RESPIRABLE QUARTZ IN COAL MINES IN THE MPUMALANGA REGION OF SOUTH AFRICA OVER THE PERIOD 2002 TO 2006

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A research report submitted to the Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Master of Public Health (Occupational Hygiene).

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ABSTRACT

Introduction:

By 2030 silicosis should be eliminated in South Africa. This statement was made by the Labour Minister, Mr. Membathisi Mdladlana on 28 June 2004 during the launch of the National Programme for the Elimination of Silicosis in Johannesburg. Following this launch the mining industry set its own milestone, which is to eradicate this disease by 2014. Historically research has generally focused on the health effects associated with exposures to coal dust, whilst limited work has been done on personal exposures to respirable crystalline silica (commonly known as quartz), which is the main cause of silicosis in the mining industry. Given the number of people that are involved in coal mining, together with the seriousness of diseases associated with respirable quartz exposure, such as silicosis and tuberculosis, it is important to quantify these exposures. The aim of this study was to ascertain the magnitude of employee exposures to respirable quartz, in the Mpumalanga region of the South African coal mining industry, over the period 2002 and 2006.

Objectives:

The objectives of this study are:

- To describe respirable quartz concentrations in 41 coal mines in the Mpumalanga region of South Africa over the period 2002 to 2006;
- To compare respirable quartz concentrations in nine magisterial districts of the Mpumalanga region of South Africa over the period 2002 to 2006, to the South African Occupational exposure limit of 0.1 mg/m^3 and the American Congress of Governmental Industrial Hygienists (ACGIH) Threshold Limit value of 0.025 mg/m^3;
- To describe twenty four activity areas in 41 coal mines in the Mpumalanga region of South Africa, over the period 2002 to 2006, which exceed 50 % of the South African Occupational exposure limit of 0.1 mg/m^3 (generally referred to as the action limit).

Methodology:

The study setting comprises the workings of coal mines within the Mpumalanga region, where various types of occupations exist. The research conducted consisted of a descriptive study of retrospective respirable Time Weighted Average quartz concentration results obtained from mines that use the company Colliery Environmental Control Services (CECS) as their occupational hygiene service provider. CECS provided the data that was analysed for this research. Sample collection and analysis for respirable quartz was done using widely accepted International methodologies.

Results:

The overall median respirable quartz concentration for all mines were 0.007 mg/m^3, whilst the mean was 0.038 mg/m^3. The highest respirable quartz concentration measured was 2.197 mg/m^3 and the lowest 0.000 mg/m^3. The majority of the mines, i.e. 30, are situated in the Kriel, Secunda and Witbank magisterial districts, these districts account for 78 % of the total number of measurements taken. A total of 191 measurements (8 %) and 674 (29 %) exceeded the South African OEL of 0.1 mg/m^3 and ACGIH TLV of 0.025 mg/m^3 respectively with the Secunda district having the most measurements that exceeded both sets of limits (58 and 205 respectively). The majority of measurements, i.e. 1784 (76 %), were from six activity areas and four hundred and ninety one (21 %) of the total measurements taken were from the continuous miner activity area. The highest ranked activity area is the longwall mining one, which has a median respirable quartz concentration of 0.044 mg/m^3. The highest respirable quartz concentration, 2.197 mg/m^3, was measured in the roving plant activity area, which was followed by measurements of 1.706 mg/m^3 and 1.528 mg/m^3 in the continuous miner and unknown activity areas respectively. The longwall mining activity area recorded the most measurements that exceeded the 50 % action limit and 0.1 mg/m^3 OEL, these been 47 and 38 respectively.

Discussion and Conclusion:

This research report describes similar exposure findings as has been reported internationally. Persons employed in the high risk activity areas on the 41 mines studied over the period 2002 to 2006 in the Mpumalanga region are at risk of developing quartz-associated diseases, such as silicosis.

Recommendations:

It is recommended that the effectiveness of implemented interventions need to be investigated and appropriate intervention strategies be implemented. Airborne quartz contents from the nine magisterial districts and 24 activity areas should be analysed and individual samples taken from the high risk tasks should be individually analysed for their percentage airborne quartz content.

DECLARATION

I, Bruce Anthony Doyle declare that that this research report is my own work. It is being submitted for the degree of Master of Public Health (Occupational Hygiene) at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at this or any other university.

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B. A. Doyle

4th day of November 2009.

DEDICATION

- My supervisor Mr. Andrew Swanepoel for his guidance through this research project;
- My colleague Mr. Russel Ramsden for his relentless motivation and advice;
- Mr. Dawie De Villiers (CECS) for his assistance with the provision of data used and for advice given; and
- To my wife Dawn and children Donna-Lee and Dylan for their patience and motivation.

DEFINITIONS

Action Limit: means a level, typically 50% of the OEL, at which the hierarchy of controls are to be implemented in order to eradicate or limit any identified occupational hygiene risk.

Activity Area: means a list of working areas in a coal mine that are used to form a Homogeneous Exposure Group, described in the South African Occupational Hygiene Programme Code Book (SAMOHP) as issued by the Department of Minerals and Energy

Homogeneous Exposure Group (HEG): means a group of employees who experience pollutant exposures similar enough that monitoring exposures of any representative sub group of employees in the group provides data useful for predicting exposures of the remaining employees.

Interquartile Range: means the range of numbers between the 25th and 75th percentile of a given set of data.

Occupational Exposure Limit (OEL): means the time weighted average concentration for a 8 hour work day and a 40 hour work week to which nearly all workers may be repeatedly exposed without adverse health effects.

Occupational Hygiene: means the anticipation, recognition, evaluation and control of conditions at a work place that may cause illness or adverse health effects to persons.

Outlier: means an observation that lies an abnormal distance from other values in a random sample from a population.

Respirable Particulates: means the particulate fraction passing a size selector with an efficiency that allows:

100% of particles of 0 μm aerodynamic diameter to enter the sampling train

50% of particles of 4 μm aerodynamic diameter to enter the sampling train

30% of particles of 5 μm aerodynamic diameter to enter the sampling train

1% of particles of 10 μm aerodynamic diameter to enter the sampling train

Threshold Limit Value (TLV): means exposures to airborne concentrations of chemical substances, which it is believed that nearly all workers may be repeatedly exposed, day after day, over a working life time, without adverse health effects.

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- American Congress on Governmental Industrial Hygienists [ACGIH];
- Coal Workers Pneumoconiosis (CWP);
- Code of Practice (COP);
- Colliery Environmental Control Services (CECS);
- Continuous Miner (CM);
- Department of Minerals and Energy (DME);
- Forced Respiratory Volume in one second (FEV_1);
- Homogeneous Exposure Groups (HEG);
- Infrared Spectrophotometry (IR);
- Inter-quartile range (IQR);
- Milligrams per cubic metre (mg/m^3);
- Mine Health and Safety Act (MHSA);
- National Institute for Occupational Health (NIOH);
- National Institute of Occupational Health and Safety (NIOSH);
- NIOSH manual of analytical methods (NMAM);
- Occupational Exposure Limit (OEL);
- Occupational Safety and Health Administration (OSHA);
- Progressive Massive Fibrosis (PMF)
- South African Mines Occupational Hygiene Programme Code Book (SAMOHP);
- Threshold Limit Value (TLV); and
- Time Weighted Average (TWA).

CHAPTER ONE – INTRODUCTION

The aim of this chapter is to provide background information on the integral components of this study.

The chapter begins by describing the formation and geology of coal seams. Consequent health impacts of exposure to inherent silica liberated into the air through mining operations are discussed. International and National perspectives are stated, together with legal requirements. Typical exposure interventions are described for the major dust generation activities, which cumulate into the penultimate and ultimate sections dealing with the importance, aims and objectives of the study.

1. BACKGROUND

1.1. Coal formation

Coal is a black or brownish black combustible mineral formed about 300 million years ago when swampy forests of giant ferns, horsetails and club mosses covered the earth. Layer upon layer of these plants died and were compressed and then covered with soil. As the layers were successively covered their access to air was limited and this stopped the full decomposition process creating peat. Over the years heat and pressure worked to force out oxygen and hydrogen, leaving carbon-rich deposits, called coal, in layers known as seams. The carbon content of the coal rises as it is compressed further and the moisture content falls. The first type of coal to form is lignite, followed by sub-bituminous coal, bituminous coal and lastly anthracite. The process is extremely long: the oldest coal has the highest carbon content (90 to 95%). (1)

Silica is the most abundant surface mineral in the earth's crust (up to 20%) and a major constituent of soils. Quartz is the primary form of crystalline silica and is a major component of airborne particulate matter in the environment. The form and severity in which silicosis manifests depends on the type and extent of the exposure to silica dusts. [2]

1.2. Geology of the South African Coalfields

The economic coal seams are contained at depths ranging from a few metres to about 300 metres in the largely horizontal Ecca Series of the Karoo Geological System, which consist mainly of reasonably soft sandstone, shale and mudstone. Intruded in these coal measures, and overlying most South African collieries are dolerite sills, which also vary in thickness from a few metres to more than a hundred metres. The dolerite intrusions are related to the outpouring of the Drakensberg volcanics and belong to the gabbro family. [3]

The characteristic Karoo dolerite generally consists of a dark medium grained rock made up of augite and plagioclase feldspar. Olivine is often present or the rock may occasionally be more acid resulting in quartz dolerites. The coalfields in the country are spread over an area of 700 kilometres from north to south and 500 kilometres from east to west. Generally the rank or carbon content of the coals increases eastwards while the number of seams and their thickness decrease. Thus, Mpumalanga and Northern Province coals are usually classified as bituminous, occurring in seams up to several metres thick, while KwaZulu-Natal coals are often anthracitic and are found in relatively thin seams. [3]

Coal reserves in South Africa are found in sediments of Permian age, which overlie a large area of the country. They generally occur as fairly thick, flat, shallow-lying coal seams. The Mpumalanga region, the area of this study as depicted in figure 1, contains extensive coal reserves and is the country's most productive coalfield, five major coal seams occur at intervals within a sedimentary sequence deposited during a 35-million year geological time period. [3]

Figure 1. Mpumalanga region of South Africa.

1.3. South African Coal Fields

South Africa is the third biggest coal producer in the world. South African collieries range in size from small operations with output limited to a few thousand tons of coal per year to Secunda, the world's largest underground coal mining complex, which has an annual production of about 35 million tons. Almost 90 per cent of the country's saleable coal is mined in Mpumalanga. (4)

The most common mining method used in the South African mining industry, which accounts for just under half of total production, is the bord and pillar method. Bord and pillar mining is ideal for relatively shallow deposits where overlying rock pressure is low. Seams are mined leaving “in situ” coal pillars, which are big enough to support the roof indefinitely, and a chequer-board pattern of mined-out 'rooms'. This method permits approximately 65 per cent of the available coal to be extracted. When the overlying strata impose no restrictions, total-extraction mining can take place. In reality however, on average somewhat less than 90 per cent of the coal reserve is recovered, when using this method. (4)

Various distinct coal fields exist in the Mpumalanga region of South Africa, these being: (3)

1.3.1 Witbank

This field extends from the northern limit of the main outcrop of Karoo rocks southward, roughly enclosed by the towns; Witbank, Springs, Devon, Hendrina and Belfast. The southern boundary is formed by a pre-Karoo felsite's ridge and the Highveld coal field lies south of this ridge. Six main coal fields are found in this field, ranging from seam widths of 2 to 6 metres. [(3)]

1.3.2 Eastern Transvaal

This field lies roughly in the area bounded by the towns; Carolina, Morgenzon, Secunda, Ermelo and, Hendrina. Three main coal fields are found in this field, ranging from seam widths of 1, 2 to 4 metres. [(3)]

1.3.3 Highveld

This is the largest of the coal fields. A partly outcropping felsites ridge that forms the northern boundary of the field separates it from the Witbank field. This field lies within the area bounded by Heidelberg, Leslie, Davel, Perdekop and Villiers. The seams mined can be correlated with those of the Witbank field. [(3)]

1.4. Health Impacts of Exposure

Through mining operations that occur on a coal mine, crystalline silica dust, which is inherent in coal mine dust, is released into the working areas of a coal mine. Silica is the most abundant surface mineral in the earth's crust (up to 20%) and a major constituent of soils. Quartz is the primary form of crystalline silica and is a major component of airborne particulate matter in the environment. The form and severity in which silicosis manifests depends on the type and extent of the exposure to silica dusts. [(2)]

Coal miners inhaling this dust are at risk of contracting respirable quartz diseases, such as silicosis. Silicosis is one of the oldest occupational diseases, which still kills thousands of people every year, everywhere in the world. It is an incurable lung disease that is irreversible and, moreover, the disease progresses even when exposure stops, the route of progress into the lungs is shown in Figure 2. Extremely high exposures are associated with much shorter latency and more rapid disease progression. It is rated by the International Agency for Research of Cancer (IARC) as being carcinogenic to humans (Group 1). [5]

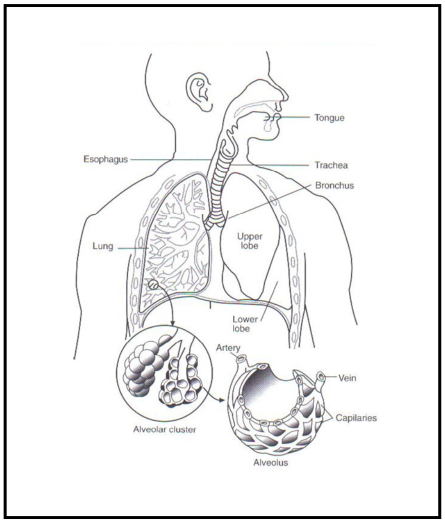

Figure 2. Inhalation diagram of the human body.

