processed real-time dust data (as discussed above) according to concentration level and respective frequency was collated and plotted. Each of the concentration-frequency data were classified according to individual mine and for average engineering dust levels less than 5 mg/m³ and greater than 5 mg/m³.

Continuous Miner Section - Mine A

There were a total of 48 underground real-time concentration data sets for various dust control system types viz., System 1 for Mine A1, System 2 for Mine A1, and System 3 for Mine A3 (See Appendix-A). The dust control system at Mine A4 did not follow any specific spray configuration with missing spray blocks and nozzles. The type of dust control system does not have any significance for this particular experiment, but peak dust values can be used as an indicator of the efficiency of the dust control system. The main data set was sub divided according to type of

dust control systems used. The sub data sets are Mine A1, Mine A2, Mine A3 and Mine A4 containing 26, 8, 10 and 4 individual real-time data sets respectively. The Mine A average engineering sample dust concentration and average shift production for the sampling period are 3.77 mg/m³ and 620 tons respectively. The average engineering sample dust level for the Mine A1, Mine A2, Mine A3 and Mine A4 are 3.66 mg/m³, 2.33 mg/m³, 4.44 mg/m³, and 5.87 mg/m³ respectively. Similarly, the average shift production for the Mine A1, Mine A2, Mine A3 and Mine A4 are 590 tons, 770 tons, 550 tons and 630 tons respectively.

Continuous Miner Section - Mine A1

In this continuous miner section, the CM was using System 1 type of dust control system and a total of 26 underground shift real-time data was collected. The average engineering sample dust concentration was 3.66 mg/m³ with an average working shift production during the test period of 590 tons. The real-time dust plot at the CM operator’s position and section return position using System 1 type dust control system for a total of 26 underground shifts are shown in Appendix (B1). The individual shift CM operator position data was analysed for peak dust levels in the respective identified ranges. The histogram data with identified range of dust level value was separated according to daily engineering dust level of greater and lesser than 5 mg/m³ respectively. Table 6.2 shows the summary of shift average dust levels and frequency of peak dust levels obtained from the real-time data in the defined dust ranges.

Table 6.2: Summary of shift dust average and frequency of peak dust levels at Mine A1

Test #	Dust Conc. mg/m ³	Frequency of peak dust level (mg/m ³) range							
		0-2	2-5	5-10	10-50	50-100	100-150	150-300	>300
1	2.664	118	122	85	72	0	0	0	0
2	4.924	311	421	112	118	22	15	5	0
3	2.292	328	255	152	104	3	0	0	0

4	0.863	674	78	34	6	0	0	0	0
5	4.763	418	643	253	278	18	3	0	0
6	6.524	91	474	453	308	44	20	6	0
7	14.74	23	394	433	300	59	20	36	7
8	2.943	216	193	59	145	14	0	0	0
9	5.583	195	308	116	179	35	5	0	0
10	2.796	324	750	148	75	0	0	0	0
11	3.256	183	391	216	184	8	0	0	0
12	5.209	47	1189	506	250	1	1	0	0
13	2.988	296	433	172	86	0	0	0	0
14	1.478	179	99	46	70	10	0	0	0
15	4.296	178	645	218	196	22	1	0	0
16	5.272	281	406	223	299	27	6	1	0
17	3.663	281	539	150	170	6	0	0	0
18	1.910	121	349	186	13	0	0	0	0
19	2.519	42	568	203	99	2	0	0	0
20	2.781	147	609	253	114	0	0	0	0
21	2.050	761	855	221	56	0	0	0	0
22	1.989	108	775	156	29	0	0	0	0
23	0.967	2363	37	11	4	0	0	0	0
24	4.241	124	690	226	96	14	1	0	0
25	2.336	122	538	39	12	1	0	0	0
26	4.186	492	780	328	229	17	1	1	0

Figures 6.1 and 6.2 show the frequency-dust concentration profiles for the continuous mining section-Mine A1.

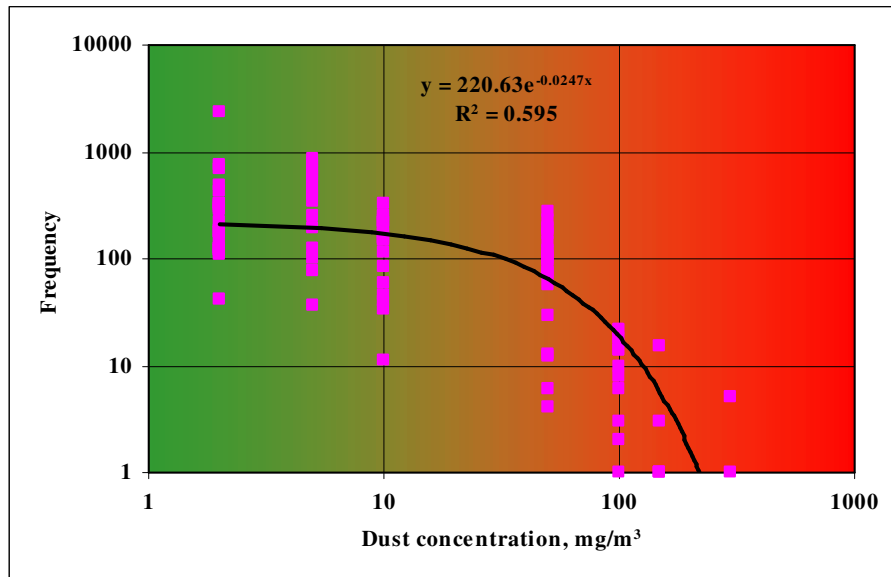


Figure 6.1: Frequency-dust concentration profile at the CM operator position for engineering dust levels < 5 mg/m³ at Mine A1

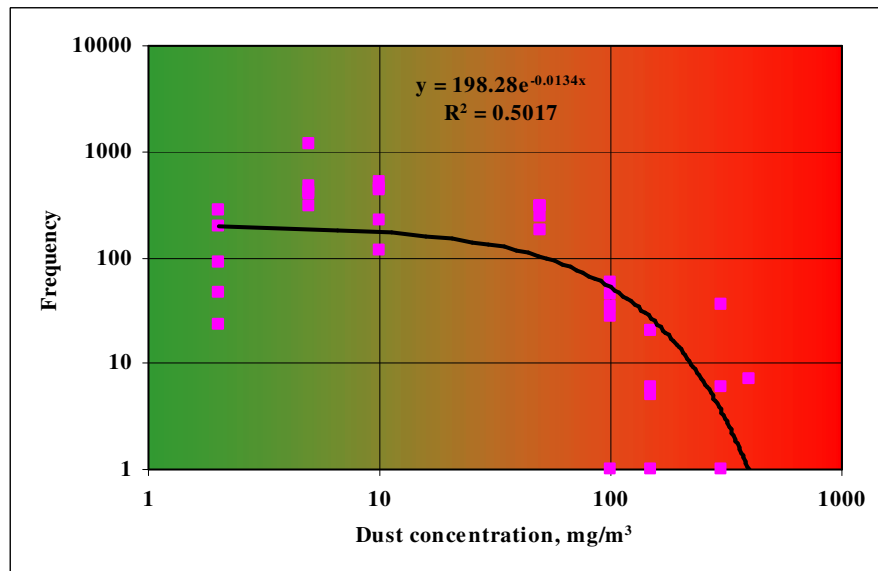


Figure 6.2: Frequency-dust concentration profile at the CM operator position for engineering dust levels > 5 mg/m³ at Mine A1

Continuous Miner Section - Mine A2

In this continuous miner section, the CM was using a System 2 type of dust control system and a total of 8 underground shift real-time data was collected. The average engineering sample dust concentration was 2.33 mg/m³ with an average working shift production during the test period of 770 tons. The real-time dust plots at the CM operator’s position and section return positions using System 2 type dust control system for a total of 8 underground shifts are shown in Appendix (B2). The individual shift data was analysed for peak dust levels in the respective identified ranges. The histogram data with identified range of dust level value was separated according to daily engineering dust level of greater and lesser than 5 mg/m³ respectively. Table 6.3 shows the summary of shift average dust levels and frequency of peak dust levels obtained from the real-time data in the defined dust ranges.

Table 6.3: Summary of shift dust average and frequency of peak dust levels at Mine A2

Test #	Dust Conc. mg/m ³	Frequency of peak dust level (mg/m ³) range							
		0-2	2-5	5-10	10-50	50-100	100-150	150-300	>300
1	1.917	784	20	3	2	0	0	0	0
2	2.511	300	1037	186	2	0	0	0	0
3	1.962	1537	516	76	40	0	0	0	0
4	3.661	885	825	438	225	6	0	0	0
5	3.068	747	619	223	133	3	0	0	0
6	0.984	783	3	0	0	0	0	0	0
7	2.236	1770	641	110	84	3	0	0	0
8	2.267	156	167	29	21	1	0	0	0

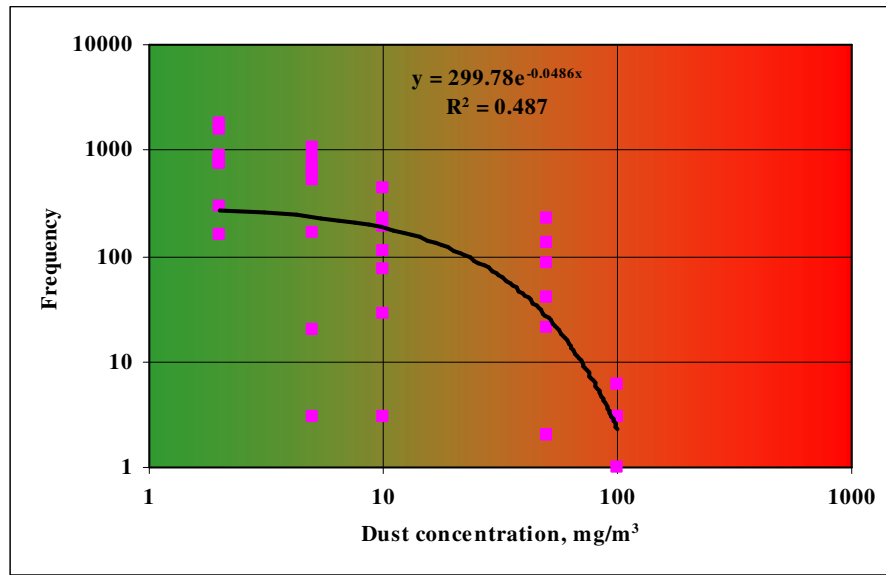


Figure 6.3: Frequency-dust concentration profile at the CM operator position for Mine A2 during engineering concentration levels < 5 mg/m³

Figure 6.3 show the frequency-dust concentration profiles for the continuous mining section-Mine A2 when the engineering sample concentration was less than 5 mg/m³. However, during this test series, the engineering dust concentration levels never exceeded the 5 mg/m³ limit.

Continuous Miner Section - Mine A3

In this continuous miner section, the CM was using System 3 type of dust control system and real-time data was collected for a total of 10 underground shifts. The average engineering sample dust concentration was 4.44 mg/m³ with an average working shift production during the test period of 550 tons. The real-time dust plots at the CM operator's position and section return position using System 3 type dust control system for a total of 10 underground shifts is shown in Appendix (B3). The individual shift data was analysed for peak dust levels in the respective identified ranges. The histogram data with identified range of dust level values

were separated according to daily engineering dust level of greater and lesser than 5 mg/m³ respectively.

Table 6.4 shows the summary of shift average dust levels and frequency of peak dust levels obtained from the real-time data in the defined dust ranges. Figures 6.4 and 6.5 show the frequency-dust concentration profiles for the continuous mining section Mine A3.

Table 6.4: Summary of shift dust average and frequency of peak dust levels at Mine A3

Test #	Dust Conc. mg/m ³	Frequency of peak dust level (mg/m ³) range							
		0-2	2-5	5-10	10-50	50-100	100-150	150-300	>300
1	4.541	22	190	222	223	15	7	7	0
2	8.562	1	94	176	427	27	12	13	0
3	3.714	177	522	330	238	6	1	0	0
4	1.587	188	56	0	0	0	0	0	0
5	5.340	758	541	246	272	31	6	6	0
6	2.942	288	442	301	136	1	0	1	0
7	3.369	323	591	179	143	13	2	0	0
8	2.180	272	830	210	13	0	0	0	0
9	1.495	1487	293	11	16	0	0	0	0
10	10.69	3	311	1038	1258	52	7	2	0

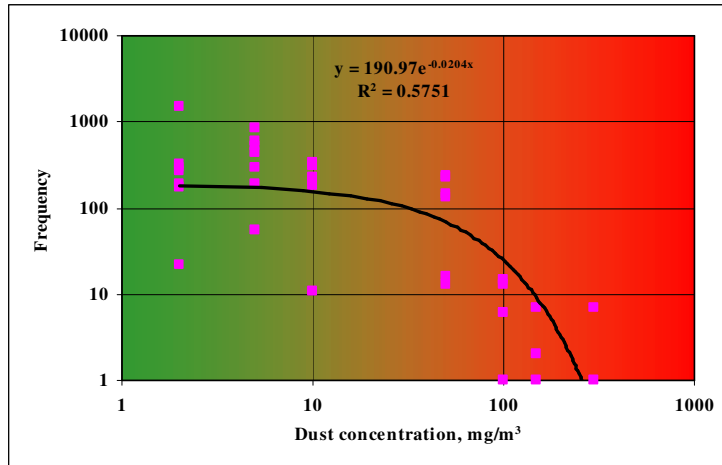


Figure 6.4: Frequency-dust concentration profile at the CM operator position for engineering dust levels < 5 mg/m³ at Mine A3

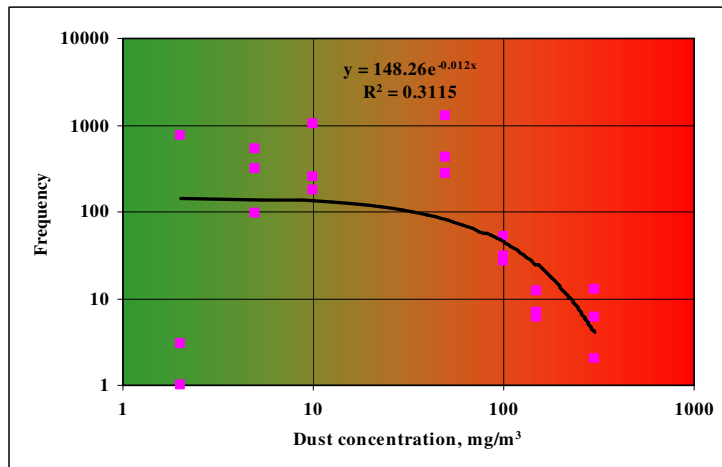


Figure 6.5: Frequency-dust concentration profile at the CM operator position for engineering dust levels > 5 mg/m³ at Mine A3

Continuous Miner Section - Mine A4

In this continuous miner section, the CM was not using any well defined type of dust control system and real-time data was collected for a total of 4 underground shifts. The average engineering sample dust concentration was 5.87 mg/m³ with an average working shift production during the test period of 630 tons. The real-time dust plots at the CM operator's position and section return position for a total of 4 underground shifts is shown in Appendix (B4). The individual shift data was analysed for peak dust levels in the respective identified ranges. The histogram data with identified range of dust level values were separated according to daily engineering dust level of greater and lesser than 5 mg/m³ respectively. Table 6.5 shows the summary of shift average dust levels and frequency of peak dust levels obtained from the real-time data in the defined dust ranges.

Table 6.5: Summary of shift dust average and frequency of peak dust levels at Mine A4

Test #	Dust Conc. mg/m ³	Frequency of peak dust level (mg/m ³) range							
		0-2	2-5	5-10	10-50	50-100	100-150	150-300	>300
1	7.409	294	854	544	353	25	4	3	0
2	7.463	49	723	595	18	1	1	0	0
3	7.916	235	403	214	317	59	22	9	0
4	0.690	410	57	15	19	0	0	0	0

Figures 6.6 and 6.7 show the frequency-dust concentration profiles for the continuous mining section-Mine A4. It was observed during the tests that the dust control system was extremely ineffective and poorly maintained.

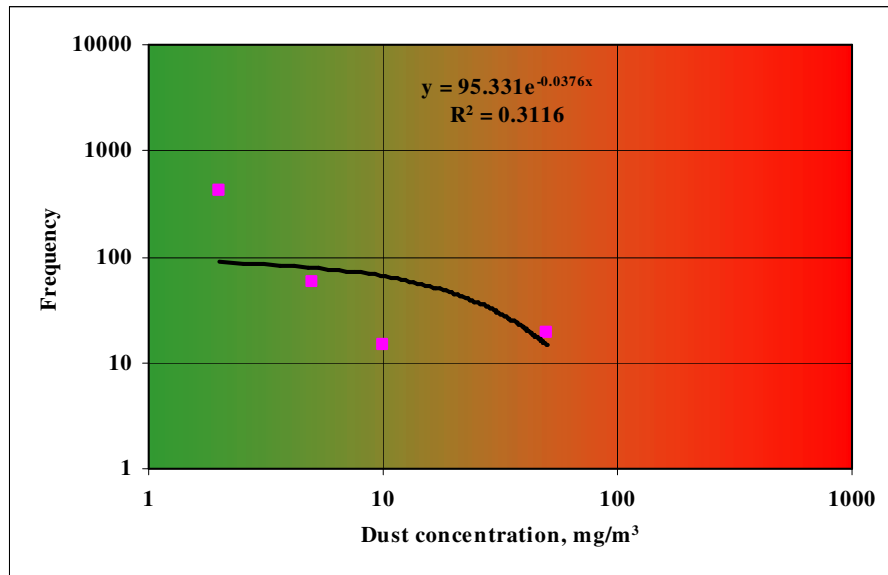


Figure 6.6: Frequency-dust concentration profile at the CM operator position for engineering dust < 5 mg/m³ for Mine A4

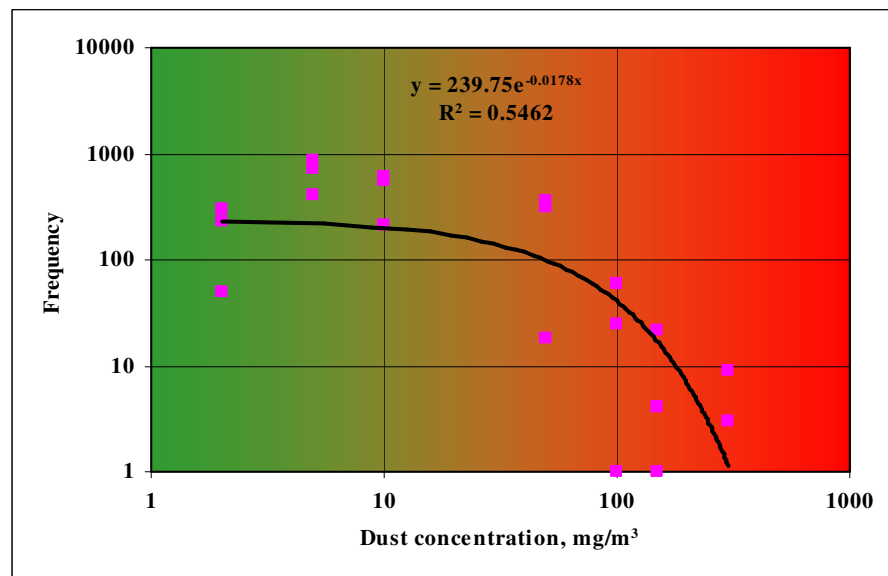


Figure 6.7: Frequency-dust concentration profile at the CM operator position for engineering dust levels > 5 mg/m³ for Mine A4

The overall frequency plot for the same mining section (Mine A) with various dust control system types was plotted together and is shown in Figures 6.8 and 6.9.

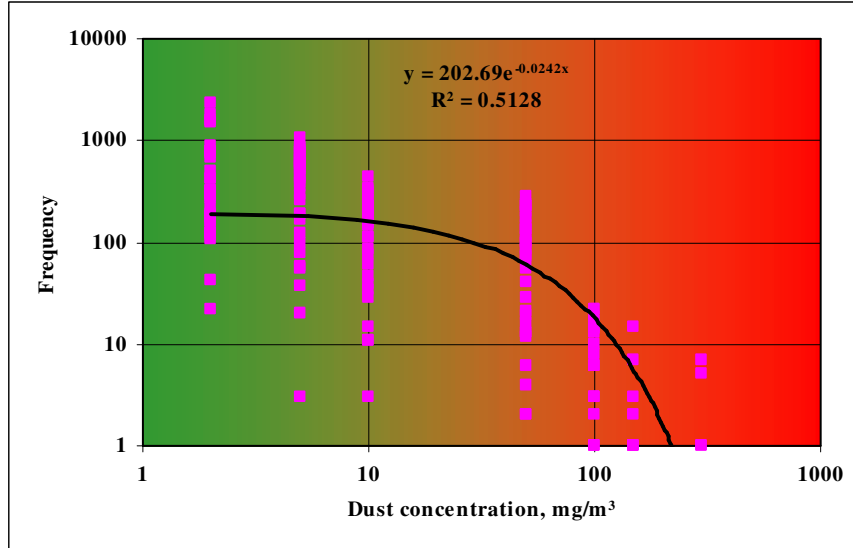


Figure 6.8: Overall frequency-dust concentration profile at the CM operator position for engineering dust levels < 5 mg/m³ for Mine A

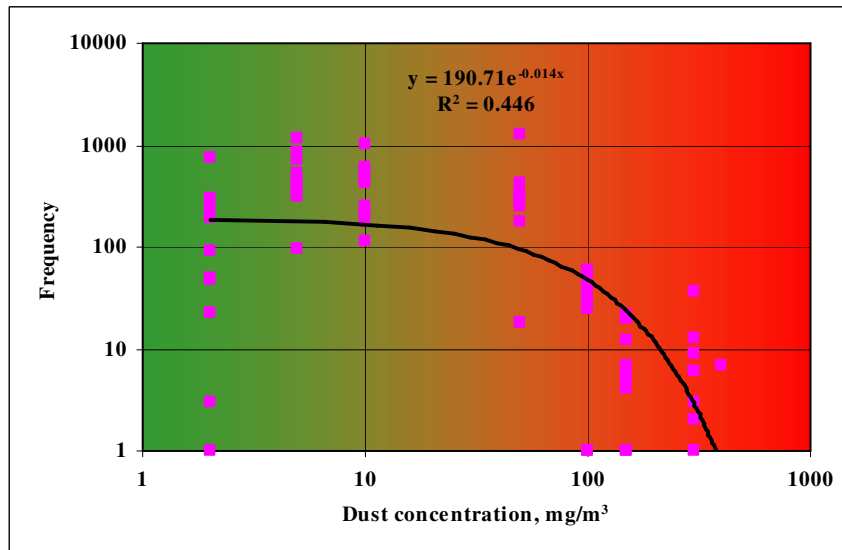


Figure 6.9: Overall frequency-dust concentration profile at the CM operator position for engineering dust levels > 5 mg/m³ for Mine A

Continuous Miner Section - Mine B

In this continuous miner section Mine B, a total of 15 underground shift real-time data were collected. The discussion of the integrated hood dust control system (System 4) used is discussed elsewhere (Appendix-A). The average engineering sample dust concentration was 5.69 mg/m^3 with an average working shift production during the test period of 570 tons. The real-time dust plot at the CM operator's position and section return positions for a total of 15 underground shifts is shown in Appendix (B5). The individual shift data was analysed for peak dust levels in the respective identified ranges. The histogram data with identified range of dust level value was separated according to daily engineering dust level of greater and lesser than 5 mg/m^3 respectively. Table 6.6 shows the summary of shift average dust levels and frequency of peak dust levels obtained from the real-time data in the defined dust ranges.

Table 6.6: Summary of shift dust average and frequency of peak dust levels at Mine B

Test #	Dust Conc. mg/m^3	Frequency of peak dust level (mg/m^3) range							
		0-2	2-5	5-10	10-50	50-100	100-150	150-300	>300
1	5.741	202	924	235	355	35	13	0	0
2	1.194	2505	32	6	21	0	0	0	0
3	7.189	636	501	400	690	2	0	0	0
4	5.317	38	952	766	279	9	6	3	0
5	2.958	25	230	77	164	0	0	0	0
6	7.51	631	652	382	275	53	22	8	1
7	6.47	347	335	282	362	43	14	3	0
8	17.79	1	1146	529	610	97	42	50	13
9	7.15	389	728	476	500	51	15	2	0
10	5.900	2	1368	880	337	16	2	0	0
11	2.034	1792	235	55	54	0	0	0	0
12	1.271	1228	204	18	6	0	0	0	0

13	2.696	339	593	135	68	9	0	0	0
14	9.015	237	827	857	503	31	10	13	8
15	3.086	40	361	312	109	0	0	0	0

Figures 6.10 and 6.11 show the frequency-dust concentration profiles for the continuous mining section-Mine B.

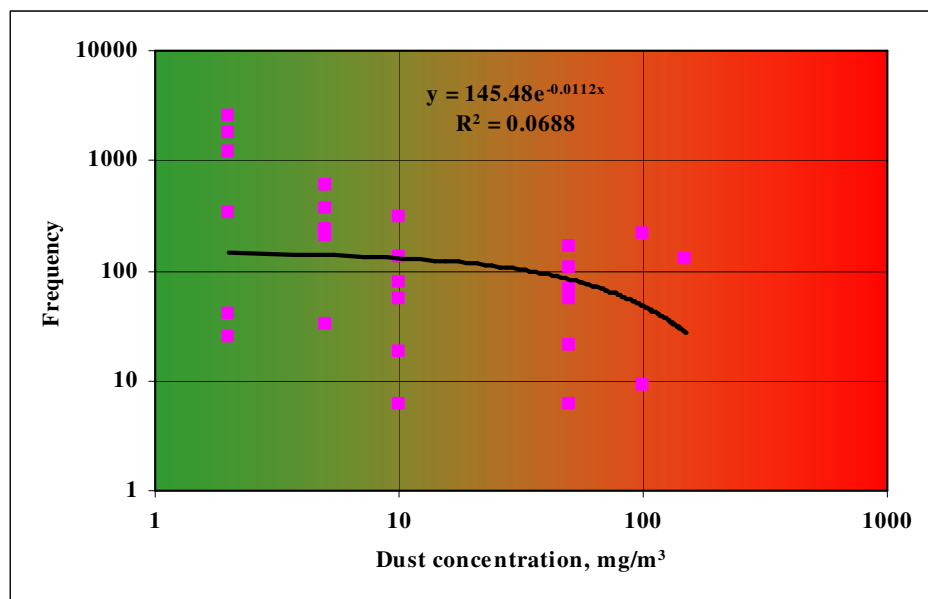


Figure 6.10: Overall frequency-dust concentration profile at the CM operator position for Mine B during engineering dust levels < 5 mg/m³

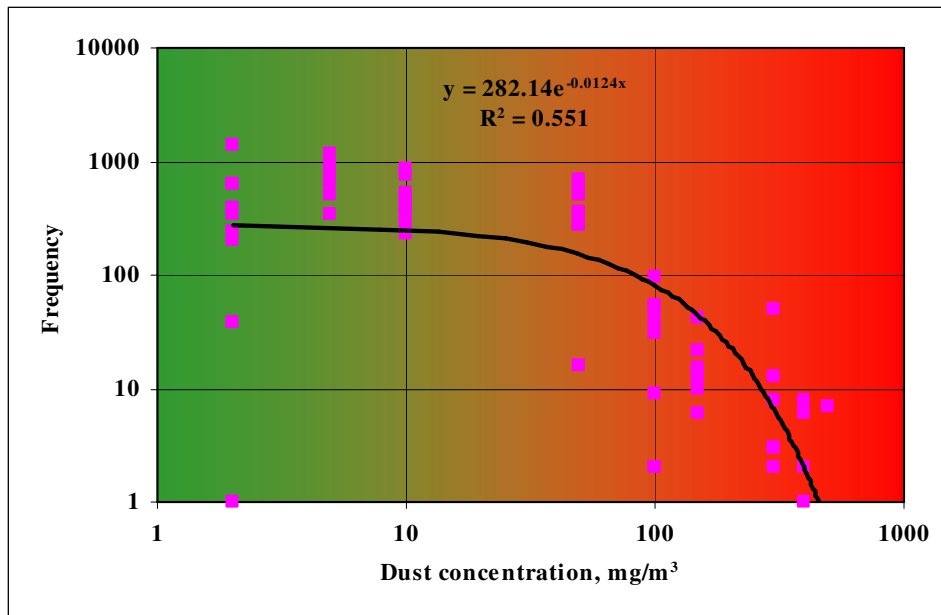


Figure 6.11: Overall frequency-dust concentration profile at the CM operator position for Mine B during engineering dust levels > 5 mg/m³

Continuous Miner Section - Mine C

In this continuous miner section Mine C, real-time data was collected for a total of 8 underground shifts. The average engineering sample dust concentration was 4.28 mg/m³ with an average working shift production during the test period of 750 tons. The real-time dust plots at the CM operator's position for a total of 8 underground shifts is shown in Appendix (B6). The individual shift data was analysed for peak dust levels in the respective identified ranges. The histogram data with identified range of dust level values were separated according to daily engineering dust level of greater and lesser than 5 mg/m³ respectively. Table 6.7 shows the summary of shift average dust levels and frequency of peak dust levels obtained from the real-time data in the defined dust ranges. Figures 6.12 and 6.13 show the frequency-dust concentration profiles for the continuous mining section- Mine C.

Table 6.7: Summary of shift dust average and frequency of peak dust levels at Mine C

Test #	Dust	Frequency of peak dust level (mg/m ³) range							
	Conc. mg/m ³	0-2	2-5	5-10	10-50	50-100	100-150	150-300	>300
1	1.973	539	457	64	6	0	0	0	0
2	3.395	1023	330	329	240	12	8	8	0
3	2.376	914	318	128	73	4	2	4	0
4	4.756	1710	1431	398	384	30	7	0	0
5	5.232	605	641	364	291	1	2	1	0
6	3.344	842	1120	294	86	4	2	1	0
7	10.29	220	1587	811	439	31	15	27	10
8	2.839	735	1676	121	17	1	0	0	0

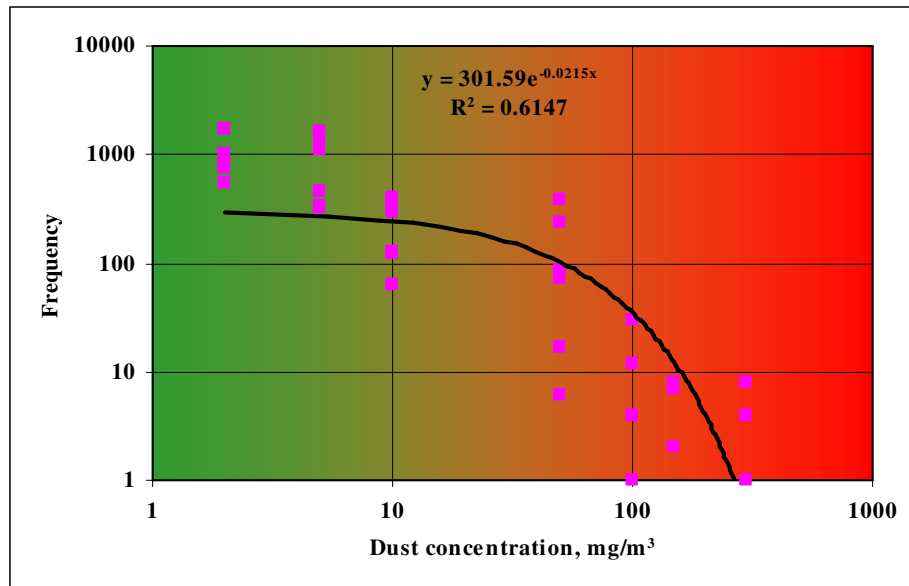


Figure 6.12: Overall frequency-dust concentration profile at the CM operator position for Mine C during engineering dust levels < 5 mg/m³

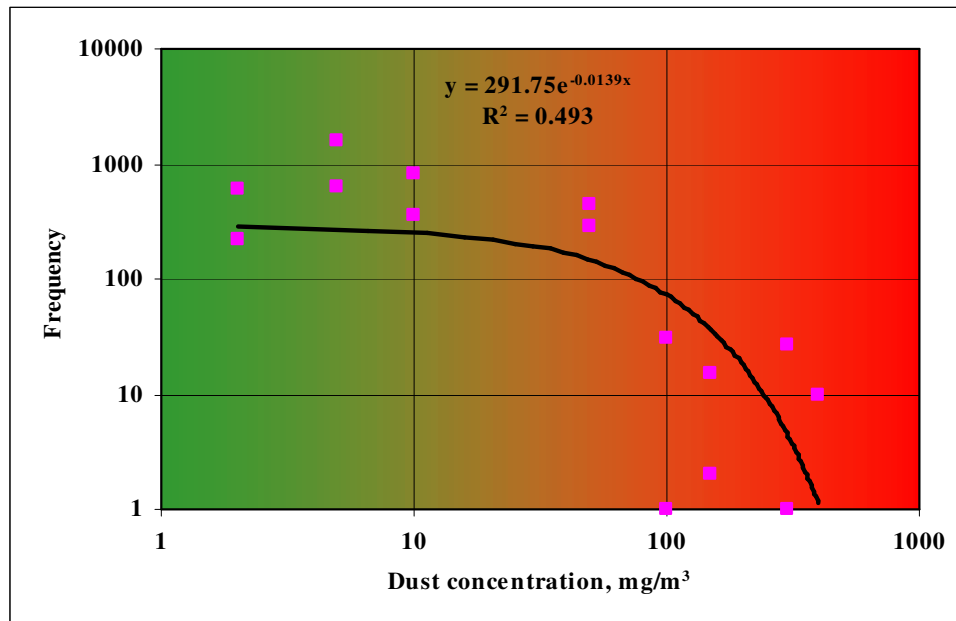


Figure 6.13: Overall frequency-dust concentration profile at the CM operator position for Mine C during engineering dust levels > 5 mg/m³

Continuous Miner Section - Mine D

In this continuous miner section Mine D, real-time data was collected for a total of 4 underground shifts. The average engineering sample dust concentration was 6.12 mg/m³ with an average working shift production during the test period of 1060 tons. The real-time dust plots at the CM operator's position and section return position for a total of 4 underground shifts is shown in Appendix (B7). The individual shift data was analysed for peak dust levels in the respective identified ranges. The histogram data with identified range of dust level values were separated according to daily engineering dust level of greater and lesser than 5 mg/m³ respectively. Table 6.8 shows the summary of shift average dust levels and frequency of peak dust levels obtained from the real-time data in the defined dust ranges.

Table 6.8: Summary of shift dust average and frequency of peak dust levels at Mine D

Test #	Dust	Frequency of peak dust level (mg/m ³) range							
	Conc. mg/m ³	0-2	2-5	5-10	10-50	50-100	100-150	150-300	>300
1	7.05	201	490	615	649	34	2	7	0
2	9.41	168	333	400	762	31	2	0	0
3	4.80	368	566	397	272	10	2	0	0
4	3.22	543	490	160	146	31	5	1	0

Figures 6.14 and 6.15 show the frequency-dust concentration profiles for the continuous mining section-Mine D.