On 28 June 2004 the Labour Minister, Mr. Membathisi Mdladlana launched the National Programme for the Elimination of Silicosis in Johannesburg. During the launch he stated that "silicosis, an incurable respiratory disease caused by the inhalation of silica, should be eliminated in South Africa by 2030" and that "we have prioritized silicosis and want to see to it that new cases are eliminated by the year 2030 in line with the mission of the ILO (International Labour Organisation)/WHO (World Health Organisation) global programme for the Elimination of Silicosis". [6] The South African mining industry has set its own milestones for the elimination of silicosis, these being:

- By December 2008, 95% of all exposure measurement results will be below the occupational exposure limit for respirable crystalline silica of 0,1 mg/m^3; and
- After December 2013, using present diagnostic techniques, no new cases of silicosis will occur among previously unexposed individuals. [6]

1.5. Exposure Interventions

Various interventions to eliminate or reduce coal dust exposures have been experimented with and implemented since the commencement of mining. The major dust sources and the intervention methods are detailed below:

1.5.1 Continuous Miners

A combination of dust control systems is required on Continuous Miners (CMs) to contain the dust cloud at the coal face and to prevent roll back of the dust contaminating the incoming air breathed by coalface workers. The most commonly used ventilation and dust control systems for CMs are on-board scrubbers, water sprays, water powered air movers and auxiliary ventilation systems such as brattices, jet fans and force ventilation systems. In addition, remote control has enabled an operator to be positioned in the fresh air intake, which significantly reduces worker exposure levels. (7)

1.5.2 Longwall Operations

Currently in South Africa there are only a handful of longwall faces in operation. Research has indicated that the highest dust exposure concentrations are being experienced in longwall mining sections. A shearer-spray-system design with adequate pressure, water quality and water delivery system is paramount in effective dust control. Ventilation in the same direction as the coal been transported is the most effective means to remove the dust from the workings. Workers downstream of the operations are issued with appropriate respiratory protective equipment. (7)

1.5.3 Conveying

A conveyor belt can generate dust from various sources. Dust can originate at transfer points and can be shaken from the belt as the belt moves over the idlers. Spillage of material from the belt can also be a big contributor. Further high air velocities of ventilating air (>4 m/s), will assist the release of dust by drying the material and entraining settled dust. (7)

Typical dust control methodologies include enclosing transfer points, which are equipped with a spray system and/or exhausting the air to a dust filtration system and ensuring that the coal being transported is kept adequately wet. [7]

1.5.4 Respiratory Protective Equipment

Respiratory protective equipment is issued to all coal mine workers who are at risk to exposures to coal dust, the type and protection factor afforded is dependant on the risk. Generally disposable masks with a protection factor of 2, as shown in Figure 3, re issued to coal mine employees. This mask covers the mouth and nose and is manufactured from filtering materials to provide protection from exposure to coal dust in airborne concentrations not exceeding 2 mg/m^3.

Figure 3. Illustration of disposal respirators typically used in underground coal mines.

For the purposes of this study other respiratory protective equipment that could be issued to coal mine employees, dependant on the risk, are inclusive of:

1.5.4.1 Half mask dust respirator

As shown in Figure 1.4, this mask also covers the mouth and nose only and is normally manufactured from silicon or rubber compounds. The mask is fitted with a suitable filter or filter cartridges through which air required by the wearer is drawn.

Figure 4. Illustration of a half mask respirator used in underground coal mines.

1.5.4.2 High efficiency dust respirators

These masks, as depicted in Figure 1.5, have full-face pieces, which cover the eyes, nose, mouth and chin. The mask is fitted with a suitable filter or filter cartridge through which air required by the wearer is drawn.

Figure 5. Illustration of a full face mask respirator used in underground coal mines.

1.6. Legal Requirements

The Mine Health and Safety Act, Act 29 of 1996 (MHSA) and regulations require that occupational hygiene monitoring programmes be implemented where significant exposures to airborne pollutants occur on mines. In terms of regulation 9.2(1) of the MHSA, all mines that have identified, through their risk assessment process, that employee exposures to coal dust are greater than or equal to 10 % of the legislated Occupational Exposure limit (OEL), are required to undertake this sampling programme. The legislated OEL for coal mine dust exposure is 2 mg/m^3, however this limit is 0,1 mg/m^3 for exposures to dusts that contain respirable crystalline quartz. All coal dust samples received are analysed for their silica quartz content. This analysis is done on composite samples collected per Homogeneous Exposure Group (HEG), for every monitoring cycle. The monitoring and analytical methodologies used must comply with international best practice. (8)

Since 2002 employee exposure data to coal mine dust has been obtained from mines. Mines are required to submit this information in terms of regulation 9.2(7) of the Mine Health and Safety Act (MHSA). The required input form is attached as Appendix 1. (8) The exposure information contained on these statutory returns is captured by the Department of Minerals and Energy (DME) on a centralized database. Not all employees are required to be sampled, as a HEG concept is used, the principles of which are described in the South African Mines Occupational Hygiene Programme Codebook (SAMOHP). (9)

As published in their annually issued Threshold Limit Value (TLV) and Biological Exposure Indices Guideline, the American Congress of Governmental Industrial Hygienists (ACGIH) have published a TLV of 0.025 mg/m^3 for silica dust. (10). This guideline states that the TLVs prescribed by ACGIH are not to be used for legislatory purposes; the MHSA prescribed OELs are however statutory, which are to be complied with.

In terms of section 9.2 of the MHSA mines are required to develop a Code of Practice (COP) for an Occupational Health Programme, which includes a section pertaining to monitoring strategies. This mine specific strategy is to comply with guidelines as issued by the DME. There is no prescriptive methodology specified, however mines are to comply with international best practices. Sections required in this mandatory COP include: (11)

- Risk assessment and control;
- Personal exposure monitoring:
    - Determination of HEGs;
    - Sampling and Analysis Methodology and Quality Control;

    - Personal Exposure Monitoring; and
    - Reporting.
- Hierarchy of controls;
- Medical surveillance; and
- Reporting and reviewing.

The monitoring programme to be implemented on the mine must be summarised in the COP in a flow chart similar to Figure 1.6. (11)

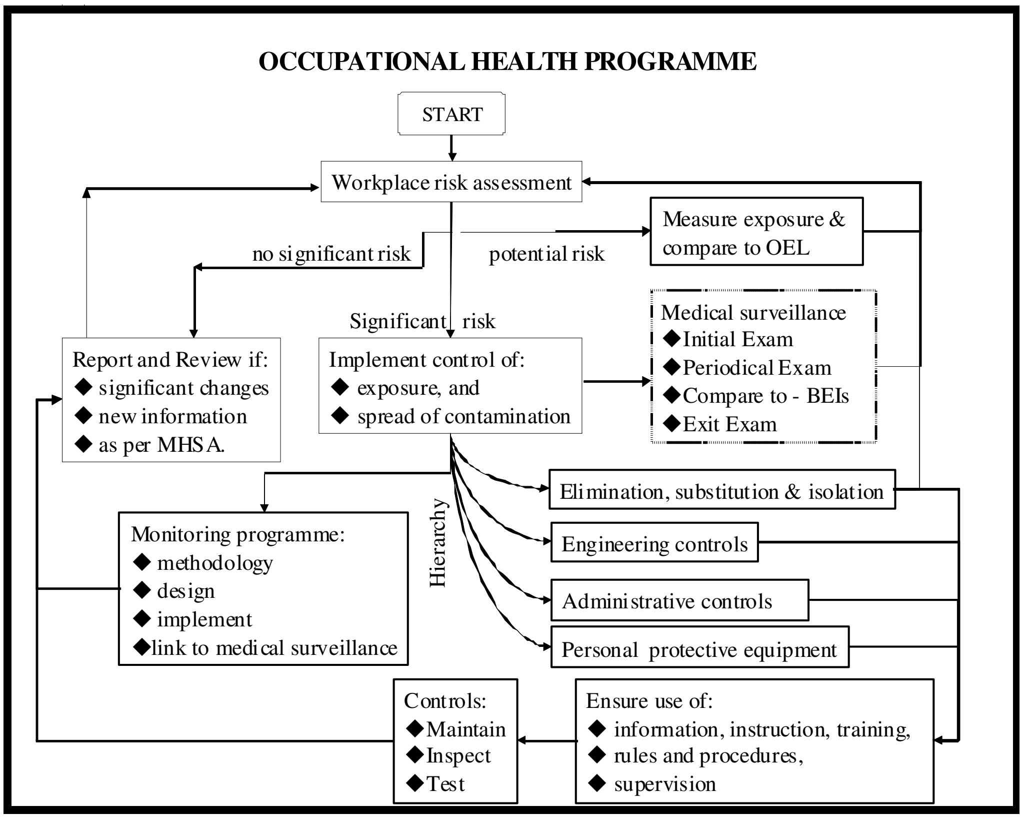

Figure 6. Depicts a flow chart of a typical occupational health programme.

2. LITERATURE REVIEW

This section investigates both International and National perspectives with regards to exposures to respirable quartz and the consequent health effects thereof.

2.1. *International Perspective*

2.1.1 Exposure to respirable quartz

Mamuya *et al.* [12] conducted a study in a labour intensive coal mine in Tanzania where the exposure to respirable quartz was quantified. This study took place over two separate time periods June to August 2003 and July to August 2004. Personal dust samples (n=125) were collected from 84 underground coal mine workers that worked in the development, mining, transport and maintenance work areas. Exposure results showed that workers in the development team had the highest exposure to respirable quartz (geometric mean 0.073 mg/m^3), 47 % of these results exceeded the TLV that was used for the study (geometric mean 0.05 mg/m^3). The transport team was the least exposed with no samples exceeding the TLV. Nine percent and two percent of the mining and maintenance results exceeded the TLV respectively. The quartz content of the respirable dust was highest for the underground maintenance team (8.7 %); followed by the development team (6.3%) and the mining team (3.9 %). In the development work area the exposure to quartz was higher for drilling (geometric mean 0.611 mg/m^3, 94 % of samples exceeding the TLV) than for blasting (0.197 mg/m^3, 67 % of samples exceeding the TLV). Drilling and blasting at the coal face were associated with significantly lower exposures than similar activities in development work (0.019 mg/m^3, 13 % of samples exceeding the TLV and 0.014 mg/m^3, 29 % respectively). Exposure to respirable quartz was highest for the development team, the tasks of drilling and blasting were the major determinants. The quartz content in the samples taken in this work area was almost 1.6 times higher than that for the mining and underground transport teams.

Piacitelli *et al.* [13] used data collected by the coal mine operators and the Mine Health and Safety Administration (MSHA), to evaluate exposure of miners to respirable coal mine dust at surface coal mines over 1982 to 1986 (n=3743). The results highlighted that at least 10 % of the samples collected from the coal preparation plant and most drilling job areas had concentrations that exceeded the 2.0 mg/m^3 limit. Of all samples collected for highwall drill operators and helpers, 77 % and 78 % exceeded the MSHA 0.1 mg/m^3 quartz exposure limit, average exposures being 0.32 mg/m^3 and 0.36 mg/m^3 respectively.

An assessment of respirable dust and its free silica content in nine Indian coal mines during 1988 to 1991 was conducted by Mukherjee *et al.* [14] The Government of India prescribed TLV was 3.0 mg/m^3. Drilling, blasting and loading were the major dusty operations in Bord and Pillar mining operations. Exposures of drillers and loaders varied between 0.81 and 9.48 mg/m^3 and 0.05 and 9.84 mg/m^3 respectively. Whereas in Longwall mining sections exposures to DOSCO loaders, shearer operators and power support face workers varied between 2.65 mg/m^3 to 9.11 mg/m^3, 0.22 mg/m^3 to 10.00 mg/m^3 and 0.12 mg/m^3 to 9.32 mg/m^3 respectively.

In Bord and Pillar operations 65.1 % of drillers results (n=43) exceeded the TLV, followed by 43.9 % (n=41) of the loaders operators and 41.4 % of the explosive gang (n=41.4 %). In Longwall operations almost all of the categories of workers had a high percentage of results exceeding the TLV, i.e., DOSCO loader 66 % (n=6), shearer operator 45.4 % (n=11), power support 38.7 % (n=31), DOSCO face worker 33.3 % (n=12) and DOSCO operator 27.2 % (n=11).

The mean silica content of airborne dust in Bord and Pillar workings (n=29) did not exceed five percent, whilst 12.5 % exceeded this value in Longwall mining (n=8).

2.1.1.1 Health effects

In most parts of the world silicosis is widely spread and millions of workers continue to be exposed to noxious dusts running an unacceptably high risk of developing the disease. Epidemiological studies show that up to 30-50 % of workers in primary industries and high-risk sectors in developing countries may suffer from silicosis and other pneumoconiosis. [11]. Table 1.1 Depicts the global WHO estimation of the silicosis epidemic. [15]

Table 1. *Current situation pertaining to silicosis internationally*

Country	Status
China	During 1991 to 1995, China recorded more than 500000 cases of silicosis, with around 6000 new cases and more than 24000 deaths occurring each year mostly among older workers.
Vietnam	The cumulative number of diagnosed cases has now reached 9000. They constitute 90% of all cases of occupationally compensated diseases. Some 18% of workers engaged in surface coal mining, quarrying, foundry and metallurgy have been found to have silicosis.
India	A prevalence of 55% was found in one group of workers engaged in the quarrying industry.
Brazil	More than 4500 workers, in one State, have been diagnosed with silicosis. A silicosis prevalence of 26% was diagnosed amongst workers involved in hand digging operations. Sand blasting operations in the State of Rio de Janeiro were banned after a quarter of the shipyard workers were found to have silicosis.
USA	It is estimated that more than one million workers are occupationally exposed to crystalline silica dusts, of which some 59000 will eventually develop silicosis. It is reported that each year in the USA about 300 people die from it, but the true number is not known.
Colombia	It is estimated that 1.8 million workers in the country are at risk of developing silicosis.
Germany	3000 new cases of silicosis annually (1990's)
France	300 new cases of silicosis annually.
Australia	1010 new cases (range 380-2410) are predicted
United Kingdom	1164 new cases of pneumoconiosis reported in 2002.

The literature review has revealed that research has largely concentrated on the clinical and health effects of exposures to coal dust. The sourced research is detailed below:

A review conducted by Coggon *et al.* on coal mining and obstructive pulmonary diseases concluded the following: [16]

Lapp *et al*. concluded on research conducted on airway obstruction and disability in coal miners that pneumoconiosis is not the only respiratory hazard of coal mining. Evidence has accumulated that miners also experience an excess of chronic obstructive pulmonary disease, which led the British government to classify chronic bronchitis and emphysema in coal miners as occupational diseases. Chronic obstructive pulmonary disease in German miners is also classified as an occupational disease. [17]

A series of studies conducted by the Pneumoconiosis Research Unit in South Wales found significantly lower mean levels of indirect maximum breathing capacity in miners and ex- miners than in non miners of the same age. There was however no clear correlation between indirect maximum breathing capacity and the duration of underground or face work. [18]

An investigation done in South Wales compared the respiratory health of miners from a single colliery with that of a control group of telecommunication workers from the same locality. This research showed that more coal miners reported symptoms of chronic bronchitis than that of a control group of telecommunication workers (31 % verses 5 %) and that their lung functions also tended to be worse. Approximately 20 % of the miners had a Forced Respiratory Volume in one second (FEV_1) less than 80 % of the predicted for their age and height, compared with only 80 % of the controls. [19]

In a study done in Belgium, Nemery and colleagues carried out a cross sectional comparison of 32 non-smoking coal miners and 34 non smoking steelworkers. The results revealed that miners had significantly lower FEV_1 values and maximum expiratory flow rates than that of steelworkers. [20]

Rogan *et al.* determined, in a sample size of 3 581 coal miners, from 20 collieries in Britain, who had been either working at the coal face or elsewhere underground that in both smokers and non-smokers there was a reduction in FEV, with an increase in dust exposure in all age groupings. Multiple regression analysis indicated an average FEV_1 loss of 100 ml in relation to the mean dust exposure of the group studied, but with greater losses at the younger than at older ages. (21)

A review by Oxman *et al.* described a study of 544 employed and retired miners from a colliery in Germany. These results showed a significant negative association between dust exposure and FEV. In addition, FEV_1 declined longitudinally in relation to concurrent dust exposure but this effect was not statistically significant. In contrast these researchers also found in an analysis of 3 850 miners from the north east of England, that there was a positive relation between FEV_1 and years worked underground. (22)

In the United States, Rockette carried out a cohort study on 23 232 coal miners who comprised a 10 % sample of men covered by the United Mine Workers Health and Retirement Funds. During follow up 12 years later it was ascertained that there was 201 deaths from bronchitis and emphysema compared with 167 expected from national mortality rates. Mortality from asthma also increased (32 from an expected 19.4), as was that from lung cancer (352 deaths from 311 expected). (23)

Cochrane *et al.* followed up on populations from British mining communities and analysed mortality according to subjects' occupations at entry to follow up. The cohort containing the largest number of miners was that from the Rhonda Fach in South Wales, and over 30 years there was a marked excess of deaths from bronchitis among these miners compared with the national population (501 deaths observed with approximately 423 expected). Mortality from bronchitis did not increase in relation to category of pneumoconiosis at the start of follow up. Mortality from lung cancer was lower than expected. Among non-miners from the same population there was a deficit of deaths from bronchitis (32 compared with approximately 41 expected). (24, 25)

A study was done by Miller and Jacobsen of mortality in 26 363 miners from 20 collieries in England and Wales. Estimates of cumulative exposure to respirable dust up to the time of the survey of the men were possible for 19 950 miners (74 %). The study concluded that there was a clear increase in mortality from bronchitis and emphysema in relation to dust exposure. No correlation trend was observed for mortality from lung cancer. [26]

Attfield *et al*. concluded in a study conducted on the prevalence of Coal Workers Pneumoconiosis (CWP) relating to indexes of dust exposure obtained from research and compliance sampling data that clear relationships existed between prevalence's of both simple CWP and Progressive Massive Fibrosis (PMF) and dust exposure. Logistic model fitting indicated that between 2 % and 12 % of miners exposed to a 2 mg/m^3 dust environment in bituminous coal mines would be expected to have Category 2 or greater CWP after a 40-yr working life; PMF would be expected for between 1.3 % and 6.7 %. [27]

A review conducted by Borm and Tran showed that lungs of coal miners with simple coal workers' pneumoconiosis typically contained up to 30 g of dust. A no observed adverse effect level for quartz of between 0.03 mg/m^3 and 0.13 mg/m^3 (40 year exposure) was derived. [28]

Attfield and Seixas determined that miners of medium to low rank coal, who work for 40 years at the current federal coal dust limit of 2 mg/m^3, are predicted to have a 1.4 % risk of having progressive massive fibrosis on retirement. Miners in high rank coal areas appear to be at greater risk than those mining medium and low rank coals. [29]

In a separate study to the review conducted by Coggon *et al*., as detailed above, Montes *et al.* conducted a cohort study on respiratory disease on 2 579 coal miners. An initial medical examination was carried out when these miners began to work on the mine, with a further three examinations performed over the 20 years of the study. The results of the study concluded that 3.8 % of the workers developed round opacities (category 1), with a greater frequency (7.3 %) among rock workers who had greater exposure to silica. No cases of lung cancer were observed and four cases of pulmonary tuberculosis were diagnosed. [30]

2.2. National Perspective

Limited information is available on actual exposure to respirable quartz results; in total only one research report could be sourced. The health aspects relating to exposure to respirable quartz are discussed in section 1.2.2.2.

2.2.1 Exposure to respirable quartz

Naidoo *et al.* [31] described the respirable coal mine dust levels in three South African coal mines over time. Investigator-collected personal dust samples were taken using standardized techniques from the face, backbye (underground jobs not at the coal face), and surface from 50 miners at each mine, repeated over three sampling cycles. Job histories and exposure information was obtained from a sample of 684 current miners and 188 ex-miners. The mean historical and investigator-collected respirable dust levels were within international norms and South African standards (2 mg/m^3). Silica content of the dust samples were below the 5% regulatory action level.

2.2.1.1 Health effects

South Africa's National Institute for Occupational Health (NIOH) has tentative data based on the Statistics SA Census 2001 Database and an estimate of the proportions of workers potentially exposed in usual "silica industries" (Mining and Quarrying, Manufacturing and Construction). A preliminary estimate is that between 199 000 to 796 000 workers are potentially exposed in South Africa.

In South Africa, the burden of diseases resulting from working in mines is unacceptably high. Approximately 25 000 compensation applications are made per year, from mine workers, for occupational lung diseases (with silicosis being the main disease). [32]

Silicotic nodules were found in 17.2 % of the lungs of autopsied miners and ex-miners where the prevalence rate varied by commodity, with gold miners 22.8 %, coal miners 7.3 % and platinum 4.4 %. The overall rate of silicosis diagnosed at autopsy has remained much the same since 1975, as depicted in Table 2. [33]

Table 2. *Rate of silicosis diagnosed per 1000 autopsies*

	1975	1980	1985	1990	1995	2000	2001
Total	**148**	**176**	**138**	**140**	**197**	**144**	**172**

The latest autopsy data, obtained from NIOH, indicates that the overall prevalence of silicosis has increased to a rate of 210 per 1000. The prevalence of silicosis for coal miners, as determined by this autopsy data, is 108/1000. [(33)]

Two recent studies on the incidence of occupational lung disease in ex-South African mineworkers have begun to reveal the dimensions of a massive occupational diseases situation that was, due to the legacy of our past, never controlled. In Thamaga, in Botswana, in a random sample of 234 underground mineworkers, Steen T.W. *et al.* found that some 31 % (310 per 1000) had pneumoconiosis. 6.8 % of these workers had `progressive massive fibrosis, the most crippling form of silicosis that rapidly leads to complete respiratory failure and death. [(34)]

Similarly, in a study of a random sample of ex South African mineworkers, in Libode in the rural Transkei (Eastern Cape), Trapido A *et al.* found a pneumoconiosis prevalence of 22 % and 37 %. [(14)]. Preliminary results of a study in Lesotho of a similar but larger cohort of former mineworkers suggest an incidence presently of 40 %. On the basis of these studies, it is estimated that there are almost half a million ex-mineworkers in southern Africa suffering from compensable lung disease, and that the total amount of unpaid compensation is of the order of R2.8 billion. [(35)]

An association exists between tuberculosis and silica exposure. Cowie found an increasing incidence of tuberculosis with increasing severity of silicosis in South African gold miners; 2.2 % in men with mild silicosis; 2.9 % with moderate silicosis; and 6.3 % with advanced silicosis. Cowie suggested that one quarter of his subjects with silicosis would have developed tuberculosis by 60 years of age. Recent studies have also found that it is not only silicosis but silica dust itself that confers an increased risk of tuberculosis and that this risk persists even after silica dust exposure ends. [(36)]

This relationship is further compounded by HIV. Corbett *et al.* have shown that the risks of silicosis and HIV infection combine multiplicatively for tuberculosis, so that tuberculosis remains as much a silica-related occupational disease in HIV-positive as in HIV-negative miners. [37]

Studies of dose-response relationships between respiratory outcomes at autopsy and coal dust exposure are limited. Naidoo *et al.* conducted a study that described the prevalence of respiratory outcomes among South African coal miners at autopsy, and determined whether dose response relationships existed between emphysema and exposure. The mean study duration of exposure was 11.0 years. Only 22.9 % of cases (n=3167) had information on smoking. The prevalence of silicosis, tuberculosis, CWP, and moderate and marked emphysema were 10.7 %, 5.2 %, 7.3 %, and 6.4 %, respectively. All diseases, except tuberculosis, were associated with exposure duration. This study concluded that there were significant dose related associations of disease, including emphysema, with coal dust exposure. [38]

Published DME exposure data, contained in the Mine Health and Safety Inspectorate Annual Reports, has indicated that for the time period 2005/6, 31 % of employees working in the coal mining industry are been over exposed to coal dust. This commodity has consistently, over the past few years, had the highest overexposure records than for any of the other commodity groups. [39]

Table 3 reflects these over exposure figures:

Table 3. *Commodity overexposure statistics – Airborne Pollutants*

Commodity	Year					
	2005/6	2004/5	2003/4	2002/3	2001/2	2000/1
Gold	16%	3,6%	4,8%	4,7%	6,6%	6,6%
Platinum	6%	4,1%	7%	0,1%	0%	1%
Coal	31%	9,7%	12,1%	19,8%	28,9%	30,9%
Other Mines	5,4%	7,6%	8,4%	6,4%	4,4%	4,2%

3. IMPORTANCE OF THE STUDY

The literature review of available research conducted has indicated that minimal work has been done on personal exposures to respirable quartz in the coal mining industry. Given the number of people that are involved in coal mining, together with the seriousness of diseases associated with respirable quartz exposure, such as silicosis and tuberculosis, it is important to quantify these exposures, which arise from the presence of quartz in the coal seams. This study is concentrated in the Mpumalanga region of South Africa as the majority of coal mines are located in this area.

4. AIMS OF THE STUDY

With the launch of the eradication of silicosis programme in South Africa it is imperative that a study into the exposures to respirable quartz concentrations in coal mines is conducted. The Mpumalanga region of South Africa is the major coal mining region in the country and hence the reason for the study to be undertaken in this area. Historically, research has generally focused on health effects associated with exposures to coal dust and exposures to respirable quartz concentrations in gold mines; whilst limited work has been done on personal exposures to respirable crystalline silica. Hence, the aims of this study are to ascertain:

- The magnitude of employee exposures to respirable quartz in the South African coal mining industry, when compared to local and generally accepted international limits, such as specified by the American Congress of Governmental Industrial Hygienists;
- Identify high risk activity areas;
- Identify high-risk magisterial districts within the sample region; and
- Identify short-comings in the present sampling systems and make recommendations.