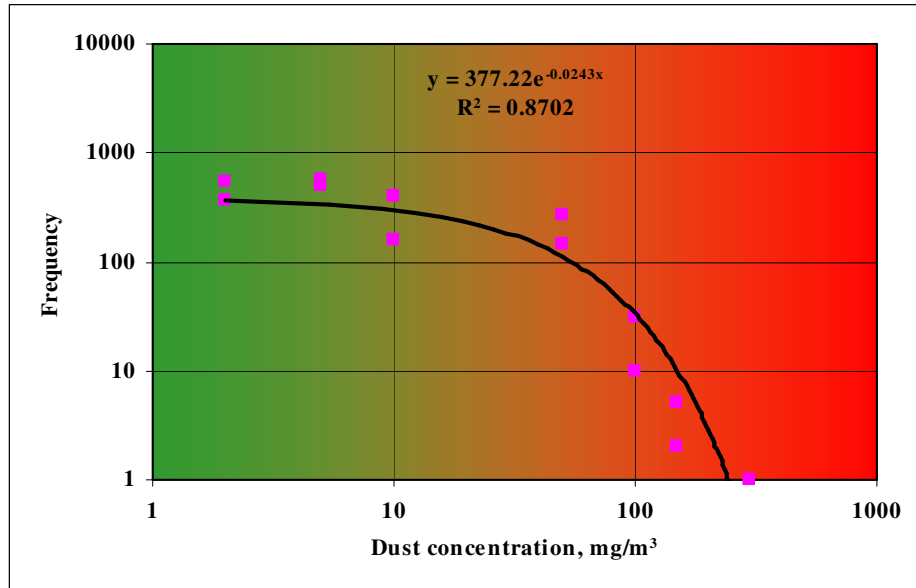


Figure 6.14: Overall frequency-dust concentration profile at the CM operator position for Mine D during engineering dust levels < 5 mg/m³

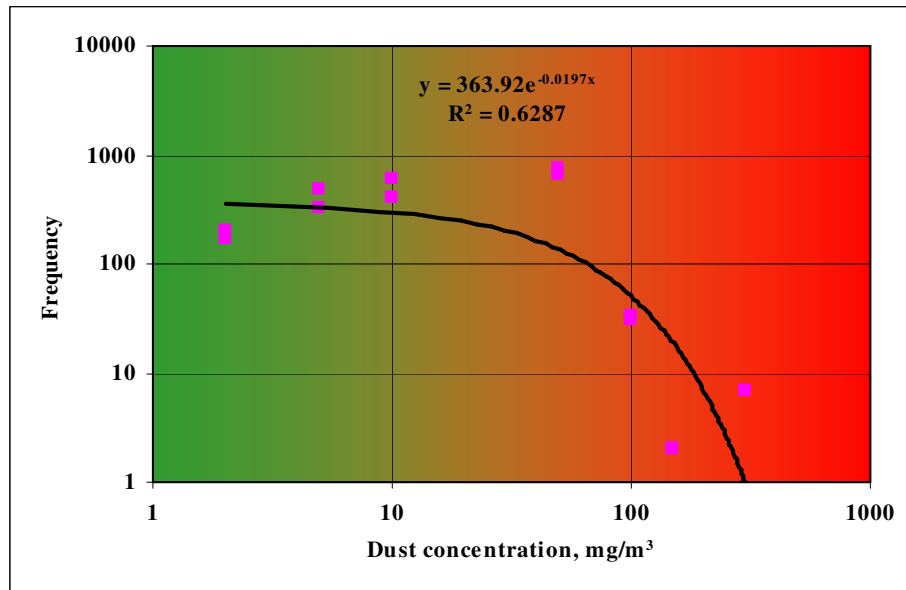


Figure 6.15: Overall frequency-dust concentration profile at the CM operator position for Mine D during engineering dust levels > 5 mg/m³

Road Header Section - Mine E

In this road header (RH) section Mine E, a total of 25 underground shift real-time data was collected. The description of the dust control system is discussed in Appendix (A). The real-time dust plots at the CM operator's position and section return position for a total of 25 underground shifts is shown in Appendix (B8). The average engineering sample dust concentration was 4.52 mg/m³ with an average working shift production during the test period of 760 tons. The individual shift data was analysed for peak dust levels in the respective identified ranges. The histogram data with identified range of dust level values were separated according to daily engineering dust level of greater and lesser than 5 mg/m³ respectively. Table 6.9 shows the summary of shift average dust levels and frequency of peak dust levels obtained from the real-time data in the defined dust ranges.

Table 6.9: Summary of shift dust average and frequency of peak dust levels at Mine E

Test #	Dust Conc. mg/m ³	Frequency of peak dust level (mg/m ³) range							
		0-2	2-5	5-10	10-50	50-100	100-150	150-300	>300
1	3.42	655	289	199	207	18	2	0	0
2	6.29	416	601	274	297	84	16	2	0
3	1.89	791	246	126	112	1	0	0	0
4	2.89	1172	506	219	128	2	0	0	0
5	4.00	357	1255	795	187	60	34	6	0
6	10.44	10	763	1177	534	77	5	1	0
7	4.45	379	736	569	212	3	2	0	0
8	6.77	27	764	1219	325	16	0	0	0
9	5.52	93	784	686	232	3	0	0	0
10	8.59	480	630	891	694	66	8	1	0
11	4.85	434	904	619	174	1	0	0	0
12	6.37	668	603	721	618	38	0	0	0
13	1.76	1572	241	173	41	1	0	0	0
14	4.24	58	555	434	221	12	0	0	0
15	3.36	1686	525	290	219	3	0	0	0
16	2.62	896	556	261	120	1	0	0	0
17	5.56	81	1752	769	345	24	1	0	0
18	4.95	337	1097	376	288	0	0	0	0
19	3.35	36	1040	152	83	0	0	0	0
20	4.37	66	937	494	202	14	7	0	0
21	2.06	1472	403	219	86	0	0	0	0
22	2.75	1261	832	234	99	4	1	0	0
23	7.48	41	1295	545	682	26	0	0	0
24	0.68	135	57	2	1	0	0	0	0
25	4.38	329	483	249	195	18	1	0	0

Figures 6.16 and 6.17 show the frequency-dust concentration profiles for the continuous mining section-Mine E.

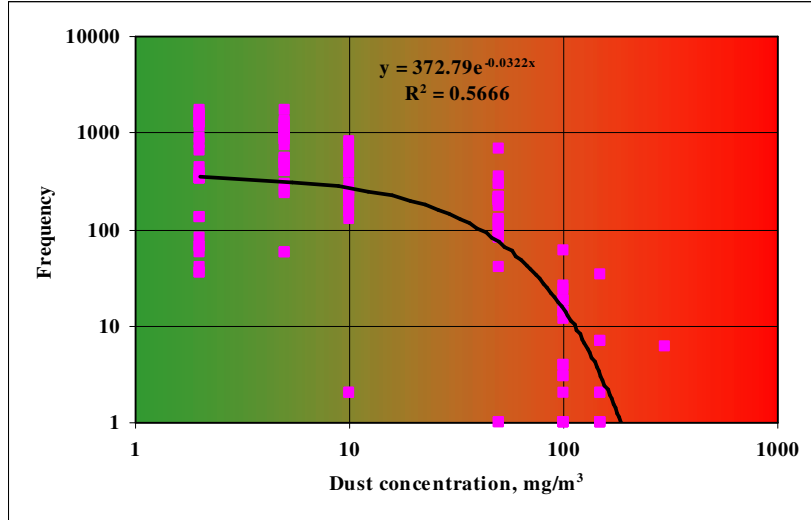


Figure 6.16: Overall frequency-dust concentration profile at the RH operator position for Mine E during engineering dust levels < 5 mg/m³

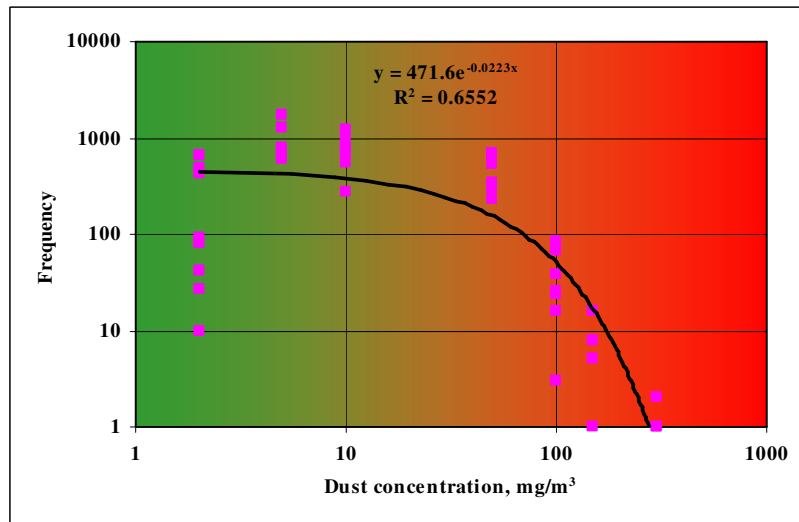


Figure 6.17: Overall frequency-dust concentration profile at the RH operator position for Mine E during engineering dust levels > 5 mg/m³

Longwall Shearer Section - Mine F

In this longwall double drum shearer section Mine F, real-time dust data was collected for a total of 4 underground shifts. The description of the longwall dust control system is summarised in Appendix (A). The average engineering sample dust concentration was 8.19 mg/m³ with an average working shift production during the test period of 3355 tons. The real-time dust plots at the feeder breaker position, headgate position, shearer mid-point sample, tailgate position, longwall return position is shown in Appendix (B9). The individual shift data was analysed for peak dust levels in the respective identified ranges. The histogram data with identified range of dust level values were separated according to daily engineering dust level of greater and lesser than 5 mg/m³ respectively. Table 6.10 shows the summary of shift average dust levels and frequency of peak dust levels obtained from the real-time data in the defined dust ranges.

Table 6.10: Summary of shift dust average and frequency of peak dust levels at Mine F

Test #	Dust Conc. mg/m ³	Frequency of peak dust level (mg/m ³) range							
		0-2	2-5	5-10	10-50	50-100	100-150	150-300	>300
1	11.84	105	463	289	646	220	29	6	0
2	9.19	47	387	218	459	141	49	6	0
3	3.53	29	724	297	248	6	1	0	0
4	8.90	14	274	193	556	223	76	17	0

Figures 6.18 and 6.19 show the frequency-dust concentration profiles for the continuous mining section-Mine F.

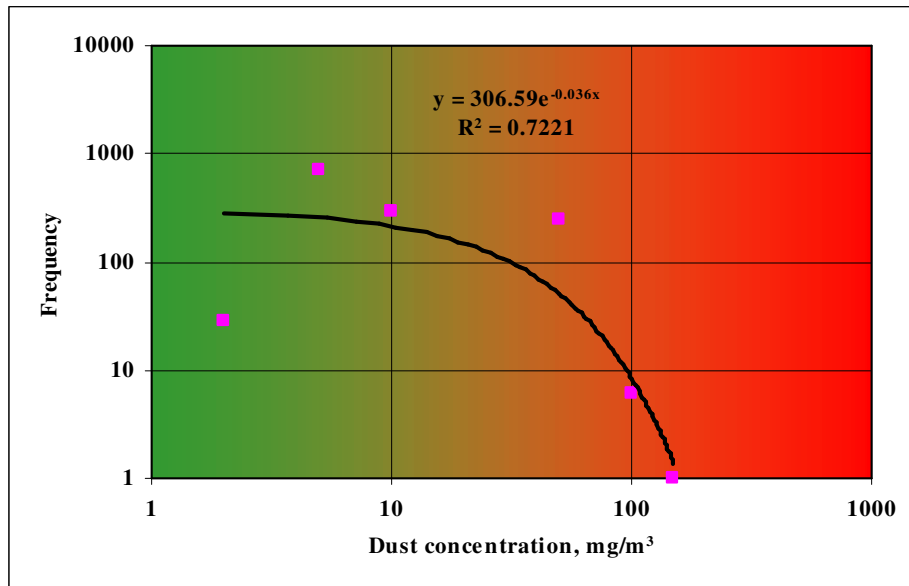


Figure 6.18: Overall frequency-dust concentration profile at the longwall shearer mid-point for Mine F during engineering dust levels < 5 mg/m³

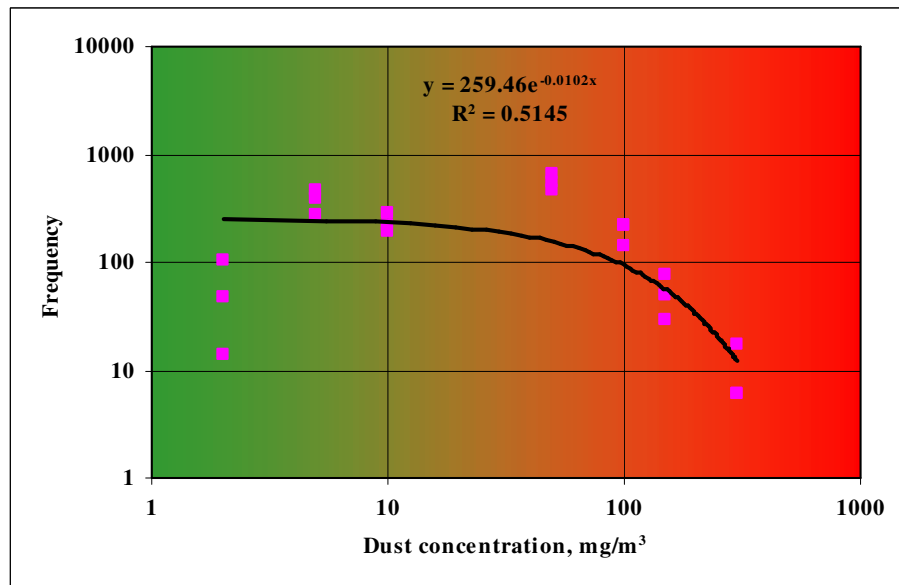


Figure 6.19: Overall frequency-dust concentration profile at the longwall shearer mid-point for Mine F during engineering dust levels > 5 mg/m³

Finally, all individual mine (mine A to mine F) frequency-dust concentration profiles according to average shift engineering dust level of greater and lesser than 5.0 mg/m³ were combined. Figures 6.20 and 6.21 show the combined frequency-dust concentration profile for the shift engineering dust value of lesser and greater than 5 mg/m³ respectively. From the plots it is evident that the average engineering dust levels were directly related to frequency of peak dust levels in the range of 100 mg/m³, 150 mg/m³ and 300 mg/m³. Comparing the average dust levels with frequency of peak dust levels indicates that frequency of occurrence of peak dust levels of 50 mg/m³ or above for an average dust level of greater than 5 mg/m³ is double that of average dust levels of less than 5 mg/m³. With the developments in real-time dust measurement technologies it is envisaged that the frequency of peak dust levels encountered during a working shift can be effectively made use of in a quick determination of worker exposure and the dust control system's efficiency.

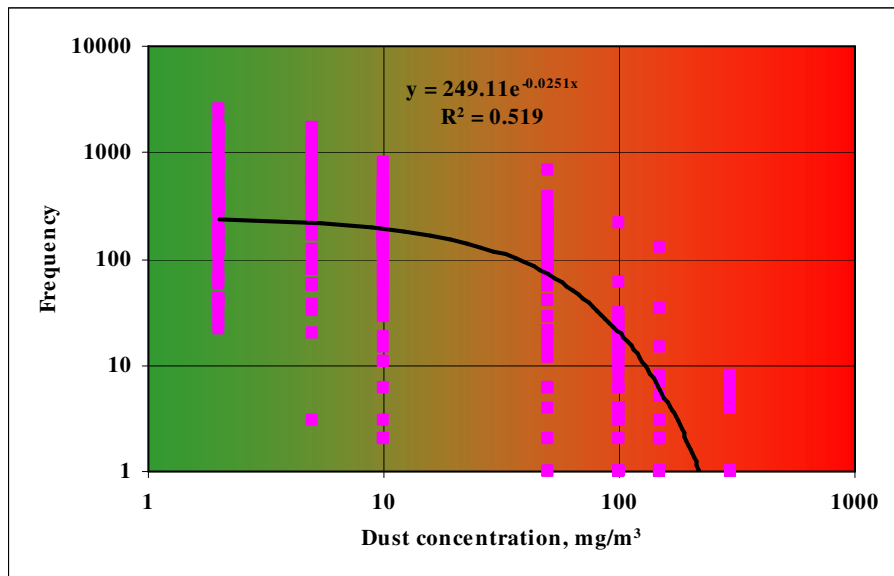


Figure 6.20: Overall frequency-dust concentration profile for all mines with engineering dust levels < 5 mg/m³

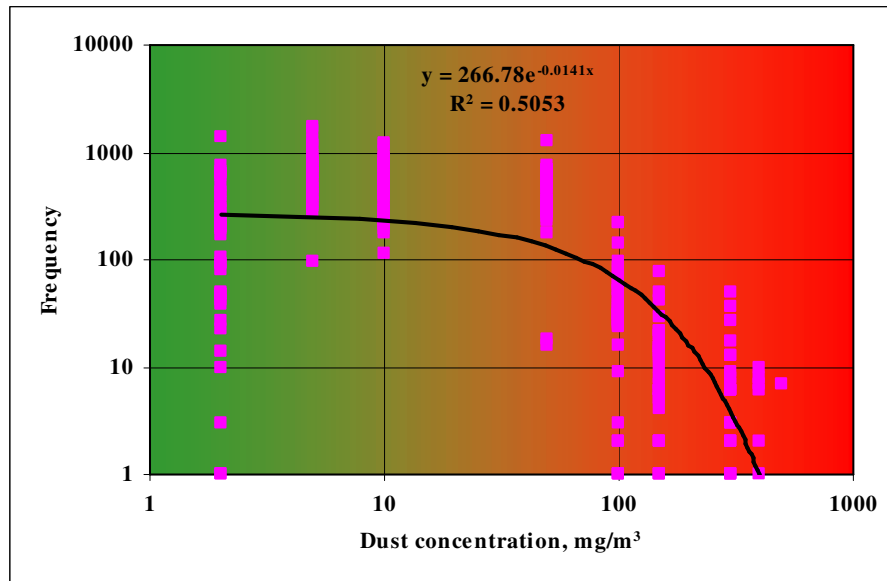


Figure 6.21: Overall frequency-dust concentration profile for all mines with engineering dust levels > 5 mg/m³

6.6 Conclusions

Occupational Exposure Level (OEL) has three basic components (Hewett, 1996): concentration, averaging time and target of the exposure, in this case the coal mine worker. There are many agencies who have designed values such as Permissible Exposure Limits (PELs) of Occupational Safety and Health Administration, Recommended Exposure Limits (RELs) of the NIOSH and the Threshold Limit values (TLVs) of ACGIH, which are intended, in principle, to be applied to the exposures experienced by a mine worker. Due to the changing working conditions and working hours, the use or comparison of the average shift dust measurements to a legal OEL (originally defined as a single shift of 8-hr) becomes questionable. Also, some of these standards developed by overseas authorities are approaching 30 years of age and these standards are always under review.

In South Africa, DME appears to have relied heavily on the world bodies such as ACGIH, NIOSH, ISO, CEN and WHO for guidelines. In South Africa, for coal

mines, we do not have a dose-response curve for Coal Workers' Pneumoconiosis (CWP). Therefore, setting up a foolproof standard or exposure level will become cumbersome and implementation thereof will be a difficult exercise where the resources are scarce. In the same vein, the need for the revision of existing exposure evaluation methods, or developing improved standards based on evidence or developing a new practical tool to exposure assessment is becoming a necessity.

In the year 1997, the DME conceived the Engineering Exposure Levels (EELs) considering the cutting machine as the target in controlling dust exposure, as this would reduce the exposure levels of the entire exposure group, work area or the section. Currently, the EEL for the coal mines is 5 mg/m^3 . However, this engineering exposure limit is not applicable for the personal exposure limit of 2 mg/m^3 . In South Africa, all the coal mining sections are repetitively collecting engineering dust samples day after day. The analysis of the vast amount of data submitted to the DME is not properly investigated due to lack of human and technical resources. This situation is not assisting either the coal mine operator or the DME in evaluating the situation or estimating the level of worker protection from dust exposures.

In practice, the gravimetric dust samples collected from the mines takes a turnover time of up to three working days to determine the shift dust concentration levels, due to transport of the dust samples to a distant laboratory, keeping the sample for acclimatisation and then weighing. In such cases, use of a real-time dust monitor available at an individual mine can be effectively made use of based on the relationship between frequency of peak dust levels and the shift engineering dust level obtained from this study. Therefore, the use of peak concentration level as a parameter in expressing dust exposure level of a worker can become the correct path for achieving the ultimate goal of zero or minimum exposure for mine workers. This can be achieved through quick reaction time for maintaining dust control systems. In order for effective use the peak dust level and its frequency of

occurrence, a matrix has been developed based on analysing the field data and is summarized in Table 6.11. The contents are based on the frequency of the peak concentrations in the respective zones as shown in Figure 6.22. The colour coding gradient from 'Green' to 'Red' in the plot represents increase in exposure levels with increase in dust concentration.

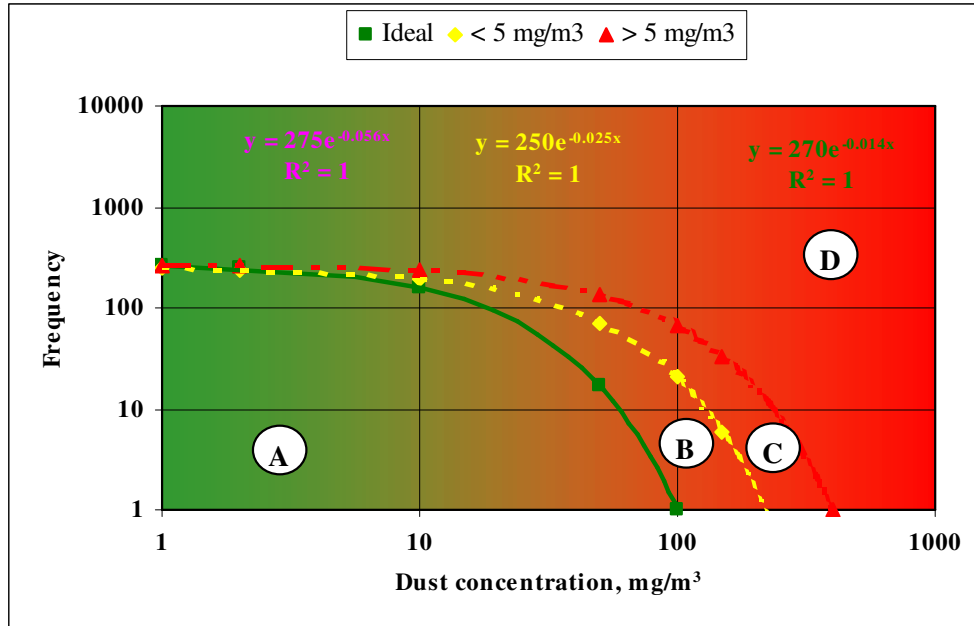


Figure 6.22: Frequency-dust concentration indicator model for dust exposure levels

Table 6.11: Frequency-dust concentration indicator models for dust exposure levels

Plot area	Line equation	Color	Exposure degree	Description
A	$Y = 275e^{-0.056x}$	Green	I	Good
B	$Y = 250e^{-0.021x}$	Yellow	II	Moderate to sensitive
C	$Y = 270e^{-0.014x}$	Orange Red	III	Unhealthy
D		Red	IV	Very Unhealthy to Hazardous

The above information can be used in practice by coal mines using any real-time dust monitor with an established gravimetric correction factor from the best-fit model. Table 6.12 shows the practical reference table on frequency-dust level obtained from the derived peak dust level model for real-time dust measured at the operator's cabin position on continuous miners and road headers. For a longwall section this would be the middle point on the shearer. Real-time dust data obtained from a coal mine section during or just after working shift can be analysed for occurrence of peak dust levels in pre-defined ranges discussed above using a simple spreadsheet programs like Microsoft Excel or in-built programme in the real-time dust monitor. After obtaining the frequency of the peak dust levels and comparing it to the reference table (Table 6.12) one can come to a general conclusion with regard to the level of dust a worker is exposed to and immediate action on maintaining the dust control systems can be taken before the beginning of the next working shift. With the existing method of gravimetric sampling it nearly takes 3 days to obtain the results and during the waiting period workers will be at risk of high dust exposures.

Table 6.12: Reference table on peak exposure levels in the coal face

Real-time dust level, mg/m ³	Frequency of dust level		
	Ideal value	Shift dust level < 5 mg/m ³	Shift dust level > 5 mg/m ³
1	260	244	266
2	246	238	263
10	157	195	235
50	17	72	134
100	1	21	67
150	0	6	33
300 or more	0	0	5

It must be borne in mind that the peak dust exposure level index was derived from the engineering dust levels measured at the operator's cabin position using real-time dust instrument measuring at every 8 seconds during the cutting operation. In summary the peak dust level index is practical in monitoring and maintaining the dust control systems and thus lower the risk of dust exposure level of workers.

6.7 Summary

The focus of this chapter is to understand the peak dust level data obtained during the coal cutting operation in a bord and pillar coal mine that can be effectively used to estimate worker exposure levels. Unlike waiting for a few days for gravimetric sample results, the real-time information can be very effectively used just after the shift for estimating the worker exposure levels. The task can be carried out using the real-time data (recorded at every 8 seconds for the cutting operations) from the monitor positioned at the machine operator's position in various underground coal mines and analysing the peak dust levels for their frequency of occurrence during the shift.

The results show a clear relationship between the average engineering dust levels and the frequency of occurrence of "peak" dust levels. Comparing shift engineering dust levels with frequency of peak dust levels indicates that frequency of occurrence of peak dust levels (50 mg/m^3 or above) during shift average dust level of greater than 5 mg/m^3 is double that of shift average dust levels of less than 5 mg/m^3 . The proposed index based on peak concentration levels are based on the hypothesis that the worker who is working in the face area is exposed to frequent peak concentration levels and thus the cumulative deposition of the respirable dust in the lungs could be much higher. Therefore, the recovery period for the worker in the face area from the deposited lung dust could also be comparatively higher. The index can be used in risk assessment and as an administrative monitoring approach for a cleaner environment.

Further, the real-time dust information can be wisely applied to evaluate the available state-of-the-art dust control technologies, best work practices, and to audit maintenance of the installed dust control systems to ensure that dust levels are controlled immediately and after every shift. It is the author's strong belief that the use of peak concentration levels is one of the most important parameter in implementing an effective dust control system and reducing the worker exposure to coal dust. This tool is recommended for dust level monitoring (exposure) by the mine environment officers, occupational hygienists and mine management. The mine can then make decisions for upgrading the dust control system or the effective use of respirators in areas where engineering dust control mechanisms do not exist. Finally, use of the peak exposure chart (Figure 6.22) and index (Tables 6.11 and 6.12) discussed in this chapter could assist to better understand the dust exposure level and the resulting medical response in future epidemiological studies. It is also recommended that a real-time peak dust level model should be established based on real-time personal sample data from South African underground coal mines.

Chapter 7 Intake Dust Concentration Levels

7.1 Fresh Intake Air

Fresh air intake in an underground mine is of critical importance to the occupational health and safety of workers due to the dynamic, confined and dangerous nature of the mining environment. If the intake air is seriously contaminated by airborne respirable dust then the exposure of the workforce in the section will constantly be elevated by that background dust level. During the mining process, various levels of dust will be generated at various dust sources, some of which will be captured and some will be re-introduced into the air. Therefore, the need for the fresh intake air to dilute and disperse the high dust concentration levels in a mining environment is very important. Also, the re-circulation of air in the mining environment is some times a part of the process. Unlike the situation in the coal mines in USA, in many mines in South Africa, belt air is not separated from the fresh air intake in the sections. High expectations in maintaining a better working environment in the face area require clean fresh air intake into the section.

Effective primary and secondary ventilation in underground mines is achieved through dividing roadways and splits into parallel circuits. Extraction of coal in deep development headings is realized through auxiliary ventilation devices such as a jet fan or force fan with columns. Dust entrainment is one of the problems deriving from high intake velocities due to the design of the mine roadways. Intake air to coal production faces generally contains dust generated by conveyor belts, transfer points and travelling roads. The long roadways, up to a few kilometres in some of the existing mines, to the coal sections involve the ventilation circuits of individual sections. This leads to a progressive increase in the intake dust levels in the fresh air and thus high dust levels in the air delivered to the working sections downstream. This could be avoided by having much

shorter and more direct ventilation circuits through each working area. However, from the practical point of view, this is almost impossible and would certainly not be cost-effective. Alternatively, the dust levels could be lowered by increasing the quantity of ventilation air at a high power cost to the mine, although there would still be limitations.

In the process of reducing the worker exposure to the dust in the face area, the attention to the monitoring of fresh intake air is given a low priority. However, the intake dust level can be used as a parameter in estimating the exposure levels of workers in the section intake and also to monitor “freshness” of intake air to the section. This information would facilitate the mine (ventilation) management’s regulation of the strategic aspect of controlling the dust in the sections and thus help to reduce worker dust exposure.

7.2 Intake Dust Levels

In order to achieve an effective reduction in personal exposure levels in coal mines, intake air concentrations of respirable coal mine dust must be kept sufficiently below the dust standards (2.0 mg/m^3) or Recommended Exposure Levels (RELs) of 1.0 mg/m^3 (NIOSH, 1995). According to 30 CFR 70.100 (MSHA Respirable dust standards):

- Each operator shall continuously maintain the average concentration of respirable dust in the mine atmosphere during each shift to which each miner in the active workings of each mine is exposed, at or below 2.0 mg/m^3 of air as measured with an approved sampling device and in terms of an equivalent concentration determined in accordance with approved sampling devices; equivalent concentrations.
- Each operator shall continuously maintain the average concentration of respirable dust within 200 feet out-by the working faces of each section in the intake airways at or below 1.0 mg/m^3 of air as measured with an

approved sampling device and in terms of an equivalent concentration determined in accordance with approved sampling devices; equivalent concentrations.

In South Africa, there are no such RELs specifically for the fresh intake air dust levels but all the personal respirable dust exposure levels should be below the standard of 2 mg/m³.

7.3 Section Intake Dust Levels in Overseas Mines

As a part of this study, data on intake dust levels measured worldwide was collected and it was found that scant research data on intake dust levels was publicly available from the literature overseas. For example, MESA studies of 1977 and the USBM studies give short term (50 minute) samples taken in intake airways in a few coal mines in USA. Some of the data found in the reports (see Table 7.1 and 7.2) does not give details of sampling period of measured intake dust levels. In the recent years, efforts have been made mainly to quantify the dust sources and levels in the face area of coal mines.

In the early 1970's a brief Bureau of Mines study of respirable dust levels in several mines, as measured by federal inspectors, suggested that in some mines respirable dust concentrations appeared to be higher in winter than in summer, but that this was not true for other mines. However, a later study in 1986 by the Bureau concluded that any seasonal effects are insignificant (Divers, E., Courtney, W., and Greninger, N., 1986). Despite this, winter alert for high dust levels is still the practice with MSHA. The study did not differentiate the influence of season on the intake dust levels. An Institute of Occupational Medicine (IOM) study carried out at a number of British coal mines showed that there were significant intake dust levels in these mines (Bodsworth et al., 1993).

An USBM study (Sharan et al., 1997) concluded that each outbye dust source by itself may not be a major contributor, but the collective contribution of all outbye sources to the intake air at the beginning of the face can be significant, as much as 80% of the Permissible Exposure Level (PEL) of 2 mg/m³ at the working face.

An extensive airborne dust survey was carried out by the Directorate General of Mines Safety (DGMS) in twenty one Indian coal mines during 1991-1996 (Ganguly, et al., 2000). Information relating specifically to the levels of district intake dust concentrations in Indian coal mines is summarized below in Table 7.1. The measurements were taken at the district intake (not section intake) and were measured using GDE-MRE 113A and AFC-123 dust samplers.

Table 7.1: Summary of district intake dust levels from Indian coal mines

Mining type	Dust concentration	
	Range, mg/m ³	Mean, mg/m ³
Manual-Mine A	0.18-0.47	0.29
Semi-Mechanized-Mine B	0.07-1.95	0.43
Semi-Mechanized-Mine C	0.24-1.44	1.02
Semi-Mechanized-Mine D	0.15-0.52	0.27
Semi-Mechanized-Mine E	0.17-0.39	0.31
Semi-Mechanized-Mine F	0.09-0.24	0.16
Semi-Mechanized-Mine G	0.08-0.29	0.14
Manual-Mine H	0.10-0.18	0.14
Mechanized-Mine I	0.11-0.41	0.27
Mechanized-Mine J	0.18-0.89	0.55
Mechanized-Mine K	0.15-0.39	0.27
Mechanized-Mine L	0.11-0.54	0.28
Mechanized-Mine M	0.28-0.90	0.47

Manual-Mine N	0.10-0.37	0.18
Semi-Mechanized-Mine O	0.11-0.34	0.23
Manual-Mine P	0.11-0.39	0.21

As we note from the above reported survey, the average district intake dust concentration for the different mines is 0.33 mg/m³ (16.3 % of the OEL of 2 mg/m³). Similarly, Table 7.2 summarizes the recorded intake dust levels from various other mines overseas.

Table 7.2 Summary of district intake dust levels from overseas mines.

Mining type	Country-mine	Dust concentration, mg/m ³			Source
		Min.	Max	Avg.	
Longwall	Poland-A	1.2	2.2	-	Koziel et al., 1999
	Poland-B	1.2	2.0	-	
	Poland-C	0.5	0.7	-	
Longwall	Poland-D	2.2	4.5	-	Koziel & Malec, 1998
	Poland-E	5.5	9.5	-	
	Poland-F	0.5	0.7	-	
	Poland-G	1.5	1.8	-	
	Poland-H	0.7	1.0	-	
Tunnel	USA-Yucca Mountain	-	-	0.6	Kissell et al., 1999
Longwall	USA-S1	-	-	0.2	Mundell & Taylor, 1977
	USA-S2	-	-	0.8	
	USA-S4	-	-	0.4	
	USA-S5	-	-	1.5	
	USA-S6	-	-	0.3	
	USA-S7	-	-	0.2	
	USA-P1	-	-	0.4	

	USA-P2			1.5	
	USA-P3			0.4	
CM Sections	USA	0.3	0.8	-	Tomb et al., 1978
Longwall	USA-Mine 1	-	-	0.1	Page et al., 1982
	USA-Mine 2	-	-	0.6	
	USA-Mine 3	-	-	1.8	
	USA-Mine 4	-	-	0.6	
	USA-Mine 5	-	-	0.3	
Longwall	USA-A	-	-	0.24	Colinet et al., 1997
	USA-B	-	-	0.25	
	USA-C	-	-	0.35	
	USA-D	-	-	0.25	
	USA-E	-	-	0.30	
	USA-F	-	-	0.33	
	USA-G	-	-	0.37	
	USA-H	-	-	0.35	
	USA-I	-	-	0.07	
	USA-J	-	-	1.10	
	USA-K	-	-	0.62	
	USA-L	-	-	0.59	
	USA-M	-	-	0.08	
CM Heading	USA-Mine A	-	-	0.29	Sharan et al., 1997
		-	-	0.28	

7.4 Intake Dust Levels in South African Mines

This section of the thesis outlines the recorded section intake dust levels in the past (Table 7.3) and dust measurements that were carried out by the researcher over a period of 5 years (1998 to 2002) in several continuous miner (CM) and longwall sections (Table 7.4).