5. OBJECTIVES OF THE STUDY

The research objectives are listed below:

- To describe respirable quartz concentrations in 41 coal mines in the Mpumalanga region of South Africa over the period 2002 to 2006;
- To compare respirable quartz concentrations in nine magisterial district of the Mpumalanga region of South Africa over the period 2002 to 2006, to the South African Occupational exposure limit of 0.1 mg/m^3 and the American Congress of Governmental Industrial Hygienists (ACGIH) Threshold Limit value of 0.025 mg/m^3;
- To describe twenty four activity areas in 41 coal mines in the Mpumalanga region of South Africa, over the period 2002 to 2006, which exceed 50 % of the South African Occupational exposure limit of 0.1 mg/m^3 (generally referred to as the action limit).

CHAPTER TWO – METHODOLOGY

The aim of this chapter is to provide background information on the materials and method components of this study.

The chapter begins by describing the study design and the population of coal mines used in the study. The various occupations employed on these mines are discussed together with the sampling strategies, which includes;

- Homogeneous Exposure Group (HEG) determination process;
- Legislated sampling frequency requirements and minimum numbers of samples required to be taken;
- Sampling processes; and
- Analytical methodology;

The chapter concludes with a description of the quality control measures employed on these mines, the data analysis method and a statement on ethics approval obtained.

1. STUDY DESIGN AND POPULATION

The research conducted consisted of a descriptive study of retrospective respirable quartz concentration results. A total of 2346 respirable quartz exposure results were obtained from 9735 samples taken in 41 coal mines located in nine magisterial districts of the Mpumalanga region, over the period 2002 to 2006.

The data used for this research was provided by the company Colliery Environmental Control Services (CECS) who provided a service to the coal mines within the sample population used. The service provided included the preparation and collection of sample equipment, weighing of the sample filters and arranging for the analysis of the samples (to determine the silica content). Once a sampling cycle had been completed and the results became available CECS prepared the legislated reporting forms for the mines, which submitted them to the DME.

Written permission to use these results for this study, attached as Appendix 2, was obtained from CECS.

Individual sample filters collected are not separately analysed for their silica content. The measurement method, NIOSH 7603, is by means of Infrared analysis, where following the weighing process, the filters from samples taken in HEGs are combined for analysis purposes.

Magisterial districts in this coal mine region are:

Belfast	Delmas	Ermelo
Kriel	Middelburg	Piet Retief
Secunda	Standerton	Witbank

It is estimated that during the study period, approximately 75 % of the collieries used the CECS as their service provider; hence the data used for this study can be considered to be representative for all collieries in this area.

2. SELECTION OF STUDY WORKPLACES

Samples were collected from the DME legislated activity areas, which are listed in Table 4.

Table 4. *Major tasks within legislated activity areas at coal mines in Mpumalanga, South Africa*

Activity Area	**Job Description**
Assay/Laboratories	Working with inter-alia heat processes and weighing equipment. Assay and laboratory staff including supervisors and assistants.
Continuous Miner [CM]	Production section occupations in either CM or road header sections including supervisors, CM operators, shuttle car operators, roof bolters, and cable handlers.
Conventional Mining	Production section occupations in drill and blast sections including supervisors, drillers, loader operators, shuttle car operators, roof bolters, and cable handlers.
Crushing	Work involved is crushing of coal to pre-determined sizes. Occupations include crusher operators and their assistants. Feeder breaker washing plant

Development Multi – Blast	All occupations dealing with development operations, inclusive of supervisors miners, roof bolters, cleaners, drillers, vehicle operators and assistants.
Development Single Shift	As per development multi-blast.
Dumps/Dumps recycling	Occupations working on mine dumps, which include vehicle operators, cleaners and rehabilitation personnel.
Ground Handling	All occupations involved with the moving of coal, these include conveyor operators and their assistants, belt cleaners and LHD operators responsible for cleaning operations.
Handgot	Mining operations using manual and not mechanical means. Occupations include miners, roof bolters, cleaners, drillers and assistants.
Longwall Mining	Production section occupations in longwall sections including supervisors, shearer operators and chock car operators.
Opencast Mining	All personnel involved with opencast mining, inclusive of drillers, rock haulers, all assistants, supervisors, explosive personnel, and other operators of machinery.
Raise Boring/Dry Drilling	Raise boring is done to connect different elevations within a mine. Holes that are not large in size, i.e. below 5 are drilled. Occupations include the driller, assistants and cleaners.
Raw Material	Persons working in stores, batching plants or at any process that requires raw materials to be mixed etc would be included under this category.
Rock Mining	Where mining through geological anomalies occur, occupations such as supervisors, drillers, loader operators and assistants need to be sampled.
Roving Plant	Any occupation that will not be at any one designated location during the shift, which could result in exposures to more that one particulate from occurring, is classed as roving. A supervisor and a cleaner could fall under this category.
Roving Underground	As per roving plant.
Roving Surface	As per roving plant.
Screening and Grading	These tasks are conducted where screening and grading of coal is done to ensure quality control requirements. Occupations include screening plant operators, persons selecting and removing "out of specification coal" and cleaners.
Separation Processes	In the plant finer coal is separated from the coarser coal. From the cyclone separators the slurry is sent to a settling pond, whilst the coarser coal is sent to the stock yard.
Stooping/Pillar Extraction	Total extraction mining method, which includes occupations such as miners, drillers, cleaners, CM operators, assistants, shuttle car operators and tip attendants.
Shafts and Services	Occupations including banksman, onsetters, lampsman [and their assistants], change house personnel.
Surface Workshops	All personnel working in the workshops, inclusive of fitters, boilermakers, electricians, instrumentation technicians and assistants.

Underground Workshops	As per underground workshops.
Unknown	This category is included in this report as the 2002 results are not linked to activity areas as this only became a legislated requirement in 2003.

3. SAMPLING STRATEGY

South African legislation is not generally prescriptive with regards to sampling strategies pertaining to methods to be employed. The methods adopted by these coal mines were based on best practice and guidelines issued by the DME.

Where new legislation, prescriptive in nature did exist, these mines complied with them; these requirements being:

3.1. Homogeneous Exposure Groups (HEG) Determination

Due to large numbers of persons employed in the coal mining industry it was not possible for every employee to be sampled. The monitoring strategies employed hence used the HEG principle approach, which focused on groups of employees doing similar jobs in similar ways. This principle allows a group of employees who experience pollutant exposures similar enough that monitoring exposures of any representative sub group of employees in the group provides data useful for predicting exposures of the remaining employees.

The regulated sequential methodology used in the HEG determination classification for these coal mines were as follows: [9, 11]

Step 1

The mines were sub-divided into Sampling Areas. (i.e. Surface = Sampling Area 1, Underground Section A = Sampling Area 2, Underground Section B = Sampling Area 3, etc).

Step 2

Sampling Areas were sub-divided into relevant coal mining activity areas as shown in Table 5. Note: For DME data capturing purposes codes are assigned to each activity area.

Table 5. *Coal mine activity areas*

Activity Area	Code	Activity Area	Code
Assay/Laboratory	32	Raw Material	19
Continuous Miner	02	Rock Mining	06
Conventional Mining	01	Roving Plant	30
Crushing	20	Roving Surface	31
Development Multi blast	10	Roving Underground	17
Development Single Shift	09	Separation Process	23
Dumps/Dumps recycling	34	Screening and Grading	22
Ground Handling	15	Shafts and Services	16
Handgot	04	Stooping/Pillar Extraction	05
Longwall Mining	03	Surface Workshops	33
Opencast	07	Underground Workshops	18
Raise Boring/Dry Drilling	12		

Step 3

The concentration of coal dust in each activity area was ascertained. Note: Due to the sampling programmes been implemented on coal mines the respirable quartz concentrations are not used to determine HEGs.

Step 4

The results of the sampling conducted in step three are compared to the Time Weighted Average (TWA) OEL for coal dust, which is 2.0 mg/m^3.

Step 5

Once the personal exposures within each Activity Area have been compared to the 2.0 mg/m^3 TWA OEL value, each activity area was categorised into classification bands, shown in Table 2.3, to determine the various HEGs within that activity area.

Table 6. *Classification bands*

	Classification Bands
Category	**Personal Exposure Level**
A	Exposures ≥ the OEL
B	Exposures ≥ 50% of the OEL
C	Exposures ≥ 10% of the OEL

Note: An Activity Area e.g. continuous miner section is not a HEG, activity areas must be subdivided into the classification bands as shown above. These classification bands are the HEGs within that particular activity area.

3.2. Monitoring Frequency/No. Samples to be taken

The mandatory sampling frequency of the data received was dependent on the category rating. Table 2.4 depicts the relevant frequency per category classification: [9, 11]

Table 7. *Minimum frequency/No. of samples*

Category	Minimum Frequency/No. Samples
A	Sample 5% of employees within a HEG on a 3 monthly basis with a minimum of 5 samples per HEG, whichever is the greater.
B	Sample 5 % of employees within a HEG on a 6 Monthly basis with a minimum of 5 samples per HEG, whichever is the greater
C	Sample 5 % of employees within a HEG on an annual basis with a minimum of 5 samples per HEG, whichever is the greater

3.3. Respirable Fraction

To ascertain the amount of dust, which is able to reach the lower bronchioles and alveolar regions of the lung, the respirable fraction of the dust was measured. The respirable fraction of airborne particulates is based on the internationally accepted

"ISO/CEN Curve" (Figure 7) for size distribution, i.e. particle aerodynamic diameter of less than 10,0 micron. (11)

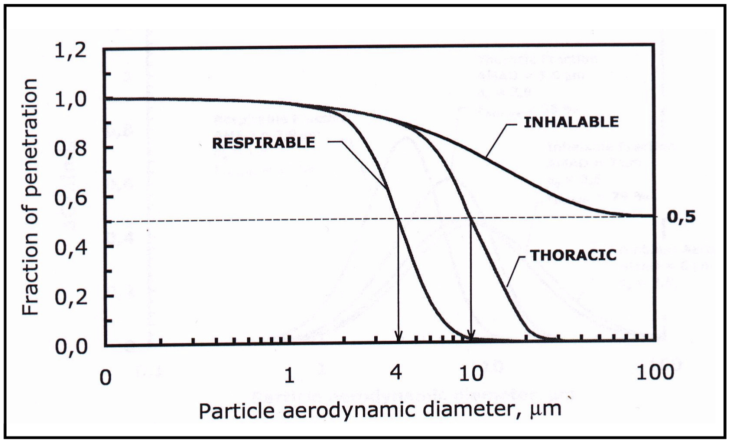

Figure 7. Is an illustration of the ISO/CEN Curve

As respirable samples are taken, cyclones, as shown in figure 2.2, were used. When using a cyclone, the larger particles are removed from the air by centrifugal force and fall into the bottom of the cyclone, while the smaller particles (respirable) will pass through the cyclone and be collected on the filter. (11)

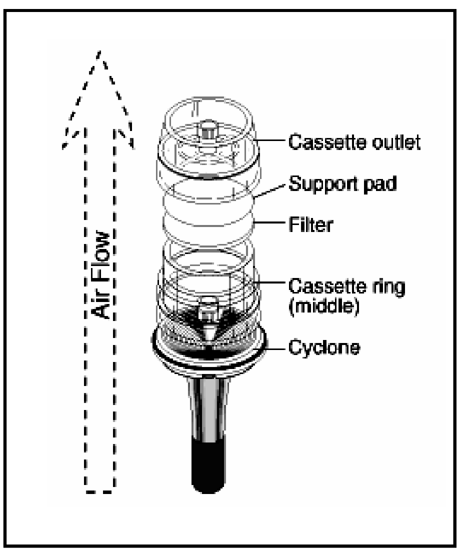

Figure 8. Is an illustration of the Cyclone

4. SAMPLING PROCESS

Gravimetric sampling of coal dust is used as the basis for measuring personal exposures to silica dust in coal mines. Personal Time Weighted Average dust samples were collected on all shifts from the employee occupation groups randomly selected. The number of samples collected and the frequency thereof were as specified by legislation.

The results are expressed as a concentration in milligrams per cubic meter of air (mg/m^3). Instruments, as shown in Figure 9, make use of a constant volume pump for the constant aspiration of air. Volume flow rates are calibrated before and checked after each sample with the sampling train in line, using a volume displacement method as the primary standard; the required flow rate is dependant on the type of cyclone being used, which is stated in the NIOSH method description. Cellulose nitrate filter material is used when monitoring coal for silica in coal mine dust. Mass determination of filter papers is done by using micro-balances capable of reading to the nearest 10 micrograms.

Figure 9. Is an illustration of a typical dust sampling pump

5. SAMPLING SCHEDULES

Once activity areas and the categorisation process have been completed, mines developed sampling schedules. These schedules specify the number of samples to be taken in the various defined HEGs over the reporting period, i.e. quarterly, 6-monthly or annually (dependant on the HEG categorisation). A random selection of occupations and shifts to be monitored is done.

6. ANALYTICAL METHOD

The method used by the laboratory that undertook the analytical process for CECS complied with the National Institute of Occupational Health and Safety (NIOSH) analytical methodology 7603, issue 2 (15 August 1994). This method, attached as Appendix 3, is titled "Silica, Crystalline in Coal Mines Dust, by IR" is described in the NIOSH manual of analytical methods (NMAM), fourth edition, 8/15/94. This prescribed method is used to determine the respirable quartz concentration contained on the collected coal samples using the Infrared analysis technique, which has a Limit of Detection 0.004 mg/m^3. Filters from samples taken in HEGs are combined, following the weighing process, for analysis purposes i.e., individual samples are not separately analysed for their silica content, resulting in a total of 2393 reported results from of 9735 sample taken.