Table 7.3 Summary of the recorded intake dust levels during 1990-1998

Mining type	Concentration, mg/m³	Data Source
CM Heading	3.5 mg/m ³ (Mine-A)	COM Report: 91/05
	2.2 mg/m ³ (Mine-A)	
	2.2 mg/m ³ (Mine-B)	
CM Heading	1.9 mg/m ³ (Mine-C)	COM Report: 91/08
	1.1 mg/m ³ (Mine-D)	
	0.9 mg/m ³ (Mine-E)	
Remote CM Heading	0.4 mg/m ³ (Test-1)	COM Report: 93/18
	0.447 mg/m ³ (Test-2)	
	0.134 mg/m ³ (Test-3)	
AM85 Voest Alpine Heading	0.46 mg/m ³	COM Report: 92/02

With the introduction of gravimetric sampling in South Africa, a dust survey was carried out by the Chamber of Mines (Sullivan, 1991) in 29 CM production sections at three coal mines. It was assumed that the gravimetric dust samplers were operated according to the BMRC size-selective curve at a flow rate of 1.9 L/min. This study showed that of all the readings, 13% were in excess of 2 mg/m³, whilst 44% were below 1.0 mg/m³. Table 7.4 shows the summary of the sampled mines and the intake sample details in the past five years by the

researcher.

Table 7.4: Summary of mines and details of section intake samples

Mine	Mining method	No. of samples	Average sampling time, mins
A	Bord and pillar	11	386
B	Bord and pillar	50	349
C	Longwall	4	350
D	Bord and pillar	13	378
E	Bord and pillar	96	308
F	Bord and pillar	48	310
G	Longwall	5	309
H	Bord and pillar	20	345
I	Bord and pillar	10	276

The average sampling period of all section intake dust samples was 330 minutes. Figure 7.1 shows typical real-time section intake dust level monitored in an underground CM section for the sampling period. Similarly, the real-time dust level plots measured in various mines at the section intake position are shown in Appendix C. Dust measurements (240 samples) taken from different bord and pillar CM sections indicate that the average section intake dust level was 0.78 mg/m^3 . Some of the high dust levels measured was due to the application of stone dusting during the beginning or in the middle of the shift. Also, the use of “double-heading” development coal sections may have contributed in increased section intake dust levels. The dust samples which were tainted by stone dust were nearly 4% of the total section intake dust samples and were usually greater than 2.5 mg/m^3 . However, this could only be noted by time study or observation of dust filter after sampling and not merely by looking at the data.

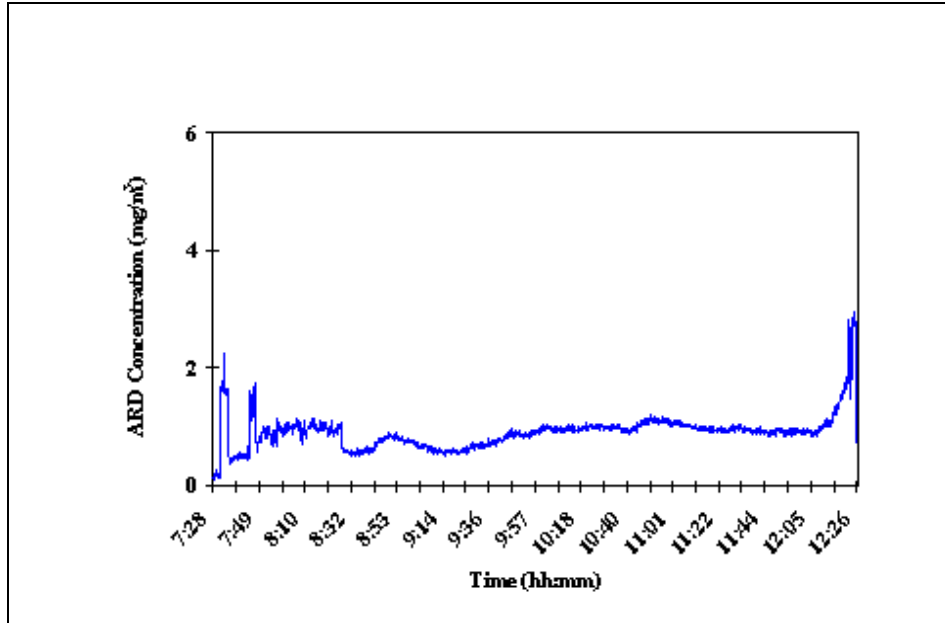


Figure 7.1: Typical real-time dust levels at the section intake of a coal mine

Figures 7.2 and 7.3 show the histogram plot of section intake levels from various bord and pillar and longwall sections. Table 7.5 shows the frequency distribution of section intake dust levels in coal mines.

From the longwall dust measurements (9 samples) carried out, the section intake dust levels was 1.41 mg/m^3 . Figure 7.4 shows the contribution of section intake dust (approximately 14.7%) to the total longwall panel dust make.

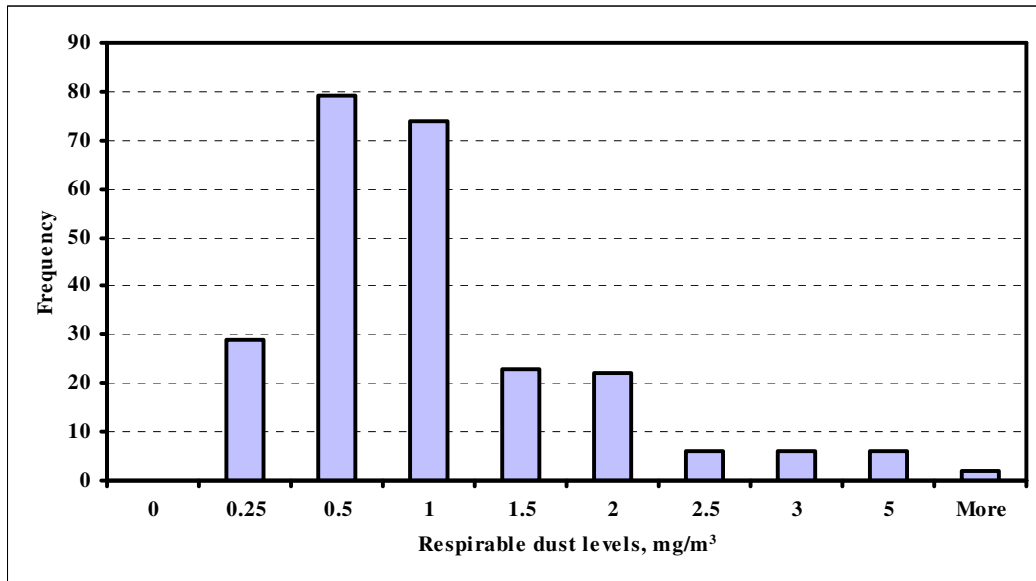


Figure 7.2: Histogram of intake dust levels in bord and pillar CM sections

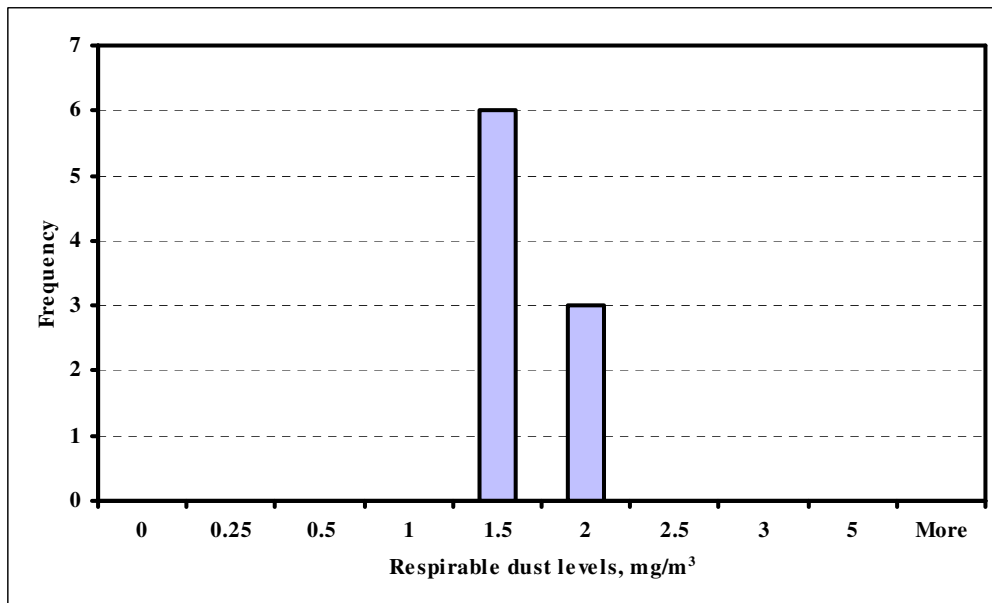


Figure 7.3: Histogram of section intake dust levels in longwall sections

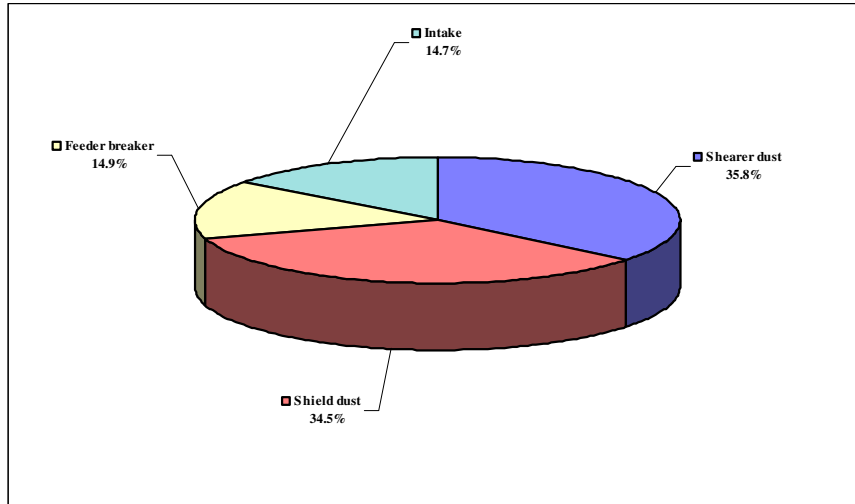


Figure 7.4: Contribution of intake dust levels in a longwall face

Table 7.5: Frequency distribution of section intake dust levels

Dust level, mg/m ³	Bord and Pillar % Samples	Longwall % Samples	Total % Samples
0	0.00	0.00	0.00
0.25	11.74	0.00	11.33
0.5	31.98	0.00	30.86
1	29.96	0.00	28.91
1.5	9.31	66.67	11.33
2	8.91	33.33	9.77
2.5	2.43	0.00	2.34
3	2.43	0.00	2.34
5	2.43	0.00	2.34
More	0.81	0.00	0.78

Table 7.6 shows the summary statistics of all the section intake concentration levels measured across various South African underground coal mines.

Table 7.6: Summary statistics of the intake concentrations

Statistic	Mine									
	A	B	C	D	E	F	G	H	I	Overall
Mean	1.475	0.717	1.426	1.315	0.509	0.783	1.399	1.862	2.522	0.898
Minimum	0.365	0.109	1.177	0.814	0.101	0.246	1.076	0.621	0.373	0.101
Maximum	3.748	4.215	1.793	2.650	1.788	1.907	1.733	3.262	6.755	6.755
Samples	11	50	4	13	96	48	5	20	10	256

A study of the literature reveals that there is no available information on dust levels in air drawn into the ventilation circuit of underground mine at the downcast shaft in coal mines. However, a recent SIMRAC health study (Naidoo et al., 2002) reported that the surface dust levels (Table 7.7) had a geometric mean (GM) of 0.25 mg/m³. The sampling position and type of dust samplers used were not reported in the study.

Table 7.7: Summary statistics of the surface dust levels (Naidoo, 2002)

Cycle	Mean (mg/m ³); SD; n		
	Mine 1	Mine 2	Mine 3
Round 1	0.35; 3.60; 2	0.04; 3.13; 2	1.23; 3.56; 5
Round 2	0.06; 1.12; 2	-	0.07; 4.85; 5
Round 3	0.63; 2.48; 4	0.29; 2.41; 4	0.03; -, 1
Overall	0.31; 3.52; 8	0.15; 3.56; 6	0.24; 7.69; 11

The calculated geometric means of the overall surface samples from Mine 1, Mine 2 and Mine 3 were 0.31 mg/m³, 0.15 mg/m³ and 0.24 mg/m³ respectively. In any event, the minimum measured surface level (0.03 mg/m³ at Mine 3) was above 1 % of the OEL of 2.0 mg/m³.

In South Africa, with the recent promulgation of dust regulations (See Chapter 2.10) and the collected section intake results in the past five years, it can be concluded that any “definable” place in an underground mine needs to be sampled on a much more frequent basis than heretofore.

7.5 Intake Dust Concentration as DELI Parameter

Apart from the dust measurement studies reported in this chapter, little or no information is available with regard to the section intake levels in South Africa. Also, the use of intake dust levels in exposure assessment or as an information tool to infer dusty conditions is not being practiced. However, the measurements carried out in various mines during the past five years by the researcher suggests that due attention is needed in the area of effective control of section intake dust in order to reduce the worker exposure. The intention of the exercise is to effectively transfer the intake concentration results into the DELI (Dust Exposure Level Index) model as a parameter for use by the mine risk assessors, ventilation officers, risk managers to protect the workers from over exposure to dust.

From this study we note that approximately 60% of the intake samples were above 0.5 mg/m^3 (or 25 % of the OEL limit of 2 mg/m^3) for the sampling period. The incidence of high levels of dust at the section intake undermines the effectiveness of the dust control systems within the section. The section intake dust levels will supplement the levels of dust generated at the face and this means that additional effort is required to control the exposure to dust. Provided there is proper maintenance of the intake roads, containing the dust at the belt transfer points will reduce the dust re-entrainment into the fresh air intake.

The levels of dust in the fresh air of a coal mine section can be an indirect indicator of exposure of workers to dust in the mining environment. Regardless of the production in the coal mine section, the workers will be exposed to this ‘base’

intake coal dust exposure whilst underground. Therefore it is possible to use this as a parameter of dust exposure level index for outbye workers and as a quick exposure risk assessment tool. In South Africa, there is no dose-response curve for CWP and use of overseas developed dose-response curve is strictly incorrect. Furthermore, it was noted that the average age and number of years spent in coal mines is not known. Unofficial source suggests that a maximum of 20 years is being spent by South African mine workers in coal mines. Based on the previous exposure-response study by Attfield and Seixas (1995), probable development of CWP among SA coal mine worker for various levels of section intake dust levels for a maximum of 15 years being spent in medium/low bituminous coal mines are estimated and shown in Table 7.8 (Excel based prediction model using Attfield and Seixas (1995) is developed and attached in Appendix-C). It should be noted that these predictions should be treated with some caution as indicated by Attfield and Seixas (1995). In the absence of critical parameters of South African workers for the model, it is unwise to judge the approach taken in this Chapter to indicate the risk using overseas work.

Table7.8: Predicted prevalences (%) of CWP 1+, CWP 2+, and PMF at Age 40 years After 15 years Exposure to various Intake Dust Levels in Low-Medium Rank South African Coal mine (based on Attfield and Seixas, 1995)

CWP-Prevalence Model (Attfield and Seixas, 1995)			
	Low-Medium Rank	Low-Medium Rank	Low-Medium Rank
Average Age of the Workers	40	40	40
Shift Respirable Concentration, mg/m³	0.50	1.00	2.00
Number of working years	15	15	15
Cumulative exposure (mg-yr/m³)	8	15	30
Prevalence Risk-CWP1 +	1.329	1.485	1.852
Prevalence Risk-CWP 2+	0.089	0.101	0.128
Prevalence Risk-PMF	0.049	0.054	0.066

A NIOSH report (1995) suggested that the risk estimate below 0.5 mg/m³ would be based on extrapolation beyond the range of the exposure-response data and would carry considerable uncertainty. Therefore, for all practical purposes, a shift fresh intake air concentration of 0.5 mg/m³ (25 % of OEL) is recommended as an

acceptable ‘good’ level of dust in the fresh air intake (although lower levels must be pursued for a better environment).

The description of intake dust levels of 0.5 mg/m^3 as “good” is based on practical feasibility and health effects data from overseas work. However, the acceptable level of 0.5 mg/m^3 does not ensure that the coal mine worker at this exposure level would be protected with a ‘zero’ risk of developing CWP. It must be borne in mind that intake dust level is a *base* to the mine worker exposed to dust without carrying out any additional work in the section.

In order for the effective use of this information, a matrix has been developed (Table 7.9) and discussed hereafter. The contents are based on the section intake dust concentration for an 8-hr period and the exposure degree are marked for the respective concentration zones as shown in Figure 7.5. Based on the intake concentration values the plot is divided into A, B, C and D categories in order for its use in DELI.

Table 7.9: Intake dust concentration levels as dust exposure level index

Concentration	Concentration zone	Color	Exposure degree	Description
$< 0.5 \text{ mg/m}^3$	A	Green	I	Good
$0.5 \text{ to } 1.0 \text{ mg/m}^3$	B	Yellow	II	Poor
$1.0 \text{ to } 1.5 \text{ mg/m}^3$	C	Orange	III	Worse
$1.5 \text{ to } 2 \text{ mg/m}^3$	D	Red	IV	Unacceptable

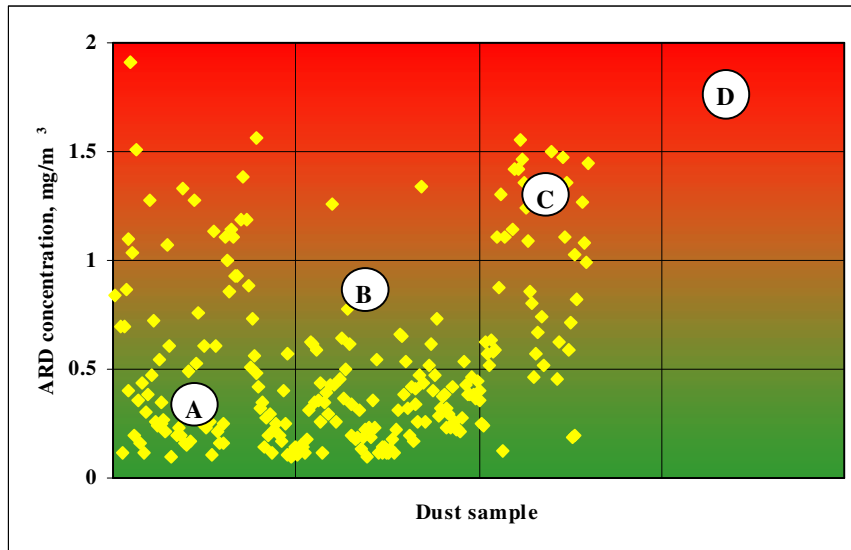


Figure 7.5: Use of the intake dust concentration parameter as DELI

7.6 Summary

This chapter summarizes the intake dust levels measured in selected South African underground coal mining sections over the past five years and its use as an index of worker exposure to dust. This study has also gathered information on intake dust levels from various other countries. There is little or no reported information on the levels of fresh air intake dust levels. Based on the measured data of the South African coal mines, the average section intake dust level was 0.80 mg/m^3 . Approximately, 60 % of the samples collected for the study have exceeded the 0.5 mg/m^3 limit. This high level of intake concentration brings into question the validity of the authorities using “zero” dust load for the non-sampling period of a shift for calculation purposes. Also, the intake concentration level measured at the longwall face was much higher than in the CM headings.

The measured section intake dust levels furnish the South African coal mining industry with the latest depiction of the level of face area particulate contamination due to the intake air. The intention to use intake dust levels as an

exposure level index is that it clearly plays a role as a corner stone in effective control of exposure to face area respirable dust. The intake dust concentration level can be used as an index in exposure assessment indirectly as it contributes in the section face area concentration. It must be borne in mind that intake dust level is a *base* to the mine worker exposed to dust without carrying out any additional work in the section. If the intake air is seriously contaminated by airborne respirable dust; then the exposure of the workforce in the section will constantly be elevated by that background dust level. This intake dust level parameter in an overall DELI tool is recommended for dust exposure level monitoring by the entire industry viz., mine environment officers, occupational hygienists and mine management.

Chapter 8 Return Dust Concentration Levels

8.1 Return Air

Return air quantity and quality in an underground mine section is an important barometer of both ventilation effectiveness as well as the environmental control systems in place in the section. This barometer can be effectively used to monitor the occupational health and safety of workers in the mine. Return air also represents the ineffectiveness of the dust control systems to suppress or dilute the dusty air in the section.

From an explosion control point of view high return air dust concentrations indicate the possibility of a large amount of dust being deposited in the return way, thereby aiding the catastrophe in the event of an explosion. The return dust concentration can be reduced through increased ventilation quantity in the section and an effective dust suppression system. With the focus of attention in this thesis on engineering sample monitoring, and in effect reducing the dust levels in the face area, scant attention was given to identify if the dust has been effectively suppressed or is just diluted in the face area.

Therefore, careful and systematic monitoring of the return air dust concentration would give the mine operator the possible exposure levels of workers carrying out their duties downwind of the continuous mining operation. Therefore, the return dust concentration level is used as a parameter, which can be effectively used indirectly in estimating the exposure levels of workers downwind of the face area and also monitor “suppression effectiveness” of the dust control system in the section. The information will also inform the section management regarding strategic aspects of controlling the dust in the section.

8.2 Return Dust Levels

The history of return dust measurement originates from the United Kingdom. In 1970, the standard average dust concentrations set by NCB for longwall coal faces in UK for an 8-hr working shift was 8.0 mg/m^3 , based on measured dust concentrations and progression of CWSP (Jacobsen et al., 1971). In 1977, the dust standard for British mines was reduced to 7.0 mg/m^3 , measured at a fixed point (70 m from the face) in the return roadway of longwall faces. Most of the coal mines in UK are longwall mines.

To assess the dust conditions at the workplaces in the face, measurements were carried out using fixed-point sampling located in the return airways approximately 70 m behind the face. The reason for this choice of location was that the results are no longer influenced by the coarse dust or the unequal distribution of the respirable dust in the air. Measurements are taken at monthly intervals for a sampling period corresponding to the time the miners stay at the workplace. At values less than 5.0 mg/m^3 one measurement per month was sufficient. At values greater than 8.0 mg/m^3 , the average value has to be calculated from up to five subsequent measurements in one week. The partial deposition of dust between the face and the measuring point is accounted for by correction factors. Application of the same correction factors worldwide and in South Africa can be questionable due to operating parameters. The development of similar correction factors in South Africa requires different (e.g., multiple or single return airways, velocity etc.) sets of factors for bord and pillar and longwall mines.

However, the use of the information collected on the measured return concentration levels can be effectively used for exposure assessment purposes. In the 1980s, results derived from extended research through measurement in the return dust concentration levels in UK longwalls confirmed the earlier dose-

response curve with a small underestimate of risk at lower concentrations (Hurley et al., 1982).

8.3 Return Dust Levels in Overseas Mines

Research data on return dust levels was found from the literature overseas. Some of the data found in the reports does not give details of sampling period or the location for measured return dust levels.

An extensive airborne dust survey was carried out by the Directorate General of Mines Safety (DGMS) in twenty one Indian coal mines during 1991-1996 (Ganguly, et al., 2000). Information relating specifically to the levels of district return dust levels are summarized below in Table 8.1.

Table 8.1: Summary of recorded district return dust levels from Indian mines (Ganguly, et al., 2000)

Mining type	Dust Concentration	
	Range, mg/m ³	Mean, mg/m ³
Manual-Mine A	0.21-0.56	0.35
Semi-Mechanized-Mine B	0.30-2.57	0.88
Semi-Mechanized-Mine C	0.35-2.73	1.72
Semi-Mechanized-Mine D	0.21-1.17	0.63
Semi-Mechanized-Mine E	0.41-0.85	0.65
Semi-Mechanized-Mine F	0.34-1.52	0.90
Semi-Mechanized-Mine G	0.10-0.36	0.20
Manual-Mine H	0.29-0.38	0.34
Mechanized-Mine I	0.41-0.76	0.54
Mechanized-Mine J	0.40-1.01	0.76

Mechanized-Mine K	0.29-0.92	0.61
Mechanized-Mine L	0.33-1.06	0.64
Mechanized-Mine M	0.43-1.47	0.75
Manual-Mine N	0.14-1.09	0.56
Semi-Mechanized-Mine O	0.15-0.87	0.37
Manual-Mine P	0.14-0.79	0.51

As we note from the above survey, the average district return dust concentration for the different mines is 0.65 mg/m³ (32.5% of the OEL of 2 mg/m³). Table 8.2 summarizes the recorded return dust levels from various mines overseas.

Table 8.2: Summary of recorded return dust levels from overseas mines

Mining type	Country-mine	Dust concentration, mg/m ³		Source
		Max	Avg.	
Longwall	Poland-A	18.5	11.2	Koziel et al., 1999
	Poland-B	6.2	3.1	
	Poland-C	12.6	8.5	
	Poland-D	130.0	75.0	Koziel & Malec, 1998
	Poland-E	56.0	35.0	
	Poland-F	56.0	31.0	
	Poland-G	6.5	5.2	
	Poland-H	67.0	11.2	
Longwall*	USA-A	-	0.96	Colinet et al., 1997
	USA-B	-	1.72	
	USA-C	-	3.27	
	USA-D	-	2.05	
	USA-E	-	2.70	

	USA-F	-	3.7	
	USA-G	-	3.16	
	USA-H	-	3.51	
	USA-I	-	2.16	
	USA-J	-	5.64	
	USA-K	-	2.91	
	USA-L	-	3.91	
	USA-M	-	10.04	

* Tailgate concentration

The calculated average district return dust level for all the recorded Indian coal mines was roughly twice (1.97) the district intake dust level (See Table 8.3). The average intake and return dust levels measured in 13 US longwall mines was 0.38 mg/m³ and 3.52 mg/m³ respectively. Therefore the calculated average return dust level for all the recorded US longwall mines was roughly nine times (9.32) the dust level measured in the intake (See Table 8.3).

Table 8.3: Comparison of intake and return dust levels from Indian and US coal mines (Ganguly, et al., 2000 and Colinet et al., 1997)

Country	Mining type	Dust concentration, mg/m ³	
		Intake	Return
India	Manual-Mine A	0.29	0.35
	Semi-Mechanized-Mine B	0.43	0.88
	Semi-Mechanized-Mine C	1.02	1.72
	Semi-Mechanized-Mine D	0.27	0.63
	Semi-Mechanized-Mine E	0.31	0.65
	Semi-Mechanized-Mine F	0.16	0.90
	Semi-Mechanized-Mine G	0.14	0.20

	Manual-Mine H	0.14	0.34
	Mechanized-Mine I	0.27	0.54
	Mechanized-Mine J	0.55	0.76
	Mechanized-Mine K	0.27	0.61
	Mechanized-Mine L	0.28	0.64
	Mechanized-Mine M	0.47	0.75
	Manual-Mine N	0.18	0.56
	Semi-Mechanized-Mine O	0.23	0.37
	Manual-Mine P	0.21	0.51
USA	Longwall-A	0.24	0.96
	Longwall-B	0.25	1.72
	Longwall-C	0.35	3.27
	Longwall-D	0.25	2.05
	Longwall-E	0.30	2.70
	Longwall-F	0.33	3.7
	Longwall-G	0.37	3.16
	Longwall-H	0.35	3.51
	Longwall-I	0.07	2.16
	Longwall-J	1.10	5.64
	Longwall-K	0.62	2.91
	Longwall-L	0.59	3.91
	Longwall-M	0.08	10.04

8.4 Return Dust Levels in South African Mines

Unlike the coal mines in UK, the measurement of section return concentrations is not carried out in the South African mines. The dust measurements carried out in

this study in various mines suggests that the data can be effectively used in monitoring the section environment in the mines. An important observation is made from the data that careful study of the data is necessary especially for very high concentrations in CM sections. These high levels ($> 10 \text{ mg/m}^3$) are possibly due to the stone dusting of the section according to the regulations.

This section outlines the recorded section return dust levels in the 90's and dust measurements that were carried out for this study over a period of 5 years (1998 to 2002) in the several continuous miner (CM) and longwall sections. A dust survey was carried out by the Chamber of Mines in 1993 in a remote CM heading (COM report 93/18) indicated that the measured average return dust level for the three tests was 10.05 mg/m^3 .

In the past five years (1998-2002), through SIMRAC dust research projects, various South African coal mines with both CM sections and longwall sections were monitored for section return dust levels. The measured section return real-time dust level plots from various mines are shown in Appendix B1 to B8. The average sampling period of all section return dust samples was 336 minutes. Section return dust measurements taken from different bord and pillar CM sections indicate that the average return dust level for the sampling period was 2.36 mg/m^3 . Figure 8.1 show the histogram plot of section return dust levels from various bord and pillar sections.

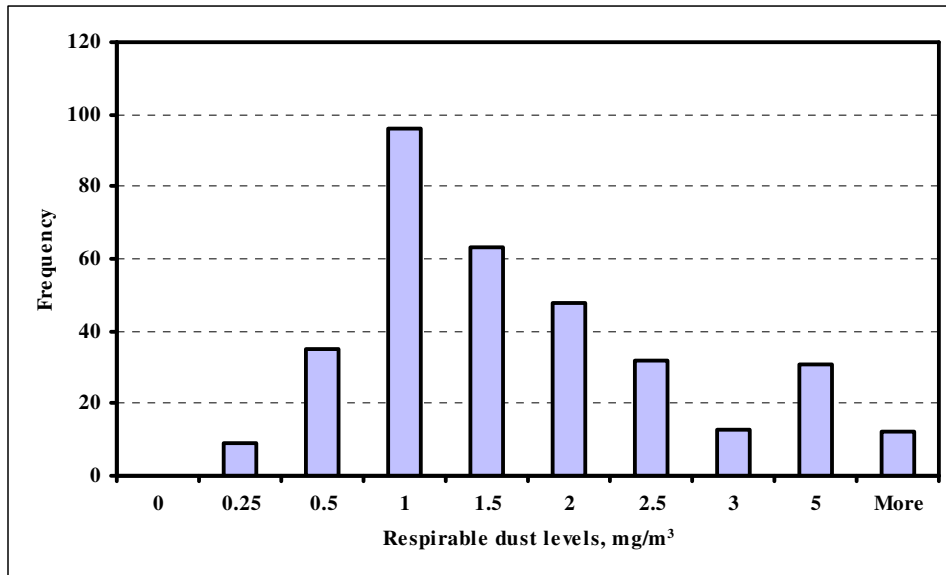


Figure 8.1: Histogram of return dust levels in bord and pillar CM sections

Some of the high dust levels measured were due to the application of stone dusting during the beginning or in the middle of the shift. The dust samples which were tainted by the stone dust were nearly 4% of the total section return dust samples collected and were usually significantly greater than 2 mg/m³.

However, the presence of stone dust can only be noted by time study or observation of dust filter after sampling and not merely by looking at the supplied data. Similarly, from the longwall dust measurements carried out, the section return dust levels was an average of 13.05 mg/m³. Figure 8.2 show the histogram plot of section return dust levels from two longwall sections. It can be seen that approximately 75 % of the measured dust levels in CM sections were below 2 mg/m³. Similarly, over 90 % of the measured dust levels in longwall return were greater than 2 mg/m³. Table 8.4 shows the frequency distribution of section return dust levels in coal mines.

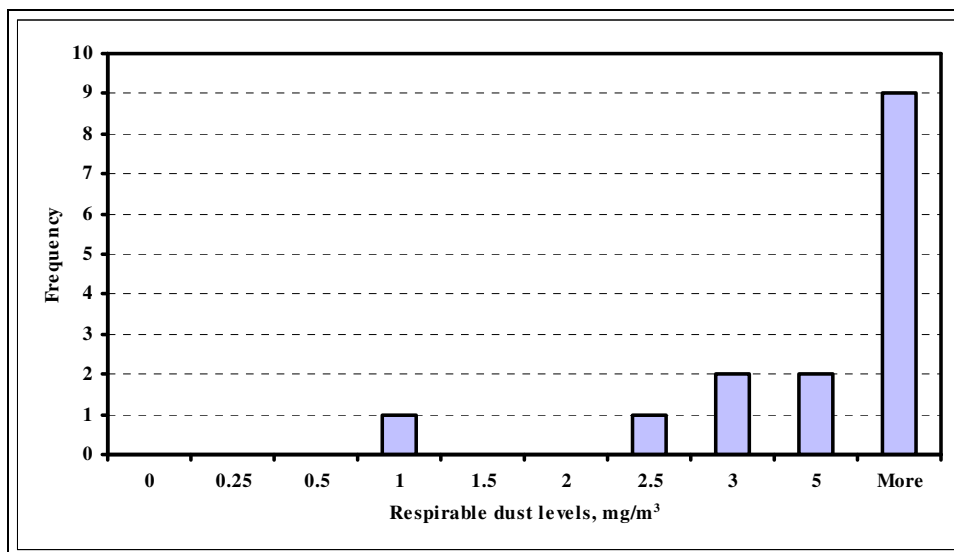


Figure 8.2: Histogram of section return dust levels in longwall sections

Table 8.4: Frequency distribution of section return dust levels

Dust level, mg/m ³	Longwall	CM	Total
	% Cumulative samples		
0	0.00	0.00	0.00
0.25	0.00	2.65	2.54
0.5	0.00	12.98	12.43
1	6.67	41.30	39.83
1.5	6.67	59.88	57.63
2	6.67	74.04	71.19
2.5	13.33	83.48	80.51
3	26.67	87.32	84.75
5	40.00	96.46	94.07
More	100.00	100.00	100.00

In general, we observe that return dust levels were on average greater than 2 mg/m³. Longwall dust control is still a problem area based on the return dust levels where section return dust levels are approximately six times the CM dust

levels indicating poor dust control systems on the shearer. It must be noted that, unlike in the past, in the existing operating coal mines workers generally do not spend any time in the section return. The return dust concentration can be easily monitored using real-time fixed point or area monitors (where the movement of machinery is limited) and requires limited human intervention.

8.5 Return Air Dust Concentration as DELI Parameter

The intention on the use of return air dust level data as a parameter in DELI model is to inform the mine risk assessors and risk managers to protect the workers from over exposure to dust as well as to encourage effective control of face area dust. Although there are no workers in the section return in a CM section, return dust levels indicate the efficiencies of the dust control systems in the coal face and the section ventilation effectiveness. In order for effective use of this information, a matrix has been developed (Table 8.5) and discussed hereafter. The contents are based on the section return dust concentration for an 8-hr period and the exposure degree is marked for the respective concentration zones as shown in Figure 8.3. Based on the return air concentration values, the plot (Figure 8.3) of return dust sample and concentration levels is divided into A, B, C and D categories in order for its use in DELI.

Table 8.5: Return dust concentration indicator model for dust exposure levels

Concentration	Concentration zone	Color*	Exposure degree	Description
< 2 mg/m ³	A	Green	I	Good
2 to 4.0 mg/m ³	B	Yellow	II	Poor and unacceptable
4.0 to 6.0 mg/m ³	C	Orange	III	Worse and unacceptable
6.0 to 8.0 mg/m ³	D	Red	IV	Unacceptable

* Intention of colour coding is two fold., viz., literacy standards in South African mining population is very low and comprehension of statistics and their meaning is virtually unknown. DELI colour coding designations enable the uneducated workforce who can understand the meaning of different colours. Obviously only 'Green' is acceptable to work underground.

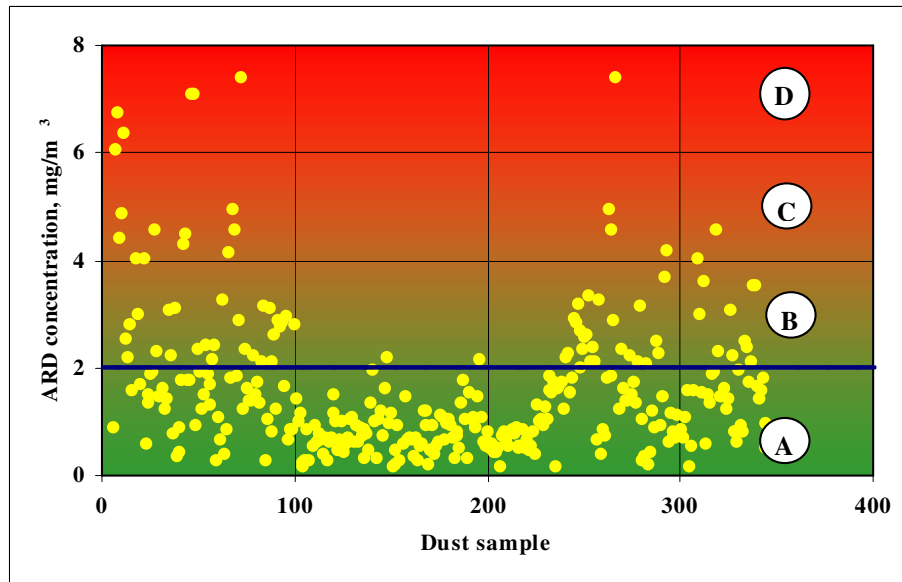


Figure 8.3: Use of the return dust concentration parameter in DELI

8.6 Summary

This chapter summarizes the section return dust levels measured in the South African underground coal mining sections over the past five years and its use as an index of worker exposure to dust. This study also gathered section return dust levels from various other countries. There is little or no reported information on the levels of return dust. Based on the measured data of the South African coal mines, the average section return dust level was greater than 2.0 mg/m^3 . Longwall section return dust levels are approximately six times the CM dust levels indicating poor dust control systems on the machines.

The intention to use the return dust levels is that they are the clear indicators of the exposure levels of the section workers to coal dust, effectiveness of the ventilation system to dilute the airborne dust and dust-control system's effectiveness. The return dust concentration can be easily monitored using fixed point samplers

(where the movement of machinery is limited) and requires less human intervention and is an easy to use parameter in exposure assessment. The return dust level parameter in an overall DELI tool is recommended for dust exposure level monitoring by the entire industry viz., mine environment officers, occupational hygienists and mine management.

Chapter 9 Use of Particle Size in Exposure Assessment

9.1 Introduction

This topic is worthy of a research study in its own right. Since the author had access to particle size distributions for a few (four) samples-a preliminary view on the effects of particle size is presented here. This chapter attempts to evaluate the use of coal dust “size” as a parameter in assessing exposure levels based on its known health risk. The effect of very fine particle size in the sampled respirable dust, and its probable health impact upon exposure, are addressed in this chapter. As stated in the literature (Chapter 2), the potential effects of dust depend on its characteristics, such as toxicity, particle size, concentration in the air and, in the case of worker exposure, the duration of such exposure. The intention of this chapter of the research study is not to advocate ‘size’ or ‘surface area’ or ‘number’ as a replacement parameter to concentration (mg/m^3) in coal dust exposure assessment but as an investigation into the presence of fine particles in the sampled dust.

With recent advances in size characterization technology, the use of particle size in assessing the severity of the exposure on health is slowly becoming a reality (Maynard, 2002). The information obtained from past studies indicate that certain coal types, for example anthracite coal, tend to produce more sub-micron particles than softer low rank coals (Thakur, 1973). Also, the influence of very fine particles on health is gaining greater attention from researchers and the public. Therefore, the percentage of dust in the fine particle size can be used as a possible parameter of assessment in the DELI and that is discussed hereafter.

In 1959, the Johannesburg International Conference on Pneumoconiosis “specifically” recommended that the mass concentration of respirable dust was the

best single descriptive parameter to measure in order to assess the hazard of pneumoconiosis from coal dust; for quartz dust the surface area of respirable particles was thought to be the best parameter to measure and that measurement of the dust hazard should extend over a full work shift (Beadle, 1965). Until 1990, respirable dust was measured in terms of the number of particles per unit volume using a microscope count method, a technique which is subject to considerable statistical and sampling errors. In the earlier years, a konometer was used for routine sampling, which provided a measure of the number concentration of the dust, i.e., it gives the result in particles per cubic centimetre (ppcc). In 1965, the diffraction size-frequency analyser (DISA) was introduced for a quicker surface area measurement for the entire particle size range (Talbot, 1965).

Latest toxicology studies indicating health effects associated with low-solubility inhaled particles may be more appropriately associated with surface area than mass and this warrants further investigation (Maynard, 2002). Such studies require exposure data on surface area of inhaled particles estimated from particle number and mass concentration using readily available direct-reading instruments. In the early years, calculation of surface area was expensive and time consuming due to the laborious nature of the electron microscopic techniques. It is essential that any dust evaluation technique of value should be sufficiently rapid to keep abreast of these developments. With the development in size-characterization instruments, it is possible to characterize the respirable dust collected using gravimetric methods. Also, the information will enable to determine if the samples which are non-compliant according to current standards (mg/m^3) are influenced by non-respirable dust samples. For example, MSHA in the USA re-assesses the non-compliant coal dust samples for the presence of non-respirable particles to investigate the influence of larger particles on dust mass. This can be attributed to the fact that the mass of a particle is proportional to the cube of its size so that the mass of even a small number of larger, non-respirable particles would be significant in a respirable sample.

9.2 Underground Respirable Sample Size Distribution

The importance of and use of dust size as an indirect exposure and health risk assessment parameter is described hereafter using size distribution data from four underground respirable coal samples. The respirable dust samples were collected from an underground CM section. The mass of dust collected on the filter was determined using sample time and flow rate. The particle size distribution of the respirable coal dust collected was carried out using a Fritsch Size Analyser (FSA) at the CSIR Miningtek laboratory. The operating principle of the FSA is based on the laser diffraction technology (Fraunhofer and/or Mie theory) and is similar to Micro Trac size analysers used in USA. The drawback of the existing FSA is that it needed a large mass of dust sample for size analysis. Therefore it precluded sample levels below 2.0 mg/m^3 limit or sample mass below 2 mg. However, an attempt was made using the limited data to evaluate the importance of particle size and its possible use as a parameter in exposure assessment.

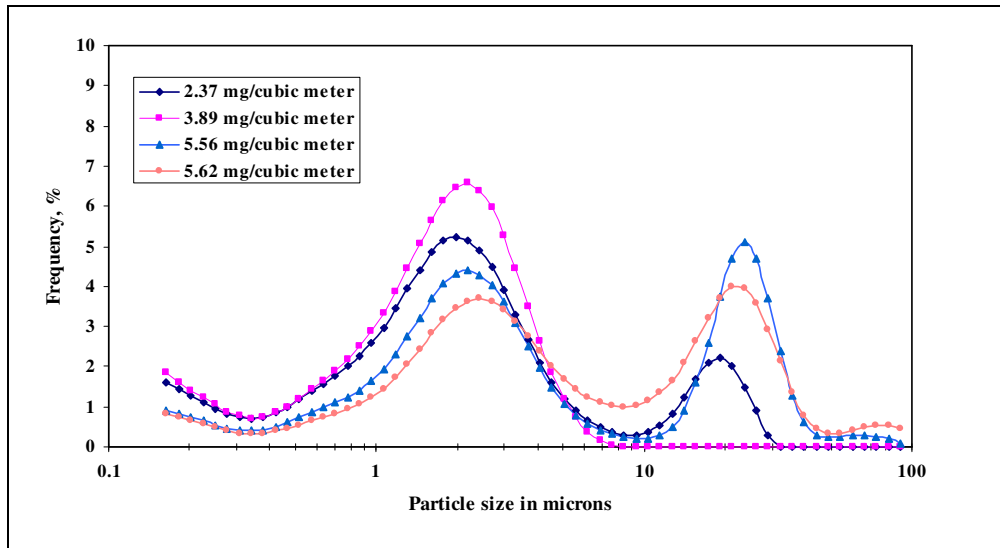


Figure 9.1: Frequency distribution of respirable dust samples of various dust concentration

For the calculation of surface area, the dust particles are considered as “spheres.’ The relationship between particle size, number of particles, and calculated surface area of the four respirable dust samples is summarised in Tables D1 and D2 (Appendix-D) and plotted in Figures D1 and D2 (Appendix-D). Figure 9.1 shows the frequency mass distribution of dust samples of different dust concentration levels.

The size analyses of the dust samples indicate that they show a bi-modal size distribution. Possible reasons can be attributed due to the multiple dust generating mechanisms in the mine or may be due to the presence of LHDs. From the plots we notice that although the operation is similar (i.e., coal cutting by the CM in the face area), it is observed that a different ‘trend’ exists in the frequency distribution of the dust samples collected on different days. Apportionment of airborne respirable particulates will vary depending on the top cut-off size, characteristics of airborne dust, the dust measurement instruments, characteristics of the mineral being mined, and the cutting mechanism as well as the rate of ventilation among other factors. In other words, the apportionment numbers are very site-specific. However, due to the few dust samples and instrument limitations, it was difficult to estimate the "average size distribution" of respirable dust during the coal cutting operation.

Table 9.1 summarizes for each dust sample, the calculated mass of non-respirable particles ($>10\ \mu\text{m}$) and fine particles (below D_{50} of $4\ \mu\text{m}$ in accordance with the new ISO/CEN/ACGIH size-selective curve) in relation to the dust mass on the filter and calculated effective respirable dust concentration levels. Adjusted respirable dust level was calculated based on the mass of particles below $10\ \mu\text{m}$ (excluding particles greater than $10\ \mu\text{m}$ in the collected dust sample) for the same sampling period and flow rates.

Table 9.1: Size analyses of the sample dust mass and effective respirable sample concentrations

Sample #	Dust level, mg/m ³	Particles > 10 µm, mg	Particles < 4 µm, mg	Effective dust level, mg/m ³
1	2.37	0.238	1.407	2.046
2	3.89	0.000	2.250	3.890
3	5.56	1.015	1.794	3.653
4	5.62	1.141	1.534	3.475

Studies have shown that when inhaling fine particles they present a much larger surface area that can interact with the scavenger cells in the lungs. Therefore, for very fine particles, it can be suggested that the total surface area of inhaled particles may also be an appropriate measure. Therefore, this limited study suggests that the mass concentration may not be the ‘only way’ of best describing the exposure to insoluble dusts over such a wide size range and its health impacts. While, surface atmosphere studies show the high impact of fine particles, there is no study clearly indicating the impact of very fine coal particles on mine workers.

The information on the presence of ‘fine’ particles can be of use for assessment by estimating the total surface area of the sampled dust. The estimated “total surface area” of the dust samples collected shows a very different picture. From the size analyses data, the calculated total surface area of respirable dust (<10 µm) for dust concentrations of 2.37 mg/m³, 3.89 mg/m³, 5.56 mg/m³ and 5.62 mg/m³ are 2.48 m², 3.76 m², 2.35 m² and 2.75 m² respectively. It is interesting to note from the calculations that there is no clear relationship between the concentration and total surface area of respirable dust. However, when the parameter of “total surface area” of respirable dust is used as the criteria for assessment, the low concentration levels show a larger surface area than the high concentration levels. This indicates that the current use of “mass” parameter may not truly reflect the unrecognised (in the mining industry) health impact to coal workers due to fine particles present in the working area, i.e. a low dust concentration level may have

larger surface area due to the presence of very fine particles than a higher dust level with small percentage of fine particles. In other words concentration alone may not truly show the influence of fine particles.

9.4 Summary

The focus of this chapter is to understand the knowledge on particle size, surface area and concentration data to effectively estimate the dust exposure and probable health impacts to workers. The task was carried out by size analyses of coal dust samples. The proposed particle size parameter is based on the hypothesis that the worker who is exposed to high percentage of fine particles is at a greater health risk than the one who is exposed to low percentage of fine particles (Stone and Donaldson, 1998).

As we observe from the plots that dust concentration in itself may give an ambivalent picture in terms of using the limit and the conclusion of “safe working environment.” From the calculation of total surface area of respirable dust, it is noticed that despite one achieving lower dust concentration levels, the parameters such as total surface area and number of fine particles could be a risk of much greater magnitude than is the case of high dust concentrations. There is also now a lot of interest in the effect of particulate air pollution on cardiovascular disease, and this seems much more likely to relate to surface area or number than mass (Ogden, 2002).

Due to the lack of state-of-the-art size characterization instruments, and the limited number of samples used, the study recognizes that the conclusions obtained on the “size” parameter cannot be used in the DELI model. Therefore, this research study recommends future work to determine the finger-print of "total surface area" of compliance respirable coal samples collected underground at various dust generating sources. With the advent of improved and faster size analysing equipment, mine ventilation engineers and occupational hygienists can

make use of a parameter such as surface area in assessing the worker exposures depending on the amount of fine respirable particles present in the dust samples.

Chapter 10 Coal Production and Dust Levels

10.1 Dust Generation and Dust Production

Coal dust is a by-product of the coal cutting operation. As the cutting rate increases, the fine dust produced also increases. However, the rate at which the fine dust is produced depends on the coal characteristics and the method of cutting and cutting tools used during the process, from hand tools to semi-mechanized coal cutting to total mechanization.

The size distribution of the generated dust is never fixed nor will it remain the same for each type of cutting. Also, the amount of dust generated and the fraction of it becoming airborne are not conclusive. This is influenced greatly by the dust control systems and auxiliary ventilation system used in the face area of a coal heading. Therefore, mine management must be able to plan the dust control system and continuously maintain the dust control system and the operation of the auxiliary ventilation parameters. However, such planning is expected to cover the maximum production expected during a shift.

In recent years, production of coal appears to have been the utmost priority due to the changing expectations of the shareholders. This increased expectation in production required greater attention towards the environment management of individual mines. Therefore, production is considered as an important parameter in the exposure assessment of the workers in a bord and pillar section of an underground coal mine.

10.2 Coal product size analysis in a South African coal mine

Dust is generated during the coal cutting operation. In order to quantify the product size, with the assistance of the CM operator, coal product samples at the face, for both the sumping and shearing cutting processes and for both the high-speed (50 rpm) and slow-speed (37 rpm) drum rotation systems were collected (Belle, 2001). It was decided to collect the samples at the face (before reaching the gathering arms and flight chain of the CM) instead of at the loading conveyor or the feeder-breaker. Two samples (one sump and one shear) were collected during the high-speed CM drum rotation (50 rpm) and four samples (two sump and two shear) during the slow-speed CM drum rotation (37 rpm) on two different test shifts. For both test speeds, product size is applicable to a four inch (100 mm) lacing on the CM drum. Coal product size was analysed in the CSIR Miningtek laboratory. Figures 10.1 and 10.2 show the product size distribution, on a cumulative percentage basis, for the six coal product samples collected in this way.

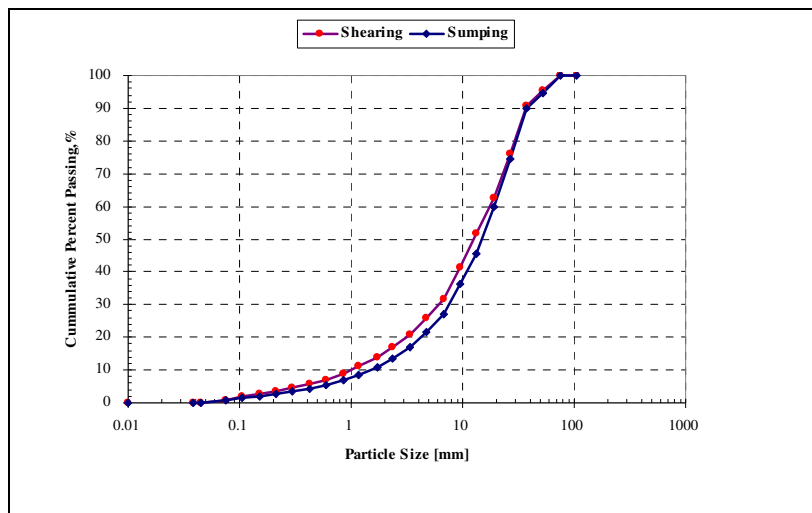


Figure 10.1: Coal product size analysis of the sump and shear samples during the high-speed (50 rpm) drum rotation cut

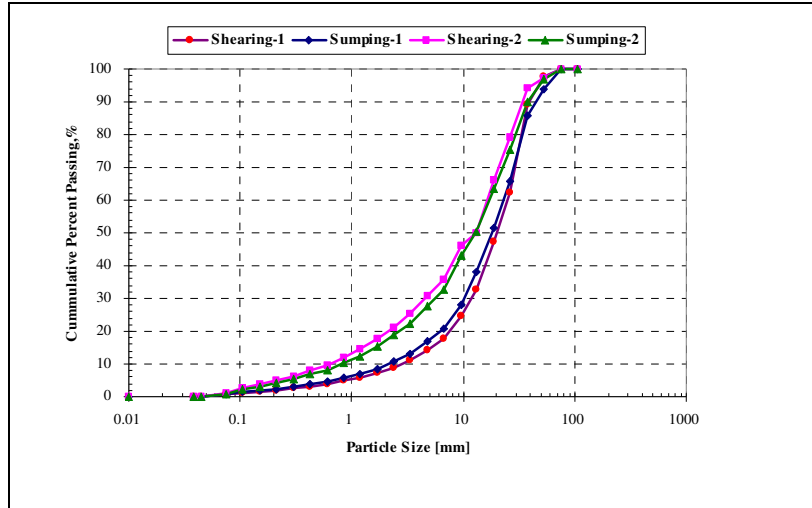


Figure 10.2: Coal product size analysis of the sump and shear samples during the slow-speed (37 rpm) drum rotation cut

As we observe from Figure 10.3, the percentage of finer coal product size collected during the two different shifts varies considerably with the same drum rotation speed. This indicates that, apart from the speed of the CM drum rotation, external factors at the time of cutting may have an influence on the amount of fines produced. The sample collected at the face area may be a better reflection of the fines generated than the samples collected at any other position in the section such as feeder breaker or after the flight conveyor of the CM.

From the size analysis data on two samples from sumping and shearing cuts, we infer that during the slow-speed drum rotation cut, there was no significant difference between the fines (< 6.7 mm) produced during sumping and shearing. However, during the high-speed drum rotation cut, the shearing cut produced approximately 5% more fines (< 6.7 mm) than the sumping cut. Figure 10.7 shows the combined results of the coal product size analysis for the samples collected during both the high-speed and slow-speed drum rotation cuts. From the plot we observe that during the high-speed shearing operation, more fines were produced than with the slow-speed drum rotation. As the coal samples were taken at the face area, the results show a remarkable conformity in terms of the amount of coal

finer produced. Approximately 14.88% and 13.77% of the product was found to be 2.36 mm and finer for the slow-speed and high-speed CM drum rotations, respectively. Overall, there is no significant difference in the coal sample fines generated (< 9.5 mm and 6.7 mm) in the face area during the high-speed and slow-speed drum rotations. Nevertheless, judging from the six independent sets of samples collected, there is a fair indication that the high-speed shearing action produces more fines than the slow-speed drum rotation.

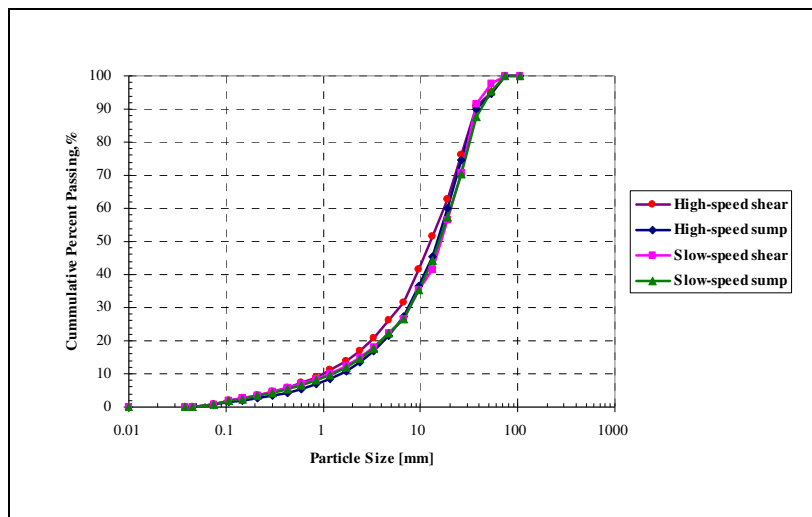


Figure 10.3: Comparison of coal product size analysis of the sump and shear samples during high-speed and slow-speed cutting

Interestingly, the percentage of finer coal product size collected during the two consecutive shifts at the same workplace with the same CM operator varied considerably, despite the same drum rotation speed being used. This indicates that, apart from the speed of the CM drum rotation, external factors such as coal seam characteristics at the time of cutting, operator inconsistency, etc., may have an influence on the amount of fines produced. During slow-speed and high-speed drum rotation, the CM operator and the shift work force remained the same.

Laboratory studies overseas have indicated that the depth of cut is the most dominant factor in dust generation and the underground study did not address it due to practical reasons. The differences in generation of product size in the respirable dust range using two different drum rotational systems could not be determined in the laboratory. Finally, the results show that when one gets to product analysis and considering the scale of machine size underground, some of the laboratory findings are over ridden by other, external factors.

10.3 Production and Airborne Respirable Dust (ARD) Levels

In order to evaluate the relationship between the dust levels and production during the shift, several coal sections operating with different dust control systems were monitored and extensive data was also gathered from the mines. Figures 10.4 to 10.7 show the plot of production levels and measured ARD dust concentration levels in various mines.

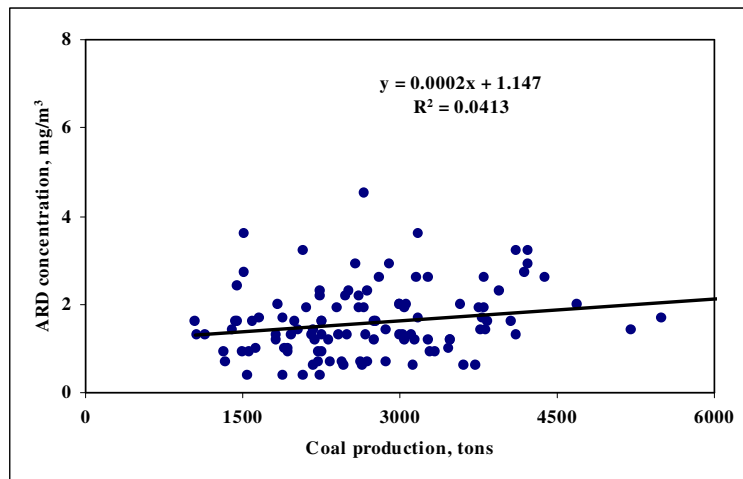


Figure 10.4: Relationship between production and ARD levels (personal) in longwall Mine A

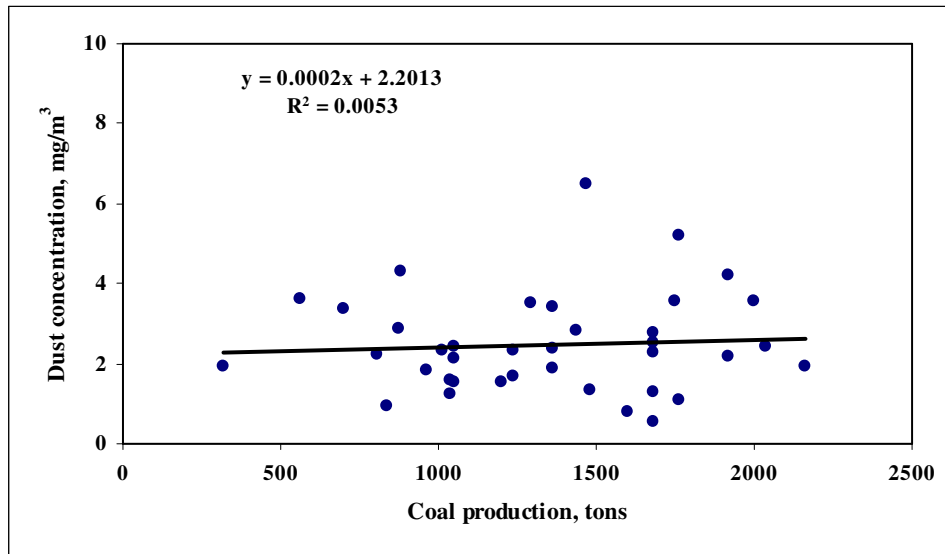


Figure 10.5: Relationship between production and ARD levels (personal) in a bord and pillar Mine B

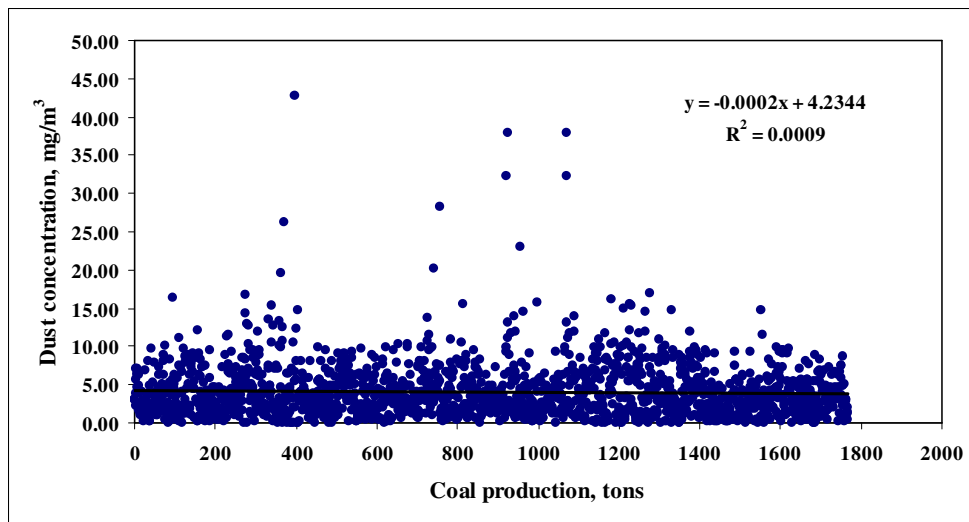


Figure 10.6: Relationship between production and engineering ARD levels in a bord and pillar Mine C

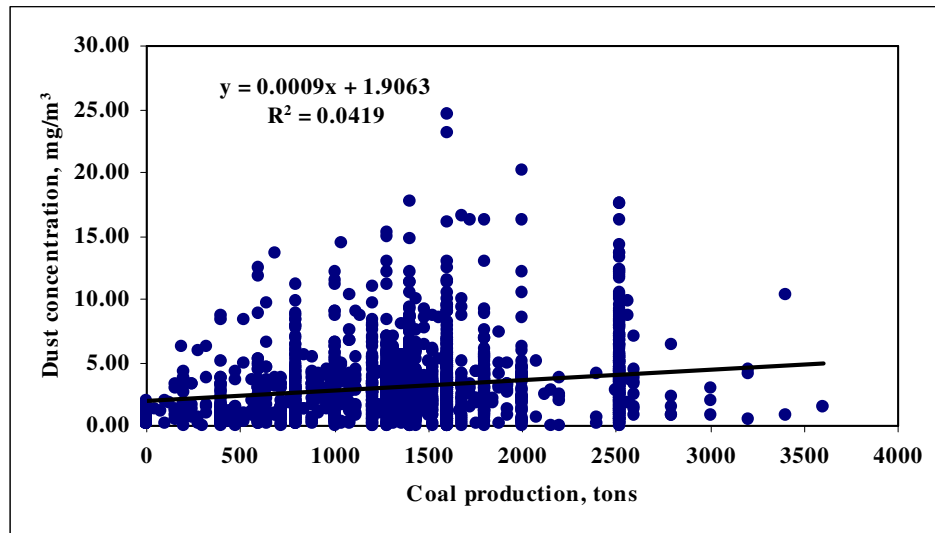


Figure 10.7: Relationship between production and engineering ARD levels in a bord and pillar Mine D

As we observe from the plots that there is no conclusive relationship between the coal production and ARD levels (personal or engineering concentrations). Despite the lack of clear evidence in terms of production/shift and concentration levels, the following holds true. In the coal mining industry, there are various types of cutting machines that can generate various fractions of respirable dust during coal production. In order to control the respirable dust and reduce worker exposure levels, various dust control systems are used. As discussed in Chapter 5 the dust control system type has a pronounced effect on measured dust levels in the mines. Therefore, the following conclusions can be made in order to use production as a parameter in estimating dust exposure levels.

The capture efficiency of any dust control system is not one hundred percent at any given time. During any cutting process for a given time and dust control type, part of the escaped respirable dust is added to the coal face atmosphere through air re-circulation. Therefore, with an increase in coal cutting rate for a given production shift, the respirable dust level has to increase. The intensity of dust exposure therefore varies with the type of dust control system. Therefore, the

production can be used as an administrative control parameter in reducing face worker exposure to dust.

With the aid of section ventilation, the dust exposure can be further reduced depending on the availability of fresh ventilating air to dilute the re-circulated dust. Since the exposure levels are directly related to the coal production and efficiency of the total dust control system, the exposure levels increase with an increase in coal production and can be expressed as below:

$$E_p = E_a + \sum_{r=0}^{480} E_r \quad (10.1)$$

Where,

- E_p = Effective personal dust exposure levels in the section, mg/m^3
- E_a = Personal dust levels due to coal production alone, mg/m^3
- E_r = Dust levels due to the escaped dust based on the efficiency of the dust control system, mg/m^3

The determination of escaped dust levels in coal mines which use a wide variety of dust control systems is extremely complex and no quantitative index is known and would need to be developed. The worker exposure to respirable dust in a section can be expressed as a function as shown below:

$$E_a = f(E_m, \text{JD}, E_s, E_o, E_{ppe}) \quad (10.2)$$

Where,

- E_a = Dust exposure levels during coal production
- E_m = Dust generation levels during coal production
- JD = Job description of the worker at the face/section
- E_s = Efficiency of the dust control system type
- E_o = Dust exposure levels from other sources in the section

E_{ppe} = Efficiency of the personal protective equipment

However, the above production-dust concentration data can be effectively used as a parameter in an exposure assessment index tool. Based on the concentration values and coal production “DELI – production” was plotted in Figure 10.8. The production values on the plot are divided into A, B, C and D categories in order for use as a parameter in DELI.

In order for effective use of this information, a matrix has been developed (Table 10.1) and discussed hereafter. The contents are based on the coal production-dust concentration levels in the respective zones as shown in Figure 10.8.

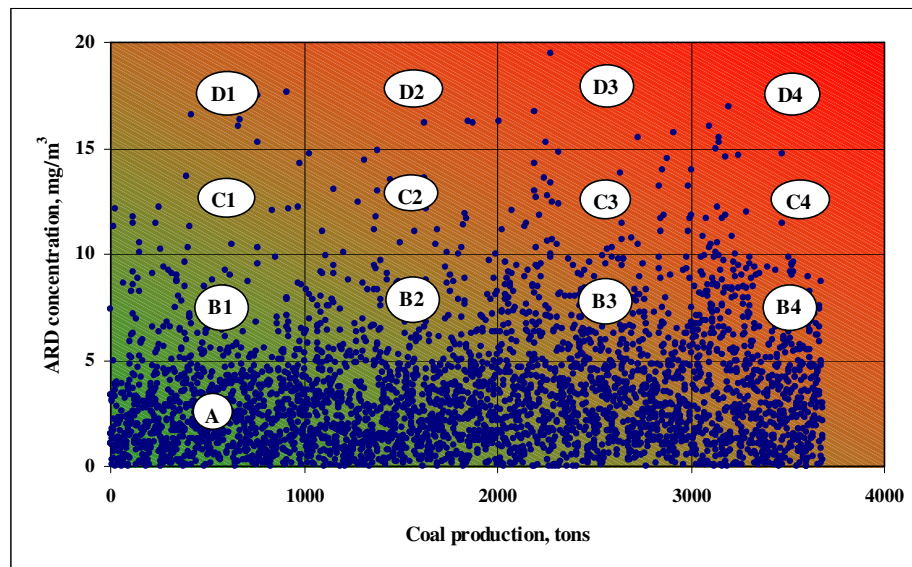


Figure 10.8: Use of the production levels as a parameter in DELI

Table 10.1: Production-dust concentration indicator models for dust exposure levels

Plot area	Production	Concentration	Exposure degree	Description
A	Any	In compliance	I	Good
B1	Low	Medium	II	Moderate to sensitive
B2	Medium	Medium	II	Moderate to sensitive
B3	High	Medium	III	Unhealthy
B4	Very high	Medium	III	Hazardous/Unhealthy
C1	Low	High	III	Unhealthy
C2	Medium	High	III	Unhealthy
C3	High	High	IV	Very unhealthy to Hazardous
C4	Very high	High	IV	Very unhealthy to Hazardous
D1	Low	Very high	IV	Very unhealthy to Hazardous
D2	Medium	Very high	IV	Very unhealthy to Hazardous
D3	High	Very high	IV	Very unhealthy to Hazardous
D4	Very high	Very high	IV	Very unhealthy to Hazardous

10.4 Summary

This chapter briefly summarizes the use of coal production and measured dust levels as a parameter in DELI for assessment of dust exposure. The intention of the use of production as a parameter is that it directly influences the ultimate dust exposure levels of workers underground and can be very effectively used as an administrative tool for prioritising the tasks and re-assigning the workers who are exposed to high levels of dust to lower areas of dust levels underground. Finally, the study recognizes the complexity of determining escaped dust levels in coal mines which use wide variety of dust control systems and recommends developing an quantitative index purely on coal production.