7. QUALITY CONTROL

In terms of section 12.1 of the MHSA, coal mines within this sample population have appointed competent persons to develop and implement systems of occupational hygiene measurements. These appointed persons would have assumed the overall responsibility and accountability for these programmes during this sample period.

All mines within the Mpumalanga region have Codes of Practices in place as required by MHSA legislation. In terms of this legislation these mines are required to develop and implement a quality control programme that will as far as reasonably possible ensure the integrity of the results obtained from the sampling process. This would include issues such as instruments to be used, issue and retrieval procedures, calibration procedures, transportation of instrumentation, weighing procedures and analytical methodologies.

A laboratory accredited by SANAS (South African National Accreditation System) was used by CECS to analyse the samples collected from the coal mines in this region over the study period.

It was also good practice for mines in this study group to appoint “partial supervisors” who undertook periodical checks on the status of personal sampling equipment issued to any person/s in the working area.

8. DATA ANALYSIS

Use of Microsoft Office Excel 2003 was made to address objectives 1 to 3, described in section 3. The software package Minitab (Copyright © 2000-2006 Minitab Inc.) was used to describe figure 4.1, “Data summary of respirable quartz concentrations in the Mpumalanga coal mine region over the period 2002 to 2006”.

For the first objective the mines are ranked from the lowest median quartz concentration to the highest. Furthermore, for every mine, the mean, minimum and maximum value and the inter-quartile range (25^{th} and 75^{th} percentiles) are shown. In addition the proportion of results, taken over the sampling period of 2002 to 2006, which exceeded the South African legislated OEL (0.1 mg/m^3) are stated for each mine. A Figure is also included that depicts the full range of measurements taken per mine, compared to the 0.1 mg/m^3 and 0.025 mg/m^3 limits. To complete this objective, a summary of the 41 coal mines in which the number of measurements per mine exceeding the ACGIH TLV and the South African OEL are shown.

The results of the second objective are presented in which the number of mines in each of the nine magisterial districts exceed the 0.1 mg/m^3 and the 0.025 mg/m^3 limits.

For the final objective the median, minimum and maximum values for the twenty four identified activity areas, as well as their Inter-Quartile range and the proportion of results that exceed 50 % and 100 % of the OEL are shown. The activity areas are ranked from the lowest median respirable quartz concentration to the highest. The full range of measurements taken per activity area, compared to the 0.1 mg/m^3 and 0.025 mg/m^3 limits are depicted in a figure. To complete this objectives result, the number of measurements per activity area exceeding the ACGIH TLV and the South African OEL are presented.

9. ETHICS

All measurements were done between 2002 and 2006. Written permission from CECS was obtained for the use of the measured data and the study was approved by the University of the Witwatersrand Human Research Ethic Committee (clearance number M080336, reference R14/49 Doyle, dated 08:04:09). Attached as Appendix 4.

CHAPTER THREE - RESULTS

The aim of this chapter is to display the results of the data analysis done for the three objectives, which are:

- To describe respirable quartz concentrations in 41 coal mines in the Mpumalanga region of South Africa over the period 2002 to 2006;
- To compare respirable quartz concentrations in nine magisterial districts of the Mpumalanga region of South Africa over the period 2002 to 2006, to the South African Occupational exposure limit of 0.1 mg/m^3 and the American Congress of Governmental Industrial Hygienists (ACGIH) Threshold Limit value of 0.025 mg/m^3;
- To describe twenty four activity areas in 41 coal mines in the Mpumalanga region of South Africa, over the period 2002 to 2006, which exceed 50 % of the South African Occupational exposure limit of 0.1 mg/m^3 (generally referred to as the action limit).

For the first objective Table 8 is presented, it ranks the mines from the lowest median quartz concentration to the highest. This Table further includes, for every mine, the mean, minimum and maximum value and the inter-quartile range (25th and 75th percentiles). In addition the proportion of results, taken over the sampling period of 2002 to 2006, which exceeded the South African legislated OEL (0.1 mg/m^3) are also stated for each mine. Figure 10 depicts the full range of measurements taken per mine, compared to the 0.1 mg/m^3 and 0.025 mg/m^3 limits. To complete this objectives results, Table 9 summarises the data sets of the 41 coal mines in which the number of measurements per mine exceeding the ACGIH TLV and the South African OEL are depicted.

The results of the second objective are presented in Table 10, which describes the number of mines in each of the nine magisterial districts that exceed the 0.1 mg/m^3 and the 0.025 mg/m^3 limits.

For the final objective Table 11 of this chapter describes the median, minimum and maximum values for the twenty four identified activity areas, as well as their Inter-Quartile range and the proportion of results that exceed 50 % and 100 % of the OEL. The activity areas are ranked from the lowest median quartz concentration to the highest. Figure 11 concludes this chapter and depicts the full range of measurements taken per activity area, compared to the 0.1 mg/m^3 and 0.025 mg/m^3 limits. To complete this objectives results, Table 12 summarises the data sets of the 24 activity areas within the 41 coal mines in which the number of measurements per activity area exceeding the ACGIH TLV and the South African OEL are depicted.

1. OBJECTIVE 1 - RESULTS

Table 8 ranks the mines according to median respirable quartz concentrations, it further describes the mean, range of concentrations, inter-quartile ranges and the percentage of results, per mine, that exceed the South African DME OEL of 0.1 mg/m^3.

Table 8. *Respirable quartz concentrations in mg/m3 for 41 coal mines in Mpumalanga over period 2002 to 2006*

Mine No.	Rank	n	Median	Mean	Minimum	Maximum	Inter Quartile Range		No. >0.1mg/m^3
28	41	16	0.003	0.006	0.000	0.029	0.002	0.006	0
36	40	62	0.003	0.005	0.000	0.038	0.001	0.006	0
6	39	4	0.003	0.003	0.000	0.007	0.001	0.006	0
27	38	73	0.004	0.085	0.000	1.706	0.002	0.020	9
35	37	54	0.004	0.022	0.000	0.466	0.002	0.013	2
37	36	83	0.004	0.016	0.000	0.265	0.002	0.009	3
24	35	40	0.005	0.011	0.000	0.086	0.002	0.013	0
2	34	10	0.005	0.095	0.001	0.012	0.003	0.006	0
15	33	42	0.005	0.019	0.000	0.185	0.003	0.022	1
38	32	45	0.005	0.021	0.000	0.305	0.003	0.016	2
20	31	97	0.005	0.017	0.000	0.179	0.003	0.022	1
22	30	53	0.006	0.015	0.000	0.110	0.002	0.018	1
3	29	10	0.006	0.030	0.000	0.155	0.003	0.006	0
11	28	64	0.006	0.016	0.000	0.110	0.003	0.021	2
31	27	52	0.006	0.025	0.000	0.121	0.003	0.035	2
1	26	45	0.006	0.038	0.000	0.184	0.002	0.020	2
26	25	76	0.006	0.035	0.001	0.476	0.004	0.026	7
13	24	56	0.007	0.015	0.000	0.180	0.002	0.018	1
30	23	28	0.007	0.013	0.001	0.128	0.004	0.011	1
4	22	54	0.007	0.012	0.000	0.081	0.004	0.013	0
18	21	86	0.007	0.056	0.001	0.787	0.003	0.038	16
33	20	9	0.007	0.010	0.001	0.023	0.006	0.015	0
19	19	96	0.008	0.024	0.000	0.219	0.003	0.029	4
39	18	42	0.010	0.032	0.001	0.320	0.005	0.034	3
41	17	40	0.010	0.016	0.000	0.095	0.003	0.022	0
10	16	55	0.011	0.033	0.000	0.529	0.003	0.023	5
5	15	78	0.011	0.030	0.001	0.174	0.004	0.038	7
21	14	100	0.011	0.037	0.000	0.288	0.005	0.032	11
17	13	70	0.011	0.045	0.000	0.868	0.004	0.039	6
23	12	86	0.012	0.039	0.000	0.345	0.004	0.046	9
34	11	153	0.012	0.032	0.000	0.602	0.005	0.031	8
32	10	50	0.014	0.035	0.001	0.227	0.004	0.036	6
12	9	77	0.014	0.023	0.000	0.165	0.005	0.035	2
16	8	35	0.015	0.034	0.000	0.252	0.004	0.038	2
9	7	52	0.016	0.086	0.001	1.354	0.003	0.069	10
7	6	48	0.020	0.072	0.001	0.593	0.006	0.088	10
40	5	51	0.021	0.043	0.000	0.411	0.006	0.036	6
8	4	36	0.025	0.089	0.000	0.710	0.011	0.092	9
25	3	79	0.029	0.091	0.000	1.284	0.008	0.077	5
29	2	72	0.033	0.136	0.000	2.197	0.007	0.113	19
14	1	67	0.052	0.096	0.000	0.693	0.010	0.134	19
Total	41	2346	0.007	0.038	0.000	2.197	0.001	0.134	191

Table 8 presented above, which was ranked by median values, shows that 191 measurements (8 %) of the results taken in the 41 coal mines in the Mpumalanga coal mining area, over the period 2002 to 2006, exceeded the South African OEL of 0.1 mg/m^3. Of the 41 mines only eight did not report any results that exceeded this limit.

Figure 10 depicts the full range of measurements taken per mine, which exceed the 0.1 mg/m^3 OEL and 0.025 mg/m^3 TLV.

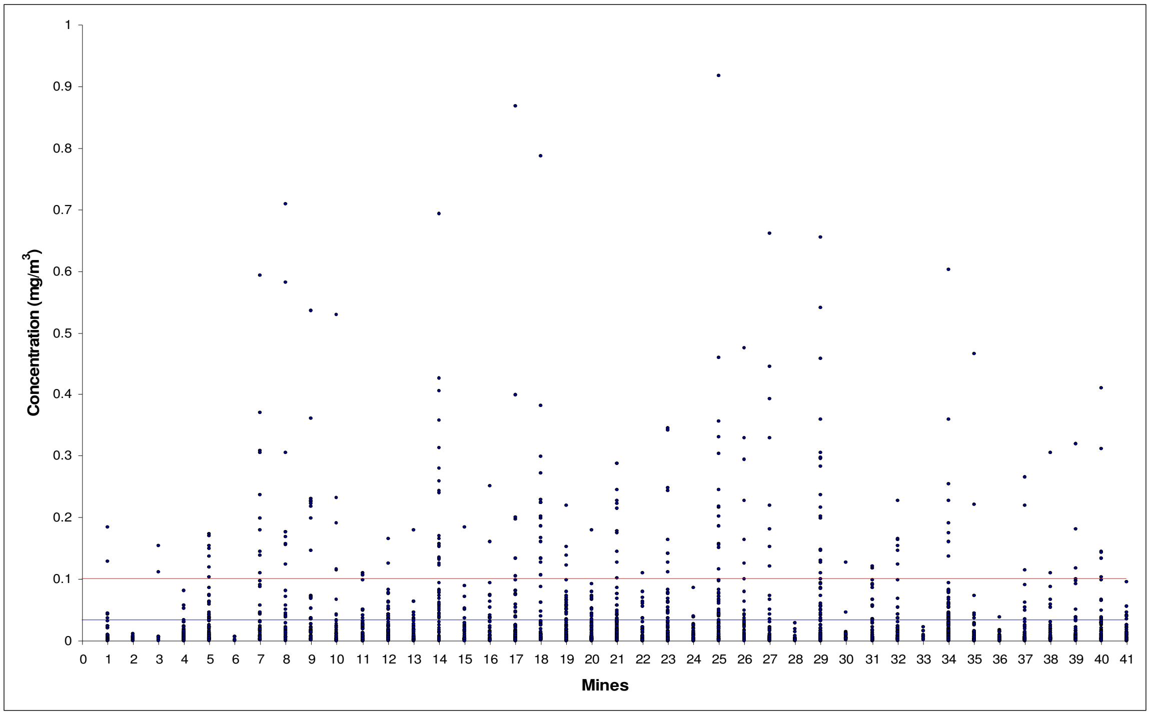

Figure 10. Range of respirable quartz concentrations in mg/m^3 for 41 coal mines in Mpumalanga over period 2002 to 2006, over the 0.1 mg/m^3 and 0.025 mg/m^3 limits.

For the purpose of generating Figure 10, measurements exceeding 1 mg/m^3, i.e. 6 thereof, were excluded; they were however not excluded from the data analysis as presented in Table 9.

Table 9 shows the data sets of the 41 coal mines in which the number of measurements per mine exceeding the ACGIH TLV and the South African OEL are depicted.