Chapter 11 Inherent Respirable Dust Generation Potential (IRDGP) of South African Coals

11.1 Introduction

This chapter attempts to evaluate the potential of different coal dust types as a parameter in assessing exposure levels based on its known health risk. The effect of inhaling different types of coal dust, and its probable health impact upon exposure is addressed in the literature (Chapter 2). The intention of this chapter of the research study is, however, to determine the Inherent Respirable Dust Generation Potential (IRDGP) of various South African coal types from various provinces and its use in dust exposure assessment. The IRDGP for this study is defined as the quantification of the airborne respirable dust for South African coals in a laboratory set-up using a specified roll-crusher.

11.2 Previous Studies Relating Coal Characteristics and Dust Generation

The epidemiological findings on the relationship between coal rank and development of CWP led to numerous studies on coal types and generation of respirable dust. Internationally, a number of laboratory studies have been conducted on the relationship between coal characteristics and respirable dust generation. Some of the findings of the past research on coal types and dust generation potential are summarized as follows:

- A laboratory study (Thakur, 1973) involving 20 coals from lignite to anthracite in the USA indicated that the yield of respirable dust varies with coal properties and coal seams.

- Higher rank coals produce larger masses of dust in the finer size range (Thakur, 1974, 2003).
- Laboratory studies indicate a consistent positive correlation between coal rank and the amount of respirable-sized particles found in the product (Srikanth et al. 1995; Moore and Bise 1984; Baafi and Ramani 1979). However, these results were based on measurement of dust in the *product* and not measurements of airborne respirable dust. In the mining and roll crushing of coal there is much less regrinding compared to jaw crushing (Organiscak and Page 1998; Ramani et al. 1987).
- The Airborne Dust Release Capacity (ADRC) defined as the ratio of the mass of dust that actually becomes airborne to the total mass of the airborne size fraction increases with coal rank (Polat, 1990).
- Work by Organiscak et al. (1992) indicated that high volatile, low ash coal seams (lower rank coals) tended to produce more airborne respirable dust.
- Airborne respirable dust (ARD) concentrations increased with volatile matter (VM) content, and decreased with increase in fixed carbon content of the bituminous coal samples tested (Page et al., 1993).
- A USBM longwall dust generation study (Organiscak et al., 1990) found that seam type was related to the amount of ARD found at the operation. Low ash, high-volatile bituminous coal seams tend to generate more dust.
- In the research study by Organiscak and Page (1998), the coal rank and CWP relationship was reported to be in part related to the increase in dust cloud charging properties of higher rank bituminous coals and the increase in lung deposition observed by Melandri et al. 1983.

The search for the cause(s) of CWP continues despite the vast amount of research that has been undertaken over the past forty to fifty years. Good correlation between the mass of dust inhaled over workers' lifetimes and the incidence of the disease has led to the development of effective standards and implementation of proper dust control procedures in the work place. Results of investigations in the field of pneumoconiosis in the past 30 years indicate that the mine dusts in the

various deposits of the European and American hard coal mines have a different fibrogenicity. With their medical surveillance program, NIOSH has recently determined that coal miners continue to have an elevated risk for CWP under the current MSHA dust standard and recommended reduced dust levels as standard. In order to achieve this goal, dust exposure of the workers must be reduced significantly. Recently, ACGIH recommended a TLV-TWA of 0.9 mg/m^3 , for miners exposed to bituminous dust or lignite coal dust and a TLV-TWA of 0.4 mg/m^3 for miners exposed to anthracite coal dust (ACGIH 2001). Therefore, it follows that inherent respirable dust generation rates of different coal types may give some administrative direction to dust control in South Africa and could probably assist in evaluating the medical surveillance data of coal mine workers.

11.3 Use of Dust Type in DELI

As discussed in the literature review of the thesis (Chapter 2), the historic research studies have indicated the influence of coal dust type on the propensity of developing CWP. Therefore, coal dust type can be viewed as an administrative (better management) parameter in controlling the worker exposure to specific dust type of dust in an operation as well as an indicator of exposure.

No literature relating South African mine workers with various CWP levels to coal rank has been found. A research study into the single breakage of nine American and four South African coals indicated that the primary respirable dust generation rates of South African coals were higher than those of six out of the nine American High volatile bituminous coals tested (Ramani and Srikanth, 1996). The primary respirable dust generation for that particular study is defined as the quantification of the generation of respirable dust in laboratory primary, single breakage experiments (Srikanth and Ramani, 1997). A single breakage process is one that does not involve secondary breakage (or regrinding). However, no study has yet been done in South Africa, to determine the inherent respirable dust generation potential (IRDGP) of various coal seams. Therefore, any new

information acquired through such a study could be used in future to investigate the relationship between the exposure levels, dust types and the disease rate among South African coal miners from a long-time perspective.

Determination of IRDGP in actual underground conditions would give discrepancies as coal-cutting involves primary, secondary and multiple breakage of coal and respective dust measurement is affected by a number of coal-specific and environment-related factors. Therefore, laboratory crushing studies would better reflect the IRDGP or dustiness of different coal types.

11.4 Experimental Procedure

The present investigation studies the inherent respirable dust generation potential (IRDGP) of different coal types. The aim of this part of the research study was to contribute to the understanding of the IRDGP or dustiness of South African coal types. The objective was to quantify the amount of inherent respirable dust that becomes airborne from a particular coal type, rather than the respirable crusher product or its size distribution.

11.4.1 Test Facility

The IRDGP test facility was built at the Kloppersbos research centre. The line diagram of the laboratory crushing set-up is shown in Figure 11.1. The laboratory test facility comprised a roll crusher located at the intake end of a 0.9 m high by 1.2 m wide wood framed hard board sheet rectangular wind tunnel 8.0 m long (Figure 11.2). An exhaust fan and a dust collector were located at the discharge end of the tunnel. The roll-crusher used for the study was similar to the specifications used by NIOSH in their dust generation research study (Organiscak, 1999).

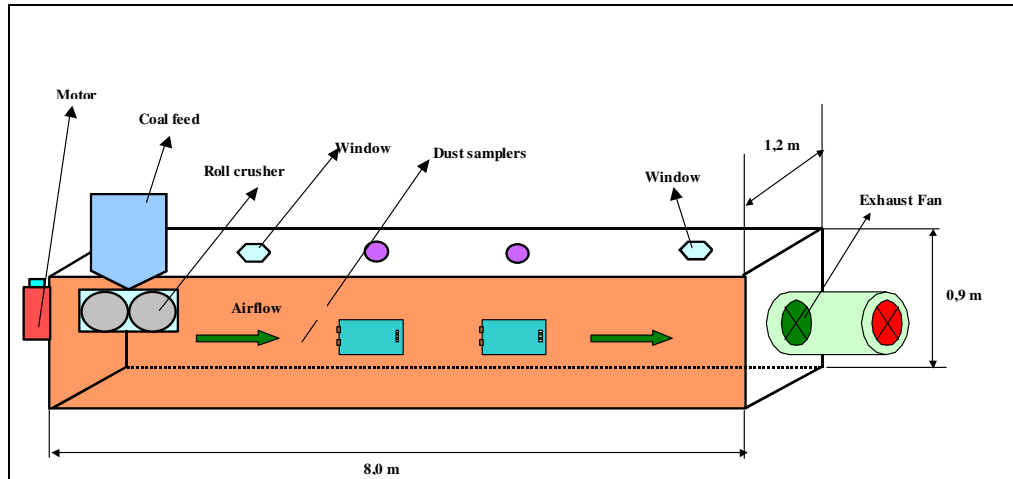


Figure 11.1: Line diagram of the test facility



Figure 11.2: Photographic view of the test facility

The crusher was a 1.1 kW compact double roll-crusher (79.4 mm diameter rolls) operating at 70 rpm consistently with twenty-four 12.7 mm high staggered teeth on each roll. The roll crusher used had a fixed gap of 28.57 mm (1.125 inches) between the rolls. The crusher was designed to produce a product size less than or

equal to 15.88 mm or 0.625 inches. Airborne gravimetric respirable dust samples were collected downstream of the crusher at an approximate distance of 2.0 m from the crusher.

11.4.2 Coal Sample Collection and Properties of SA coals

The majority of coal mined in South Africa comes from five different numbered seams, viz., Seam 1, Seam 2, Seam 3, Seam 4 and Seam 5. Coal seams are numbered according to geological formation (bottom-up). In South Africa, coal mines are found in Mpumalanga, Kwa Zulu Natal, Free State and Limpopo (Northern) provinces (Figure 11.3).



Figure 11.3: South African provinces

Table 11.1 below shows the summary of Run-of-Mine (ROM) coal samples used for the roll-crusher experiments.

Table 11.1: Summary of Run Of Mine (ROM) coal samples for the tests

Province	Operator	Mine	Coal seam	Coal type	Coal Rank
Limpopo	A	Elisras	Bench 2	Bituminous	Medium-Rank C
		Elisras	Bench 3	Bituminous	Medium-Rank C
		Elisras	Bench 4	Bituminous	Medium-Rank C
		Elisras	Bench 5	Bituminous	Medium-Rank C
		Elisras	Bench 6	Bituminous	Medium-Rank C
		Elisras	Bench 7B	Bituminous	Medium-Rank C
		Elisras	Bench 9A	Bituminous	Medium-Rank C
		Elisras	Bench 9B	Bituminous	Medium-Rank C
		Elisras	Bench 11	Bituminous	Medium-Rank C
Mpumalanga	B	Bosspruit	4	Bituminous	Medium-Rank C
		Twistdraai West	4	Bituminous	Medium-Rank C
		Syferfontein	4	Bituminous	Medium-Rank C
		Middlebult	4	Bituminous	Medium-Rank C
		Boosjespruit	4	Bituminous	Medium-Rank C
		Twistdraai East	4	Bituminous	Medium-Rank C
		Sigma colliery	2	Bituminous	Medium-Rank C
		Sigma colliery	2	Bituminous	Medium-Rank C
		Brandspruit	4	Bituminous	Medium-Rank C
		Twistdraai Central	4	Bituminous	Medium-Rank C
Mpumalanga	C	NDC	4	Bituminous	Medium-Rank C
		Goedhoep	2	Bituminous	Medium-Rank C
		Goedhoep	4	Bituminous	Medium-Rank C
		Bank	2	Bituminous	Medium-Rank C
		Bank	5	Bituminous	Medium-Rank C
Mpumalanga	D	Khutala	4	Bituminous	Medium-Rank C
		Rietspruit	1	Bituminous	Medium-Rank C
		Rietspruit	4	Bituminous	Medium-Rank C

		Rietspruit	5	Bituminous	Medium-Rank C
		Middleburg	1	Bituminous	Medium-Rank C
		Middleburg	2	Bituminous	Medium-Rank C
		Middleburg	4	Bituminous	Medium-Rank C
		Middleburg	5	Bituminous	Medium-Rank C
		Koornfontein	2	Bituminous	Medium-Rank C
		Douglas	2	Bituminous	Medium-Rank C
		Douglas	4	Bituminous	Medium-Rank C
		Douglas	5	Bituminous	Medium-Rank C
		Optimum	2	Bituminous	Medium-Rank C
		ATC	5	Bituminous	Medium-Rank C
Kwa Zulu Natal		Zululand Anthracite	Main	Anthracite	Medium-Rank B

For the laboratory tests, the bulk run of mine (ROM) coal samples were collected from four different operators representing different coal seams, coal types and geographical regions. The ROM coal samples with an approximate size of 120 mm in thickness representing various coal types were collected from face areas. Of note, there were no operating coal mines with coal seam number 3. The majority of the coal samples collected were from coal seam 2 and 4.

Based on the rank designation parameter (Vitrinite Random Reflectance-VRT), all South African bituminous coals fall under the Medium-Rank C (Ortho-Bituminous) category except Kwa Zulu-Natal Anthracite coals which fall in to category Medium-Rank B (Meta-Bituminous) in accordance with the International Classification of Coal Seams Using Rank Parameter (Energy/WP.1/R.50; Bulletin 112, 1998). In summary, it can be concluded that there are only two coal types in South Africa, i.e., bituminous coals and Kwa Zulu Natal higher rank anthracite coals. An ash content of between 15 and 20 percent is fairly common in most of the South African coals, except anthracite coal which has an ash content of less than 10%.

11.4.3 Dust Instrumentation

Dust sampling was carried out using a Hund real-time dust monitor and three gravimetric samplers operated at 2.2 L/min according to the new ISO/CEN/ACGIH respirable size-selective curve. A Hund real-time monitor continuously monitored the respirable fraction of the dust and was positioned in the middle of the chamber facing the air stream consistently for the duration of the tests. All the gravimetric dust sampler inlets were positioned facing towards the airflow. Preliminary crushing trials indicated that the dust chamber air velocity to maximize dust concentrations in order for quicker mass collection on the filter was 0.8 m/sec; therefore, the chamber air velocity was maintained at 0.8 m/sec for all the experiments.

11.4.4 Laboratory Experimental Procedure

The following procedure was followed during the laboratory studies:

1. Before commencement of the experiment, the intake end of the dust chamber and intake feeder of the crusher were cleaned. Clean air was passed using exhaust fan for over five minutes to create a continuous fresh airflow prior to the introduction of the coal sample.
2. Prior to the tests, all the dust pumps were calibrated. A Gilibrator primary standard flow meter was used to establish the required air flow rate using an equivalent pressure restriction of the cyclone and filter assembly.
3. The dust monitors were placed inside the chamber at their identified position and the crusher was then switched on.
4. After approximately five minutes, a fixed mass of different coal sample mix was fed manually into the crusher hopper in order to obtain enough dust on the filters.

5. The coal samples were randomly run in the roll crusher test facility. The airborne respirable dust generated per unit of coal crushed in the air-stream was determined by gravimetric sampling along the length of the test chamber.
6. After sampling ceased, the air pumps and real-time monitors were turned off and the time noted. Throughout the experiment, the air pumps and the condition and operation of the sampling train were monitored.
7. The dust samples were removed from the samplers for determination of mass.
8. At the conclusion of the test, a PC was used to download data from the Hund real-time monitor. This data was then translated into an ASCII text file that may be read with a spreadsheet program to calculate average dust concentrations during the test periods.
9. After each test, dust monitors were then cleaned, new filters installed, and prepared for the next test.
10. After completion of each test, the roll-crusher was switched off and the dust chamber was cleaned.
11. In each experiment, data on gravimetric dust samples, instantaneous concentrations recorded by real-time monitor, amount of batch feed coal sample, and crushing times were recorded.

11.4.5 Data Analysis

The gravimetric dust samples collected during the experiments were analysed to determine the airborne respirable dust levels. Using the real-time data, individual respirable dust levels were determined for each coal sample crushed. The specific inherent respirable dust generation potential (IRDGP) for each crushed coal sample was calculated as follows:

$$\text{SRDM (mg)} = \frac{\text{SC (mg/m}^3\text{)} \times 2.2 \times \text{Sampling Time (min.)}}{1000} \quad (11.1)$$

Where,

SRDM is the sample respirable dust mass for the crushed coal samples
 SC is the sample concentration for the crushed coal sample
 2.2 is the sampling flow rate (L/min) of cyclone

$$TMIRD = SRDM \times 0.864 \times \text{Crushing Time (sec)} \quad (11.2)$$

Where,

TMIRD is the total mass of inherent respirable dust for the air volume (mg)
 0.864 is the volume of air through the chamber (m³/sec)
 [0.9 m × 1.2 m × 0.8 m/sec]

Therefore, inherent respirable dust generation potential (IRDGP) is equal to:

$$IRDGP = \frac{TMIRD}{CSW \times 0.001} \quad (11.3)$$

where,

IRDGP is the inherent respirable dust generation potential (mg/ton)
 TMIRD is the total mass of inherent respirable dust mass (mg)
 CSW is the crushed coal sample mass (kg)

Essentially the IRDGP data will be in the form of IRDGP_{ij} (mg/ton). The subscripts have the following definitions:

i = coal seam type, i = 1 is seam #1; i = 2 is seam #2; i = 3 is seam #4; i = 4 is seam #5

j = coal rank type, j = 1 is Bituminous coal; j = 2 is Anthracite coal; k = Waterberg coal

Associations between the experimental variables on the IRDGP were analysed by scatter plot examination and statistical analysis of significance of individual parameters. The statistical package MINITAB 13.0 was used for analysis purposes. The IRDGP information on different coal samples was used as a tool for classification of the coal type in dust control mechanisms and, in assessing the worker exposure based on the dust generation potential of coal.

11.5 Results and Discussions

The following paragraphs discuss the IRDGP results of various ROM coal samples crushed during the tests. The real-time data of the experiments are shown in Appendix E.

11.5.1 IRDGP of ROM Coal Samples-Kumba Resources

Table 11.2 summarizes the relevant measured and calculated parameters for the ROM coal samples from Kumba resources. The coal samples represent Bituminous medium rank C and were from an opencast operation in Limpopo province. There were a total of 29 coal samples crushed with an average feed mass of 14.56 kg and average crushing time of 149 seconds. The analysis of the crushing data indicated that there was no clear relationship between crushing time and feed mass.

Table 11.2: Summary of ROM coal samples from Kumba mines

Sample #	Sample weight	Crushing time	Respirable dust level	IRDGP
	Kg	Secs.	mg/m ³	mg/ton
E-3	14.40	106	50.48	1247.71
E-3	12.70	110	39.61	1195.46

E-7b	15.00	95	12.71	242.23
E-7b	15.30	99	10.04	203.70
E-7b	16.60	137	10.62	380.28
E-7b	15.50	171	11.77	703.26
E-5	13.30	176	7.25	534.94
E-5	14.70	179	9.92	684.81
E-5	13.40	127	8.50	324.11
E-5	13.20	116	10.76	347.54
E-2	13.50	205	11.51	1134.66
E-2	14.70	183	15.96	1151.74
E-2	15.50	145	9.66	415.33
E-2	17.50	140	13.65	484.23
E-11	14.90	270	12.04	1866.30
E-11	12.40	222	19.15	2411.21
E-11	15.80	224	13.87	1395.50
E-11	15.00	96	12.91	251.20
E-4	15.10	156	11.87	785.97
E-4	12.60	192	12.95	1028.04
E-4	14.60	144	16.16	1106.88
E-9B	16.10	166	21.42	1161.32
E-9B	13.50	172	21.25	1475.57
E-9A	14.70	197	21.47	1795.39
E-9A	10.90	104	19.13	601.51
E-9A	13.10	140	25.22	1195.41
E-6	14.20	89	15.70	277.36
E-6	15.00	79	17.84	235.15
E-6	19.00	85	26.78	322.57

Figure 11.4 shows the IRDGP of Kumba resources coal samples from different operating benches.

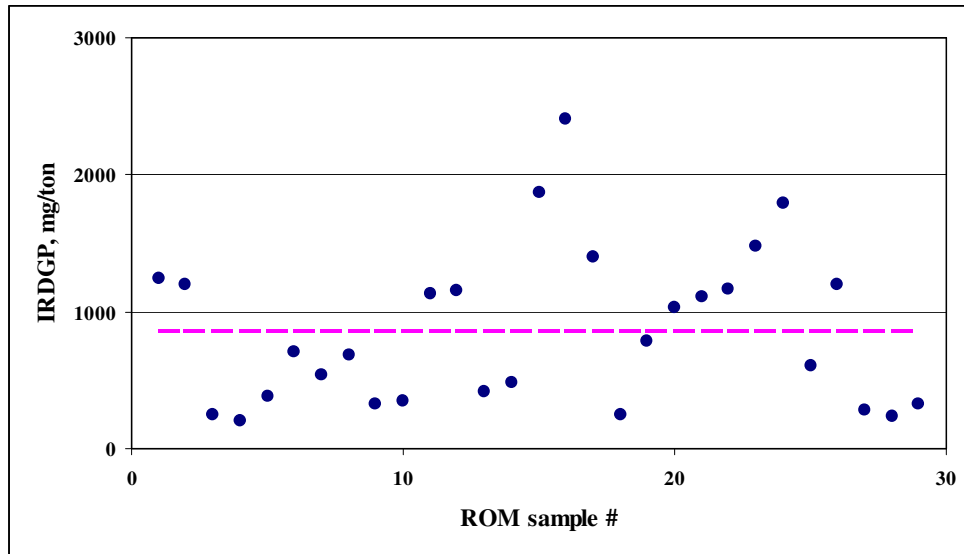


Figure 11.4: IRDGP of ROM coal samples from Kumba Resources

The mean or average IRDGP of Kumba resources coal samples was 860 mg/ton with minimum and maximum IRDGP values of 204 mg/ton and 2411 mg/ton respectively for the test conditions. From the plot, it can be seen that scatter is wide and approximately 45% of the samples were above average IRDGP of the ROM coal samples crushed. The reasons can be attributed to the coal samples which contained host rock materials such as sandstone and shale bands and it took a longer time to crush the coal samples.

11.5.2 IRDGP of ROM Coal Samples-Sasol Mines

Table 11.3 summarizes the pertinent measured and calculated parameters for the Sasol coal mine ROM samples. The coal samples crushed represent Bituminous medium rank C and were from underground operations from seam 1, 2 and 4 in Mpumalanga province. There were a total of 28 coal samples with an average feed mass of 14.00 kg of coal and average crushing time of 146 seconds for individual tests.

Table 11.3: Summary of ROM coal samples from Sasol mines

Sample #	Sample weight	Crushing time	Respirable dust level	IRDGP
	Kg	Secs.	mg/m ³	mg/ton
Bosjesspruit-1	13.00	171	9.42	724.26
Bosjesspruit-2	12.20	63	1.03	84.73
Bosjesspruit-3	9.50	54	0.76	79.83
Bosjesspruit-4	14.50	253	58.71	4048.97
Syferfontein-1	14.50	75	3.88	267.87
Syferfontein-2	14.80	107	6.07	409.97
Syferfontein-3	11.60	73	2.18	188.32
Syferfontein-4	12.30	138	9.94	807.92
Middelbult	7.00	31	0.39	56.01
Sigma-S1	12.20	162	5.90	483.28
Sigma-S2	14.40	116	3.13	217.46
Sigma-S3	16.50	136	4.39	266.29
Sigma-S4	13.20	72	2.13	161.47
Twistdraai W1	11.90	117	4.37	367.59
Twistdraai-E1	18.00	180	11.21	622.81
Twistdraai-E2	14.20	116	5.09	358.48
Twistdraai-E3	13.40	142	8.51	635.09
Twistdraai-E4	16.00	284	16.56	1034.98
Twistdraai-E5	14.00	101	2.97	212.18
Twistdraai-C1	14.80	242	49.53	3346.79
Twistdraai-C2	14.00	206	38.60	2757.04
Twistdraai-C3	12.00	238	43.08	3589.82
Twistdraai-C4	14.50	154	15.55	1072.30
Twistdraai-C5	17.40	106	11.96	687.64
Twistdraai-C6	16.00	176	19.15	1197.10
Brandspruit-1	12.70	224	21.18	1667.64

Brandspruit-2	13.20	106	5.73	434.29
Brandspruit-3	23.00	245	31.41	1365.72

Figure 11.5 shows the Inherent Respirable Dust Generation Potential (IRDGP) of Sasol mine coal samples.

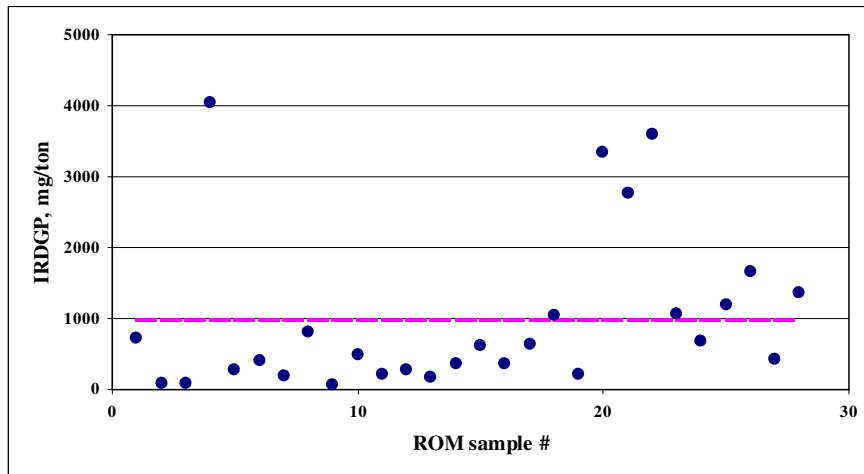


Figure 11.5: IRDGP of ROM coal samples from Sasol mines

The mean or average IRDGP of Sasol mine coal samples was 970 mg/ton with minimum and maximum IRDGP values of 56 mg/ton and 4048 mg/ton respectively. The outliers in the plot are due to the long crushing time of coal samples and not necessarily due to the differences in type of coal seam. This can be attributed to the presence of host rock material. From the plot we notice that approximately 32% of the samples were above average IRDGP for the coal samples crushed.

11.5.3 IRDGP of ROM coal samples-Amcoal mines

Table 11.4 summarizes the pertinent measured and calculated parameters for the Amcoal ROM coal mine samples. The coal samples crushed represent Bituminous medium rank C and were from underground operations from seam 2, 4 and 5 in

Mpumalanga province. There were a total of 40 coal samples with an average feed mass of 14.56 kg and average crushing time of 153 seconds. The analysis of the crushing data indicated that there was no clear relationship between crushing time and feed mass.

Table 11.4: Summary of ROM coal samples from Amcoal mines

Sample #	Sample weight	Crushing time	Respirable dust level	IRDGP
	kg	Secs.	mg/m ³	mg/ton
Bank Coal-2	11.80	218	24.67	3147.27
Bank Coal-2	11.90	143	20.56	1119.32
Bank Coal-2	11.80	215	19.95	2475.59
Bank Coal-2	12.00	180	21.32	1823.92
Bank Coal-2	11.90	95	26.32	632.39
Bank Coal-2	12.10	237	13.56	1993.82
Bank Coal-2	11.90	144	19.23	1061.68
Bank Coal-2	16.40	192	27.16	1934.14
Bank Coal-2	14.10	108	17.85	467.68
Bank Coal-2	14.60	142	18.74	819.83
Bank Coal-2	12.70	254	14.17	2279.82
Bank Coal-2	12.90	246	12.93	1920.91
Bank Coal-2	12.90	86	18.52	336.38
Bank Coal-2	14.80	236	11.49	1369.91
Bank Coal-5	12.90	112	15.93	490.86
Bank Coal-5	12.90	130	9.95	413.01
Bank Coal-5	12.90	178	6.72	523.06
Bank Coal-5	12.00	179	6.08	513.90
Bank Coal-5	13.00	93	13.52	285.01
Bank Coal-5	13.00	117	12.60	420.27
Bank Coal-5	13.00	103	14.00	361.82

Bank Coal-5	12.50	76	15.48	226.63
Goedhope-2	12.90	196	22.44	2116.74
Goedhope-2	12.70	146	19.68	1046.26
Goedhope-2	13.00	196	15.23	1425.86
Goedhope-2	12.70	150	25.49	1430.41
Goedhope-4	13.50	174	21.14	1501.83
Goedhope-4	13.70	150	22.14	1151.74
Goedhope-4	15.20	248	13.69	1754.84
Goedhope-4	14.60	121	11.89	377.71
Goedhope-4	15.20	115	12.09	333.34
Goedhope-4	14.50	173	11.76	769.07
Goedhope-4	16.00	211	10.13	892.75
Goedhope-4	19.70	181	13.33	702.12
NDC-4	15.00	97	13.77	273.66
NDC-4	14.10	90	12.79	232.79
NDC-4	15.10	111	10.17	262.91
NDC-4	15.10	82	18.69	263.61
NDC-4	15.90	144	11.92	492.29
NDC-4	15.60	94	17.70	317.56
NDC-4	15.50	111	15.86	399.52

Figure 11.6 shows the Inherent Respirable Dust Generation Potential (IRDGP) of Amcoal ROM coal samples. The coal samples crushed represent Bituminous medium rank C and were from underground operations in Mpumalanga province. The average IRDGP of operator C samples was 984 mg/ton with minimum and maximum IRDGP values of 227 mg/ton and 3147 mg/ton respectively. From the plot, it can be seen that approximately 42% of the samples were above average IRDGP for the coal samples crushed.

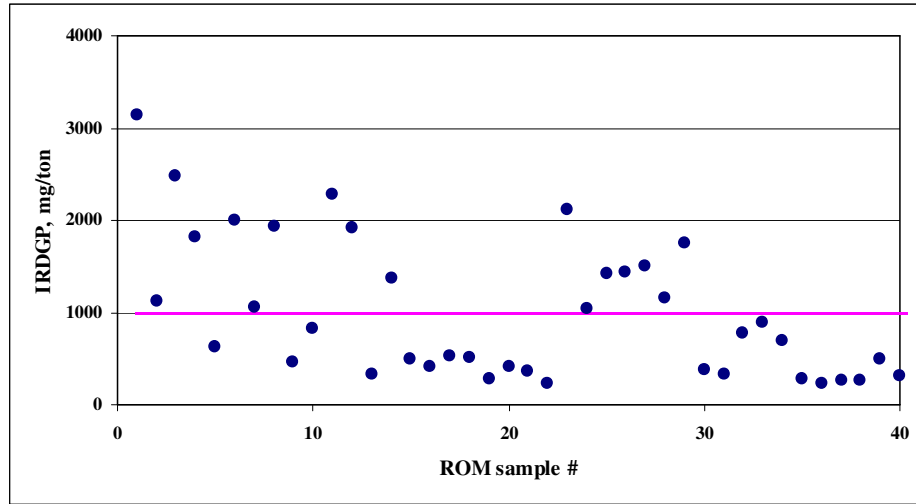


Figure 11.6: IRDGP of ROM coal samples from Amcoal mines

11.5.4 IRDGP of Coal Samples-Ingwe Mines

Table 11.5 summarizes the pertinent measured and calculated parameters for the Ingwe ROM coal mine samples. The coal samples crushed represent Bituminous medium rank C and were from underground operations from seam 1, 2, 4 and 5 in Mpumalanga province. Also, anthracite coal samples of medium rank B from the underground operations in the main seam in Kwa Zulu Natal province were crushed. There were a total of 77 coal samples with an average feed mass of 12 kg and average crushing time of 186 seconds.

Table 11.5: Summary of ROM coal samples from Ingwe mines

Sample #	Sample weight	Crushing time	Respirable dust level	IRDGP
	kg	Secs.	mg/m ³	mg/ton
Middleburg-4	12.00	120	0.83	68.83
Middleburg-4	15.00	178	1.90	126.63
Middleburg-5	10.30	108	1.44	139.98
Middleburg-5	10.00	128	2.31	230.56

Middleburg-4	10.30	110	1.21	117.91
Middleburg-4	10.90	168	4.63	424.77
Middleburg-4	7.70	128	3.48	451.69
Middleburg-4	11.40	294	10.39	911.67
Middleburg-2	11.20	98	2.55	227.95
Middleburg-2	12.20	120	5.10	418.35
Middleburg-2	9.60	102	3.69	384.76
Middleburg-2	11.20	212	9.65	861.47
Middleburg-2	11.10	156	9.15	824.61
Middleburg-2	11.50	104	4.93	429.09
Middleburg-2	11.90	112	1.55	130.30
Middleburg-2	11.30	148	6.77	599.48
Middleburg-2	11.30	210	10.45	924.67
Middleburg-4	12.80	141	6.51	508.58
Middleburg-4	12.80	107	5.64	440.93
Middleburg-4	12.80	207	13.47	1052.50
Middleburg-4	12.80	194	18.13	1416.24
Middleburg-4	11.60	168	9.20	793.38
Middleburg-2	12.80	295	14.68	1146.78
Middleburg-2	12.80	117	5.76	449.82
Middleburg-2	12.70	145	7.83	616.16
Middleburg-2	12.90	77	2.86	221.56
Middleburg-2	12.80	126	8.26	645.38
Middleburg-2	12.80	92	3.64	284.57
Middleburg-1	12.90	204	16.07	1245.82
Middleburg-1	12.80	121	6.29	491.72
Middleburg-1	12.80	130	6.87	536.41
Middleburg-1	13.40	186	11.73	875.65
Middleburg-5	12.90	278	17.52	1358.12
Middleburg-5	13.00	166	12.16	935.32

Middleburg-4	12.80	136	9.32	728.37
Middleburg-4	12.70	233	12.87	1013.00
Middleburg-4	13.50	254	15.67	1160.64

Table 11.5: Contd. Summary of ROM coal samples from Ingwe mines

Sample #	Sample weight	Crushing time	Respirable dust level	IRDGP
	kg	Secs.	mg/m ³	mg/ton
Koornfontein-2	11.00	116	1.41	127.85
Koornfontein-2	10.00	168	2.51	251.27
Koornfontein-2	11.60	149	3.25	279.99
Koornfontein-2	10.00	136	2.05	205.09
Koornfontein-2	11.60	91	1.77	152.42
Koornfontein-2	11.00	164	3.19	289.86
Douglas-1	10.20	162	3.42	334.92
Douglas-2	13.20	388	7.23	547.59
Douglas-2	11.90	430	5.60	470.56
Douglas-4	12.00	212	5.22	435.33
Douglas-5	11.00	324	5.11	464.44
KZN-E	13.00	174	18.32	1408.99
KZN-E	12.70	145	20.94	1648.52
KZN-E	12.40	631	206.30	16637.07
KZN-Main	12.90	226	53.29	4130.63
KZN-Main	18.00	469	391.53	21751.69
KZN-Main	11.90	303	32.77	2753.44
KZN-Main	18.70	727	256.69	13726.76
KZN-Main	12.80	243	69.46	5426.81
KZN-Main	12.20	184	34.28	2810.00
Optimum-2	6.40	56	1.18	184.45

Optimum-2	12.50	128	7.25	580.36
Optimum-4	10.00	165	9.96	996.49
Rietspruit-5	12.90	162	8.33	645.76
Rietspruit-5	12.90	98	4.43	343.67
Rietspruit-5	13.00	80	3.62	278.58
Rietspruit-5	12.90	273	8.16	632.70
Rietspruit-5	14.00	177	9.71	693.80
Rietspruit-4	13.00	134	8.04	618.76
Rietspruit-4	13.00	170	15.56	1196.66
Rietspruit-4	12.90	184	6.32	490.11
Rietspruit-4	13.00	138	5.88	452.32
Rietspruit-4	13.00	190	19.24	1479.88
Rietspruit-4	13.10	244	14.79	1128.78
Rietspruit-4	14.60	148	7.79	533.90
Rietspruit-1	13.10	208	12.98	990.65
Rietspruit-1	12.80	188	12.43	971.20
Duiker-5	4.00	52	2.11	527.58
Duiker-5	8.20	126	8.05	981.45
Khutala-4	10.00	55	2.29	228.65

Figure 11.7 shows the Inherent Respirable Dust Generation Potential (IRDGP) of Ingwe coal mine samples.

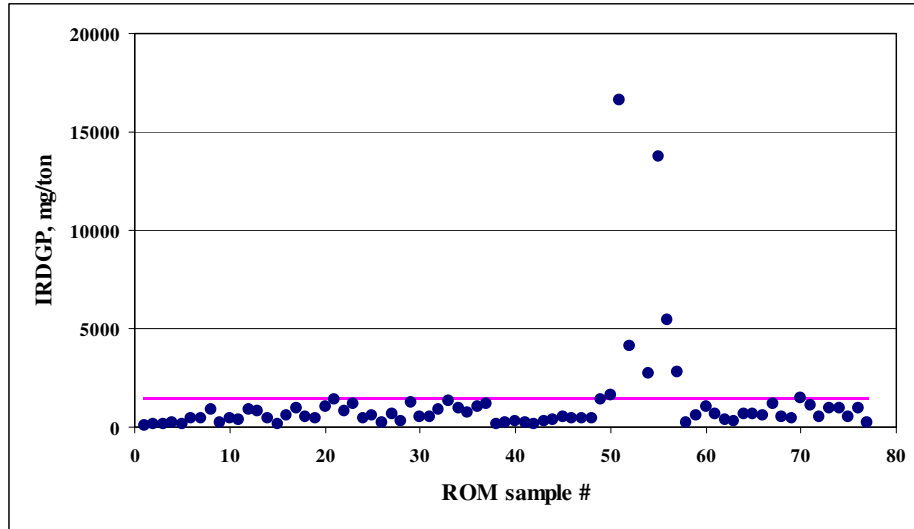


Figure 11.7: IRDGP of ROM coal samples from Ingwe mines

The average IRDGP of Ingwe mine coal samples was 1442 mg/ton with minimum and maximum IRDGP values of 69 mg/ton and 21751 mg/ton respectively. Excluding the Kwa Zulu Natal coal samples, the IRDGP for the Ingwe mine samples was 590 mg/ton. The average IRDGP for the Kwa Zulu Natal anthracite coal was 7810 mg/ton. From the plot, a clear distinction between the coal types was noticeable. Kwa Zulu Natal coals are anthracite (medium rank B) and other coals were bituminous coals (medium rank C).

Table 11.6 summarizes the IRDGP of different coal types and coal seams for all the test samples. Figure 11.8 shows the average IRDGP for different coal types, coal seams and mine operators during the study.

Table 11.6: Summary of average IRDGP data for the ROM coal samples

Description	IRDGP Data, mg/ton				
	Minimum	Maximum	Average	No. of Samples	Avg. crushing time, sec.
Coal Seam-1	335	1246	778	7	171
Coal Seam-2	128	3147	847	47	162
Coal Seam-4	56	4049	833	63	155
Coal Seam-5	140	1358	523	20	148
Elisras Coal	204	2411	860	29	149
Natal Coal	1409	21752	7810	9	345

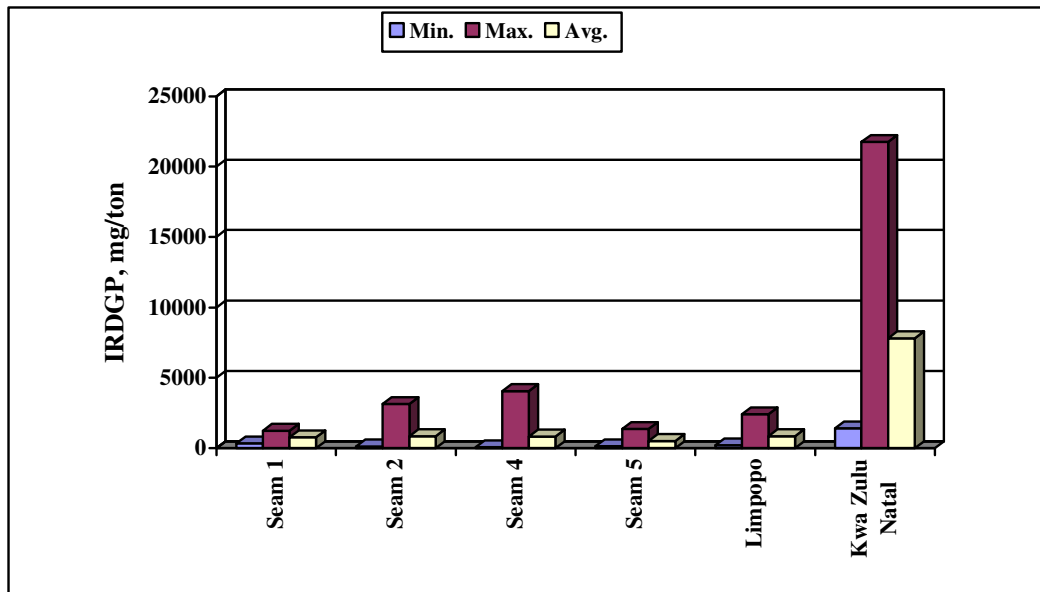


Figure 11.8: Summary of IRDGP of ROM coal samples

Statistical analyses was carried out on the IRDGP data obtained from this laboratory study. Analysis of Variance (ANOVA) was used to test the effect of coal rank and coal seam on IRDGP. The results of ANOVA on the coal rank and

IRDGP data and coal seam type and IRDGP data was done separately and are summarised in Table 11.7.

Table 11.8: Results of Analysis of Variance (ANOVA)

Sources of Variation	Df	MS	F value	Pr>F
Coal Type (semi-bituminous, semi-anthracite and Waterberg coal)	2	210055705	67.84	0.000
Error	173	3096133		
Total	175			
Coal Seam Type (1, 2, 4 and 5)	3	538221	1.05	0.373
Error	134	513195		
Total	137			

The main factors of the statistical analysis were: coal type and coal seam. The value of the F-ratio obtained from the coal type and IRDGP data for the experiments was 67.84; and the p-value was 0.000 at the 5 % level of significance indicating that coal rank influences the IRDGP of coals. Similarly, there was no significant effect of coal seam type data ($p = 0.373$) on IRDGP for this study.

11.6 Inherent Respirable Airborne Silica Content

Efforts have been made in the past to quantify the inherent silica content in the South African coal seams, since scant published research data are available for the coal mining industry. A SIMRAC handbook of occupational health practice in the South African mining industry reports that Mpumalanga, Gauteng and Free State coal have a quartz content of about 2%, whereas Kwa Zulu Natal coal contains 3% quartz. Fundamental studies on the relationship between quartz levels in the coal

seam and the respirable dust generated during coal mining have indicated that the quartz contents in the airborne dust in U.S. coal mines are generally higher than those in the coal seam (Ramani et al., 1987) due to the need to mine roof material together with generally thinner coal seams.

As a part of this study, investigations were extended to quantify the inherent respirable silica content of different coal seams and coal types, representing various coal mines operating in different provinces. From these tests, 25 different airborne respirable coal dust samples representing SA coal seams were analysed for inherent silica content. Inherent silica content is defined as the percentage silica content measured in the respirable dust of the crushed coal samples for the study. The probable sources of silica in the coal are the presence of thin layers of white sandstone bands (origin of the name 'Witbank' coal fields in South Africa). Figure 11.9 shows the silica content of the inherent respirable dust samples representing various coal types in South Africa.

From the results, it is seen that 54 % of the analysed coal dust samples did not have any detectable silica content. The maximum measured silica content of the South African coal seam was from a surface mine coal sample with 6.6 % silica content. This is probably due to the presence of shale or other host rock containing silica. The average measured silica content of all the coal seams containing silica was 3.5 %. In summary, it can be concluded that the inherent silica content is less than 5 % in the test samples of South African coal mines. Based on the inherent silica content of the South African coal, worker exposure to silica dust is relatively low compared to gold mines. The comparison was made due to the fact that South African gold mines have a high prevalence of silicosis due to the presence of high levels of silica dust in the host rock.

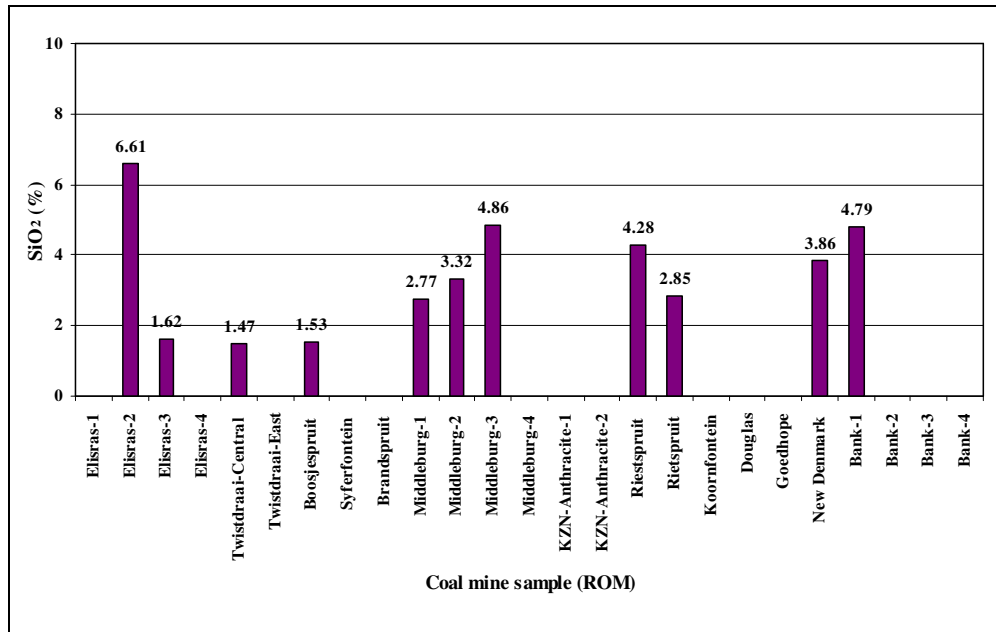


Figure 11.9: Inherent respirable silica content of the South African coals

11.7 Conclusions of the Laboratory Work

In summary, the following observations can be made from the IRDGP data of the test coal samples:

- For the first time, a clear delineation of coal types (Bituminous and Anthracite) that possess the most inherent respirable dust generation potential was possible.
- There is no conclusive relationship between different coal seams (1, 2, 4 and 5) and inherent respirable dust generation potential (IRDGP). The majority of the mine operators are currently exploiting coal from seams 2 and 4.
- Average crushing time of coal samples for this study indicated that the crushing time decreases in the order of seams 1 to 5. Kwa Zulu Natal coals took the highest crushing time during the tests when compared to the other coal seams and coal types. The reasons can be attributed due to inherent coal properties of high rank anthracite coals.

- Measured IRDGP of Limpopo coal was less than commonly occurring seam 2 and seam 4 coals in Mpumalanga province.
- Inherent silica content of South African coal seams indicate that average inherent silica for the test coals was 3.54%.
- Statistical analyses have indicated that the coal rank has a significant influence ($p = 0.000$) on inherent respirable dust generation potential (IRDGP) and inconclusive relationship between SA coal seams and IRDGP ($p = 0.373$).

11.8 Coal Dust Type as DELI Parameter

The intention of determining the IRDGP of South African coals is to effectively transmit the new information and model to the mine risk assessors and risk managers. The information will assist the coal mining industry to protect the workers from exposure to specific dust, as well as to encourage effective control of face area dust. Mass distributions of respirable dust from various coal samples from US mines have indicated that anthracite coal produces larger masses of dust in the finer size range when using similar breakage techniques in anthracite and bituminous coal. Consequently, the mass of dust permanently deposited in the lungs per unit time, which determines the degree of hazard, is higher for anthracite than high volatile bituminous coal (Thakur, 1974).

Mine dust standards are applied uniformly to every coal mine type in South Africa. However, ACGIH recommends a TLV-TWA of 0.9 mg/m^3 , for miners exposed to bituminous dust or lignite coal dust and an TLV-TWA of 0.4 mg/m^3 for miners exposed to anthracite coal dust (ACGIH 2001). Therefore, based on the knowledge of past studies on the effect of coal dust type on health and inherent respirable dust generation studies, effective use of coal dust type is therefore proposed and a matrix has been developed (Table 11.8). The contents are based on the IRDGP data, dust level for an 8-hr period and health risk on exposure is marked for the respective concentration zones as shown in Figure 11.10. Based on

the dust levels and coal type, the plot (Figure 11.10) is divided into A, B, C and D categories in order for its use in DELI.

Table 11.8: Coal dust type indicator model for dust exposure levels

Concentration	Coal Type	Concentration zone	Colour	Health Risk	Description
< 1 mg/m ³	Bituminous	A	Green	I	Good
< 1 mg/m ³	Anthracite	D	Green	II	Average
1 to 2.0 mg/m ³	Bituminous	B	Yellow	II	Average
1 to 2.0 mg/m ³	Anthracite	E	Orange	III	Poor
> 2 mg/m ³	Bituminous	C	Red	III	Unacceptable
> 2 mg/m ³	Anthracite	F	Red	IV	Unacceptable

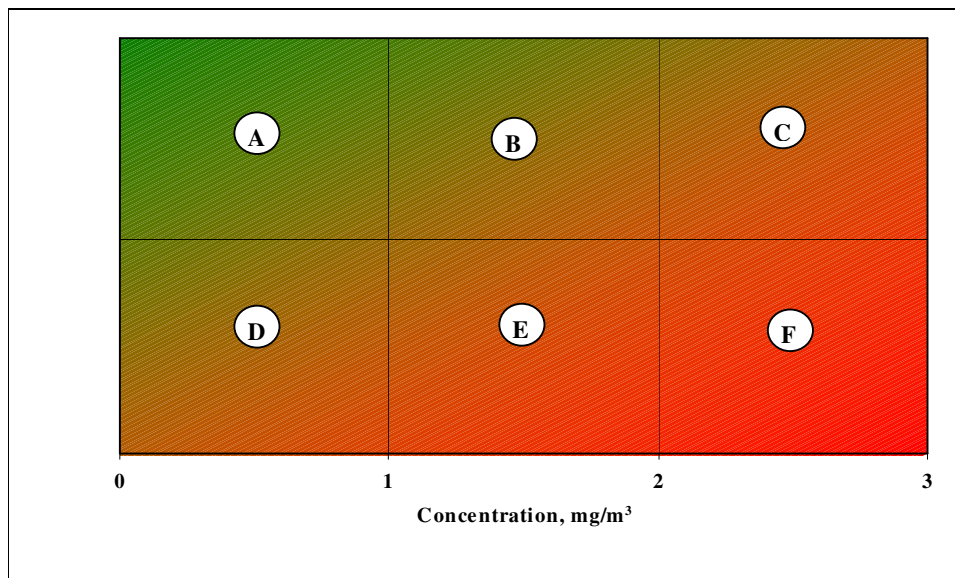


Figure 11.10: Use of the coal dust type parameter in DELI

11.9 Summary

This chapter summarizes the inherent respirable dust generation potential (IRDGP) of South African coals. The resulting information and its use as an index of worker exposure to dust is discussed. This study carried out experimental work that resulted in critical information on dust type and inherent respirable dust generation potential for the first time for South African coals. Based on the measured respirable dust data of the South African coals, it can be concluded that majority of the coal mining operation provinces such as Mpumalanga, Free State and Limpopo have, on average, similar IRDGP, while Kwa Zulu Natal coal samples which are anthracite type coal have greater IRDGP.

This information will be helpful for dust control in both surface and underground operations. The intention to use the coal dust type is that it is a clear parameter that will assist in assessing dust exposure risk of workers to coal dust. Also, the effectiveness of a dust-control system is also dependent on coal dust type. Therefore, coal dust type can be used as an administrative type of exposure control parameter and as an exposure index for health risk where the management can effectively rotate the worker to different operations so as to reduce the increased risk of CWP. The coal dust type parameter in an overall DELI tool is recommended for use in exposure surveillance by the occupational hygiene professionals for developing dose-response relationships for South African coal miners working in different coal types. To date there has been no clear delineation for South African workers who are exposed to different dust types. Therefore, it is recommended that a research study be conducted to investigate prevalence of CWP among workers in Kwa Zulu Natal coal mines and other provinces with the DELI tool to assist in determining historic dose and developing dose-response curve that will ascertain the overseas health research studies.

Chapter 12 Conclusions and Recommendations

The dust hazard to miners in South Africa was first specifically recognized and brought under intensive study during the early years of this century. In the coal mining world, South Africa has some of the best mining conditions resulting in bord and pillar mining in long development headings and increased production. With the enticement for coal production and resulting financial rewards, the focus on the working environment has often been neglected or has taken a back seat. The Leon Commission of Inquiry (1994) looked into Occupational Health and Safety (OHS) in the South African mining industry over the past 30 years or more. In South Africa, the burden of diseases from working in mines was unacceptably high, with a peak of about 25 000 per annum of applications for compensation for occupational lung diseases (Annon, 2002).

In previous years, the main emphasis and focus of occupational health activity on the mines has been on regulating the compensation for occupational diseases rather than the prevention thereof. The Minerals Act (1971) focused predominantly on safety issues in the mining industry with no emphasis on promoting the occupational health status of workers. The deficiencies were overcome by the new Mine Health and Safety Act (MHSA, 1996) to provide a comprehensive legal framework for creating a healthy and safe working environment. The Mine Health and Safety Act of 1996 entrenches the right of workers to refuse to do dangerous work, thereby paving the way for improved health and safety conditions in the mining industry.

According to the World Health Organization (WHO) report (2002), development of work-related lung diseases is influenced by the amount of exposure and the toxicity of the dust, and the diseases are characterized by long latency periods. Therefore, even in countries in which exposures have been recognized and

controlled, the disease rates are only gradually declining (NIOSH, 1999). However rate trends in developing countries like South Africa are mostly unknown but the magnitude of the problem appears to be substantial when compared with developed countries (Chen et al., 2001).

Most of the exposure-based epidemiological studies have assumed that cumulative exposure is a good measure. The drawback of such types of studies is that it requires an accurate knowledge of past exposures of individuals or populations as functions of time over the periods of interest. Health risk assessment of exposure to coal dust involves historic data on worker exposure to dust. Prevention and control of CWP requires detailed information on the past and present dust level workers are exposed to. Many of the “dose-response” curves for coal dust were derived from specific “sampling projects” in different countries, viz., Pneumoconiosis Research Unit (PRU) in Great Britain, Germany and USA. In Great Britain and Germany, a dose-response curve was obtained using fixed samples in the return airways. However, in South Africa, the past data are not readily available, so one requires reconstruction of the exposure assessment through various mathematical models and probabilistic reasoning. Therefore, to develop a systematic framework of a dust exposure level index with the currently available data and the knowledge leading to probable exposure would be of great benefit to all the parties involved.

In recent years, CWP and other occupation related lung diseases are becoming a high-litigation risk in terms of potential claims for the South African mining operations. Use of true dust exposure data results in a more accurate dose-response curve. There is no clear dose-response relationship for the South African coal mine workers for CWP. Due to the lack of critically important data to review the current dust standards, and no information on dose-response curves, this thesis has set out to examine several critical exposures related parameters that were not previously investigated or evaluated and those could be used in developing CWP dose-response curve for South Africa.

The data gathered in this thesis is well documented and has been measured following strict protocols and is, therefore, reliable information that can be used in future. The dust data obtained in this research study is from engineering, and static dust measurement methods in the South African coal mines and infers the possible health effects on the worker from overseas developed dose-response models. Practical experience and various historical methods highlight the convenience of easily interpreting the critical scientific data in a simple and understandable way. The introduction of such indices into the mining industry is not strange to people in the mining world. However, from the dust pollution and exposure point of view there is no such tool available to-date in South Africa.

The research proposed in this study had the objective of the development of a unique index to evaluate the coal dust exposure of a worker while underground. The index is called the Dust Exposure Level Index (DELI). This index will be unique as it depends on many parameters discussed in this Thesis, and combinations of these parameters in dust exposure assessment were not used heretofore. With the evolvement of effective dust control techniques, better understanding of size-selective sampling, and newly developed real-time monitoring instruments, the monitoring of respirable dust is now a practical possibility. Therefore, focusing attention to quantitatively measure the exposure levels through a qualitative index is appropriate. It is hoped that the DELI would provide critical priorities to evaluate efficiency of dust control systems and identify new, better ways of reducing dust in the coal mines.

The main objectives of this research work was the development of DELI using various identified parameters as they are expected to achieve the following:

- DELI will be an administrative tool incorporating the set of controllable parameters that greatly influence the assessment of worker dust exposure levels. It will be useful to mine operators to check on their process,

mineworkers to identify their estimated qualitative exposure levels and the enforcement authorities to have their views influenced by the index.

- It will identify the major operational factors affecting the exposure level of workers to coal dust.
- As the development of a comprehensive index of exposure has not been done anywhere in the world, this will be unique to the South African coal mining industry.
- Clarifies the current disagreement, where mines, are under non-compliance due to the uncontrollable natural circumstances that differ from mine to mine. This would enable the non-compliant mine operator to search for innovative production techniques in order to reduce the dust levels.

The research concentrated on developing a new investigative tool or method of assessing the dust exposure of workers by mainly focusing on controllable factors, which are influential in reducing the dust exposure. Figure 12.1 outlines the parameters that are mostly controllable in order to minimize the worker’s exposure to dust and considered important for inclusion in the DELI.

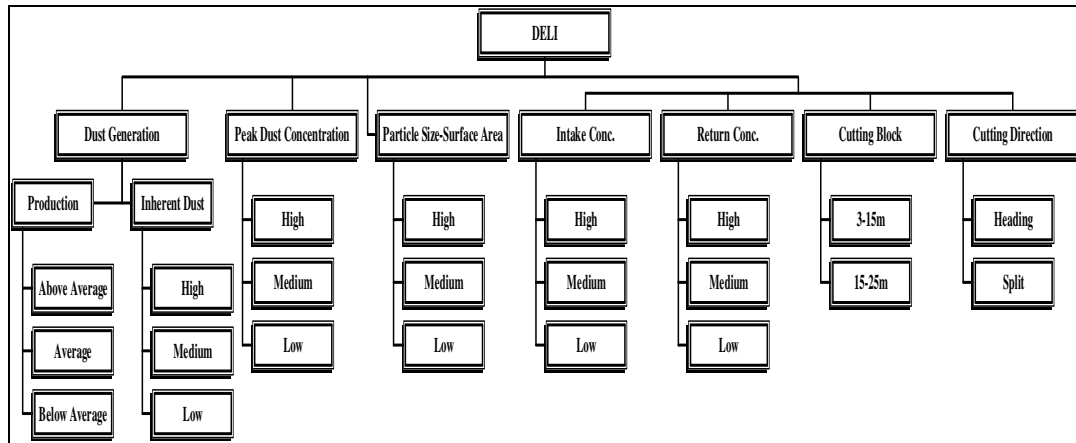


Figure 12.1: Parameters of DELI

Each parameter has been discussed in the respective chapters of the thesis. The data for developing an index, DELI, was based on analysing extensive

underground sampling data collected according to the new ACGIH/ISO/CEN size-selective respirable curve and measured in underground production sections. The results of analyses of these parameters are summarised in the conclusions below.

12.1 Conclusions

The research work described in this thesis has led to very explicit conclusions, which were made at appropriate places in the Chapters of this thesis. As expected, a large amount of dust related information was gathered during the course of this research study. Conclusions obtained for the various identified controllable parameters to be used in DELI are as follows:

Conclusions on Historic Dust Exposure Data

Published historic information on coal dust exposure data in South African coal mines could not be found in the literature. It was reported in 1996 that South African coal mines showed gravimetric dust readings far exceeding the acceptable range and were often as high as 120 mg/m^3 (Safety Management, 1996). The calculated average of the dust level data collected as part of this study during 1990 in conventional, continuous mining and longwall mining operations were 4.42 mg/m^3 , 5.92 mg/m^3 and 3.71 mg/m^3 respectively. This indicates that the dust levels have increased with mechanisation, i.e. with the move from conventional mining to continuous mining. This to be expected as production per shift increased considerably during this changeover. From the data it is noted that the CM operations made higher dust levels than the longwall operations (only a few in South Africa), probably due to the lack of auxiliary ventilation control devices available at the time. Similarly, during the longwall operations, the measured dust levels were lower than the conventional mining. This can be attributed to effective dust control systems on the shearers and ease of ventilation of longwall faces.

Conclusions on contribution of stone dust in collected dust samples

The application of stone dust was introduced in the early 1990s and regulations came in to effect in 1998 in order to reduce the coal dust explosion risks in South African coal mines. The stone dust and coal dust levels derived from personal real-time dust data indicated that longer exposure to stone dust or contamination of coal dust samples due to stone dusting can result in significantly higher non-compliance personal or engineering dust samples. Further, this also may give a “false” indication of the efficiencies of the dust-control systems in the sections.

Conclusion on Effect of Cutting Block and Cutting Direction

The dust exposure levels in the various working areas (i.e., heading or split) during coal cutting in a bord and pillar coal mine was carried out indirectly through a detailed analysis of the efficacy of the 12 m rule as defined in the 1997 directive. The study indicated that a worker positioned inside the cabin of a CM during the cutting of a 24 m block is usually at a higher exposure risk than the worker when cutting a 12 m block. Based on the mean dust levels, the miner who is operating in a heading is exposed to more dust than when operating in a split. Analysis of the dust levels at the CM operator’s position indicated that the application of a 12 m rule on its own does not solve the dust problems, but that meticulous application of available state-of-the-art dust control technologies, best work practices, and the regular maintenance of the installed system can have a significant effect.

Conclusion on Influence of Peak Dust Concentration Levels

The average or cumulative dust values used in exposure assessment or dose-response curves for a working period does not discriminate between dust levels which are nearly constant and when frequent peak dust levels occur during an operating shift. *The peak dust levels for the study are defined as the respirable*

dust level recorded by the real-time dust monitor at the CM operator's position during an underground working shift which is a multiples of the statutory compliance level of 2.0 mg/m³.

As discussed in Chapter 6, the occurrence of peak dust levels is determined using real-time dust monitors. Unlike waiting a few days for conventional gravimetric sample results, the real-time information can be very effectively used just after the shift for estimating the worker exposure level. The task can be carried out using the real-time monitor data positioned at the machine operator's position and analysing the peak dust levels for their frequency during the shift. The real-time data can be downloaded and quickly analysed using the peak model of DELI.

The results show a clear relationship between the average dust levels and the frequency of occurrence of "peak" dust levels. Comparing shift dust levels with frequency of peak dust levels indicates that frequency of occurrence of peak dust levels (50 mg/m³ or above) during a shift average dust level of greater than 5 mg/m³ is double that of shift average dust levels of less than 5 mg/m³. The use of the peak dust level parameter is based on the hypothesis that a worker who is working in the face area and is exposed to frequent peak concentration levels could be subjected to such a dust deposition in the alveolar region of the lung that the clearance capacity of the lungs is overcharged. Therefore, more dust is retained and more severe and frequent radiological changes develop. Also, the recovery period for the worker in the face area from the deposited lung dust is also comparatively higher. Despite the lack of medical evidence on the influence of 'peak' dust exposure levels on health for coal dust, it has been noted that this is an important factor for dust control and thus exposure assessment purposes. In any event, the long-term peak dust influence on health can only be examined with an adequate record of peak dust levels. Further, the real-time dust information can be wisely applied to evaluate the available state-of-the-art dust control technologies, best work practices, and to audit maintenance of the installed dust control systems to ensure that dust levels are controlled immediately and after every shift.

Conclusion on Influence of Section Intake Dust Levels

As a part of this research study, the section intake dust levels measured over the five year period in selected South African underground coal mines indicated that the average section intake dust level was 0.80 mg/m^3 . Approximately, 60% of the intake samples collected for the study have exceeded the 0.5 mg/m^3 limit (or 25 % of the OEL of 2 mg/m^3). Also, the intake concentration level measured at the longwall face was much higher than in the CM headings.

The intention to use intake dust levels as an exposure level index is that it clearly plays the part as a corner stone in the effective control of exposure to face area respirable dust. It must be borne in mind that the section intake dust level is a *base* to the mine worker exposed to dust without carrying out any additional work in the section. If the intake air is seriously contaminated by airborne respirable dust, then the exposure of the workforce in the section will constantly be elevated by that background dust level.

Conclusions on Influence of Section Return Dust Levels

As a part of this research study, the section return dust levels measured over a five year period in the South African underground coal mines indicated that the average section return dust level was greater than 2 mg/m^3 . Longwall section return dust levels are approximately six times the CM dust levels. The reasons can be attributed to the method of mining, coal production per shift, method of dust control systems (i.e., dust suppression or dust dilution), and ventilation systems. The intention to use the return dust levels is that they are the clear indicators of the exposure levels of the section workers to coal dust, effectiveness of the ventilation system to dilute the airborne dust and dust-control system's effectiveness. The return dust levels can be easily monitored using fixed point samplers (where the

movement of machinery is limited) and requires less human intervention and is an easy to use parameter in dust exposure assessment.

Conclusion on Influence of Coal Production and Dust Exposure Levels

The research study indicated that there is no conclusive relationship between coal production and respirable dust levels. Despite the lack of clear evidence in terms of production and concentration levels, the following holds true with high confidence levels. In the coal mining industry, there are various types of cutting machines that can generate various fractions of respirable dust during coal production. In order to control the respirable dust and reduce worker exposure levels, various dust control systems are being used in the mines. This research study has shown that the type of dust control system type has a pronounced effect on the measured dust levels in the mines. However, the following conclusions can be made in order to use production as a parameter in estimating dust exposure levels.

The capture efficiency of any dust control system is not one hundred percent at any given time. During any cutting process for a given time and dust control type, part of the escaped respirable dust is added to the coal face atmosphere through air re-circulation. Therefore, respirable dust levels can be expected to increase with time during the shift, even at constant production levels. The intensity of dust exposure therefore varies with the type of dust control system. Since the exposure levels are directly related to coal production and efficiency of the total dust control system, the exposure levels increase with an increase in coal production.

Therefore, use of production, as a parameter in DELI exposure assessment is that it directly influences the ultimate dust exposure levels of workers underground and can be very effectively used as an administrative tool for prioritising the tasks and re-assigning the workers who are exposed to high levels of dust to areas of less dust underground. It will also provide an opportunity to evaluate the

administrative approaches in prioritising the dust control measures versus coal production.

Conclusion on Influence of Fine Particles

The proposed particle size parameter is based on the hypothesis that the worker who is exposed to high percentages of fine particles is at a greater health risk than the one who is exposed to low percentage of fine particles. From the size analyses data, the calculated total surface area of respirable dust (<10 µm) for dust concentrations of 2.37 mg/m³, 3.89 mg/m³, 5.56 mg/m³ and 5.62 mg/m³ are 2.48 m², 3.76 m², 2.35 m² and 2.75 m² respectively. It is interesting to note from the calculations that there is no clear relationship between the concentration and total surface area of respirable dust. Due to the lack of state-of-the-art size characterization instruments, and the limited number of samples used, this study recognizes that the conclusions obtained on the “size” parameter cannot be used in the DELI model. Therefore, one of the recommendations of this thesis is that future work is conducted to determine the finger-print of "total surface area" of compliance respirable coal samples collected underground at various dust generating sources.

Conclusion on Influence of Inherent Dust Generation Potential

For the first time, a clear delineation of coal types (semi-bituminous and semi-anthracite) and inherent respirable dust generation potential (IRDGP) was possible. Apart from a small amount of semi-anthracite found in Kwa Zulu Natal, most of the South African coal is of the semi-bituminous type. The typical range of volatile matter of coal is between 25 % and 31 %, while ash content is 10 % to 24 %. Analysis of Variance (ANOVA) results of this study indicated that coal rank influences the IRDGP of coals (p = 0.000). There is no conclusive relationship between different coal seams (1, 2, 4 and 5) and IRDGP (p = 0.373) as they are all of semi-bituminous type. The majority of the mine operators are

currently exploiting coals from seam 2 and 4. For the test conditions, Kwa Zulu Natal coals took the highest crushing time during the tests when compared to the other coal seams and coal types. Measured IRDGP of Limpopo coal was less than the commonly occurring seam 2 and seam 4 coals in the Mpumalanga province.

Conclusion on Silica Content

Inherent silica content of South African coal seams indicate that average inherent silica for the test coals was 3.54 %. However, historically analysed airborne coal dust samples for quartz has indicated that they were below the limit of detection of X-ray spectrometer. However, caution must be exercised when assessing exposure specifically in the presence of sandstone bands and roof-bolt operators.

12.2 Air Quality Index (AQI)

The following paragraphs discuss the practical aspects of assessment of dust exposures using Air Quality Index (AQI) in the coal mines. AQI is generally expressed as a single unit number. Its usually expressed in DME public information reports as a percentage of personal respirable dust samples collected in a mine with an AQI of greater than “one.” AQI of less than or equal to the value of “one” indicates that the dust exposures are below the Occupational Exposure Limits (OELs) used at the time of evaluation. In the coal mines, personal dust samples are collected bi-annually for various occupation groups. AQI for coal dust is expressed as

$$\text{AQI coal dust} = \sum \frac{C_s}{C_{\text{OEL}}} + \frac{Q_s}{Q_{\text{OEL}}} \quad (12.1)$$

Where,

C_s = the coal dust concentration level of the sample in mg/m^3

C_{OEL} = the OEL for coal dust in mg/m^3 (for personal samples it is $2 mg/m^3$ and for engineering dust samples it is $5 mg/m^3$)

Q_S = the quartz level in coal dust in mg/m^3

Q_{OEL} = the occupational exposure limit for quartz dust, i.e., $0.1 mg/m^3$

A typical way of using AQI in the mines and their reports is through the number of occupationally exposed persons exposed to $AQI \geq 1$ (See example Table 12.1). The problems with the usage of AQI is the poor descriptions of dust problem areas and its magnitude. The values of AQI are obtained once a year by various mines and are used more on a reactive basis and for levy determination. It must be noted that coal mines in the country continuously take vast numbers of dust samples, analyse them and then submit the dust values to the DME.

Table 12.1: Typical use of AQI in the publicly available reports

Mineral	No of Mines	Number of Occupationally exposed Persons Employed	Number of Occupationally exposed Persons Exposed to An $AQI \geq 1.0$	% Persons Exposed to an $AQI \geq 1.0$				
				2002	2001	2000	1999	1998
Gold	52	109843	5213	4.75	6.65	6.62	4.92	7.37
Platinum	15	80221	134	0.17	0	1.03	1.09	0.80
Coal	73	37178	7374	19.83	28.92	30.94	25.1	34.3
Asbestos	0	No operating mines – All mines closed -						
Other Mines	140	18523	1196	6.46	4.40	4.23	5.65	13.9
TOTAL	280	245765	13917	5.66	6.94	8.52	6.14	9.01

It is estimated that the coal mining industry spends just over R15 million annually on dust sample analysis alone. This does not include the human resource cost to the industry. However, there are no avenues to analyse the quality of the submitted dust levels and one cannot distinguish whether the significant number of non-compliant samples or significant number of very low concentrations (VLC) in the data drastically obscures the worker dosage expressed in “average” terms. Non-

availability of valid data or AQI numbers leads to limited proactive steps in developing new dust control technologies under the assumption of “no dust problem situation.”