Table 9. *Summary of respirable quartz measurements exceeding the ACGIH TLV of 0.025 mg/m^3 and the South African OEL of 0.1 mg/m^3 in 41 coal mines in Mpumalanga over the period 2002 to 2006.*

Mine No.	n	No. Exceeding TLV (0.025mg/m^3)	No. Exceeding OEL (0.1mg/m^3)
1	45	7	2
2	10	0	0
3	10	2	0
4	54	6	0
5	78	28	7
6	4	0	0
7	48	21	10
8	36	18	9
9	52	20	10
10	55	13	5
11	64	14	2
12	77	24	2
13	56	10	1
14	67	44	19
15	42	9	1
16	35	14	2
17	70	21	6
18	86	29	16
19	96	28	4
20	97	20	1
21	100	33	11
22	53	9	1
23	86	30	9
24	40	5	0
25	79	36	5
26	76	21	7
27	73	16	9
28	16	1	0
29	72	38	19
30	28	2	1
31	52	18	2
32	50	15	6
33	9	0	0
34	153	50	8
35	54	9	2
36	62	1	0
37	83	8	3
38	45	5	2
39	42	9	3
40	51	18	6
41	40	8	0
Totals	2346	660	191

Table 9 presented above shows that 191 measurements (8 %) of the results taken in the 41 coal mines in the Mpumalanga area, over the period 2002 to 2006, exceeded the South African OEL of 0.1 mg/m^3. Six hundred and sixty measurements (28 %) exceeded the ACGIH limit of 0.025 mg/m^3.

2. OBJECTIVE 2 - RESULTS

Table 10 shows the number of results that exceed the South African DME OEL of 0.1 mg/m^3 and the ACGIH TLV of 0.025 mg/m^3 in the nine magisterial districts in which the 41 coal mines are located. It further describes the number of mines in the districts that exceeded both these limits.

Table 10. *Respirable quartz concentrations in Mpumalanga Magisterial Districts >0.1mg/m^3 and 0.025mg/^{3} over the period 2002 to 2006*

Magisterial District	No. Mines in District*	n	No. Results >0.1mg/m^3**	% Results >0.1mg/m^3	No. Results >0 025mg/m^3***	%. Results >0 025mg/m^3	No. Mines in District > OEL	No. Mines in District > TLV
Belfast	3	65	4	6	10	15	2	2
Delmas	1	54	0	0	6	11	0	1
Ermelo	4	166	26	15	66	40	3	3
Kriel	8	448	44	10	144	32	7	8
Middelburg	1	70	6	9	20	29	1	1
Piet Retief	1	86	0	0	29	34	1	1
Secunda	10	715	58	9	205	29	8	10
Standerton	1	72	20	28	38	53	1	1
Witbank	12	670	33	5	156	23	9	11
Total	41	2346	191	Ave 8%	674	Ave 29%	8(9)	9(9)

Note* No. of mines in the magisterial district that were sampled by CECS
Note** South African Occupational Exposure Limit (OEL)
Note*** American Congress of Governmental Industrial Hygienists Limit (TLV)

Table 10 presented above shows that eight out of the nine districts mines recorded results exceeding the OEL, whilst all the districts had mines which exceeded the TLV. It further shows that 191 measurements (8 %) of the results taken in the nine districts of the Mpumalanga area, over the period 2002 to 2006, exceeded the South African OEL of 0.1 mg/m^3. Six hundred and sixty measurements (28 %) exceeded the ACGIH limit of 0.025 mg/m^3.

The districts are ranked below based on their risk, i.e. percentage of results exceeding the OEL and TLV values are (ranked from low risk to high risk):

- Delmas;
- Pit Retief;
- Witbank;
- Belfast;
- Secunda;
- Middelburg;
- Kriel;
- Ermelo; and
- Standerton.

3. OBJECTIVE 3 - RESULTS

Table 3.4 shows the 24 activity areas by quartz concentrations, ranked by median values, and by concentrations exceeding 50 % of the 0.1 mg/m^3 OEL and 100 % of the 0.1 mg/m^3 OEL.

Table 11. *Respirable quartz concentrations (mg/m^3) in Mpumalanga coal mine activity areas exceeding 50% of 0.1 mg/m^3 and 100% of 0.1 mg/m^3 over the period 2002 to 2006*

Activity Area	Rank	n	Minimum	Maximum	Median	Inter Quartile Range		Proportion of Results >50% of OEL (%)	Proportion of Results >100% of OEL (%)
Dumps/Dump Recycling	24	11	0.000	0.602	0.002	0.001	0.006	10	9
Raw material	23	3	0.002	0.024	0.003	0.002	0.014	0	0
Surface Workshops	22	140	0.000	0.582	0.004	0.002	0.009	4	3
Shafts & Services	21	112	0.000	0.221	0.004	0.002	0.008	3	3
Roving Surface	20	248	0.000	0.305	0.004	0.002	0.008	4	2
Assay/Laboratory	19	20	0.001	0.058	0.004	0.003	0.010	10	5
U/g workshops	18	52	0.001	0.038	0.004	0.002	0.009	0	0
Roving Plant	17	196	0.000	2.197	0.005	0.002	0.013	5	3
Separation Processes	16	6	0.003	0.080	0.005	0.003	0.010	16	0
Crushing	15	6	0.003	0.080	0.007	0.004	0.020	16	0
Ground Handling	14	29	0.000	0.072	0.007	0.003	0.014	7	0
Opencast	13	91	0.000	0.466	0.007	0.003	0.016	10	5
Roving Underground	12	338	0.000	0.370	0.008	0.003	0.021	10	4
Unknown*	11	371	0.000	1.528	0.008	0.003	0.030	17	10
Screening/Grading	10	27	0.000	0.064	0.009	0.004	0.021	11	0
Development (Single shift)	9	12	0.003	0.050	0.013	0.009	0.029	0	0
Rock Mining Coal	8	21	0.001	0.134	0.015	0.004	0.062	29	10
Conventional Mining	7	127	0.000	1.354	0.023	0.009	0.043	25	9
Raise Boring/Dry Drilling	6	5	0.004	0.090	0.026	0.005	0.049	20	0
Stooping/Pillar Extraction	5	12	0.003	0.100	0.030	0.016	0.048	25	8
Development (Multiblast)	4	6	0.019	0.068	0.035	0.029	0.044	17	0
Continuous Miners	3	491	0.000	1.706	0.036	0.012	0.089	41	23
Handgot	2	1	0.036	0.036	0.036	0.036	0.036	0	0
Longwall Mining	1	21	0.001	0.259	0.044	0.009	0.134	47	38
All Activity Areas	24	2346	0.000	2.197	0.007	0.001	0.134	14	8

Note* Reporting of results in Activity Areas only commenced in 2003.

The longwall activity area reported the most results exceeding 50 % of the 0.1 mg/m^3 OEL and 100 % of the 0.1 mg/m^3 OEL; the continuous mines activity area followed this. Due to mining of coal occurring in these activity areas these results could have been expected.

Figure 11 depicted below displays the full range of measurements taken per activity area, compared to the 0.1 mg/m^3 OEL and 0.025 mg/m^3 TLV.

The activity areas are displayed according to their DME assigned code numbers. As stated in section describing Homogeneous Exposure Groups (HEG) Determination, these code numbers relate to the following activity areas.

Conventional Mining	01	Roving Underground	17
Continuous Miner	02	Underground Workshops	18
Longwall Mining	03	Raw Material	19
Handgot	04	Crushing	20
Stooping/Pillar Extraction	05	Screening and Grading	22
Rock Mining	06	Separation Process	23
Opencast	07	Roving Plant	30
Development Single Shift	09	Roving Surface	31
Development Multi blast	10	Assay/Laboratory	32
Raise Boring/Dry Drilling	12	Surface Workshops	33
Ground Handling	15	Dumps/Dumps recycling	34
Shafts and Services	16	Unknown	35

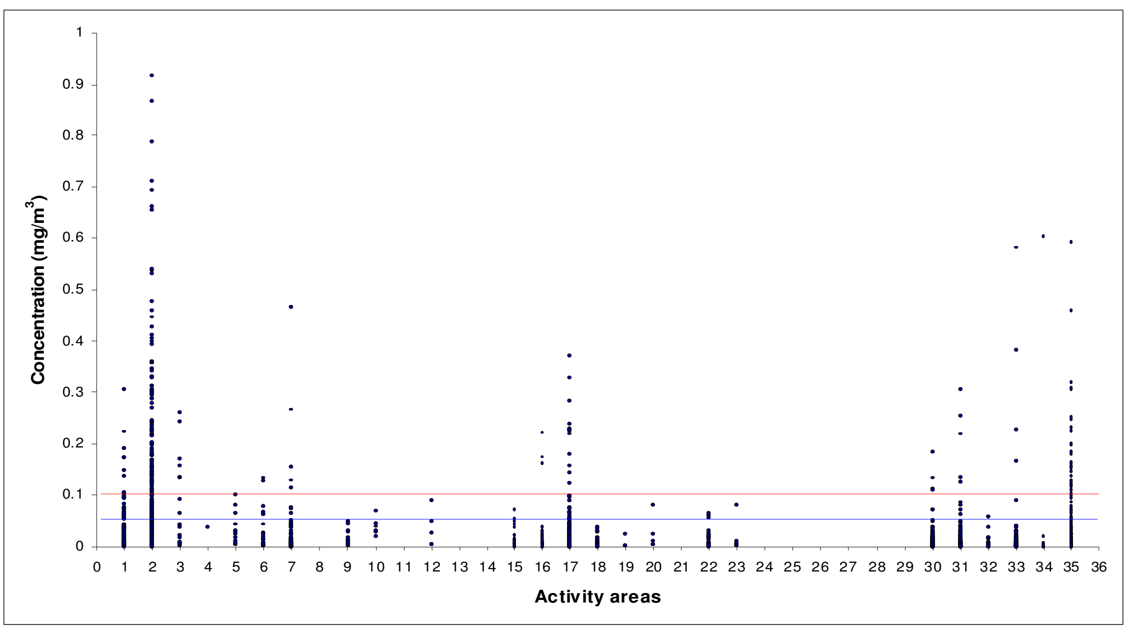

Figure 11. Range of respirable quartz concentrations in mg/m^3 for 24 activity areas in the 41 coal mines in Mpumalanga over the period 2002 to 2006, over the 0.1 mg/m^3 and 0.025 mg/m^3 limits.

For the purpose of generating Figure 11, measurements exceeding 1 mg/m^3, i.e. 6 thereof, were excluded; they were however not excluded from the data presented in Table 12.

Table 12 summarises the data sets of the 24 activity areas in 41 coal mines in which the number of measurements per activity area exceed the ACGIH TLV and the South African OEL.

Table 12. *Respirable quartz measurements exceeding the ACGIH TLV and the South African OEL of 0.025 mg/m^3 and 0.1 mg/m^3 respectively in 24 activity areas in the 41 coal mines in Mpumalanga over the period 2002 to 2006.*

Activity Area No.	Activity Area Description	n	No. Exceeding TLV (0.025mg/m^3)	No. Exceeding OEL (0.1mg/m^3)
1	Conventional Mining	127	63	10
2	Continuous Miner	491	287	103
3	Longwall Mining	21	13	8
4	Handgot	1	1	0
5	Stooping/Pillar Extraction	12	7	1
6	Rock Mining	21	8	2
7	Opencast	91	17	5
9	Development Single Shift	12	4	0
10	Development Multi blast	6	5	0
12	Raise Boring/Dry Drilling	5	3	0
15	Ground Handling	29	5	0
16	Shafts and Services	112	6	3
17	Roving Underground	338	74	12
18	Underground Workshops	52	6	0
19	Raw Material	3	0	0
20	Crushing	6	1	0
22	Screening and Grading	27	5	0
23	Separation Process	6	1	0
30	Roving Plant	196	21	5
31	Roving Surface	248	23	5
32	Assay/Laboratory	20	2	0
33	Surface Workshops	140	12	4
34	Dumps/Dumps recycling	11	1	1
35	Unknown	371	109	32
Totals		2346	674	191

Table 12 shows that the continuous miner, conventional mining and roving underground activity areas recorded the most measurements exceeding the TLV and OEL values of 0,025 mg/m^3 and 0.1 mg/m^3 respectively.

CHAPTER FOUR – DISCUSSION AND CONCLUSION

The aim of this chapter is to discuss the three objectives analysis results, as contained in chapter 3. For all three objectives there were 2346 measurement results obtained from 24 activity areas within the 41 mines which formed the project population.

1. OBJECTIVE 1

This objective required respirable quartz concentrations in 41 coal mines in the Mpumalanga region of South Africa over the period 2002 to 2006 to be described. Mine 21 undertook the most measurements, which was 100, whilst the least number of measurements taken by a mine was four (mine 6). Table 8 ranked the 41 mines from lowest to highest according to their median respirable silica concentrations; with mine number 14 being the highest ranked mine, with a median concentration of 0.052 mg/m^3. Mines 6, 28, and 36 had the lowest median concentrations of 0.003 mg/m^3.

There is a significant variability in the median and mean respirable quartz concentrations results. Overall median is 0.007 mg/m^3, whilst the mean is 0.038 mg/m^3, this variability is indicative of outliers being present in the measurement results. Outliers are defined as being observations that lie an abnormal distance from other values in a random sample from a population, possible causes of this could include:

- Intentional/unintentional "salting" of the sample;
- Instrumentation (pumps) not being properly calibrated;
- Weighing procedures being suspect; and
- Actual measurement;

Mean respirable quartz measurements ranged from 0 to 2.197 mg/m^3, ten of the 41 mines reported minimum respirable quartz concentrations of 0.001 mg/m^3.

Mine 29 reported a mean respirable quartz concentration of 0.136 mg/m^3 with the highest measurement of 2.197mg/m^3, the median being 0.033 mg/m^3. The mean and median concentrations are further indicative of the presence of outliers in the data sets.