It is observed that AQI shows (See Table 12.1) the value of greater than “one” but would not give the exact location of dust problem ‘areas’ immediately. Lack of human resources and technical skills, makes it difficult to analyse the submitted AQI values and pinpoint the problem areas. Add to that, due to the lag time between the submitted dust values and the arrival of the results, some sections will be already moved or some are closed down. Therefore, it is of less or no use to know the AQI values when that mine is no longer working or workers have been retrenched or no longer in employment. Since 1997, as per the DME directive, dust samples are collected at the CM operator cabin, at every continuous mining machine. However, no proper analyses of dust values can be obtained. It is to be hoped that DELI would assist in a better way of dealing with the dust exposure assessment of workers and be beneficial to coal mines.

12.3 Development of Dust Exposure Level Index (DELI)

The main objective while developing DELI was to provide critical information as an index for the coal mine sector as a whole, i.e., to show whether the environment is dusty, border line or relatively free of dust and effectiveness of administrative and engineering dust control measures.

An appropriate and efficient method of judging a workplace for level of dust exposure is to understand the working place and identified parameters influencing the dust exposures as discussed in this Thesis. After determining the values for each parameters, values can be assigned for each parameters as given in a DELI index chart developed herein. According to this chart, a coal mine section can be judged for its dust levels with various identified parameters influencing dust

exposures. It would therefore be advantageous for mine officials to evaluate that “entire mine dust control system” as well as exposure levels.

In comparison to AQI, DELI is based on the dust levels at a source, i.e., CM operator cabin and in addition other controllable parameters that can assist in evaluating and reducing the exposure levels in the working places. DELI is expected to give a ‘picture’ of how average dust levels increase or decrease in the air as it flows through the mine, and shows the areas in which the dust reaches undesirable levels due to natural, engineering and administrative factors. This is achieved through ‘selective’ dust measurements in the section. Input for the DELI model is based on the parameters identified and analysed in previous chapters and is shown in Figure 12.1.

The DELI is based upon the information from fixed sample dust levels at identified positions as well as the CM operator sample. The benefits of fixed position sampling are that they are measured at the same positions unlike personal sampling. Although personal dust sampling gives the breathing zone samples, the dust values thus obtained will have large variances and may obscure the “true” dust levels depending on the wearer. It was assumed that fixed-point dust sampling represented in this research study could be functionally related to places where miners are working. Also, as in Britain and Germany, where dose-response curves were developed and have been used, fixed-point samplers are used in the return airway. British studies have suggested that on average the men on the face area are subjected to about 70% of dust levels measured in the return airway of a single entry/exit longwalls and it must be borne in mind that this relationship will not be applicable to the continuous miner bord and pillar sections or multiple entry longwall or longwalls with different ventilation configurations.

This study takes into account, the merits of personal exposure level data in exposure assessment, and the limitations and quality of the data one obtains in the South African situation using fixed-point sampling. Furthermore, fixed position

sample values used in DELI need only a few ‘representative’ measurements, as they will be able to provide adequate information on the general average dust level in that mine or a section. Also, with the greatly improved and practical methods of dust sampling available, one can make use of positional sampling and obtain critical information, which is currently lacking for epidemiological studies.

In order to provide useful guidance to the uneducated workforce and also to the management on dust conditions in the mine, it is desirable that some definite “limit of acceptability” be set. These limits used in DELI are based upon recommended guidelines, coal dust standards prescribed by the compliance authorities in countries worldwide or best standards in practice and latest information available based on epidemiological studies on coal dust exposure. Such acceptable limits are coal dust standards for example, OELs by HSE, PELs of OSHA, RELs of NIOSH, TLVs of ACGIH etc., Some of the other influencing parameters (for example., cutting distance, cutting direction, peak dust levels etc.,) are based on extensive analyses of dust data as discussed in various Chapters in this Thesis and the authors’ experience underground in relation to the parameters identified which influences the dust exposure. The colour index used in DELI charts and the designated points for various parameters (which are highly subjective and applicable to South African conditions) are summarised in Table 12.2.

However, it must be noted that the assignment of DELI points and DELI colour is purely subjective and based on the conclusions arrived from this work and the professional experience of the author.

Table 12.2: Summary of assigned points and color code for the DELI parameters

DELI Parameter	Levels	DELI Point	DELI Colour	DELI Description
Section Intake Dust	< 0.5 mg/m ³	10	Green	Good
	< 1.0 mg/m ³	7.5	Yellow	Average
	< 1.5 mg/m ³	5	Red	Unsatisfactory
	> 1.5 mg/m ³	2.5	Red	Unhealthy and Unsafe
Section Return Dust	< 1.5 mg/m ³	10	Green	Good
	< 2.0 mg/m ³	7.5	Yellow	Average
	< 2.5 mg/m ³	5	Red	Unsatisfactory
	> 2.5 mg/m ³	2.5	Red	Unhealthy and Unsafe
Engineering Dust level	< 5 mg/m ³	10	Green	Good
	< 6 mg/m ³	7.5	Yellow	Average
	< 7.5 mg/m ³	5	Red	Unsatisfactory
	> 7.5 mg/m ³	2.5	Red	Unhealthy and Unsafe
Personal Operator Dust	< 2 mg/m ³	10	Green	Good
	< 2.5 mg/m ³	7.5	Yellow	Average
	< 3 mg/m ³	5	Red	Unsatisfactory
	> 3 mg/m ³	2.5	Red	Unhealthy and Unsafe
Cutting Direction	Heading [H]	5	Red	Unsatisfactory
	Split [S]	10	Green	Good
Cutting Distance	15	10	Green	Good
	20	7.5	Yellow	Average
	24	5	Red	Unsatisfactory
	30	2.5	Red	Unhealthy and Unsafe
Average shift production	500	10	Green	Good
	750	7.5	Yellow	Average
	1000	5	Red	Unsatisfactory
	1200	2.5	Red	Unhealthy and Unsafe

Peak (>100 mg/m ³) dust frequency	< 12	10	Green	Good
	< 20	7.5	Yellow	Average
	< 25	5	Red	Unsatisfactory
	> 30	2.5	Red	Unhealthy and Unsafe
Coal Dust Type	Bituminous	5	Green	Good
	Anthracite	2.5	Red	Unsatisfactory
Respirable silica levels, %	< 5	10	Green	Good
	10	7.5	Yellow	Average
	15	5	Red	Unsatisfactory
	> 20	2.5	Red	Unhealthy and Unsafe

It has become obvious during this study that a large number of dust measurements (engineering and personal samples) have been made over the years (up to 80,000 dust samples per annum) and are being recorded but without any feedback on any valuable information to the industry. On the other hand due to its in-built controllable parameters the DELI can provide useful information on dust exposure levels at the working place. Figure 12.2 and 12.3 show the input to the DELI model (including AQI calculations) and developed DELI model output which is easy to interpret and can be used after every shift.

Air Quality index (AQI)									
AQI Input Sheet			Gravimetric Sampler Description						
Organization/Company			Type of Sampler		SA cyclone				
University of Witwatersrand			Sampling Rate (L/min)		2.20				
Prepared By B.K. Belle@2003			Respirable Curve		ISO/CEN/A CCIH				
University of Witwatersrand			D50 of the sampling curve		4.00 microns				
User:			Sample date						
XXXXX			13-XX-03						
Data Analysis By:			Data Analysis Date:						
XYZ			13-XX-03						
Shift Production, Tons			Type of Mining (CM /RH/Wall)			Coal Type			
600.00			Continuous Miner			Anthracite			
Cutting Direction			Cutting Distance			Peak Dust Frequency			
Heading			21.00						
Lab Filter Correction factor (mg)			Quartz Analysis Lab Name						
0.00									
Filter Number #	Sampling Location	Filter Pre-Weight (mg)	Filter Post-Weight (mg)	Corrected Mass (mg)	Sampling Time (minutes)	Dust Level (mg/m ³)	Quartz Content %	Quartz Level (mg/m ³)	
1	Section Intake	1.00	2.00	1.00	480.00	0.946	5.00	0.047	
2	Section Return	1.00	2.00	1.00	480.00	0.946	3.00	0.028	
3	Operator-Engineering	1.00	7.13	6.13	480.00	5.108	6.00	0.348	
4	Operator-Personal	1.00	3.00	2.00	480.00	1.893	3.00	0.057	
AQI Coal Dust		1.16							
AQI Quartz Dust		3.48							
All other cells are protected.									
To use spreadsheet, fill in yellow cells: All values are automatically calculated.									

Figure 12.2: DELI input model (including AQI)

DELI-DUST EXPOSURE LEVEL INDEX						
	DELI POINTS	Good	Average	Unsatisfactory	Unhealthy and Unsafe	
Section Intake Dust	1.89	2.5	10	7.5	5	2.5
Section Return Dust	2.84	2.5	10	7.5	5	2.5
CM Engineering Dust Level	5.81	7.5	10	7.5	5	2.5
Personal CM Operator Dust	2.07	7.5	10	7.5	5	2.5
CM Cutting Direction	S	10	10	7.5	5	2.5
CM Cutting Distance	18.00	7.5	10	7.5	5	2.5
Average Shift Production	1400.00	0	10	7.5	5	2.5
Peak Dust Levels	0	10	10	7.5	5	2.5
Coal Dust Type	Bituminous	5	10	7.5	5	2.5
Inherent or Airborne Silica, %	6.00	7.5	10	7.5	5	2.5
Dust Exposure Level Index	60	100	75	50	25	

DELI COLOUR INDEX	 UNSATISFACTORY
	 BORDER LINE
	 SATISFACTORY
DELI POINT INDEX	100-75 Good
	74-50 Average
	49-25 Unsatisfactory
	24-0 Unhealthy and Unsafe

Figure 12.3: Developed model output of Dust Exposure Level Index (DELI)

The DELI model also considers the visual “colour” coding for easy interpretation and understanding of exposure dust levels to uneducated workforce. Therefore, the DELI model colour code is “RED” if the dust conditions and exposure levels are “Unsatisfactory”, is YELLOW if “Borderline” and is GREEN if “Satisfactory.” The DELI range is subdivided into four general descriptor categories; good, fair, poor and very poor. The good range is from 100-75, the average range is 74-50, the unsatisfactory range is from 49-25 and the unhealthy and unsafe range is 24-0. The ultimate convention for the design of DELI is that 'DELI - 100' corresponds to a measured coal dust exposure level that will have a very low level of health hazard. The index decreases with deteriorating underground dust concentration levels at various places. The value 100 corresponds to the maximum desirable level while 75 correspond to the maximum acceptable level and 50 correspond to the maximum tolerable level. Modifications to these values can be made after the actual use of the DELI model in many coal mines and experiences has been gained.

12.3.1 DELI Advantages

It is rarely that the mine operator achieves (but uses as a guideline) an internal policy that company Occupational Exposure Limit (OEL) is less than the legal limit.

In the South African scenario, some of the problems encountered in obtaining reliable and quality exposure data during the years has resulted in no dose-response curves for the Coal Worker’s Pneumoconiosis (CWP). Based on the extensive underground measurements from this research study, various dust exposure levels in underground workings have been identified and the DELI model has been developed. Although underground coal mining started in South Africa in the 1850’s dust measurements were by particle counting from the 1940’s until 1990. Over the subsequent years (particularly since 1996), vast amounts of data has been gathered using valuable resources but has not been properly

analysed for determining the exposure levels. Some of the reasons being available assessment methods, which are impractical at the mine levels for quick exposure assessment and feedback. The intention of this exercise was to effectively transmit the exposure results from this study and recommendations to mine risk assessors and risk managers to protect the workers from over exposure.

One of the greatest envisaged benefits of the DELI is through issuance of the information in the following form at the mines on a daily, weekly or shift basis, viz., dust control plans, mining bulletins, miner health hot lines, safety reports, safety meetings, sign boards near waiting places, underground, surface places, DME references, individual mine benchmarking exercises. This type of DELI index representation gives a clearer and more concise picture of the mine or various section dust conditions. The DELI model can also result in a useful advice and feedback tool at the work place in controlling dust.

The DELI model technique is expected to give valid results because it is based on latest recommended size-selective sampling methods and instrument; the data gathered at various locations over a five-year period covering various mines and sections; and based on the vast amount of measured data, which was not previously available. DELI is a relatively simple tool to use based on the results obtained at the identified sampling positions to obtain a “ good overall” picture of dusty conditions in the mine and to prioritise the administrative actions on dust control. Also, the study contributes to the belief that no mining machinery should be allowed underground until it has been equipped with proper dust control systems that limit its dust production rate to acceptable levels.

12.4 Application of the DELI Model

As required by Section 11 (1) of the Mine Health and Safety Act of 1996, suitable and sufficient assessments of occupational health risk must be made at the work place. In the case of coal dust, this requires quantifying the following: potential

exposures in the work place, risks based upon exposures, and efficiency of existing dust control measures. Health risk assessment of dust exposure should be continuous and not regarded as a one-off exercise. In that perspective DELI looks into critical areas of dust exposure and prioritises the areas for managing the dust exposure.

The “DELI” is a good measure of the overall dust hazard or exposure level index because it takes into account different operational parameters as well as the different parts of the mine where the method of DELI information presentation gives mine management and workers a clearer picture of the exposure levels and dusty situations on the mines than the current AQI, which is number based and unclear. In future, data-logger/instrument manufacturers can accommodate features of DELI in their dust monitoring devices and an enforcement agency such as the Department of Minerals and Energy (DME) could opt for a system that can be effectively hardwired into the central dust database management system.

The application of the results of this research using the DELI model is evaluated for coal mine data obtained by carrying out dust measurements at relevant locations identified in the model and a short self-explanatory example is included in Appendix (F) to illustrate the use of DELI and its comparison with AQI. It can be seen that the DELI model provides greater detail on dust levels in a simple and easy to use format. As the final overall conclusion, the newly developed DELI model from this research study can be an appropriate diagnostic exposure assessment tool to give a fair reflection of dust levels in a coal mine section.

12.5 Recommendations

During the course of this research study to develop the Dust Exposure Level Index (DELI) model for South African underground coal mines, several areas of specific research that needs to be continued for a further understanding of coal dust

exposure trends and the ultimate reduction of CWP were identified for further research:

- In South Africa, the availability of dust exposure data is scant for evaluation or at least confirming the various overseas-developed dose-response curves and validating the usage of current occupational exposure limits (OELs). The study recommends the urgent need for developing and obtaining the dose-response curve for the South African coal mine workers. Due to poor information on available dust exposure data, an Internet based system should be developed.
- The developed DELI model is recommended for use in volunteer mines as a way to estimate the areas of exposure levels and efficiency of dust control systems and evaluate them to quantify the usefulness of the model with the AQL.
- The coal dust type in the DELI tool is recommended for use in exposure surveillance by the medical fraternity for developing dose-response relationship for the South African coal miners working in different coal types since there is no clear delineation for South African workers who are exposed to different dust types. Therefore, it is recommended that a research study investigating prevalence of CWP among historic workers in Kwa Zulu Natal mines and other provinces and also check whether the historic dose will relate to the overseas health research studies.
- The study identifies the need for determining the relationship between fine particles and compliance dust levels and for developing “average size distribution characteristics of respirable dust” from coal mines.
- Developing DELI model parameter “distribution of peak levels” based on the personal dust measurement data is recommended which assists in quick personal estimation of dust levels using a real-time dust monitoring instrument.
- Further investigations are necessary to quantify the amount of stone dust in the personal samples obtained from the mines and their frequency occurrence. In the mean time, the times at which stone dusting is done during the shifts

should also be noted in the dust sample results.

- The capture efficiency of any dust control system is not hundred percent at any given time. During any cutting process for a given time and dust control type, part of the escaped respirable dust is added to the coal face atmosphere through air re-circulation. The study recognises the complexity of determining the escaped dust levels in coal mines, which use variety of dust control systems and recommends developing a quantitative index of personal exposure with increases in coal production.
- An investigative research study be carried out into the question of the validity of the use by the authorities of “zero” dust load for the non-sampling period of a shift by the authorities for calculation purposes when section intake dust levels are high.

Finally, it is hoped that the DELI will be used as a pragmatic diagnostic information tool for the coal mining industry to determine a fair reflection of coal dust exposures in South African underground coal mines on an ongoing basis.

13 References

ACGIH, (1998), American Conference of Governmental Industrial Hygienists, Coal Dust: TLV Chemical Substances, Cincinnati, OH.

ACGIH, (1998), American Conference of Governmental Industrial Hygienists, Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices, American Conference of Governmental Industrial Hygienists, USA.

ACGIH, (2001), American Conference of Governmental Industrial Hygienists, Coal Dust: TLV Chemical Substances, 7th Edition Documentation, Cincinnati, OH.

ASTM Standard E1156-87, (1987), Health Requirements for Occupational Exposure to Synthetic Amorphous Silica. American Society for Testing and Materials, Philadelphia, USA.

Alaboyun, A.R. (1989), The Effect of Surfactant on Suppression of Coal Dust Particles, Master of Science Thesis in Mineral Processing, The Pennsylvania State University, University Park, PA, 123 pp.

Althouse, R.B., Bang, K.M., Castellan, R.M. (1995), Tuberculosis Co-mortality with Silicosis-United States, 1979-1991. *Appl. Occup Environ Hyg* 10(12):1037-1041.

Amartin, J. (2002), Personal Communications, INERIS, France.

Annon, (1990), Measured Dust Tables, Chamber of Mines, South Africa.

Anon., (2001), Chamber of Mines, South Africa.

Annon, (2002), Business Report, South Africa's National Financial Daily, South Africa, p14.

Annon, 2002, Discussions, South Africa.

Attfield, M. and Hudak, J. (1981), National Coal Study—Prevalence of Coal Workers' Pneumoconiosis—Comparison of First and Second Rounds, Appalachian Laboratory for Occupational Safety and Health, NIOSH.

Attfield, M.D., Moring, K. (1992), The Derivation of Estimated Dust Exposures for U.S. Coal Miners Working Before 1970, Am. Ind. Hyg. Assoc. J. 53 (4): 248-255.

Attfield, M.D., Moring, K. (1992), An Investigation into the Relationship Between CWP and Dust Exposure in U.S. Coal Mines, Am. Ind. Hyg. Assoc. J. 53 (8): 486-492.

Attfield, M.D., and Hodous, T. K. (1992), Pulmonary Function of U.S. Coal Miners Related to Dust Exposure Estimates, American Review of Respiratory Diseases, Vol. 145, pp. 605-609.

Attfield, M.D., Seixas, N.S. (1995), Prevalence of Pneumoconiosis and its Relationship to Dust Exposure in a Cohort of U.S. Bituminous Coal Miners and Ex-miners, Am. Journal Ind. Med 27:137-151.

Attfield et al. (1995), The Prevalence of Pneumoconiosis and its Relationship to Dust Exposure in a Cohort of U.S. Bituminous Coal Miners and Ex-miners, Journal of American Studies, USA.

Baafi, E. Y.; Ramani, R. V. (1979), Rank and Macarel Effects on Coal Dust Generation, International Journal of Rock Mechanics and Mining Science. 16(2): 107-115.

Bauer H.D., Werner W., Stoyke, G. (1990), Messung der personenbezogenen Staubbelastung, vor allem mit CIP10-Geräten, mit Schwerpunkt für einzelne Beschäftigte in abbaubetrieben und Vergleich mit den durch das Routinemessverfahren für diese Personen ermittelten Expositionsdaten, Wissenschaftlicher Abschlussbericht no. 7260-03/051/01. Luxemburg:Kommission der Europäischen Gemeinschaften.

Beadle, D.G. (1965), The Need for Dust Sampling, Journal of Mine Ventilation Society of South Africa, Vol. 18, No. 1.

Bedford, E. and Warner, C.G. (1943), Chronic Pulmonary Diseases in South Wales Coal Miners, II, Environmental Studies, Medical Research Council Special Report Series No. 244, HMSO, London, 233p.

Berg, P., Jaakmees, V., and Bodin, L. (1999), Comparison of Dust Sampling Methods in Estonia and Sweden-A Field Study, Applied Occupational and Environmental Hygiene, Volume 14 (9): 592-597.

Bell S. L., and Lynch, P.J. (1997), A Respirable Dust Survey of Various Metalliferous Mine Sites in Queensland, Australia, Sampling and Control of Mine Dust, pp 1019-1024.

Belle, B.K. (1996), Evaluation of a Two-Phase Spray System for Dust Suppression, Master of Science Thesis in Mineral Processing, The Pennsylvania State University, University Park, PA, pp. 75-79.

Belle, B.K. and du Plessis, J.J.L. (1998a), Summary Report on Underground Mechanical Miner Environmental Control, SIMRAC Report, South Africa.

Belle, B.K., and Du Plessis, J.J.L. (1998b), Underground Mechanical Miner Environmental Control-Integrated Hood System, SIMRAC Research Report, ESH 98-0350, South Africa.

Belle, B.K. (2000), Baseline Evaluation of Dust Levels and Control Techniques in an Underground Shortwall Mine, CSIR-Report, South Africa.

Belle, B.K., Van Zyl, F. J., and Du Plessis, J.J.L. (2001), Summary report on Underground Road Header Environmental Control, SIMRAC Research Report, ESH 00-0206, South Africa.

Belle, B.K. (2001), Evaluation of Slow-Speed and High-Speed Drum CM Dust Control Systems in an Underground Coal Mine, CSIR-Report, South Africa.

Belle, B.K., Van Zyl, F. J., Hole, B.J., and Du Plessis, J.J.L. (2002), Bank 2002 Road Header Environmental Control System for High Seam South African Bord and Pillar Coal Mines, 9th North American Ventilation Symposium, Canada, pp 613-618.

Belle, B.K., and Clapham, S. (2002), An Improved Wet-Head System: Prevention of Incendive Ignitions and Dust Control, 9th North American Ventilation Symposium, Canada, pp 479-486.

Belle, B.K. (2002), Dust Control for Thick Seam Wall Mines, COL 807, SIMRAC Report, South Africa.

Belle, B.K. (2002), Respirable Dust in Coal Mines – Status Report, Confidential Report, EC 02-0608, South Africa.

Belle, B.K. (2002), Unpublished Confidential Work, CSIR, South Africa.

Belle, B.K. (2002), Evaluation of Newly Developed Real-time and Gravimetric Dust-Monitoring Instruments for Personal Dust Sampling For South African Mines, Health 704, SIMRAC Report, EC02-0606, South Africa.

Biffi, M., Belle, B.K. (1999), Proposed Rational Strategic Criteria for Routine Measurement of Exposure to Respirable dust in South African Mines, SIMHEALTH 604b Report, SA.

Blanc, P. D., Wong, H., Bernstein, M.S., and Boushey, H.A. (1991), An Experimental Human Model of Metal Fume Fever, *Ann. Intern. Med.* 114: 930-936.

Blanc, P. D., Boushey, H.A., Wong, H., Wintermeyer, S.F., and Bernstein, M.S. (1993), Cytokines in Metal fume Fever, *Ann. Rev. Resp. Dis.* 147:134-138.

Black Lung Benefits Annual Report to Congress, 2003, Coal Workers' Pneumoconiosis and Related Exposures, Section 2, pp 42.

Bodsworth et al. (1993), Dust Sampling Strategy on Coal Faces in Relation to Modern Coal Mining Methods, Institute of Occupational Medicine (IOM) Report, UK.

Bowie, D., Stewart. J. (1978), Ferro Alloy Workers Disease. *Cent. Afr. J. Med.* 24:81-86.

Breslin, J.A., Page, S.J., Jankowski, R.A. (1983), Precision of Personal Sampling of Respirable Dust in Coal Mines, USBM RI 8740.

BMRC, (1952), British Medical Research Council Report, UK.

Bulletin 112, (1998), Analyses of Coal Product Samples of Producing South African Collieries), SABS, pp 43.

Busch, K. A. and Taylor, D. G. (1981), Statistical Protocol for the NIOSH Validation Tests, In: Choudhary, G, ed. "Chemical Hazards in the Workplace - Measurement and Control", Washington DC: American Chemical Society, ACS Symposium Series 149.

CEN (Comité European de Normalisation), (1993), Workplace Atmospheres - Size fraction definitions for measurement of airborne particles, Brussels, Belgium: Comité European de Normalisation, Central Secretariat, European pre-standard EN/232.

Caplan, A., (1960), Rheumatoid disease and pneumoconiosis. In: (Ed. King and Fletcher), Industrial Pulmonary Diseases.

Cartwright, J., and Nagelschmidt, G. (1961), The Size and Shape of Dust from Human Lungs and Its Relation to Selective Sampling, Inhaled Particles and Vapours: Proceedings of the 1st International Symposium, Oxford, March 1960. Ed. C. N. Davies. Oxford, Pergamon Press, 445-452.

Cartwright, J. (1966), Airborne Dust in Coal Mines: The Particle Size selection Characteristics of Dust-Sampling Instruments. Inhaled Particles and Vapours. II: Proceedings of the 2nd International Symposium, Cambridge, September 1965. Ed. C. N. Davies. Oxford, Pergamon Press.

Casswell, C., Bergman, I., and Rossiter, C.E., (1971), The Relation of Radiological Appearance of CWSP to the Content and Composition of the Lung. In: Inhaled Particles III (Ed. W. H. Walton), Unwin Bros. 713-724.

Chen, G.X., Burnett, C.A., Cameron, L.L., et al., (1997), Tuberculosis Mortality and Silica Exposure: A Case-Control Study Based on a National Mortality Database for the Years 1983-1992. *Int. Journal of Occupational Health* 3:163-170.

Chen W, Zhuang Z, Attfield MD, Chen BT, Gao P, Harrison JC, et al., (2001), Exposure to silica and silicosis among tin miners in China: exposure-response analyses and risk assessment. *Occupational and Environmental Medicine*, 58: 31-7.

Cherry, N.M., Burgess, G.L., Turner, S., et al., (1998), Crystalline Silica and Risk of Lung Cancer in the Potteries. *Occup Environ Med* 55:779-55785.

Cinkotai, F. F., Gibbs, A. C. C., Sharpe, T. C. (1984), A Comparison of Exposure to Airborne Dust in Cotton Processing Plants Estimated From Personal and Work zone Samples, *Ann. Occup. Hyg.* 28(3): 347-352.

Colinet et al., (1997), Status of Dust Control Technology on US Longwalls, 6th International Mine Ventilation Congress, Pittsburgh, USA, Chapter 55, pp 345-351.

Costello, J., Castellan, R.M., Sweeker, G.S., et al., (1995), Mortality of Cohort of US workers Employed in the Crushed Stone Industry. *A J Ind Med* 27 (5):625-640.

Croner's Occupational Hygiene Magazine, (1999).

CMRS, (1986), Status of Research report on Mine Environment, Central Mining Research Station, Dhanbad.

CNR (Commission of National Resources), (1976), Mineral Resources and the Environment, Supplementary report: Coal Workers' Pneumoconiosis-Medical Considerations, Some Social Implications," Washington, D.C.: National Academy of Sciences.

COM, (1991), Chamber Of Mines Report, 91/05, Internal Report, South Africa.

COM, (1991), Chamber Of Mines Report, 91/08, Internal Report, South Africa.

COM, (1992), Chamber Of Mines Report, 92/02, Internal Report, South Africa.

COM , (1993), Chamber Of Mines Report, 93/18, Internal Report, South Africa.

Davis, J.M.G., (1979), Autopsy studies of miners lungs, Final Report (TM/79/9), Edinburgh, Institution of Occupational Medicine, UK.

Davies, C.N. (1952), Dust Sampling and Lung Disease, Br. J. Ind. Med., 9, 1952, 120-126.

Davies, O.L. (1956), The Design and Analysis of Industrial Experiments, Hafner Publishing Company, New York, PA, 636 pp.

DME, (1994), Parent Document, 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, South Africa.

DME, (1995), Guidelines for the Gravimetric Sampling of Airborne Particulate for Risk Assessment in Terms of the Occupational Diseases in Mines and Works Act # 78 of 1978, Parent Document, 3rd Edition, South Africa.

DME, (1997), South African Department of Minerals and Energy Directive, South Africa.

DME, (2002), 16/3/2/1-A3, Codebook, South African Mines Occupational Health Programme (SAMOHP), DME, South Africa.

Divers, E., Courtney, W., and Greninger, N. (1986), Seasonal Variation in Respirable Dust Concentration in U.S. Coal Mines, Bureau of Mines Report of Investigations, RI 9014, USA.

Dockery, D.W., Pope, C.A. III, Xu, X., Spengler, J.D., Ware, J., Fay, M.E., Ferris, B.G., Jr., and Speizer, F.E. (1993), An Association Between Air Pollution and Mortality in Six U.S. Cities, *N. Engl. J. Med.* 329 (24):1753-1759.

Douglas, A.M. (1986), Dust Exposure, Dust Recovered from the Lung and Associated Pathology in a group of British Coal Miners, *British Journal of Industrial Medicine*.

Donaldson, K., Stone, V. (1998), Small Particles – Big Problem, Newsletter No. 33, Special Edition, The Aerosol Society, UK.

Drinker, P., Thomson, R.M., and Finn, J.L. (1927), Metal Fume Fever: II. Resistance Acquired by Inhalation of Zinc Oxide on Two Successive Days, *J. Ind. Hyg. Toxicol.* 9(3):98-105.

Du Plessis, J.J.L. and Belle, B.K. (1998), Evaluation of Ventilation and Dust Control Systems in a South African Ventilation Simulation Tunnel, Proc. 2nd International Symposium on Mine Environmental Engineering, Brunel University, UK, pp 100-107.

Du Plessis, J.J.L., Belle, B.K., and Vassard, P. (1998), Evaluation of Ventilation and Dust Control Systems in a South African Ventilation Simulation Tunnel, SIMRAC Research Report, ESH 98-0249, South Africa.

Duckering, E. (1910), Report on an Investigation of the Air of Work-Places in Potteries, In: report of the departmental Committee Appointed to Enquire into dangers Attendant on the use of Lead and the Danger of Injury to health arising from Dust and other Causes in the Manufacture of Earth ware and China and in the Processes Incidental Thereto, Including the Making of Lithographic Transfers, Vol 2, Cd 5219, London:HMSO.

Dyer, C. (1998), Miners win Historic Battle for Compensation, BMJ 1998 (January): 316:327, UK.

Department of Labour (DOL), Pretoria.

Evelyn, J. Fumifugium, (1661), London.

Energy/WP.1/R.50, International Classification of Coals.

ECSC, (1997), Research Project Final Report, No. 7263-02/101/08.

Ennals, R. (2002), Partnership for Sustainable healthy Workplaces, Ann. Occup. Hug., Vol. 46, No. 4, pp. 423-428.

Fabries, J.F. (1993), Calculation of the Physical Characteristics of Deposited Particles in the Respiratory Airways, 9th Congress of the International Society for Aerosols in Medicine, Garmish-Partnkirchen, Germany, March 30-April 3, Abstract II-5, Journal of Aerosol Medicine 6 (suppl.): 22.

Fritsch GmbH, (1994), Instruction Manual, Laser Particle Sizer, Analysette 22, Germany.

Fuchs, N.A. (1964), *The Mechanics of Aerosols*, Pergamon Press, Oxford, UK.

Ganguly, et al., (2000), *Exposure to Respirable Dust: Case Studies of Jharia and Raniganj Coalfields*, Mine Environment and Ventilation, Chapter 21, pp 181-191.

Gero, A., and Tomb, T. (1988), Laboratory Evaluation of the CIP 10 Personal Dust Sampler, *Am. Ind. Hyg. Assoc. J.* 49 (6): 286-292.

Gibson, M. (1833-34), On the phthisis melanotica (so-called) of coal miners. *Lancet*, 1833-34, ii: 838-9.

Goldstein, B. and Webster, I. (1966), Intratracheal Injection into Rats of size-graded Silica Particles, *Br. J. Ind. Med.*, 23, pp 71-74.

Goldstein, M., Weiss, H., Wade, K., Penek, J., Andrews, L., and Brandt-Rauf, P. (1987), An Outbreak of Fume Fever in an Electronics Instrument Testing Laboratory, *J. Occup. Med.*, 29:746-749.

Gordon, T., Chen, L.C., Fine, J.M., Schlesinger, R.B., Su, W.Y., Kimmel, T.A., and Amdur, M.O. (1992), Pulmonary Effects of Inhaled Zinc Oxide in Human Subjects, Guinea Pigs, rats, and Rabbits, *Am. Ind. Hyg. Assoc. J.* 53(8):503-509.

Government Accounting Office, (1975), *Improvements Still Needed in Coal Mine Dust Sampling Program and Penalty Assessment and Collection*, Report RED-76-56.

Green, H.L., and Lane, W.R. (1964), Particle clouds: dust, smokes, and mists, Spon, London, No. 2nd edn.

Gregory, J. C. (1831), Case of peculiar black infiltration of the whole lungs, resembling melanosis, Edinburgh Medicine and Surgery Journal, 36, pp. 389.

Glenn, B. (1998), Silicosis: A Sad Challenge for the 21st Century, Pit and Quarry, pp 14-16.

Groth, D.H., Moorman, W. J., Lynch, D. W., Stettler, L.E., Wagner, W.D., Hornung, R. W. (1981), Chronic Effects of Inhaled Amorphous Silicas in Animals, In Health Effects of Synthetic Particulates, ASTM STP 732, Dunnom, D. D., Ed. ASTM, Philadelphia.

Hadden, G.C., Jones, C.O., and Morgan D.C. (1966), A Study of Volumes of Respired Air in Relation to Dust Exposures of Coal Miners, Inhaled Particles and Vapours II: Proceedings of the 2nd International Symposium, Cambridge, Ed. C. N. Davies. Oxford, Pergamon Press.

Hall, T. A., Corn, M., Zeger, S. (1997), Respirable Dust and Free Silica Variation in Mine Environments, Strategies for Mine Dust Measurement.

Hamilton, R.J., and Walton, W.J. (1961), The Selective Sampling of Respirable Dust, Inhaled Particles and Vapours I, Ed. By C. N. Davies, Oxford, Pergamon, Press, 465p.

Hamilton, R.J., Morgan, G.D., and Walton, W.J. (1966), The Relationship Between Measurements of Respirable Dust by Mass and by Number in British Coal Mines, Inhaled Particles and Vapours II, ed. By C. N. Davies, Oxford, Pergamon, Press, 533p.

Hart, Pd'A and Aslett, E.A. (1942), Chronic Pulmonary Diseases in South Wales Coal Miners, I, Medical Studies, Medical Research Council, Special Report Series No. 243, HMSO, London.

Heyder, J., Gebhart, J., Rudolf, G., Schiller, C.F., Stahlhofen, W. (1986), Deposition of Particles in the Human respiratory Tract in the Size Range 0.005-155 microns, Journal of Aerosol Science 17:811-825.

Hewett, P. (1996), Interpretation and Use of Occupational Exposure Limits for Chronic Disease Agents, Occupational medicine: State of the Art Reviews, Vol. 11, No. 3, pp 561-590.

Hicks, D., Fay, J.W.T., Ashford, J.R., and Rae, S. (1961), The Relationship between Pneumoconiosis and Environmental Conditions, National Coal Board (Pneumoconiosis Field Research), London.

Hinds, W.C. (1982), Aerosol technology, John Wiley and Sons, New York, USA.

Hnizdo, E., Sluis-Cremer, G.K. (1991), Silica Exposure, Silicosis, and Lung Cancer: A mortality Study of South African Gold Miners. Br. J Ind Med 48:53-60.

Hnizdo, E. (1990), Combined Effect of silica Dust and Tobacco Smoking on Mortality from Chronic Obstructive Lung Disease in Gold Miners. B J Ind Med 47:656-664.

Hnizdo E, Rees D. (1997), Surveillance of occupational diseases - where does SORDSA fit in? Occupational Health Southern Africa, 3:26-31.

Hurley, J.F. et al., (1979), Simple pneumoconiosis and exposure to Respirable dust; relationships from twenty-five years' research at ten British coal mines, Edinburgh: Institute of Occupational Medicine.

Hurley, J.F. et al., (1982), Coal workers simple pneumoconiosis and exposure to dust at ten British coalmines, *British Journal of Industrial Medicine*, 39, 120-127.

Hurley, J.F., Maclaren, W.M. (1984), Factors Influencing the Occurrence of Progressive Massive Fibrosis in British Coal Miners, IOM Report No. TM/84/2. CEC Contract 7256-34/016/08. IOM, Edinburgh.

Hurley, J.F., Maclaren, W.M. (1987), Dust-related risks of radiological changes in coal miners over a 40-year working life, Report on work commissioned by NIOSH, Edinburgh, Scotland, UK: IOM, Report No. TM/87/09.

Hurley, J. F., Kenny, L., and Miller, B. (2002), Health Impact Estimates of Dust-Related Disease in UK Coal Miners: Methodological and Practical Issues, *Ann. Occup. Hyg.*, Vol. 46, Supplement 1, pp. 261-264.

Hu, Qingchun. (1992), The Dust Removal by Surfactant Containing Water Sprays, Master of Science Thesis in Mineral Processing, The Pennsylvania State University, University Park, PA, 123 pp.

IARC, (1997), International Agency for Research on Cancer, IARC monographs on the Evaluation of Carcinogenic Risks to Humans: Silica, Some Silicates, Coal Dust and Para-aramid Fibrils. World Health Organization (WHO) Ed, Lyon 68.

ILO, (1967), DeGuedre G, Dust Sampling in Mines, Occupational Safety and Health Series No 9. Geneva, International Labour Office, 88 pp.

ILO, (1980), International Labour Office, International Classification of Radiographs of Pneumoconiosis.

IMA Europe, (2003), Silica Occupational Exposure Limits.

ISO, (1993), International Organization for Standardization, Air Quality - Particle Size Fraction Definitions for Health-Related Sampling, Geneva, Switzerland: ISO Report No. ISO 7708.

Jacobsen, M., Rae, S., Walton, W. H. and Rogan, J. M. (1970), New Dust Standards for British Coal Mines, *Nature*, Vol. 227, pp 445-447.

Jacobsen, M., Rae, S., Walton, W. H. and Rogan, J. M. (1971), The Relationship between Pneumoconiosis and Dust Exposure in British Coal Mines, In: Walton W.H., ed, "Inhaled Particles III", Vol. 2, Surrey, UK, Unwin Brothers Ltd, Gresham Press, pp 903-919.

Jacobsen, M. (1973), Progression of Coal Workers' Pneumoconiosis in Britain in Relation to Environmental Conditions Underground, In: "Proceedings of Conference on Technical Measures of Dust Prevention and Suppression in Mines", Luxembourg, October 11-13, Luxembourg: Commission of the European Communities, pp 77-93.

Jacobsen, M. (1979), Effect of Further Dust Exposure among Men with Early and More Advanced Signs of Simple Pneumoconiosis, Edinburgh Institute of Occupational Medicine, Final Report on CEC Contract 6244-00/8/107, Report No. TM/79/16.

Jacobsen et al., (1980), New Data on the Relationship Between Simple Pneumoconiosis and Exposure to Coal Mine Dust, *Chest* 78, Supplement 408.

Jayaraman, N. I. (1979), Dust Control For a Borer Type Continuous Mines Using a Venturi Scrubber on a Transfer Car, U.S. Bureau of Mines Report of Investigations 8408, 12 pp.

Jayaraman, N.I., Schroeder, W.E., and Kissell, F.N. (1984), Studies of Dust Knockdown by Water Sprays using a Full-Scale Model Mine Entry, Transactions of the Society of Mining Engineers of AIME, Vol. 278, pp 1875-1882.

Jayaraman, N. I., Jankowski, R.A. (1988), Atomisation of Water Sprays for Quartz Dust Control, Applied Industrial Hygiene, Vol 3, No.12, pp 327-331.

Jayaraman, N.I., Jankowski, R.A., Babbit, C.A. (1989), High Pressure Water-Powered Scrubbers for Continuous Miner Dust Control, Proceedings of the 4th U.S.Mine Ventilation Symposium, Edited by McPherson, M.J., SME, Littleton, CO, pp 437-441.

Jayaraman, N. I., Colinet, J.F., Jankowski, R.A. (1991), Evaluation of a two-phase flow scrubber in a model mine, Proceedings of the 3rd Symposium on Respirable Dust, Society for Mining, Metallurgy and Exploration, Inc., pp 223-236.

Jurinski, J.B., and Jurinski, N.B. (1997), A proposed control limit for exposure to airborne erionite fibres, Applied Occupational Environmental Hygiene, Vol. 12 (6), pp. 429-434.

Kask, M., Uibo, M. (1963), Practical Hygiene, Government of Estonia (in Estonian), pp. 71-73.

Kenny, L. C., and Maynard, A. D. (1995), Performance Assessment of Three Personal Cyclone Models using an Aerodynamic Particle Sizer, Journal of Aerosol Science, Vol. 26, No. 4, pp 671-684.

Kenny, L. C., Baldwin, P.E.J., and Maynard, A. D. (1997), Respirable Dust Sampling at Very High Concentrations, HSL, UK.

Kenny, L. (2002), Improved dust sampling methods for mines: Final report. Health and Safety Laboratory Report, HSL/2000/06, UK.

Kielblock, A.J., Franz, R.M., Unsted, A.D., Van der Linde, A., Ashworth, S.G.E. (1997), Quantification of Occupational Health Risks in the South African Mining Industry and Assessment of Sources of Uncertainty in the Estimates, SIMRISK 401, South Africa, pp 76.

King, E.J., Mohanty, G.P., Harrison, C. V., and Nagelschmidt, G. (1953), The Actions of Different forms of Pure Silica on the Lungs of Rats, Br. J. Ind. Med., 10, pp 9-17.

King, A.M. (1980), Comparative studies of steam and other fine droplet sprays for dust suppression, MRDE Report 94., National Coal Board, Great Britain, 39 pp.

Kissell, F. N., Ruggier, S. K., Jankowski, R.A. (1986), How to Improve the Accuracy of Coal Mine Dust Sampling, Am. Ind. Hyg. Assoc. J. 47 (10):602-606 (1986).

Kissell, F. N., and Jankowski, R.A. (1993), Fixed-Point and Personal Sampling of Respirable Dust for Coal Mine Face Workers, Proceedings, Sixth U.S. Mine Ventilation Symposium, June 21-23, Salt Lake City, UT.

Klosterkotter, W. (1954), Zur Frage der silikogenen Wirkung des amorphen Siliciumdioxide in Jotten, K.W. Klosterkotter, W.: Die Staublungenerkrankungen, Vol. 2., pp 73-84, Steinkopf, Darmstadt.

Koskela, R.S., Klockars, M., Laurent, H., et al., (1994), Silica Dust Exposure and Lung Cancer. Scan J Work Environ Health 20 (6):407-416.

Koziel and Malec, (1998), Polish Longwall Dust Report, Poland.

Koziel A., Malec, M., Wardas, E. (1999), The Influence of Coal Physical and Mechanical Properties and Mining Energy Consumption Factor on Airborne Respirable Dust Level, Proceedings of the 8th US Mine Ventilation Symposium, pp. 241-248.

Kogut, J., Tomb, T.F., Parobeck, A., Gero, J., and Suppers, K.L. (1997), Measurement Precision with the Coal Mine Dust Personal Sampler, Applied Occupational Environmental Hygiene, Vol 12 No.12 , pp 999-1006.

Laennec, R. T. G. (1819), Traite de l'auscultation mediate, ed. 4, Paris.

Landman, G. V.R. (1992), Ignition and Initiation of Coal Mine Explosions, Doctor of Philosophy Thesis, University of Witwatersrand, South Africa.

Land, (1998), Joint Coal Board Retains Order 40, JCB, Australia

Larson, J.W. (1981), Coal Structure, Chap. 1. Am. Inst. Physics Proc. 70:1-27.

Leon, R.N., Salmon, M.D.G., Davies, A.W. and Davies, J.C.A. (1995), Commission of Inquiry into Safety and Health in the Mining Industry, South Africa.

Leiteritz, H., Einbrodt, H.J., and Klosterkotter, W. (1966), Grain Size and Mineral Content of Lung Dust of Coal Miners Compared with Mine dust, Inhaled Particles and Vapours. II: Proceedings of the 2nd International Symposium, Cambridge, September 1965. Ed. C. N. Davies. Oxford, Pergamon Press.

Le Bouffant et al., (1977), The therapeutic action of Aluminium compounds on the development of experimental lesions produced by pure quartz or mixed dust. (Ed. Walton), Inhaled Particles IV, 389-400.

Lippman, M. et al., (1973), The prevalence of circulating anti-nuclear antibody and rheumatoid factors in U.S. coalminers. *Annual Internal Medicine*, 79, 807.

Lippman, M. (1977), Regional Deposition of Particles in the Human Respiratory Tract, In: *Handbook of Physiology, Section 9, Reactions to Environmental Agents* (D.H.K. Lee, H.L. Falk and S.D. Murphy, Eds.), American Physiological Society, Bethesda, MD, pp. 213-232.

Linch, A. L., Wiest, E. G., Carter, M. D. (1970), Evaluation of Tetraalkyl Lead Exposure by Personnel Monitor Surveys, *Am. Ind. Hyg. Assoc. Journal*, 31: 170-179.

Linch, A. L., Pfaff, H. V. (1971), Carbon Monoxide-Evaluation of Exposure Potential by Personnel Monitor Surveys, *Am. Ind. Hyg. Assoc. Journal*, 32: 745-752.

Lilienfeld, P. (2002), Personal Communications, Thermo Anderson, USA.

MacFarland, H.N. (1976), *Respiratory Toxicology Essays in Toxicology*, W.J. Hayes ed., Academic Press, New York, pp 121-154.

Maclaren, W.M., Hurley, J.F., Collins, H.P.R., and Cowie, A.J. (1989), Factors associated with the development of PMF in British coalminers: A case/control study. *British J. of Ind. Med.* 46, 597-607.

Maharaj, A. (1998), Dust Suppression for the Pillar Extraction Mining Method at Durban Navigation Colliery Road Header Section, B.SC. Thesis, University of Witwatersrand, Johannesburg, pp. 28.

Malmberg, P., Hedenstrom, H., Sundblad, B.M. (1993), Changes in Lung Function of Granite Crushers Exposed to Moderately High Silica Concentrations: A 12 Year Follow-Up. *Br. J Ind Med* 50 (8):726-731

Makellor, A. (1845), Black phthisis, or ulceration induced by carbonaceous accumulation in the lungs of coal miners, *Monthly Journal of Med. Science*, 5, 645-653.

Makulova, I. D. (1965), The Clinical picture in Acute Perfluoroisbutylene Poisoning, *Gig. Tr. Prof. Zabol.* 9:20-23.

Mark, D., Hunneyball, S.R., Leeming, R.J., and Jobling, S. (2003), Problems with the Introduction of Personal Sampling of Respirable Dust in Underground Coal Miens in the UK, Unpublished Paper, 30th International Conference of Safety in Mines Research Institutes, SAIMM, SA.

Marple, V. A., Rubow, K. L., and Zhang, Z. (1997), Experimental and Theoretical Measurement of the Aerodynamic Diameter of Irregular Shaped Particles, *Dust Measurement*, pp 663-667.

Maynard, A.D. (2002), Estimating Aerosol Surface Area from Number and Mass Concentration Measurements, *Annals of Occupational Hygiene*, 47 (2):123.

McLintock, J.S. (1972), The Changing Prevalence of Coal Worker's Pneumoconiosis in Great Britain. In. *Coal Workers' Pneumoconiosis*. Ann. N.Y. Acad. Sci. 200:278-291.

Melandri, C., Tarroni, G., Podi, V., De Zaiacomo, T., Formignani, M., Lombardi, C.C. (1983), Deposition of charged particles in the human airways, *Journal of Aerosol Science*, I4(15):657-669.

Miles, W.J. (1999), Issues and controversy: The Measurement of Crystalline Silica; Review Papers on Analytical Methods, American Industrial Hygiene Association Journal, 60:396-402.

Miller, I., and Freund, J.E. (1965), Probability and Statistics for Engineers, Prentice-Hall, Inc., New Jersey, 432 pp.

Minerals Act and Regulations, (1971), Butterworth Publishers (Pty) Ltd., South Africa.

Minerals Act and Regulations, (2001), Butterworth Publishers (Pty) Ltd., South Africa, pp 485.

Morgan, W.K.C. et al., (1973), The prevalence of coal workers' pneumoconiosis in U.S. Coal Mines, Arch. Environ. Health 27, 221-226.

Morfeld, P., Ambrosy, J., Bengtsson, U., Bicker, H., Kalowsky, B., Kosters, A., Lenaerts, H., Ruther, M., Vautrin, H.J., and Piekarski, C. (2002), The Risk of Developing Coal Workers' Pneumoconiosis in German Coal Mining Under Modern Mining Conditions, Ann. Occup. Hyg., Vol. 46, Supplement 1, pp. 251-253.

Morgan, W.K.C., Reger, R., Burgess, D.B., Shoub, E. (1972), A Comparison of the Prevalence of CWP and Respiratory Impairment in Pennsylvania Bituminous and Anthracite Miners. In: Coal Workers' Pneumoconiosis. ANN. N.Y. Acad. Sci. 200: 252-259.

Moore, M. P.; Bise, C. J. (1984), The Relationship Between Hardgrove Grindability Index and the Potential for Respirable Dust Generation. Proceedings of the Coal Mine Dust Conference, Morgantown, WV, pp. 250-255. S. S. Peng, Ed.

Mundell, R.L., and Taylor, C.D., 1977, Quantitative Respirable Dust Levels During Longwall Mining Operations, MESA Information Report No. 1061, Technical Support Center, Pittsburgh, PA, USA, pp 27.

Mutmansky, J. M. (1984), An analysis of Coal and Geologic Variables Related to CWP. In: Proceedings of the Lakeview Conference, Centre for Generic Respirable Disease Studies, Lakeview, WV.

MRC, (1966), Medical Research Council, Panel I on measurement and Compliance of dust. Letter to Mr. A. M. Wandless, Chairman of the N.J.P.C. sub-committee on dust sampling.

Nagelschmidt, G. (1965), The Study of Lung Dust in Pneumoconiosis, American Industrial Hygiene Association Journal, Vol. 26, No. 1, pp. 1-7.

Naidoo, R., Robins, T., and Seixas, N. (2002), Respiratory Diseases among South African Coalminers, SIMHEALTH 607 report, 123 pp.

NAPCA, (1970), National Air Pollution Control Administration, Air Quality criteria for Hydrocarbons, Publ. No. AP-64, Superintendent of Documents, U.S. Government Printing Office, Washington, D.C.

NIOSH, (1976), CDC, Statistical Analysis of (Mining Enforcement Safety Administration) Respirable Dust Data.

NIOSH, (1993), 0500 NIOSH Manual of Analytical Methods, 4th ed., USA.

NIOSH, (1995), Criteria for a Recommended Standard: Occupational Exposure to Respirable Coal Mine Dust, NIOSH, USA, pp 336.

NIOSH, (1999), National Institute of Occupational Safety and Health, 1999, Work-related lung disease surveillance report, Cincinnati (OH): Division of Respiratory Disease Studies.

National Research Council, (1980), Measurement and Control of Respirable Dust in Mines, NMAB-363, National Academy of Science, Washington, D.C.

National Bureau of Standards, (1975), An Evaluation of the Accuracy of the Coal Mine Dust Sampling Program Administered by the Department of Interior, Final Report to the Senate Committee on Labour and Public Welfare, Washington, D.C.

NCOH (1996), Proposed Restructuring of the Chief Directorate: Occupational Health, Including the National Centre for Occupational Health (NCOH) and the Medical Bureau for Occupational Disease (MBOD), National Centre for Occupational Health, Johannesburg.

Niewiadomski, G.E. (1999), Mine Safety and Health Administration (MSHA), USA.

Niven R. M., Fishwick, D., Pickering, C. A. C., Fletcher, A. M., Warburton, C. J., Crank P. (1992), A Study of the Performance and Comparability of the Sampling response to Cotton Dust of Work Area and Personal Sampling Techniques, Ann. Occup. Hyg. 36(4): 349-362.

Oberdorster, G., Ferin, J., Gelein, R., Soderholm, S.C., and Finkelstein, J. (1992), Role of the Alveolar Macrophage in Lung Injury: Studies with Ultra fine Particles, Environ. Health Perspect. 97:193-197.

Oberdorster, G., Ferin, J., and Lehnert, B.E. (1994), Correlation Between particle Size, in vivo Particle Persistence and Lung Injury, Environ. Health Perspect. 102: Suppl5: 173-179.

Oberdorster, G., Gelein, R., Ferin, J., Weiss, B. (1995), Association of Particulate Air Pollution and Acute Mortality: Involvement of Ultra fine Particles?, *Inhalation Toxicology*, 7:111-124.

Oberholzer, J. (1998), CSIR-Miningtek Report, South Africa.

Ogden, T. (2002), Personal Communications, UK.

Organiscak, J. A., Page, S. J., Jankowski, R. A. (1990), Investigation of Coal Seam Parameters and Airborne Respirable Dust at Longwalls. U. S. Bureau of Mines Information Circular 9425.

Organiscak, J.A., Page, S.J., and Jankowski, R.A. (1992), Relationship of Coal Seam Parameters and Airborne Respirable Dust at Longwalls, U.S. Department of Interior, Bureau of Mines RI 9425.

Organiscak, J. A.; Page, S. J. (1993), Laboratory Investigation of Coal Grindability and Airborne Respirable Dust. *Journal of the Mine Ventilation Society of South Africa*, 46(7): 98-105.

Organiscak, J. A., and Leon, M. H. (1994), Influence of Coal Type on Water Spray Suppression of Airborne Respirable Dust, *Aerosol Science and Technology*, Vol. 21, No. 2, pp. 110-118.

Organiscak, J.A., and Page, S.J. (1998), Investigation of coal properties and airborne Respirable dust generation, RI 9645, NIOSH, USA.

Oudiz, J. (1986), Silica Exposure Levels in United States Foundries. *Silica, Silicosis and Cancer*. Edited by Goldsmith, D.F., Winn, D.M., Shy, C.M., pp. 21-28.

Page, S., Jankowski, R., Kissell, F.N., (1982), How to Evaluate Longwall Dust Sources with Gravimetric Personal Samplers, BuMines IC 8894.

Page, S., Jankowski, R. (1984), Correlations Between Measurements with RAM-1 and Gravimetric Samplers on Longwall Shearer Faces. Am. Ind. Hyg. Assoc. J. 45(9):610-616.

Page, S. J.; Organiscak, J. A.; Quattro, J. (1993), Coal Proximate Analyses Correlation with Airborne Respirable Dust. Fuel. 72(7): 965-969.

Page, S. J.; Organiscak, J. A. (2001), Using Proximate Analyses to Characterize Airborne Dust Generation from Bituminous Coals, Aerosol Science and Technology, Vol. 36, No. 6, pp. 721-733.

Parkes, R.W. (1982), Pneumoconiosis Due to Coal and Carbon. In: Occupational Lung Disorders, 2nd ed., Butterworths, London, pp. 175-232.

Parkes, W.R. (1982), Occupational Lung Disorders, 2nd Edition, pp. 138 and 158-159.

Parobeck, P., Ainsworth, S. and Tomb, T. (1997), Analysis of Respirable Coal Mine Dust Samples by Infrared Spectroscopy, Strategies for Mine Dust Measurement. pp. 1142-1147.

Pearson, G. (1813), Phil. Trans. Royal Society, London, pp. 103.

Peavy, H.S., Rowe, D.R., Tchobanoglous, G. (1998), Air Quality: Definitions, Characteristics, and Perspectives, Chapter Seven, Environmental Engineering, McGraw-Hill Publishing Company, pp 417-481.

Piney, M. (2001), OELs and the Effective Control of Exposure to Substances Hazardous to health in the UK, HSE, pp 27.

Polat, M. (1990), Characterization of Freshly Generated Airborne Dust, Master of Science Thesis in Mineral Processing, The Pennsylvania State University, University Park, PA.

Pope, C.A. III., Dockery, D.W., Spengler, J.D., and Raizenne, M.E. (1991), Respiratory Health and PM-10 Pollution, *Am. Rev. Respir. Dis.* 144:668-674.

Prinz, B., Stolz, R., and Ruhrkohle, A.G., Essen, (1998), Effect of the Measuring Strategy on the Determination of the Respirable Dust Concentration in the Breathable Air at Underground Workplaces, *Strategies for Mine Dust Measurement*, pp 1148-1151.

Proceedings of Third International Conference of Experts on Pneumoconiosis, Sydney, March 1950

Ramani, R. V., Mutmansky, J. M., Bhaskar, R., and Qin, J. (1987), Fundamental Studies on the Relationship Between Quartz Levels in the Host Material and the Respirable Dust Generated During Mining, Final Report, USBM Contract H0358031, The Pennsylvania State University, USA.

Ramani, R.V., and Srikanth, R. (1996), Coal Characteristics and Dust Generation Rates of Four South African Coals, Research Report Submitted to CSIR-Miningtek, South Africa.

Ramani, R.V., and Belle, B.K. (1997), Evaluation of two-Phase Spray System for Airborne Dust Control in a Longwall Gallery, Research Report Submitted to NIOSH, PRL, USA.

Ratney, R. S. (1997), The Threshold Limit Value for Various Forms of Amorphous Silica, Strategies for Mine Dust Measurement, pp 1134-1135.

Reisner, M.T.R. (1971), Results of Epidemiological Studies of Pneumoconiosis in West German Coal Miners, (Ed. Walton), Inhaled Particle III, Unwin Bros. Old Woking, Surrey, 921-931.

Reisner, M. (1973), Pneumoconiosis and dust exposure-epidemiological studies in the Ruhr coal mines during a periods of 14 years, Silikosebericht Nordrhein-Westfalen 10, 209-231.

Reisner, M.T.R. (1977), Results of Epidemiological, Mineralogical and Cytological Studies on the Pathogenicity of Coal Mine Dust. (Ed. Walton), Inhaled Particle IV, Oxford, Pergamon, 703-715.

Rekus, J. (1988), Working on structural steel: the lead hazard, Journal of Protective Coatings and Linings, 5(10):38-44.

Report of the Committee of Inquiry into a National Health and Safety Council in South Africa (1997).

Report of the Committee on Occupational Health (1996). Department of Health, Pretoria.

Report of Exposure and Health Assessment of Vanadium Workers (1997). NCOH Report 3/1997. National Centre for Occupational Health, Johannesburg.

Roach, S.A. (1958), Counting Errors Due to Overlapping Particles in Thermal precipitator Samples, Br. J. Ind. Med., 15, pp 250-257.

Roach, S.A., and Rappaport, S.M. (1990), But they are not Thresholds-A critical Analysis of the Documentation of threshold Limit Values, *Am. J. Ind. Med.*, 17, pp 727-753.

Rivers, D., Wise, M.E., King, E.J. and Nagelschmidt, G. (1960), Dust Content, Radiology and pathology in simple pneumoconiosis of Coal Workers, *Br. J. Ind. Med.*, 17, 87-108.

Rossiter, C.E. (1972), Relation between Content and Composition of Coal Workers Lungs and Radiological Appearances, *Br. J. Ind. Med.*, 29, 31-44.

Rudolf, G., Gebhart, J., Scheuch, G., Stahlhofen, W. (1988), Mass Deposition from inspired Polydisperse Aerosols, In: *Inhaled Particles VI* (Dodgson, McCallum, Bailey, Fisher, Eds.), Pergamon Press, Oxford, UK, pp 919-938.

Sabastien, P. (1989), The scientific basis for controlling exposures to phyllosilicate dust at the workplace. In: (Ed. J. Bignon), *Health Related Effects of Phyllosilicates*.

Safety Management, (1996), Dust Can Blind our View of Employees Health, pp 16-17.

SADC, (2001), Health and Sustainable Development, SADC Ministerial Meeting, 20-22 January, Pretoria: SADC.

Saltsman, R.D., and Costantino, J.P., Coal Mine Dust control and Pneumoconiosis Research in Europe and the United States, pp 73-78.

Scheffe, H. (1961), *Analysis of Variance*, John Wiley and Sons, Inc., New York, 477 pp.

Schepers, G.W., Durkan, T.M., Delahant, A.B., Credon, F.T., Redlin, A.J. (1957), The Biological Action of Degussa Submicron Amorphous Silica Dust. *AMA Arch. Ind. Health* 16:125-46, 203-244, 280-301.

Schwartz, J., and Dockery, D.W. (1992a), Particulate Air Pollution and Daily Mortality in Steubenville, OH. *Am. J. Epidemiol.* 125 (1):12-19.

Schwartz, J., and Dockery, D.W. (1992b), Increased Mortality in Philadelphia Associated with daily Air Pollution concentrations, *Am. Rev. Respir. Dis.* 145:600-604.

Schwartz, J., Spix, C., Wichmann, H.E., and Malin, E. (1991), Air Pollution and Acute Respiratory Illness in five German Communities, *Environ. Res.* 56:1-14.

Schroder, H.H.E. (1980), A Note on the Time Weighted Average (TWA) Threshold Limit Values, *Journal of Mine Ventilation Society of South Africa*, Vol. 33, No. 10, pp 180-184.

Seaton, A., MacNee, W., Donaldson, K., Godden, D. (1995), Particulate Air Pollution and Acute health Effects, *The Lancet*, Vol 345, pp 176-178.

Sharan, S. (2000), Personal Communications, CMPD, Dhanbad, India.

Sharan, S., Srikanth, R., Liu, P., Sun, G., Belle, B.K., and Ramani, R.V. (1997), Dust Contamination of Panel/Face Intake Air, *Proceedings of the 6th International Mine Ventilation Congress, USA*, Chapter 56, pp, 353-359.

Skidmore, J. W., Morris, T.G., Nagelschmidt, G., and King E. J. (1965), The Retention of High and Low Rank Coals in rats' Lungs, *Ann. Occup. Hyg.*, 8, 183-192.

Soutar, C.A., Miller, B.G., Gregg, N., Jones, A.D., Cullen, R.T., Bolton, R.E. (1997), Assessment of human risks from exposure to low toxicity occupational dusts, *Annals of Occupational Hygiene*, Vol. 41, pp. 123-133.

Soderholm, S. C. (1989), Proposed International Conventions for Particle Size - Selective Sampling, *Ann. Occupational Hygiene*, Vol. 33, No. 3, pp 301-320.

Soderholm, S. C. (1991a), Why Change ACGIH's Definition of Respirable Dust? *Applied Occupational Hygiene*, Vol. 6, No. 4, pp 248-250.

Soderholm, S. C. (1991b), Correction, *Ann. Occupational Hygiene*, Vol. 35, No.3, pp 357-358.

Srikanth, R., Zhao, R., and Ramani, R.V. (1995), Relationships between Coal Properties and Respirable Dust Generation, In *Proceedings of 7th U.S. Mine Ventilation Symposium*, June 5-7. SME, Lexington, KY, pp. 301-309.

Srikanth, R. (1997), Personal Communications, The Pennsylvania State University, USA.

Srikanth, R., and Ramani, R.V. (1997), Relationships Between Coal Properties and Respirable Dust Generation Potential-II, *Proceedings of the 6th International Mine Ventilation Congress*, USA. Pp 7.

Stopford, W., Bundy, S. D., Goldwater, L. J., Bittikofer, J. A. (1978), Micro-environmental Exposure to Mercury Vapour, *Am. Ind. Hyg. Ass. Jour.*, 39: 378-384.

Sullivan, S. (1991), *Chamber of Mines Report: 91/05*, South Africa.

SIMRAC Handbook, (2001), Handbook of Occupational Health Practice in the South African Mining Industry, South Africa, pp 453.

SUSC (1988), Soviet Union Standard Committee, General Sanitary Requirements for Working Zone Air, No. 12.1.005-88, Soviet Union.

Talbot, J.H. (1965), Investigation of Submicroscopic Particles, Journal of Mine Ventilation Society of South Africa, Vol. 18, No.1, p 11.

Thakur, P. C.; Sinha, A. K. (1973), Respirable Dust Index for U.S. Coals, Colliery Guardian. 221(8); pp. 294-298.

Thakur, P.C. (1974), The Mass Distribution of Respirable Coal Dust Particles from US Coals, Colliery Guardian, 222(4); pp. 236-239.

Thakur, P.C. (2003), Personal Communications, USA.

Tickner, J. (1997), Dust Control and occupational Exposure to Silica in the United Kingdom, Sampling and Control of Mineral Dust, pp 1008-1010.

Tomb, T. F., Ondrey, R. S. (1976), Determining the Feasibility of Area Sampling to Enforce the Respirable Dust Standard in Underground Coal Mines, Pittsburgh, PA: Pittsburgh Technical Support Centre, MSHA, IR 1037.

Tomb, T.F., Mundell, R.L., and Jankowski, R.A., 1978, Comparison of Respirable Dust Concentrations Measured with Personal Gravimetric Sampling Instruments Operated On-Section and Portal –to-Portal, MESA Information Report No. 1064, Technical Support Center, Pittsburgh, PA, USA, pp 7.

Tomb, T.F. (1997), Measurement strategies in US Underground coal mines, Strategies for Dust Measurement, 1124-1133

Trapido, A.S., Mqoqi, N.P., Williams, B.G. (1998), Prevalence of Occupational Lung Disease in a Random Sample of Former Mine Workers, Libode District, Eastern Cape province, South Africa. *American Journal of Industrial Medicine*, 34: 305-313.

Trapido, A. (1999), Unpublished Report, Personal Communications, South Africa.

Third International Conference of Experts on Pneumoconiosis, (1950).

The National Insurance Act, (1946).

Unsted, A.D. (1996), Personal Gravimetric Dust Sampling and Risk Assessment, SIMRAC Final Project report, GAP 046, SIMRAC Report, South Africa.

Unsted, A.D. (1998), Gravimetric dust sampling for control purposes and occupational dust sampling, *Journal of Mine Ventilation Society of South Africa*, Volume 51, Number 1, pp 24-27.

US Federal Register, (1991), Washington D.C., USA.

US Federal Register, (1995), Vol. 60, No. 20, Notices, USA.

Vincent, J. H. (1989), *Aerosol Sampling: Science and Practice*, Wiley and Sons, Chichester, UK.

Vincent, J. H., Mark, D., Jones, A.D., and Donaldson, K. (1990), A Rationale for Assessing Exposure-Dose-Response Relationships for Occupational Dust-Related Lung Disease, *Epidemiology-Coal II*, pp 151-157.

Vincent, J. H. (1994), Measurement of Coarse Aerosols in Workplaces: a review, *Analyst* 119:13-18.

Vincent, J. H. (1995), *Aerosol Science for Industrial Hygienists*, Pergamon Press, Elsevier Science, Oxford, UK.

Vincent, J. H. (1997), Joint European Investigations of New Generations of Dust Sampling Instrument, *Instrumentation for Dust Measurement*, pp 618-624.

Vincent, J. H. (2001), Particle Size-Selective Sampling for Particulate Air Contaminants, *ACGIH Worldwide*, pp 251.

Vincent, J. H. (2001), Personal Communications, USA.

Walton, W.H. (1966), The airborne dust problems in coal mines in Great Britain, *Mining Engineer*, Volume 126, No 73-84, pp. 97-117.

Weeks, J.L. (1995), Estimating Possible Fraud in coal Mine Operators' Samples of Respirable Dust, *Am. Ind. Hyg. Assoc. J.* 56: 328-332.

Weeks, J.L. (2003), The Fox Guarding the Chicken Coop: Monitoring Exposure to respirable Coal Mine dust, 1969-2000, *American Journal of Public Health*, Vol. 93, No. 8, pp 1236-1244.

Williams, B., (1999), Personal Communications, CSIR-Miningtek, South Africa.

Williams, C.D. (1965), Calculation of the Respirable Surface Area of Dust Samples, *Journal of Mine Ventilation Society of South Africa*, Vol. 18, No.1, p10.

Willeke, K., and Baron, P.A. (1993), *Aerosol Measurement: Principles, Techniques and Applications*, Van Nostrand-Reinhold, New York.

Wilson, W.E., Spiller, L.L., Ellestad, T.G., Lamothe, P.J., Dzubay, T.G., Stevens, R.K., Macias, E.S., Fletcher, R.A., Husar, J.D., Husar, R.B., Whitby, K.T., Kittelson, D.B., and Cantrell, B.K. (1977), General Motors Sulphate Dispersion Experiment: Summary of EPA Measurements, *J. Air Pollut. Control Assoc.* 27(1):46-51.

Wright, B.M. (1953), The Importance of the Time Factor in the Measurement of Dust Exposure, *British Journal of Ind. Med.*, Vol. 10, pp. 235-240

Wright, B. M. (1957), Experimental Studies on the Relative Importance of Concentration and Duration of Exposure to Dust Inhalation, *British Journal of Ind. Med.*, Vol. 14, pp. 219-228.

White, N. (2001), Occupational Lung Disease, A Handbook on Occupational Health Practice in the South African Mining Industry, Eds., Guild R., Ehrlich, R. I., Johnston, J.R., and Ross, M.H., Chapter 5, pp 119-151.

WHO, (1999), Prevention and Control Exchange: PACE, Hazard Prevention and Control in the Work Environment: Airborne Dust, WHO/SDE/OEH/99.14

WHO, (2002), Reducing Risks, Promoting Healthy Life, The World Health Report.

Yoshida, M., Yamauchi, H., Yamaura, Y. (1980), A Study of Mercury Exposure Monitoring-Comparison of Environmental and Personal Monitoring, *Jpn J Hyg* 35 (3):543-549.

Zaidi, S.H., King, E.J., Harrison, C. V., and Nagelschmidt, G. (1956), Fibrogenic Activity of Free Silica of Different Particle Sizes, *A.M.A. Archs. Ind. Health*, 13, pp 122-132.

Zitter, M., Mahieu, B., De Surgy, D., Auburtin, G., Mas, A. (1998), Assessment of Personal Dust Exposure with the CIP 10 for a better medical Management of the Pneumoconiosis Risk in Coal Workers, HBL, France, Instrumentation for Dust Measurement.