The overall 25th percentile (first quartile) measurement result is reported to be 0.003 mg/m^3, whilst the 75th percentile (third quartile) measurement result is 0.038 mg/m^3. The overall mean and third quartile results reflect the same measurement result, which as shown in Figure 12 represents a skewing to the right.

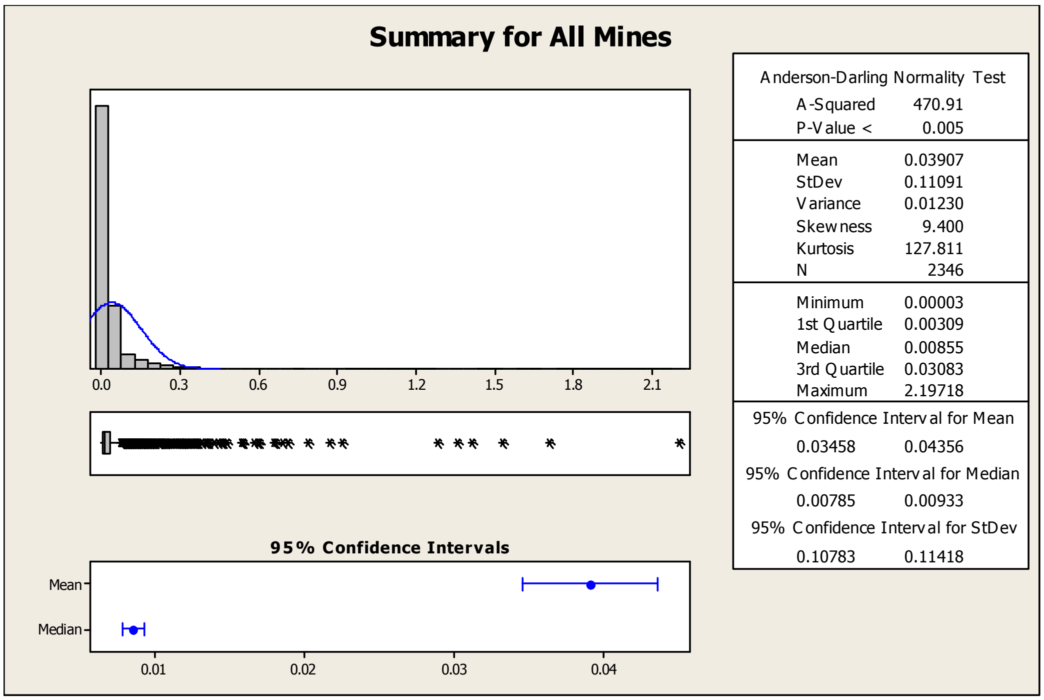

Figure 12. Data summary of respirable quartz concentrations in the Mpumalanga coal mine region over the period 2002 to 2006.

Any symmetric data set should have a skewness value of near to 0; this data set has a positive skew value of 9.402, which further indicates that the data is significantly skewed to the right. The kurtosis value of 127.864 indicates that the data set has a heavy tail. The kurtosis for a standard normal distribution is 3.

Of interest is that although some mines are ranked low, with regards to their median concentration, they have relatively large numbers of measurements that exceed the

OEL of 0.1 mg/m^3, e.g., mine numbers 27 and 3, ranked 4 and 13 (one being the lowest ranking), have 14 and 20 measurements exceeding the limit, whilst the 37th highest ranked mine has 12 measurements over the limit. This could be due to the mine specific inherent silica content in the coal seam, or due to mining of seams that have waste intrusions containing silica.

Table 9 reflects that the number of measurements exceeding the ACGIH TLV of 0.025 mg/m^3 and South African OEL of 0.1 mg/m^3 are 674 (29 %) and 191 (8 %) respectively. Seventy one percent of the measurements were below the ACGIH TLV of 0.025 mg/m^3.

2. OBJECTIVE 2

This objective required a comparison of respirable quartz concentrations in the nine magisterial districts of the Mpumalanga region of South Africa over the period 2002 to 2006, to the South African OEL of 0.1 mg/m^3 and the ACGIH TLV of 0.025 mg/m^3. Table 3.3 depicts this comparison. The majority of the mines, i.e. 30, are situated in the Kriel, Secunda and Witbank magisterial districts, these districts account for 78% of the total number of measurements taken. Four other districts, Delmas, Middelburg, Piet Retief and Standerton have only one mine, whilst the remaining two districts Belfast and Ermelo have three and four mines respectively.

A total of 191 measurements (8 %) exceeded the South African OEL of 0.1 mg/m^3 and 674 (29 %) the ACGIH TLV of 0.025 mg/m^3. The Secunda district had the most measurements that exceeded both sets of limits, i.e., 58 exceeding the South African OEL and 205 exceeding the ACGIH TLV. This district did however contribute to 30% of the total number of measurements taken. Mines in the Delmas and Kriel districts did not record any measurements that exceeded the 0.1 mg/m^3 OEL, however all districts recorded measurements exceeding the 0.025 mg/m^3 TLV.

3. OBJECTIVE 3

This objective required that the 24 activity areas, in which measurements were taken in the 41 coal mines in the Mpumalanga region of South Africa, over the period 2002 to 2006, which exceeded 50 % (action limit) of the South African OEL of 0.1 mg/m^3 be described. Table 11 ranked these activity areas from lowest to highest according to the median respirable silica concentrations. Note: Although this objective only required an analysis to be done on the action limit, a further analysis was also done on the OEL of 0.1 mg/m^3.

Four hundred and ninety one (21 %) of the total measurements taken were from the continuous miner activity area. The majority of measurements, i.e. 1784 (76 %), were from six activity areas, these been continuous miner, roving surface, roving plant, roving underground, surface workshops and the unknown category. Legislation only required the reporting of results per activity area from 2003, hence the unknown category of activity areas.

The longwall mining activity area is ranked the highest with a median concentration of 0.044 mg/m^3. Dumps/dump recycling activity area had the lowest median concentration of 0.002 mg/m^3. Only one measurement of 0.036 mg/m^3 was taken in the handgot activity area, which resulted in it being ranked as the second highest, it should therefore be interpreted with caution.

The highest respirable quartz concentration, 2.197 mg/m^3, was measured in the roving plant activity area, which was followed by measurements of 1.706 mg/m^3 and 1.528 mg/m^3 in the continuous miner and unknown activity areas respectively. The raw material activity area recorded the lowest measurement in the maximum category of 0.024 mg/m^3.

The highest ranked activity areas were in the production zones with the longwall mining activity area recording the most measurements that exceeded the 50 % action limit and 0.1 mg/m^3 OEL, these been 47 and 38 respectively. This activity area was followed in ranking by the following:

- Handgot;
- Continuous miners;
- Multi blast development;
- Stooping;
- Raise boring;
- Conventional mining; and
- Rock mining.

A total of four activity areas recorded nil measurements above these limits, these being raw material, underground workshops, development single shift and handgot.

Table 12 reflects that the number of measurements exceeding the ACGIH TLV of 0.025 mg/m^3 and South African OEL of 0.1 mg/m^3 are 674 (29 %) and 191 (8 %) respectively. Seventy one percent of the measurements were below the ACGIH TLV of 0.025 mg/m^3.

CHAPTER FIVE – LIMITATIONS, CONCLUSIONS AND RECOMMENDATIONS

The aim of this chapter is to discuss the limitations of the study, to conclude and make recommendations emanating from the outcomes of the three objectives of the study conducted on the 41 coal mines in Mpumalanga over the period 2002 to 2006.

1. LIMITATIONS

In order to determine the respirable quartz concentrations, samples were grouped for analysis purposes, therefore no individual personal respirable quartz exposures are reported. Grouping of samples for silica analysis by means of Infra Red does not allow for individual samples to be analysed for their percentage quartz content, which could have the implication of results been under or over stated.

The objectives for this study could have included the requirement for an analysis on airborne silica content to be reported on. This could have highlighted areas where high quartz contents are present, which would have had a significant impact on the respirable quartz concentrations.

Activity areas are not sub divided into tasks. This would have highlighted the individual job categories where high exposures are reported.

2. CONCLUSIONS

This study clearly indicates over-exposures to respirable quartz in selected settings in coal mines, in particular in the longwall (38 %) and continuous miner (23 %) activity areas. These results concur with that of Mukherjee [(14)], who in a study conducted in Indian coal mines describes that almost all of the longwall job categories exceeded the prescribed TLV. The number of results per job category that exceeded this limit varied between 66 % for loader operators to 27 % for DOSCO operators. In Bord and Pillar operations, although not using continuous miners, Mukherjee made similar comparisons on over exposures as this research report has described i.e., number of results per job category exceeding the TLV in production sections, which ranged from 65.1 % for drillers to 43.9 % of loader operators.

Mamuya [12] made an interesting observation that 94 % of the drilling task results in the development work area exceeded the TLV of 0.05 mg/m^3, whilst at the coal face only 13 % of the driller task results exceeded this limit. This could have been attributed to the varying airborne quartz concentrations in the two areas, i.e. development 6.3 % and at the coal face 3.9 %.

Mpumalanga coal workers employed in high risk activity areas are at risk of developing quartz-associated diseases, such as silicosis; this risk varies between the magisterial districts, with some displaying considerably higher over exposures than the rest, i.e. 28 % in the Standerton magisterial district, 15 % in the Ermelo district and 10 % in the Kriel district etc.

Note: Silicosis has recently been classified as a human carcinogen (Group 1) by the International Agency for Research on Cancer (IARC) [5]

An interesting finding is the correlation between this study and the research work conducted by Murray *et al.* [33] The NIOH study indicated that silicotic nodules were found in 7.3 % of autopsied coal miners (N=4), which could be an indication that 8 % of the miners investigated in this study could develop silicosis as 8 % of the respirable quartz samples reported in this study exceeded the South African OEL of 0.1 mg/m^3, as identified in the 41 coal mines in Mpumalanga over 200 2 to 2006.

As per Naidoo *et al,* employees at these 41 mines, which are being exposed to coal dust, are at risk of contracting diseases such as silicosis, tuberculosis, coal workers' pneumoconiosis (CWP), and moderate and marked emphysema. [38]

Further to the above, these miners that are exposed to coal dust, as per Attfield *et al.* may develop Progressive Massive Fibrosis (PMF), as their research concluded that clear relationships existed between prevalence's of both CWP and PMF. The research indicated that between 2 % and 12 % of miners exposed to a 2 mg/m^3 dust environment in bituminous coal mines would be expected to have Category 2 or greater CWP after a 40-yr working life; PMF would be expected for between 1.3 % and 6.7 %. [27]

As described by Lapp *et al*. miners working in the mines investigated in this study may also experience chronic obstructive pulmonary disease. [17]

In conclusion coal miners in the Mpumalanga coal mining region, working in the 41 mines over the study period are at risk of contracting the following diseases:

- Silicosis;
- Coal Workers Pneumoconiosis;
- Chronic Obstructive Airway disease;
- Progressive Massive Fibrosis;
- Reduction in Forced Respiratory Volume;
- Bronchitis; and
- Emphysema

Persons working in the longwall (38 % over exposed) and continuous miner (23 % over exposed) activity areas are most at risk of contracting occupational diseases related to exposure to respirable quartz. These areas are the main coal producing areas on coal mines; hence persons working in these areas are more at risk to exposures to dust. The concern that this project has identified is the magnitude of these exposures to respirable quartz. Generally these coal mines would have prioritized data relating to exposures to coal dust, which has a South African OEL of 2.0 mg/m^3. Quartz analysis occurs at the completion of a sampling cycle, which depending on the HEG categorisation category could occur after 3, 6 or 12 months. At the best, i.e. following a 3-month sampling cycle, actual quartz concentrations would only be obtained approximately 4 to 5 months after the sampling process. This results in timeous interventions from being implemented to prevent employee exposures to respirable quartz.

3. RECOMMENDATIONS

In order to mitigate these health risks the following recommendations are proposed:

- Individual samples taken from the high risk activity areas, i.e., longwalls and continuous miner sections should be individually analysed for their percentage respirable quartz content. This will allow for accurate and timeous determinations to be made of worker exposures to respirable quartz, allowing appropriate interventions to be implemented within an acceptable time period.

- A need for further research into dust controls at longwall and continuous miner section activity areas is recommended. Dust laden air must be prevented from being liberated from the mining operations into the breathing zone.

- The effectiveness of present implemented interventions needs to be investigated. Investigation should include the following:
  1. Compliance with mine operational standards;
  2. Compliance with mine maintenance procedures and schedules; and
  3. Operator and supervisor knowledge on the use of current interventions and reporting of malfunctioning equipment.

- Area monitoring should be considered to determine if current control systems and newly implemented control systems are operating effectively according to manufacturers specifications.

- A need for further research into the airborne silica content is recommended. This would highlight areas in which high contents are prevalent.

- A need for further research into the individual job categories, within an activity area is recommended. This would highlight specific tasks in which high exposures to respirable quartz is occurring.

- Awareness programmes should be initiated at all coal mines where the effects of exposure to respirable quartz are described to all levels of employees.

- Furthermore the various controls in place are to be discussed, together with any recommendations that may arise from the employees.

REFERENCES

1 Coal Formation. <http://www.planete-energies.com/content/coal/formation.html [Accessed 2.1.2008].

2 Dubovsky, H. Pneumoconiosis and tractor ploughing. South African Medical Journal. 1999;89:366.

3 Lurie, J. South African Geology for Mining, Metallurgical, Hydrological and Civil Engineering. ISBN 0 07 091350 1, 1985.

4 Chamber of Mines of South Africa 2007: Annual review of the Coal Mining Industry in South Africa. <http://www.bullion.org [Accessed 8.1.2009].

5 International Agency for Research on Cancer (IARC): IARC Monographs of the Evaluation of the Carcinogenic Risk of Chemicals to Humans. Silica and Some Silicates. Lyon, France: IARC, 1997.

6 Mine Health and Safety Council: Proceedings of the 2003 Mining Summit, 2003.

7 David W Stanton *et al:* South African Mining Best Practice on the Prevention of Silicosis. Mine Health and Safety Council, March 2006.

8 Mine Health and Safety Act (29/1996): Amendment to the Regulations in respect of occupational hygiene R. 989. p3, Gazette no. 29276.

9 Department of Minerals and Energy: South African Mines Occupational Hygiene Code Book, 2002.

10 American Conference of Governmental Industrial Hygienists:Threshold Limit Values handbook, 2008.

11 Department of Minerals and Energy: Guideline for the compilation of a mandatory Occupational Hygiene Code of Practice for Airborne Pollutants, 2002 and revised edition approved by the Mine Health and Safety Council, 2002.

12 Mamuya S *et al*: High exposure to respirable dust and quartz in a labour intensive coal mine in Tanzania. *Annals of Occupational Hygiene*, 2006;50:197-204.

13 Piacitelli G *et al*: Respirable dust exposures in US surface coal mines over 1982-1986. *Annals of Occupational Hygiene*, 2006;50:197-204.

14 Mukherjee A *et al*: Assessment of respirable dust and its free silica contents in different Indian coal mines during. *Industrial Health*, 2005;43:277-284.

15 Federov I: ILO/WHO Global Programme for the Elimination of Silicosis, 2003.

16 Coggon D and Taylor A N: Coal mining and chronic obstructive pulmonary disease: a review of the evidence. *Thorax* 1998;53;398-407.

17 Lapp NL, Morgan WKC, Zaldivar G: Airways obstruction, coal mining and and disability. *Occup Environ Med*,1994;52:234-8.

18 Higgins TT, Oldham PD: Ventilation capacity in miners. *Br J Ind Med*, 1962:19;65-76.

19 Lloyd MH, Gauld SJ, Soutar CA: Respiratory ill health among coal workers and telecommunication workers in South Wales. *Br J Ind Med*, 1986:43;177-81.

20 Nemery B, Brasseur L, Venter C, *et al*. Impairment of ventilation function and pulmonary gas exchange in noin smoking coal miners. *Lancet*, 1987;1427-30.

21 Rogan JM, Attfield MD, Jacobsen M, *et al*. Role of dust in the working environment in development of chronic bronchitis in British coal miners. *Br J Ind Med*, 1973;30:217-26.

22 Oxman AD, Muir DCF, Shannon HS *et al*. Occupational dust exposure and chronic obstructive pulmonary disease. *Am Rev Resp Dis*, 1993;148:38-48.

23 Rockette HE. Cause specific mortality of coal miners. *J Occup Med,* 1977;19:795-801.

24 Cochrane AL, Haley TJL, Moore F, *et al*. The mortality of men in the Rhonda Fach 1950-1970. *Br J Ind Med*, 1979;36:15-22.

25 Atuhaire LK, Campbell MJ, Cochrane AL, *et al*. Mortality of men in the Rhonda Fach 1950-1980. *Br J Ind Med*, 1985;42:741-5.

26 Miller BJ, Jacobsen M. Dust exposure, pneumoconiosis and mortality of coal miners. *Br J Ind Med*, 1985;42:723-33.

27 Attfield MD and Morring K. An investigation into the relationship between coal workers pneumoconiosis and dust exposure in US coal miners. *Br J Ind Med*, 1985;42:723-33.

28 Borm PJ and Tran L: From quartz hazard to quartz risk: the coal mines revisited. *Annals of Occupational Hygiene,* 2002;46:25-32.

29 Attfield MD and Seixas NS: Prevalence of pneumoconiosis and its relationship to dust exposure in a cohort of U.S. bituminous coal miners and ex-miners. Br J Ind Med, 1988;42:743-48.

30 Montes II. Respiratory disease in a cohort of 2579 coal miners followed up over a 20-year period. CHEST, 2004; 126:622-629.

31 Naidoo R, Seixas N and Robins T. Estimation of respirable dust exposure among coal miners in South Africa. Journal of Occupational and Environmental Hygiene, 2006;3(6):293–300.

32 Rees: Silicosis elimination in South Africa, National Institute for Occupational Health, School of Public Health, University of the Witwatersrand, South Africa. IOHA 2005.

33 Murray J, Ndlovu N *et al*. National Institute of Occupational Health. Pathology division surveillance internal report: Demographic data and disease rates for January to December 2006.

34 Steen T et al. Prevalence of occupational lung disease among Botswana men formerly employed in the South African mining industry. *Occupational and Environmental Medicine* 1997;54:19-26.

35 Trapido A. Prevalence of occupational lung disease in a random sample of former mineworkers, Libode district, Eastern Cape Province, South Africa. *Am. J. Ind. Med*, 1998;34:305-313.

36 Cowie R.L: The epidemiology of tuberculosis in gold miners with silicosis. *Am J Respir Crit Care Med,* 1994;150:1460-1462.

37 Corbett E.L. Churchyard, G.J. Clayton, *et al*. HIV infection and silicosis: the impact of two potent risk factors on the incidence of mycobacterial disease in South African miners. *AIDS,* 2000;14:2759-2768.

38 Naidoo R. Robins T. Murray J: Respiratory outcomes among south African coal miners at autopsy. *American Journal of Industrial Medicine*, 2005;48:217-224.

39 Mine Health and Safety Inspectorate Annual Report, 2005/6.

APPENDIX 1 **Statutory Reporting Input Form**

CHAPTER 21

Airborne Pollutants - Particulates Personal Exposure Report Form 21.9(2)(a)

In terms of regulation 9.2. (7)

General:

1. Reporting Period as per table below.

HEG Category Classification Band	Airborne Particulates
A	Quarterly reports ending March, June, Sep and December
B	Bi-annual reports ending June and December
C	Annual reports ending December

2. The monitoring frequency and number of samples to be used are specified in the SAMOHP
3. Complete one form for each homogeneous exposure group
4. Codes to be used in this form are specified in the SAMOHP
5. Attach Operation Details – Report Form 21.9(2)(f) when submitting asrequired by regulation 9.2(7)
6. The results of samples taken from randomly selected occupations within a HEG must be assigned to that specific occupation code, where occupations within a HEG were not sampled the HEG mean pollutant concentration must be allocated to those occupations.
7. All sample concentrations must be 8 hour equivalents

Information in shaded area not to be included in statutory report submitted to DME; see examples in SAMOHP Code Book

Main Commodity Code:	
Sample Area	
Activity Area Code:	
HEG Classification Band (90th Percentile value of pollutant concentration):	

DME Mine Code:	
Sub Mine Code:	
Reporting Period:	
Start	End

HEG		Pollutant Code	Sample Concentration per Occupation (TWA-8h) mg/m³	Analysis %	Mean Pollutant Concentration Dose Allocated to Medical Record (Tick appropriate box) mg/m³ f/ml	90th Percentile HEG Classification	Range of Pollutant Concentration		OEL (Tick appropriate box) mg/m³ f/ml	Pollutant Index	AQI
Occupations Codes in HEG	Number of Persons per Occupation		(A)	(B)	(C=Avg A*B%)		Min	Max	(D)	(E=C/D)	(F=SUM E)
Total											

* Note: Mean Pollutant Concentration needs to be calculated at 95% Confidence Interval (see explanation in SAMOHP Code Book)

APPENDIX 2 CECS Permission letter

Permission Letter Obtained From CECS to Use Their Data

A Division of Colliery Training College (Pty) Ltd.
Incorporated in the Republic of South Africa
Reg. No. 1965/007106/07

Collieries Environmental Control Service

MANAGER'S OFFICE
P.O. BOX 206; EVANDER; 2280
TEL.: (017) 632 1030/1
FAX.: (017) 632 4125
E-mail : cecs@secunda.co.za

Ref.: 08/03/07

21 August 2007

TO WHOM IT MAY CONCERN

Sir/Madam

CONSENT FOR USE OF DATA

It is hereby certified that permission has been granted to Mr. B.A. Doyle to use the data supplied by us for analysis purposes.

The data supplied does not contain any names of collieries under investigation, nor does it contain any personal information that could lead to the identification of any company or individual.

A copy of the final report is required for verification and informatory purposes.

Yours sincerely.

D.J. DE VILLIERS
MANAGER : CECS

DIRECTORS

P.C. Henderson, Z. Jojwana, A.F. Roux, P.A. Scheepers, J.H.L. van Rensburg, P.Y. Williamson (Chairman)

APPENDIX 3 NIOSH Analytical Method

SILICA, CRYSTALLINE in coal mine dust, by IR 7603

SiO_2 MW: 60.08 CAS: 14808-60-7 RTECS: VV7330000

METHOD: 7603, Issue 2 **EVALUATION:** UNRATED **Issue 1:** 15 May 1989 **Issue 2:** 15 August 1994

quartz (respirable):
OSHA : 10 mg/m³/(%SiO_2 + 2)
NIOSH: 0.05 mg/m³ (suspect carcinogen)
ACGIH: 0.1 mg/m³

PROPERTIES: solid; crystalline transformations: quartz to tridymite @ 867 °C: tridymite to crystobalite @ 1470 °C; α-quartz to β-quartz @ 573 °C

SYNONYMS: free crystalline silica; silicon dioxide

SAMPLING

SAMPLER: CYCLONE + PREWEIGHED FILTER (10-mm cyclone, nylon, or Higgins-Dewell (HD), and PVC filter, 37-mm, 5-µm)

FLOW RATE: HD cyclone: 2.2 L/min
nylon cyclone: 1.7 L/min

VOL-MIN: 300 L @ 0.1 mg/m³
-MAX: 1000 L

SHIPMENT: routine

SAMPLE STABILITY: stable

BLANKS: 2 to 10 field blanks per set

BULK SAMPLE: required for OSHA standard calculations; area respirable or settled dust

ACCURACY

RANGE STUDIED: 25 to 160 µg/sample [1] (2 mg quartz/m³ atmosphere)

BIAS: unknown

OVERALL PRECISION ($\hat{S}_{rT}$): 0.13 to 0.22 (varies with sample loading and matrix)

ACCURACY: ±25.6 to 43.4%

MEASUREMENT

TECHNIQUE: INFRARED SPECTROPHOTOMETRY (IR)

ANALYTE: quartz

WEIGH: dust cassette

ASH: muffle furnace or RF plasma asher

REDEPOSIT: 0.45-µm acrylic copolymer membrane filter

IR: scan, 1000 to 650 cm^{-1}, absorbance mode with blank filter in reference beam

CALIBRATION: standard suspension of quartz in 2-propanol

RANGE: 30 to 250 µg quartz per sample [1]

ESTIMATED LOD: 10 µg quartz per sample [1]

PRECISION ($\hat{S}_r$): 0.098 @ 100 to 500 µg per sample (varies with sample matrix) [1]

APPLICABILITY: The working range is 0.03 to 2 mg/m³ for a 1000-L sample. The method was specifically developed for respirable coal mine dust samples [2]. The precisions ($\hat{S}_r$ & $\hat{S}_{rT}$) stated above are based on ruggedization data [1].

INTERFERENCES: Calcite is used as a dusting agent in coal mines and interferences by reacting with quartz during muffle furnace treatment resulting in low quartz assay. Kaolinite is sometimes present in coal dust and interferes by absorbing radiation at the quartz analytical wavelength of 800 cm^{-1}. These interferences are corrected by procedures given in this method. Muscovite does not interfere. Cristobalite and tridymite have absorbance peaks at 800 cm^{-1}. Cristobalite and tridymite have not been detected in coal mine dust.

OTHER METHODS: This method was based on an unpublished Bureau of Mines method that was collaboratively tested [1]. Quartz can also be determined by NIOSH Methods 7500 (XRD), 7602 (IR), and 7601 (UV-VIS) and MSHA Method P7 [3].

NIOSH Manual of Analytical Methods (NMAM), Fourth Edition, 8/15/94

APPENDIX 4 Ethics Approval

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

Division of the Deputy Registrar (Research)

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)
R14/49 Doyle

CLEARANCE CERTIFICATE	**PROTOCOL NUMBER M080336**
PROJECT	Respirable Quartz in Coal Mines in the Mpumalanga region of South Africa over 2002 to 2006
INVESTIGATORS	Mr BA Doyle
DEPARTMENT	School of Public Health
DATE CONSIDERED	08.03.25
DECISION OF THE COMMITTEE*	Approved unconditionally

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

DATE 08.04.09 **CHAIRPERSON** ....
(Professor P E Cleaton Jones)

*Guidelines for written 'informed consent' attached where applicable

cc: Supervisor : Mr A Swanepoel

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10004, 10th Floor, Senate House, University.
I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee. **I agree to a completion of a yearly progress report.**

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES