SAFETY IN MINES RESEARCH ADVISORY COMMITTEE

FINAL REPORT

Proposed rational strategic criteria for routine measurement of exposure to respirable dust in South African mines

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Executive Summary

The incidence of lung and respiratory system diseases in workers employed in the South African Mining Industry is unacceptably high. Dust has been recognized as the most serious occupational health hazard across the South African Mining Industry. The need to address this problem in its totality requires the creation of effective monitoring systems designed to estimate the exposure of workers to dust for epidemiological purposes. Systems employed in South Africa up to now have proved to be inadequate to characterize workers' exposure to respirable dust for the purpose of providing a basis on which epidemiological studies may be structured and to provide a database of information for medical surveillance.

As part of the background work to this project, extensive research into the pathogenic effects of dust failed to deliver conclusive evidence as to which dust property or combination of properties is responsible for the pathogenesis of respirable dust. An important assumption made in defining the sampling criteria outlined in this report is that, due to this lack of this knowledge, it is assumed that full shift gravimetric sampling should be employed as a surrogate measurement of exposure.

The criteria presented in this report are based on subdividing the exposed workforce into a number of sectors within the South African Mining Industry. Each sector is representative of similar mineral/ore/commodity production defining to a broad extent exposure as a function of the mining method. Each sector is divided further into sub-sectors that relate to various, broadly similar activities within the production and beneficiation cycle. It is assumed that the full shift samples collected as part of this programme are associated with an occupational group defined in this manner - although it is accepted that gravimetric sampling alone is not the most accurate surrogate for dust exposure. However, this method may be useful to gather data representative of the respirable fraction of the dust inhaled by workers and could be used to validate some of the assumptions made. This data, together with the "fingerprinting" of samples done in parallel with the gravimetric sampling, could provide a meaningful base from which information may be generated for future monitoring programmes.

It is stressed that the strategy defined by these criteria must be underpinned by a series of parallel and coordinated pilot studies aimed at increasing the volume of meaningful information required to obtain valid and accurate information on exposures.

It is proposed that all data collected from each mine be stored in a single data management system. This system will be used to analyse the data and to produce a reports that will reflect trends of exposures for mines, mining sectors and the Mining Industry as a whole. The data management system will also enable medical practitioners and researchers to assign a surrogate exposure levels to every worker given the worker employment history.

The work presented in this report discusses criteria only for a proposed method of sampling. It is recommended that these criteria be encompassed into a more detailed set of guidelines that will facilitate the implementation of a new sampling strategy on every mining operation

The criteria for routine sampling discussed in this report are part of the efforts necessary to reduce workers' exposure to dust and ultimately reduce the incidence of occupational lung diseases. The strategies proposed are supportive of an overall initiative aimed at achieving these objectives. The creation of a managed centre of data and information should be seen as the nucleus for much broader research efforts and intervention activities. Within an industry that experiences a high incidence of occupational respiratory diseases (primarily silicosis and tuberculosis) superimposed to a high incidence of HIV/AIDS amongst mineworkers, it is felt that this wider, more co-ordinated and revitalized research programme will address adequately the impact of these diseases. It is important, therefore, that the creation of such a system not be seen in isolation and should be structured to allow for the expansion necessary to accommodate the need of future initiatives.

The strategies, leadership and co-ordination required for these initiatives should be sourced from a central body representative of all stakeholders. Furthermore, although important, the determination of workers' exposure is but a part of a properly structured and effective drive designed at characterizing the emission of dust from a number of mining activities and at designing effective suppression methods that will eventually reduce workers' exposure. The generation of information about workers' exposures to respirable dust is the basis on which knowledge linking exposure to outcome is structured. A process designed at studying and minimizing emission of dust into the environment must complement any initiative that may arise from this work.

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Abbreviations

ACGIH	American Conference of Governmental Industrial Hygienists
ASTM	American Society for Testing and Materials
BMRC	British Medical Research Council
C_i	Corrected initial filter mass (mg)
C_f	Corrected final filter mass (mg)
CEN	Committee on European Standardization
CM	Continuous Miner
CWP	Coal Worker's Pneumoconiosis
CWSP	Coal Worker's Simple Pneumoconiosis
DME	Department of Minerals and Energy (S A)
ECSC	European Committee of Science Council
ESM	Estonian Standard Method
FCS	Free Crystalline Silica
Fl	Sample flow rate (m^3/min)
FRG	Federal Republic of Germany
IARC	International Agency for Research on Cancer
IPM	Inhalable Particulate Mass
ISO	International Organization for Standardization
LTR	Last Through Road
MRC	Medical Research Council (SA)
MSHA	Mine Safety and Health Administration (USA)
NCB	National Coal Board (UK)
NCOH	National Centre for Occupational Health (SA)
NIOSH	National Institute of Occupational Safety and Health (USA)
OSHA	Occupational Safety and Health Administration (USA)
PEL	Personal Exposure Limit
PMF	Progressive Massive Fibrosis
RPM	Respirable Particulate Mass
SA	South Africa
SC	Sample dust concentration (mg/m^3)
SEM	Scanning Electronic Microscopy
SSM	Swedish Standard Method

T	Sampling time (min)
TLV	Threshold Limit Value
TLV-TWA	Threshold Limit Value - Time Weighted Average (From the ACGIH)
TPM	Thoracic Particulate Mass
TWA-CONC.	Time-weighted average dust concentration
UK	United Kingdom
USA	United States of America
USSR	United Sovereign Soviet Republic
WHO	World Health Organization

Symbols

µm	micrometer
g/m^3	grams per cubic meter
l/min	litres per minute
m/s	metres per second
m^2	square metres
m^3/s	cubic metres per second
mg/m^3	milligrams per cubic metre
mm	millimetre
nm	nanometre

1 Introduction

Silicosis and other occupational respiratory diseases are the most severe occupational health hazards encountered in mining operations. This conclusion was drawn by Gürtünca in 1997 and shows that, in terms of risk, dust induced lung disease is amongst the highest contributors to loss of working life expectancy in all sectors of the South African Mining Industry (1). The research work, on which this report is based, also indicates that there are a number of uncertainties in arriving at these risk values. These are related mainly to the way in which sampling equipment is designed and used to determine exposure or risk for workers in different occupations (2). These variations are ascribed mainly to the variable nature of dust clouds and to the difficulties experienced in operating the instrumentation used in a way that replicates the varying respiration rates. The SIMRISK report, although considering the effects of radiation-induced cancer, does not consider the synergism between inhaled dust, diesel particulate and radionuclides as a quantifiable risk.

The incidence of silicosis in the South African Mining Industry is relatively high – the gold mining industry alone contributing to some 2000 new cases annually (3). The costs relating to the care of workers and compensation place a significant and increasing burden on the public, business and private sectors. In addition, the high incidence of HIV/AIDS amongst mine workers compounds the complexity of the situation and exacerbates the need to ameliorate the environmental conditions to which mine workers are exposed.

The purpose behind SIMRAC project SIMRISK 401 was to prioritise all risks encountered in the South African Mining Industry thereby assisting SIMRAC in prioritising future research efforts. This project is the result of one of the recommendations made in SIMRISK 401: "... the problems in the Occupational Health area have been neglected over the years and the research efforts should be built over the future years to address the problems in this area. Firstly, the problems should be quantified by constructing comprehensive databases and research should be carried out to understand the epidemiology in these areas. This would enable a soundly based research strategy to be developed in the Occupational Health Area." (1).

The work commissioned by SIMRAC and presented in this report is aimed at gaining a greater understanding of occupational respiratory diseases. The brief to the project team was that the criteria should be aimed at defining sampling to be used in epidemiological studies. It should not be seen as a classic occupational hygiene tool aimed at controlling dust levels directly but rather as a step in defining more closely the epidemiology of diseases caused by respirable dust. The outcome of this work is to form part of a series of inputs aimed at structuring a definite strategy aimed at combating these diseases.

2 Scope and methodology

The project was sub-divided into four distinct phases:

- Phase 1: A review of the pathogenic characteristics of dusts encountered in South African mines.
- Phase 2: A critical review of the scientific principles underlying present rational sampling procedures for the routine measurements of occupational exposure to airborne contaminants.
- Phase 3: A critical review of routine dust sampling protocols and procedures adopted in South Africa and globally.
- Phase 4: Compilation of criteria based on findings.

In phases 1, 2 and 3 of this project, analysis of the status–quo regarding dust sampling procedures and the pathological properties of dust was performed. The purpose of this was to seek guidance as well as assessing which methodologies could best be included in the criteria considering the brief given.

It is significant to note that in analysing the risk profile as part of project SIMRISK 401, researchers concluded that in occupational health hazards, and in particular, when considering respiratory diseases, " …issues relating to lack of understanding of the risk dominate" risk considerations. Work by Beadle (1967) and Unsted (1995 and 1996) point to the absence of scientifically meaningful data and measurement methodologies that would be indicative of routine dust exposure levels for workers. The challenge that faced the project team was to define a set of criteria that could be applied at present and in the future given the possibility that further research would be motivated to reduce such uncertainties and information lacunae.

It is stressed at this stage that strategic criteria were prepared considering the hazard posed by dust alone. Due care was taken in structuring these criteria and some cognisance was taken of other air pollutants such as fibres, diesel exhaust particulates and radionuclides. However, priority was given in examining the problem with respect to airborne dusts. The presence of the other pollutants may require further refinements should this strategy be used to link workers' exposures to the other respirable contaminants listed above.

3 Findings

3.1 Background

Dust is an immediate by product of any type of industrial operation, both underground and surface, involving ores and minerals. Preparation plants, processing plants and materials-handling sites such as harbours are also operations that present a wide variety of dust problems.

Dust is defined as a solid particle aerosol (excluding the fibre) formed by the mechanical disintegration of a parent material by various processes such as crushing and grinding. An aerosol is in turn defined as an airborne particle, solid or liquid and the surrounding gases – air or vapours (ACGIH 1998). In mining operations, dust is generated in the blasting, crushing, grinding transfer, and transport of minerals.

An aerosol consists of particles and the gas in which they are suspended. All aerosols are temporally unstable, i.e. they experience change with the passage of time. Some important aerosol characteristics that can change are: total mass concentration of a contaminant (sum of mass concentrations in the vapour and particle phases), the fraction of a contaminant in the particle or vapour phase, and particle size distribution. A wide variety of aerosol instabilities must be considered because they may influence sampling strategy, occurrence of artefacts in samples, and extrapolation of aerosol characteristics to earlier or later times (Soderholm, 1990).

Air contamination occurs whenever an atmospheric pollutant is emitted by a source. It may mix with and be diluted by ambient air and it travels to a target, which may be a person, an object or an area where it has the potential to exert an effect, usually after being deposited. The physical dimensions involved in this process may be millimetres to kilometres and the times may be milliseconds to virtually years. Air sampling may be performed near the source, in the ambient air, or near the target to characterize the source emission, identify the source, or predict the quality and quantity of the contaminant reaching the target.

Aerosol behaviour needs to be taken into account when dust sampling strategies and techniques are considered. The implications of particulate characteristics and behaviour on the repeatability of results should be borne in mind when compliance testing is considered.

Three important questions need to be answered when particulate sampling strategies and techniques are considered:

1) What should be measured?
2) What can be measured?
3) What are the exposure limits of the pollutants?

When considering a cocktail of contaminants there are additional questions to be asked:

1) Which are the most important or significant pollutants?
2) What are the major risk factors?
3) What are the potential health effects?
4) Which determinants of exposure are relevant in the mining industry?

Answers to all these questions need to be established before embarking on what, why, where, when and how to sample exposure in the workplace.

An understanding of the physical properties of airborne particulates will often be beneficial in formulating monitoring strategies, assuming the pathogenesis is also understood.
A number of parameters or combination of these parameters have been made to define or describe airborne particulates, especially dust, and the extent to which they are present in the atmosphere. The airborne hazard may be characterized in terms of:

1) the number of particles per unit volume
2) the size distribution of the particles
3) the mass per unit volume
4) the surface area, especially of dust
5) the chemical composition
6) the mineralogical nature of the particles

The first four of these parameters are dependent on the mode of formation as well as on the physical properties of the particles themselves, especially with the passage of time. Size distribution is of prime importance because the particle size governs the length of time for which the particle will remain suspended in the air, the manner in which it will settle and the air velocity required to remove the particles from the workings. Furthermore, the size of the particles will determine how the human body will deal with the assault of the particles and the penetration and retention characteristics of the particles, (Schroder, 1982).

The atmospheric environment in a mine can be regarded as a microcosm of the Earth's atmosphere. Where air enters a mine it contains the particulates associated with the geographical location of the mine. In the mine workings there may be a wide variety of activities and processes creating or dispersing additional particulates. Mineral dusts produced by mining operations generally represent the more important source of additional particulates in mine atmospheres but diesel soot, oil mists from drills and other machinery, pathogenic micro flora and particulates from other sources may be equally important in some work environments.

Although sources of dust are well known little is known about characterizing a source or cloud of dust in terms of all the physical parameters outlined above. It is not known, for instance, if the size distribution of dust from drilling operations is the same as or even similar to that from, for example, tipping operations. Furthermore, variation in size distribution from identical dust producing operations does not appear to have been studied or documented.

Pneumoconiosis is the general term used for diseases of the lungs caused by dusts. Pneumoconiosis is defined as "a diagnosable disease of the lungs produced by the inhalation of dust, the term being understood to refer to particulate matter in the solid phase, but excluding living organisms," (3rd International Conference of Experts on Pneumoconiosis, 1950). There are many types of pneumoconiosis such as silicosis, siderosis and fibrosis. The hazard of breathing dust depends greatly on the composition of the dust, the concentration, particle size and duration of exposure. The aetiology of pulmonary diseases varies depending on the pollutant(s) inhaled and depends on the way in which they affect the different regions of the respiratory system where they may be deposited.

The presence of crystalline free silica, commonly called quartz, can cause silicosis, which is a disabling, irreversible form of pneumoconiosis. Silicosis is incurable and results in disability or death and is caused by the deposition of silica dust in the alveolar region of the lungs. The silica has a debilitating effect on the metabolism of the alveolar microphages, promoting fibrosis of the lung tissue. As the fibrosis spreads, the gaseous exchange function of the affected tissue is impaired. This gives rise to difficulty in breathing and fatigue (NIOSH, 1995). In smokers, silica dust may result in the lesion of the alveolar wall and in emphysema. The effect of silica on the macrophage metabolism may also lead to the weakening of the anti-bacterial defence of the lung tissue and increasing the risk of workers contracting pulmonary tuberculosis.

In 1997, crystalline silica in the form of quartz or cristobalite was categorised as a human carcinogen by the International Agency for Research on Cancer (IARC).

Black lung or Coal Worker's Pneumoconiosis (CWP)" was recognized in Britain over 300 years ago (Evelyn, 1661). In the 1800s disease was referred to as *spurious melanosis, miners' asthma, anthracosis, black phthisis and silicosis* (Gregory, 1831; Laennec, 1819; Pearson, 1813; Gibson, 1833, Makellor, 1845). Up until the 1920s it was thought that lung disease associated with coal mining was caused by silica dust rather than the coal dust itself.

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

Other contaminants such as lead can be absorbed through the alveolar wall into the blood stream to be deposited into the kidneys for later excretion. In general, particulate matter not exhaled, and not absorbed by the lungs will be expelled by the mucociliary escalator or absorbed in the lymphatic system. This implies that the lymphatic and digestive systems may absorb inhaled toxic substances.

The above is but a brief and elementary overview of the effects of inhaled dusts. It highlights, however the complexity involved in defining paths and properties that can be monitored to establish a cause and effect relationship.

3.2 Epidemiological Research

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

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

Since the early research, cumulative exposure has been identified as one of the most critical factors in the development of pneumoconiosis. Duration of exposure and the amount of airborne respirable dust present in the mining environment have a significant influence upon the prevalence of the disease. In 1971, Reisner concluded that the development of CWP was '*largely due*' to the frequency and severity of exposure. Further, Reisner (1971) suggested that individual large exposures to mixed dust could be important in certain cases. The findings indicated the distinct correlation between a worker's estimated exposure and the risk of developing CWSP (Jacobsen et al., 1980; Attfield et al., 1995).

Inhaled respirable dust particles will reach the alveoli of the lungs and trigger protective reactions that may lead to detrimental effects. Experiments on animals have revealed that the potential hazard associated with the dust present in inhaled air as suspensions of solid particles, depends on both the particle size and the mass concentration due to:

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

Studies have shown that the risk of progression to a higher category of pneumoconiosis increases with increasing intensity of exposure, represented by the mean dust concentration (Jacobsen *et al.*, 1970, 1971), and with increasing cumulative exposure, represented by the product of intensity and duration (Jacobsen, 1973, 1979). However, the results of medical research are inconclusive in identifying in advance individuals who show a greater propensity in developing pneumoconiosis in response to dust exposure. Typically, pulmonary function is measured at the pre-employment and subsequent medical examinations. These tests are not predictive of individuals' susceptibility to dust exposure and therefore only offer a retrospective view of the pathogenesis.

The introduction of automation and remotely controlled processes in mining operations will effectively reduce the duration, severity and intensity of workers' exposure to dust. Although this may reduce the incidence of pneumoconiosis cases, the risk will not necessarily be lessened for certain hypersensitive individuals. Although recent analyses of the incidence of pneumoconiosis internationally show favourable trends, latest studies by British scientists and by NIOSH indicate that the risk of developing the most serious form of CWP at the present exposure level standard (2 mg/m^3) is higher than had been previously believed. However, Australian researchers have reported that they have no evidence of CWP at the 3.0 mg/m^3 standard. Evidence of tampering with respirable dust samples in the USA, raises questions about the validity of dust exposure levels reported by US coal mines being below 2.0 mg/m^3 as reported officially (US Federal Register, 1995). Table 3.2 summarizes the various dust types, dust sources and related health hazards.

Table 3.2

Dust types, sources and health hazards (Source: ACGIH, 1998)

Dust Type	*Source*	*Health Hazard*
Aluminium	Mining, processing	Lung irritation
Antimony dust	Metal works	Pneumonitis
Arsenic	Mining, processing	Lung cancer
Barium sulphate	Metal works	Fibrosis
Beryllium dust	Beryllium ore mining	Berylliosis
Cadmium	Other works	Cancer, kidneys
Cement	Plants and other works	Dermatitis
Chrome dust	Metal works	Lung cancer
Coal dust	Mining, preparation plants	Pneumoconiosis
Cobalt dust or salt	Metal works	Interstitial fibrosis
Corundum	Mills	Fibrosis
Graphite	Non-metal works	Fibrosis
Iron dust	Mines, foundries, welding	Siderosis
Kaolin	Metal works	Fibrosis
Magnesium oxide	Metal works	Metal fume fever
Manganese dioxide	Metal works	Manganism, lungs
Mica	Metal works	Silicosis
Platinum	Metal works	Silicosis and others
Silica dust	Metal and non-metal works	Silicosis
Sericite - Micaceous	Metal works	Pneumoconiosis
Silver	Metal works	Argyria, bronchitis
Sulphur	Quarry works	Pneumoconiosis
Tin	Metal works	Stannosis
Talc	Other works	Pneumoconiosis
Tellurium	Other works	Cyanosis, liver
Tungsten	Metal works	Irritation
Uranium	Other works	Kidneys, cancer
Vanadium	Metal works	Lung irritation
Zinc chromate	Metal works	Lung cancer

3.3 Major Pathogenic characteristics of respirable dust

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

The production of fibrogenic tissue resulting from the irritation of the alveolar tissue is a known effect. This leads to the irreversible damage of the elastic lung tissue and reduces the oxygen absorption capacity of the lung (Schroeder, 1989). In addition, observations have shown that the presence of irritating material in the interstitium may alter the blood's ability to coagulate and lead to the triggering of heart failure as documented by Seaton (1995) and Schroeder (1989)

Coal dust and silica dust are the predominant dust types historically presenting health effects to the worker's in the mining industry (coal and gold). Therefore, the major factors implicated in the pathogenic characteristics of respirable dust in this century (ECSC, 1997) are discussed below:

3.3.1 Dust type

In the past few decades, several health studies have indicating the role of the dust type (e.g., silica or coal) plays a crucial on the miner's health. Coals are classified into ranks in relation to their calorific values and carbon content. High rank coals are of the greatest geological age and consequently have a high percentage of carbon but a low proportion of volatile matter. Conversely, low rank coals have lower carbon content but higher levels of volatile matter. High coal rank mines have been generally found to produce a coal dust with a lower ash, including quartz content (Casswell et al., 1971; Douglas, 1986).

Toxicity studies have confirmed that there are pronounced differences in specific risk from different fine coal dusts. Reisner's (1971) study to investigate the cytotoxic effect of different fine coal dusts showed increased cytotoxicity related to higher rank coals.

Reisner (1971) and Jacobsen's (1980) observations in coal miner's data showed that very strong variations existed in the prevalence and progression of CWP between different regions and individual mines, despite similar cumulative exposures and quartz contents of the coal dusts. However, these studies were unable to identify specific factors causing the variation, suggesting that some mines produce coal dust that is more pathogenic than others.

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

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

Experiments by Skidmore et al., (1965) using rats were designed to determine whether lung retention of high rank coal dust is greater than low rank coal dust. Results of this research proved to be inconclusive. Therefore, it might be concluded that the retention of dust particles in lungs is independent of coal type or rank. On the other hand, high rank coal dust is characterized by coarse dust particles enriched with high mineral content with average density greater than low rank coal. This might explain the apparently greater hazard of breathing high rank coals. Opinions were expressed on the consideration of concentration levels for specific seams, known to be of a higher risk to the work force. This was found however not to be practicable. Interestingly enough, pneumoconiosis was diagnosed occasionally at post-mortem in cases where it was not detected during routine previous medical controls.

No literature relating South African mine workers with various pneumoconiosis levels to coal rank has been found. Studies were carried out in the USA relating the dust generation potential (g/ton) to the coal rank. No study has yet been done in South Africa, to determine the dust generation potential of various coal seams. Therefore, any correlation found by such a study could be used subsequently to investigate relationships between the exposure levels and the disease (or risk) rate among various sectors of South African coal miners.

3.3.2 Particle charges

The effect of charged dust particles in the atmosphere results in the coagulation of smaller dust particles into larger conglomerates held together by relatively strong intermolecular Van der Waals forces. It is in the deposition of dust particulate that the electrostatic charge of dust particles plays a part. Previous research has shown that lung deposition of aerosol particles increases directly with the aerosol's charge properties (Melandri, et al., 1983). In the research study by Organiscak and Page (1998), coal rank and CWP relationship was reported to be related in part to the increase in the dust cloud charging properties of higher rank bituminous coals. Charging of quartzite dust particles as air flows in tunnels is also common.

In all cases the electrostatic charge in particulate may be determinant of the deposition mechanism within the respiratory system and retention of respired particulate within the respiratory organs.

3.3.3 Silica content

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

Quartz was originally believed to be the primary agent in the pathogenesis of CWP. However, it was subsequently found that workers such as dock labourers, who had contact only with the pure coal product, were also susceptible to the disease. On the other hand, high rank coalmines, with the highest incidence rate of CWP, produce airborne dust that tends to have lower quartz content (Casswell et al., 1971; Douglas, 1986). Experimental work (Reisner, 1971) has shown that increased quartz content of dust leads to an enhanced pathological effect. A pathological study by Davis (1979) suggested that PMF in miners previously employed in low rank coal mines may be induced primarily by the quartz and mineral particles in the dust. A study by Hurley et al., (1982) rejected the idea that CWP in the general mine population is caused by quartz in coal dust. In addition, a specific study on men who showed unusual changes in radiographic evidence indicated that some individuals are at greater risk from quartz exposure than a majority within the general mining population. In the UK and South Africa, high rank coals are generally found in thinner seams. This implies that more of the host rock, with higher silica content is mined to access the seam more effectively.

Klosterkotter (1954) showed that silica gel injected in the trachea of rats did not cause fibrosis. Schepers et al (1957) observed no fibrosis development in guinea pigs and rabbits exposed to the inhalation of 126 mg/m^3 of silica for two years despite observing macrophage accumulations and mild proliferation of reticulin fibres. In a group of 165 workers exposed to precipitated silica, estimated to be near or below 10 mg/m^3, for an average of 8,6 years (Wilson et al., 1979) no serial changes in pulmonary function nor chest radiographs was observed.

Fumed silica and silica fume, which are ultra fine solid particulates formed in gas phase reactions, display entirely different toxicities (Ratney, 1997). ASTM standard E1156-87 reviewed three studies involving a total of 353 workers exposed for up to 32 years to fumed silica concentrations from 1,6 to 53 mg/m^3 (ASTM, 1987). No pulmonary dysfunction was observed except in smokers. Schepers (1957) exposed rats, rabbits and guinea pigs to fumed silica at 53 mg/m^3 for a year causing emphysema that reversed after exposure ceased and fibrosis that partially reversed. Groth (1981) observed significant interstitial hyperplasia and collagen deposition in monkeys exposed to 15 mg/m^3 of fumed silica for 13 months. However, the monkeys' lungs showed the presence of mineral dust that had apparently been inhaled in the wild or in captivity prior to purchase of the animals. On the other hand, several studies in the elemental silicon and ferrosilicon industries show that silica fumes produce a unique complex of acute and chronic effects which are reversible after exposure ceases (Bowie, 1978).

Various studies have related dust exposures of foundry workers to mixed dust fibrosis (Oudiz, 1986; Parkes, 1982). Study on smokers and silica exposure demonstrated the synergistic action of both agents causing chronic obstructive lung disease (Hnizdo and Sluis-Cremer, 1991; Hnizdo, 1990 and Malmberg et al., 1993). There were also studies that reported the association of silica exposure with other lung diseases, such as tuberculosis (Chen and Burnett, 1997; Althouse and Bang, 1995) and lung cancer (Cherry et al., 1998; Costello et al., 1995; Koseka et al., 1994). In 1996, the International Agency for Research on Cancer (IARC) reviewed additional literature and studies published in the intervening decade and recommended that quartz and crystobalite, two polymorphs of crystalline silica, is listed as Group 1, carcinogenic to humans. The findings of this IARC report (1997) are:

- There is sufficient evidence in studies of humans that show the carcinogenic nature of inhaled crystalline silica in the forms of quartz or crystobalite from occupational sources.
- There is sufficient evidence in experimental animal studies confirming the carcinogenic nature of quartz and crystobalite.
- There is limited evidence in experimental animal studies of the carcinogenic nature of tridymite.
- There is inadequate evidence in studies of humans to confirm the carcinogenic nature of amorphous silica.
- There is inadequate evidence in experimental animal studies of the carcinogenic nature of synthetic amorphous silica.

In an Australian sampling study by Bell and Lynch (1997) for quartz dust indicated that approximately 20 % of occupations surveyed failed the respirable quartz TLV of 0,2 mg/m^3 while over 60 % failed when the level is lowered to 0,1 mg/m^3. The situation with quarries and gold mines was generally worse with the figures being 40 % to 90 % and 30 % to 50 % respectively. However, epidemiological evidence in Australian context was not been established at the time of the study. In the UK, occupational exposure limit for respirable crystalline silica is 0,1 mg/m^3. In UK quarrying industry, higher dust concentrations were found-64 % of 474 samples exceeded 0,1 mg/m^3, with 10 % in excess of 0,5 mg/m^3 (Tickner, 1997).

3.3.4 Clay minerals

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

3.3.5 Particle size

Particle size is an important parameter for characterizing the behaviour of dust. One of the important measurable factors with regard to health effects on human beings is the particle size. In most situations where dusts are found, there is a very wide range of particle sizes in the air. In this report, "size" refers to the projected area diameter (d_p) (Schroeder, 1989) of the particles in micrometers (μm). The effect of "size" of dust particles on the deposition in the respiratory region of the lungs has been investigated by two methods:

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

The dusts liberated typically in the environment during mining operations display a very wide range of particle sizes (Figure 3.3.5a). There have been a number of experimental studies comparing the lung's response to fine low toxic dusts, some of which are discussed by Soutar and others (Soutar, et al., 1997). All of the ultra-fine dusts were found to produce more damage to the lungs than the same mass of the identical material of fine particles around 250 nm diameter. It is important to consider carefully the possible effects of fine particles on health when the exposure risk assessment or measurement strategies are developed. In view of the emerging evidence about the importance of particle size in toxicity, sampling should also focus on to exposure of workers to high concentrations of very fine particles. High concentrations of ultra-fine particles (d_p = 25 – 250 nm) are characterized by relatively large surface areas that interfere with the dust-clearing mechanisms of the lungs as described above.

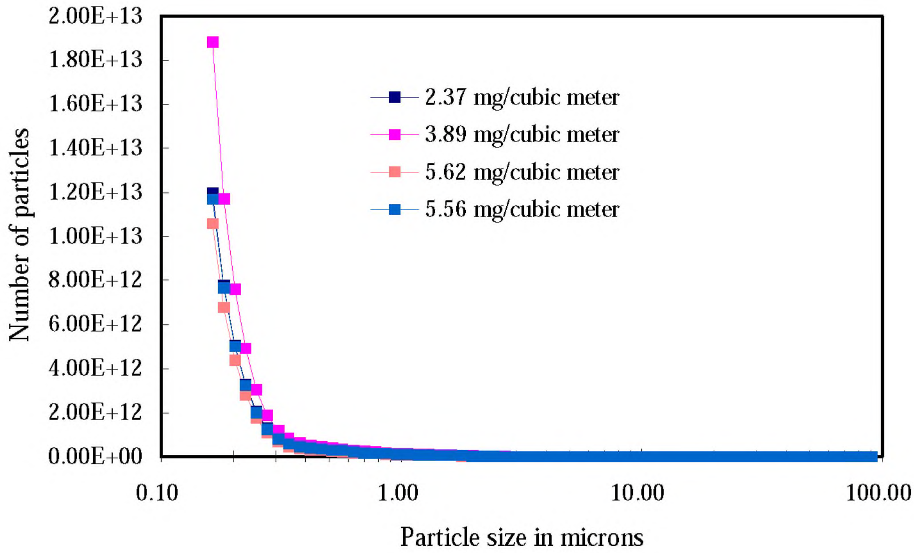


Figure 3.3.5a: Relationship between particle size, number of particles and sample dust concentration (Belle 2000)

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

Recent research work in connection with particulate size and health has drawn attention to overlooked factors. Dusts that have a local effect in the lung are measured using a size-selective sampling system that collects the finer fraction of the airborne dust, the fraction that is likely to penetrate to the gas exchange region of the lung. This is defined by the ISO as the respirable size fraction. There is often a presumption that coarser particles of such substances have little or no effect on health, and there is almost never any distinction made between the risks from different size particles within the respirable size range. Scientific evidence concerning the hazard from very small particles shows that it may not be appropriate to ignore a specific effect of these small particles on workers' health. Renowned researchers have reviewed the risks from dusts, which do not readily dissolve in the lung. They suggest that it is possible to link the results of animal experiments with the risks observed in epidemiological studies and in this way it may be possible to infer something about the risks for dusts where good human data are not available (Cherrie, 1999). Epidemiological studies predictably show that some dusts are more toxic than others and that the higher the toxicity the higher the risk will be. Figure 1 shows the risks of noticeable chest x-ray changes (category 1/0 or greater on the International Labour Organization (ILO) scale for small opacities, for men in their fifties) against cumulative exposure to respirable quartz, PVC and high ranked coal dust i.e. coal with a high carbon content.

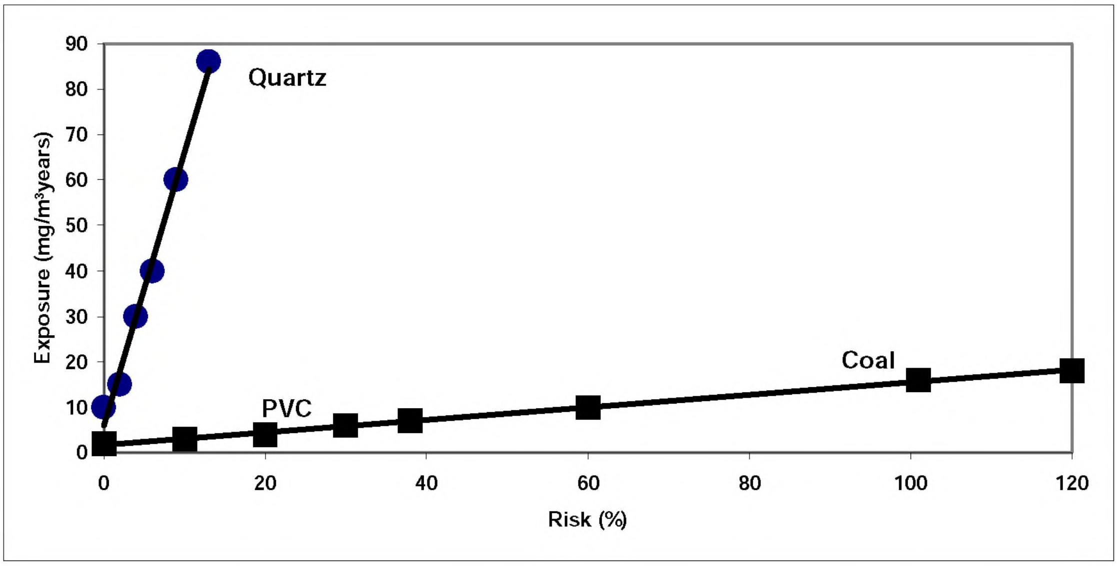


Figure 3.3.5b: Risk of pneumoconiosis compared to cumulative exposure

In Figure 3.3.5b, the exposure is shown in units of mg/m^3.years i.e. cumulative exposure. This is the product of the average exposure level and the duration of the exposure. Hence, for a man who had worked 30 years in coal mining, 120 mg/m^3.years would correspond to an average exposure level of 4 mg/m^3 of respirable coal dust.

The data for the three dusts show increasing risk of changes on workers' chest x-rays with increasing cumulative exposure, but the rate of increase is much steeper for quartz than for the two low toxicity dusts.

Studying the retention and clearance of dusts from the lungs of experimental animals is another approach to investigating their relative hazard. This is because it is believed that a longer residence time for particles in the lung results from impairment of the ability of the lung's scavenger cells, the alveolar macrophages, to remove the particles either from the toxic effects of the particles e.g. quartz, or because the particle load in the lung exceeds the capacity of the alveolar macrophages to remove the dust. Figure 3.3.5c shows the change in clearance half –time with dust loading for two dusts already mentioned and for another low toxicity dust, titanium dioxide (TiO_2). The data ignored differences in exposure duration, which was considered less important than the difference between dusts. The similarity of the relative differences between dusts in the animal model and their morbidity in the human populations was seen to be striking. This might form a basis for understanding much of the differences in the effects of particles in the lung.

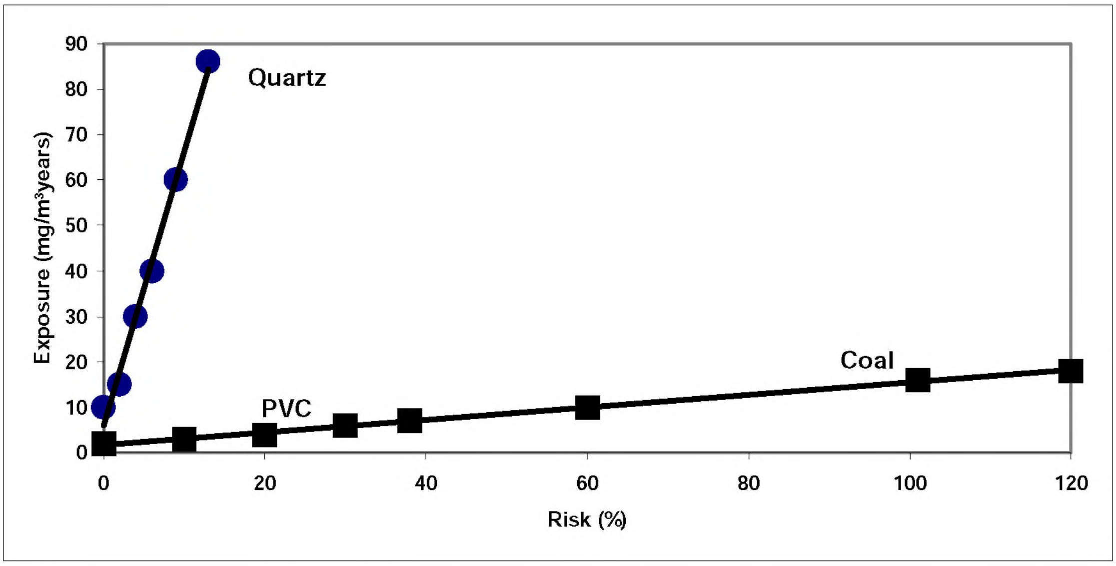


Figure 3.3.5c: Clearance half-time in animals compared to dust concentration

In most industrial situations where dusts are found there is a very wide range of particle sizes in the air. The largest particles, which are considered to be respirable, are about 10µm in diameter. The finest particles that can be found in the air in workplaces are about 1 000 times smaller than this i.e. about 0.01 µm in diameter. These are generally described as **ultra fine** particles or sometimes as nanometer particles.

There have recently been a number of experimental studies, which have compared the lung's response to ultra fine dusts. The dusts that have been used in these studies are those generally considered to have low toxicity e.g. titanium dioxide, aluminium oxide and carbon. All of the ultra fine dusts were found to produce more damage to the lungs than the same mass of identical material of fine particles around 250 nm diameter. Rodents exposed to a concentration of 23mg/m^3 TiO_2 presented considerable inflammation in their lungs if they were exposed to ultra fine dust but little effect with the coarser dust .In other work which investigated the clearance of particles from the lungs of rodents, for fine TiO_2 around 250 nm the clearance half-time was found to be 117 days whereas for the ultra fine dust it was found to be 541 days.

The lung is well adapted to deal with inhaled organisms such as bacteria and it tries, with some success, to deal with insoluble particles. Inside the alveolar space there are a large number of mobile cells, macrophages, which can engulf particles and transport them out of the lung. However, this process can break down when either the macrophages have to deal with a toxic dust that impairs the lung's ability to clear the particles or where there are so many particles that they cannot be effectively cleared. In both cases some of the inhaled particles will cross the cell barrier around the alveoli (the epithelium) and penetrate into the underlying cells around the blood vessels (the interstitium). It is here that the particles may produce inflammation and ultimately fibrosis or, for some dusts, perhaps cancer.

Why does the size of the particles make such a difference to the way the lung responds? It may be because of the sheer number of ultra fine particles present. One mg of fine dust (250 nm diameter) may contain about 10^{10} particles. For ultra fine material (25 nm) there would be about 10^{13} particles. When inhaled these particles present a much larger surface area that can interact with the scavenger cells in the lungs, about 100 times more area. Figure 3.3.5d shows how the of surface area of an observed dust sample varies as a function of particle size.

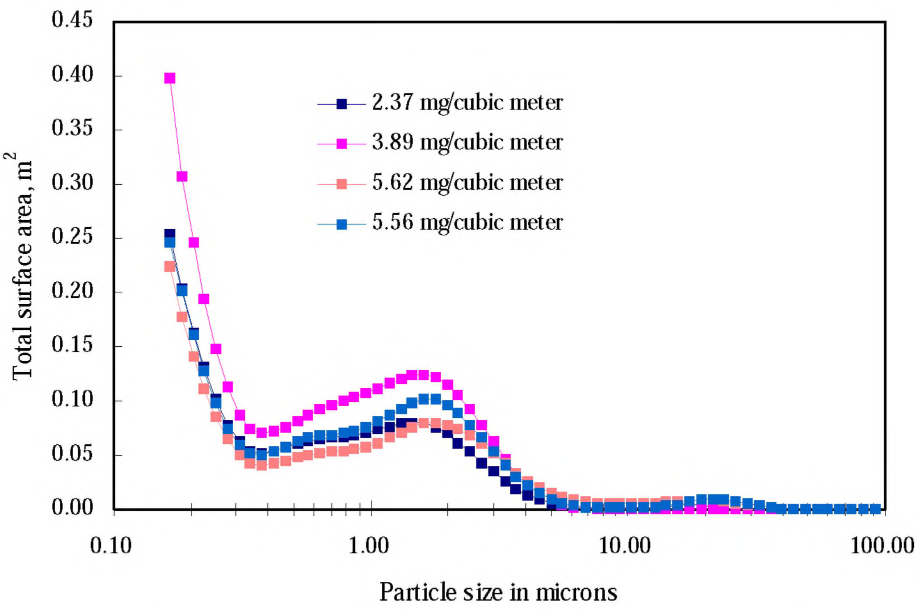


Figure 3.3.5d: Relationship between particle size, total surface area and sample dust concentration (ref: Belle)

The ultra fine dusts appear to have much the same effect on clearance of particles, as does the toxic dust. In a coarser form they do not display any significant toxicity. Thus, it is not likely to be the chemistry of these ultra fine materials that gives rise to these effects. Therefore it must be some other property of the particles. Some have suggested that the total surface area of inhaled particles may be an appropriate measure while others consider the particle number more suitable. In any case it is clear that mass concentration is not the best way of describing the exposure to insoluble dusts over such a wide size range (Cherrie, 1999).

It is also evident that the combination of toxic material with ultra fine particle size, for example quartz, should be viewed with concern.

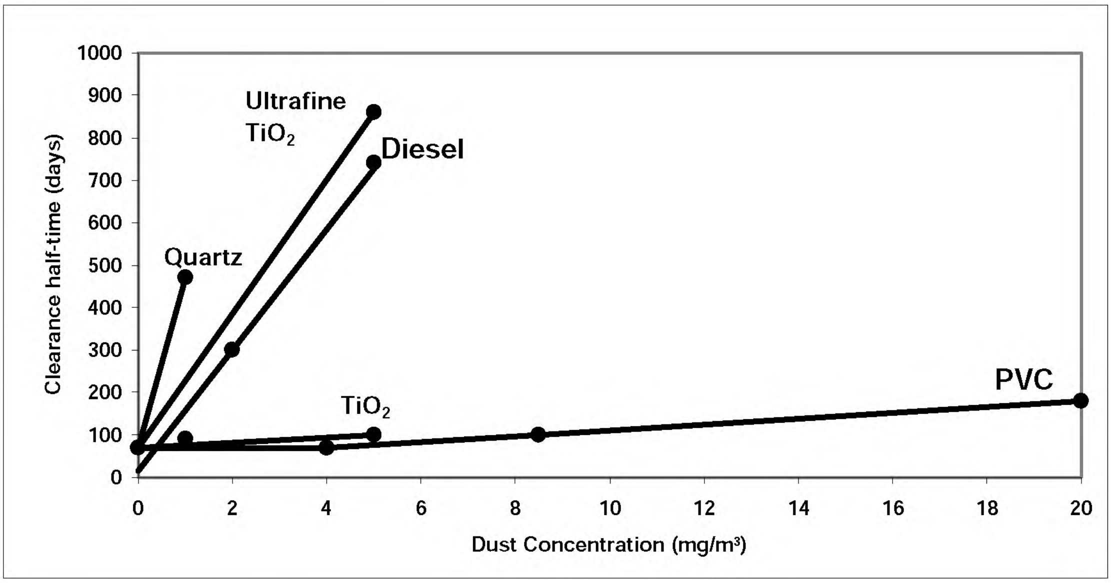


Figure 3.3.5e: Clearance half time for ultra fine and other dusts

Further inaccuracies in the collected samples have been introduced in the assessment of exposure levels. All samplers collect airborne particulates at a fixed flow rate yet people change inspiration rates throughout the working day due to exertion or heat factors. Modern technology could help address this anomaly and assist in providing variable sampling rates based on, for example, heart rates.

From the research work discussed it was shown that particle size seems to be an important parameter of insoluble dusts that helps to explain how the lung may be affected when they are inhaled. There is evidence from animal studies that large numbers of ultra fine particles probably impair the lungs' defences causing some of the dust to lodge in the interstitium where it can cause an adverse reaction. It appears that the effect of ultra fine particles made from toxic materials is greater than ultra fine particles of low toxicity materials. Also, exposure to ultra fine particles of toxic material is likely to be more harmful than exposure to coarser particles of the same material.

3.3.6 Individual susceptibility

Although individual susceptibility is not a pathogenic characteristic of a dust particle, the factor plays an important role in the disease. A study by Maclaren et al (1989) indicated that there was an increased prevalence of PMF amongst men of aesthetic build than any other group. It was suggested that the increased rate of disease reflect the greater respiratory effort exerted by a tall man working in a restricted environment. Increased respiratory effort could lead to increased dust deposition in the worker's lungs. One remarkable response to coal dust pathogens occurred in individuals who have distinct rheumatoid factor. Caplan's syndrome (1960), a form of CWP characterized by multiple small lesions, 0,5 to 5 cm in diameter usually originating in the periphery of the lung, highlighted the importance of immunological responses in the development of CWP.

Cherrie (1998) also highlights the fact that individual propensity to asthma can increase sensitivity particularly for ultra-fine dusts. In his summation, he argues that susceptible individuals may be affected at concentrations up to 100 times less than the accepted exposure limit.

3.4 Dust measurement

The measurement of dust in mines is usually carried out by using various air-sampling instruments. The collected sample amount is expressed as mass of dust per cubic meter (mg/m^3) of air or number of particles per cubic meter (ppm^3) or per millilitre (ppml) of air and generally referred to as "dust concentration or dust count" in the air. The standard sampling instrument used in the 1950's for dust measurement was the thermal precipitator, and collected dust samples were evaluated by counting the particles under a microscope. This process was time consuming and prone to errors. Roach (1958) showed that the chance of deposition of particles on top of one another in thermal precipitator samples could seriously reduce the count by up to 50 per cent or even more, depending on the number of particles sampled and their size. This aspect discredits the use of particle size counting to evaluate the exposure of individuals to dust.

The primary purpose of dust sampling is therefore to characterize (with regard to mass and size) the dust present in the environment of individual workers in order to evaluate their dust exposure. Other reasons for sampling include evaluating the effectiveness of engineering controls and changes in dust levels as a result of process change. Dust sampling is also used as a surrogate for dose in epidemiological studies. The mass of respirable dust sampled is representative of the dust mass inhaled – but not deposited or retained.

Usually, respirable dust sampling is performed using a sampling train consisting of:

- A size-selective device – A two-stage, 10-millimetre nylon size-selective sampler which separates the larger particles in the dust and allows respirable particles to pass through the cyclone, where they are collected on the filter to determine concentration levels

- Filters and filter holders - The cyclone assembly is connected to a two-piece 37-millimetre cassette containing a collecting medium which consists of a filter with a 0,5 μm pore size
- A sampling pump - A portable battery-operated pump that will draw air at a specified rate (L/min) for at least eight hours is used as a vacuum source and is equipped with flow-compensating features to maintain the desired flow rate automatically as dust loading on the filter increases
- Tubing connecting the cyclone to the pump.

To measure the total dust in an atmosphere, the above sampling train is used without the nylon cyclone.

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

$$SC = \frac{(C_f - C_i)}{((FI)\,x\,(T))} \quad (1)$$

where:

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

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

$$TWA - CONC = \frac{(SC\,x\,T)}{480} \quad (2)$$

where:

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

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

Worker exposures in terms of the concentration levels of respirable dust obtained from personal sampling must be compared with the accepted Threshold Limit Value (TLV) for that substance to determine whether the amount of dust the worker breathes during the workday exceeds the set limit. This is done by using a single full-shift sample collected with a sampling device that operates in accordance with the NIOSH accuracy criteria (Busch and Taylor 1981) and the international definition of respirable dust (ACGIH, 1998; CEN, 1992; ISO, 1993; Soderholm, 1991a,b; 1989).

Table 3.4

Occupational exposure limits for respirable coal dust and free crystalline silica in various countries (NIOSH, 1995)

Country	Recommended Value	Comment
Australia	3 mg/m^3	5 % respirable free silica
Belgium	10 mg/m^3 / (% quartz + 2)	
Brazil	8 mg/m^3 / (% quartz + 2)	
Finland	2,0 mg/m^3	Coal dust
	0,2 mg/m^3	Quartz (fine dust < 5 μm)
	0,1 mg/m^3	Silica: cristobalite, tridymite
Germany	0,15 mg/m^3	Quartz
	4 mg/m^3	Dust with quartz (> 1% by wt)
Italy	3,33 mg/m^3	Coal dust with < 1 % quartz
	10 mg/m^3 / (% quartz + 3)	Coal dust with > 1 % quartz
Netherlands	2,0 mg/m^3	< 5 % respirable quartz
	0,075 mg/m^3	Silica
South Africa	0,1 mg/m^3	Alpha quartz > 5 %
	2,0 mg/m^3	Alpha quartz < 5 %
	3,0 mg/m^3 (platinum mines)	Alpha quartz < 5 %

Table 3.4 - continued

Country	Recommended Value	Comment
Sweden	0,05 mg/m^3	Silica: cristobalite, tridymite
UK	3,8 mg/m^3	At coal face
USA	2,0 mg/m^3	< 5 % silica
	10 mg/m^3 / (% quartz)	Coal dust with > 5 % silica
	10 mg/m^3/ (% quartz + 2)	Silica: quartz
	Half of the value for quartz	Silica: cristobalite, tridymite
Yugoslavia	4,0 mg/m^3	< 2 % free crystalline silica
	0,07 mg/m^3 (100) / (% FCS)	> 2 % free crystalline silica
	0,07 mg/m^3	Pure quartz (fine dust)

3.4.1 Dust exposure limits

In order to reduce or eliminate the health risk of exposure to dust, several studies have been carried out in the USA, the UK and other European countries on dust exposure limits. These exposure limits provide the necessary guidance for planning, engineering, monitoring and controlling the systems and work practices for effective dust control. There are wide variations in the dust exposure limits as defined by regulatory authorities such as the OSHA, MSHA, NIOSH, WHO and ACGIH. To determine the exposure limits, sampling of airborne particulate is widely used. The exposure limits of various countries cannot be compared directly because of differences in each country's measurement strategies. TLVs refer to airborne concentrations of substances and represent conditions to which it is believed that nearly all workers may be repeatedly exposed day after day without adverse health effects. "TLV" is a copyrighted trademark of the ACGIH (American Conference of Governmental Industrial Hygienists) and TLVs are not mandatory Federal or State employee exposure standards. These limits are updated annually and reflect generally the current professional recommendations on workers' exposures to specific substances. Table 3.2 lists the exposure limits for respirable coal dust and crystalline silica in various countries.

3.4.2 Threshold Limit Values/Occupational Exposure Limits (OELs)

The establishment of a TLV is essentially an exercise in dose-response relationships. In principle, the incidence of adverse health effects in people or animals is observed at different exposure levels. The level at which no adverse health effects occur is then determined, alternatively, the level where some effect is observed but at a rate that is somehow considered to be "acceptable". Although this appears to be very rational approach, every word in the previous sentence is loaded with ambiguity and uncertainty. Only by assuring an understanding of every term is it possible to assure that a recommended exposure limit will be accepted by affected parties.

It is surprising to find out the material suspected of causing adverse health effects is not actually the aetiological agent. In toxicological research, the test agent is carefully defined and its purity carefully controlled. In the workplace, exposures are to mixtures and frequently the nature of the materials is not well defined.

In studying the effects of toxic substances in humans, experimental exposures are becoming less and less common. Most commonly, the health status is determined for persons who are exposed to hazardous materials in their normal work situations. Doses, of course, cannot be measured. Rather, airborne exposure concentrations are measured and it is assumed that they are proportional to inhaled doses. This assumption is only approximately correct. People vary in their breathing rates depending on body size, race, and gender and the fraction of an inhaled dose deposited in the lungs depends on breathing rate, particle size, solubility and mouth versus nose breathing. This means that the dose received by different groups of workers may not be completely characterized by their airborne exposures.

The major causes of inaccuracy in characterizing exposure, and thus dose, are the scarcity of exposure measurements and the inappropriateness of the measurement protocol. In most cases, airborne exposures have not been measured with a view toward supporting the development of an occupational exposure limit. Measurements are frequently taken to assess compliance with existing standards and in South Africa measurements were taken for the calculation of risk levies. Measuring exposures in a systematic way can be expensive and unless employers can see benefits for themselves, they will be reluctant to do it.

It has been accepted for several years that the time periods over which airborne exposures are measured should be similar to the biological time periods over which adverse health effects develop. Hence, for primary irritants, which act almost instantaneously, very short sampling times or direct-reading instruments are needed. Where the health effect is the result of the cumulative dose during a single work shift an 8-hour time weighted average could be considered. However, this technique would ignore any high or peak exposures during the shift and since the role of these short duration-high exposures in the development or advancement of pneumoconiosis not fully understood average full shift exposures should be used with caution and perhaps used with additional measurements. Where an effect is the result of a very long exposure, such as lung fibrosis, then complex statistical methods are needed to calculate a "life-time" cumulative exposure from a set of exposure measurements taken over a long period of time. Exposures in the past are frequently estimated using records from the past but more often using present records. The dangers of using these methods are that past records may not be available, especially if a mine has closed down and, secondly, present exposure levels may not be anywhere near what past levels used to be. Estimations may not only be non-representative but also far off the mark. (Ratney, 1989).

The definition of TLVs as levels that protect "nearly all workers" gives the clear impression that these limits are based primarily on health considerations. Unfortunately, the lack of exposure-response data provided by the ACGIH casts doubt on this interpretation. In fact, the documentation supporting a particular TLV typically consists of little more than a page of reference material with no formal analysis of exposure-response relationships (Rappaport, 1991).

Although the TLV committee has acknowledged short-term fluctuations in airborne concentrations and used this variation to justify Short-Term Exposure-Limits (STEL) of 15-minute duration, and excursion limits, the variation of shift-long exposures has not been addressed.

3.4.3 Time Weighted Averages (8-hour)

Time Weighted Average (TWA) underpins many exposure limits. Its limitations are recognized but its use and elements have received surprisingly little criticism, although there have been questions from time to time. It seems to have been used first as an index of exposure and subsequently as an index of dose. However, exposure and dose should not be confounded. Exposure-response relations and dose-response are important in occupational and environmental health, and the aim of epidemiological studies, needed for true risk assessment, is to compare the effects of exposure in terms of time and dose.

The assessment of compliance is based on the exposure of the individual worker, usually expressed as the 8-hr Time Weighted Average (TWA) concentration. On a day-by-day basis, this exposure has to remain under a pre-set concentration level, irrespective of the different tasks the worker performs using normal work procedures. The period over which samples are collected (observation period) is usually very short compared to the un-sampled period. Statistical data analysis is therefore required to make extrapolations over the un-sampled period.

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

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

Toxicologists have not always appreciated that the correlation of the biological result of an inhalation study with contamination and time ***does not*** constitute a dose-response relation, as ordinarily understood. Incorrectly, concentration/time is relied on as the central expression of dose-response.

Single values as an index of exposure should be treated with due concern because

a. simple averages or integration with time and concentration of exposure may be a practical expedient, but they may produce erroneous results because toxicological response cannot be expected to be a linear function of time and concentration and,

b. the amplitude and frequency of variation from a defined mean, currently ignored may be very important.

A warning on the use of TWA states: "it is certain that with some chemicals a given Time Weighted Average concentration including major peaks during the day is more likely to injure than is the same average concentration during substantially constant exposure."

The Time Weighted Average may be applied universally *only* if two conditions are met:

a. the numerical values of concentration-time (CT) are directly proportional severity of toxic effect for all possible values of (CT)

   i.e. CT = k and,

b. the toxic effect or "value" of any one component of a day's exposure, C_bT_b, C_cT_c, etc are of equal value.

Various scientific studies have indicated the following:

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

It must therefore be concluded that there is no scientific basis for the use of the time-weighted average to integrate varying exposures. Eight-hour TWA exposure limits may not be appropriate for controlling pneumoconiosis because lung impairment may be induced by transient peak exposures rather than by sustained exposure levels (Atherley, 1995).

3.4.4 Peak concentrations

One of the biggest problems to emerge with regards to gravimetric dust sampling has been the attempt to describe exposures in terms of average dust concentrations. It is well known that a low average concentration for a shift cannot accurately indicate any extreme conditions encountered during the shift. There is a growing awareness of the importance of peak concentrations and their effects on the human body. For example, occupational asthma and other attacks may be triggered by transient peak exposures rather than by sustained exposure levels. This point of view opposes the concept of Threshold Limit Values (TLV) that also does not take into account exposure to a high concentration of material for only a short period of time. (Rekus, 1996). This is an acknowledged limitation of 8-hour averaging. This single, high-level exposure could in itself result in adverse effects, even though the 8-hour time weighted average is below the TLV.

If the rates of biological elimination and repair are rapid, then the burden of damage can be significantly affected by the amount of chemical absorbed during a single shift.

Even so, in the absence of non-linear effects, individual risk would be related to the cumulative history of exposure. If non-linear effects are involved, then isolated peak exposures might contribute disproportionately to chronic damage or might trigger the first stage in a multi-stage progression of disease. The frequency with which a particular threshold is exceeded could be an appropriate index of exposure (Rappaport, 1990).

3.5 Dust concentration

In 1956, the NCB (UK) adopted the convention of sampling throughout periods of mining activity but not when production was interrupted. In the light of the problems of dust counting and of measuring fluctuating concentrations, Bedford and Warner (1943), from whose work the 1949 limits for approved NCB conditions were mainly derived, considered that the hazard of exposure would be best represented by the mass concentration of dust particles less than 5 μm. Moreover, they did not refer to peaks of dust production and it appears that their proposals were intended to relate to the average concentration.

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

The Johannesburg curve and BMRC curve (Hamilton, et al., 1967) do not provide for particles with falling speeds greater than that of a unit density sphere 7.1 microns diameter, 50 percent of 5 micron unit density spheres and 100 percent at very small sizes. There is no simple relationship between gravimetric concentrations and number counts; indeed, the results reported by Hamilton et al., (1967) show variations in the mass-number index (defined as mass concentrations in mg/m^3 per 1,000 particles/cm^3 1-5 μm) from about 6 to 33. The variations are reasoned to be due to the particle density, shape and state of aggregation of the particles as well as in their size distribution.

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

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

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

Wright has discussed whether peaks of dust exposure or the average level provide the best measure of the hazard. He concluded that any evidence does not support the "peak hypothesis". Although it could not be stated with certainty that the "average" hypothesis is perfectly correct, it was simple and reasonable and did not conflict with anything known about the mechanism of dust inhalation and retention.

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

Based on the studies of Trapido (1999), it can be concluded that the face workers are apparently showing high levels of silicosis compared to the workers with the supervisory roles in South African mines. The most probable plausible theory is that the face mineworkers are intermittently exposed to very high dust levels that overwhelm the lungs' dust clearing mechanisms (Trapido 1999, Williams, 1999). One further possibility to be considered in this connection is that periods of high dust concentration might coincide with periods of high work rate and consequently with larger volumes of air breathed. This has been studied by Hadden et al., (1966), whose results indicate that exposures obtained by summing the products of concentration and respired volume for successive short periods throughout the shift may sometimes exceed the product of mean concentration and total respired volume by as much as 20 percent. Hadden et al., (1966) also showed that a man doing heavy work at the face area may breathe up to 5 times more air in a shift than a man doing light work in the same area. The effect of these differences on the amount of dust retained in the lungs is not fully known. It may be argued that the diminution in the time of residence of air in the lungs may, in part, compensate for increased volume breathed.

After the research in the 1960's, it was accepted that particles may be defined to be dangerous if they have particle sizes smaller than 5 μm diameter. However, the lower limits for such definitions were not defined. It can be easily hypothesized that dusts may become more harmful when delivered to the lungs in the form fine dusts. In such cases, it may be prudent to measure the fine particle concentration and control exposure to levels lower than the current limits for size specific criteria. Some of the recent scientific evidence concerning the hazard from very small particles argues that it may not be appropriate to ignore a specific effect of these on worker's health.

Castronova et al had previously reported in 1996 that grinding silica generates radicals on its cleavage planes and that this fresh dust is more cytotoxic *in vitro* than aged silica. The report listed presented results that confirmed that freshly fractured silica was more toxic and inflammatory in vivo than aged silica of the same composition and particle size. The surface activities of freshly ground dust were compared with that of dust stored for two months and verified enhanced activity. Male Fisher rats were exposed to fresh or aged silica dust and pulmonary responses were determined one to three days after exposure.

Exposure to aged silica dust resulted in an increase in total cells, red blood cells, lymphocytes, and granulocytes harvested by bronchoalveolar lavage, and in elevated cellular lavage proteins and phospholipid levels. Furthermore, inhalation of aged silica activated alveolar macrophages and resulted in induction of nitric oxide synthase in these cells. In comparison, inhalation of freshly cleaved silica resulted in dramatically greater increases in all these parameters than did aged silica.

This is an aspect of pollution not considered in mines and the implications are that research is warranted in the quest to address missing data in the understanding of pneumoconiosis, its formation and control.

3.6 Sampling (measurement) methods

For chemical substances present in inhaled air as suspensions of solid particles for droplets, the potential hazard depends on particle size as well as mass concentration because of:

1) The effects of particle size on the deposition site within the respiratory tract
2) The tendency of many occupational diseases to be associated with material deposited in particular regions of the respiratory tract

The Chemical Substances TLV Committee of the American Conference of Governmental Industrial Hygienists (ACGIH) has recommended size-selective TLVs for crystalline silica for many years in recognition of the apparent association between silicosis and respirable mass concentrations. The Committee is now re-examining other chemical substances encountered in particulate form in occupational environments with the objective of defining:

1) the size fraction most closely associated with the health effect of concern, and
2) the mass concentration within that size fraction which should represent the TLV.

The Particle Size-Selective TLVs (PSS-TLVs) are expressed in three forms:

1. *Inhalable Particulate Mass TLVs* (IPM-TLVs) for those materials that are hazardous when deposited anywhere in the respiratory tract.
2. *Thoracic Particulate Mass TLVs (TPM-TLVs)* for those materials that are hazardous when deposited anywhere within the lung airways and gas exchange region.
3. *Respirable Particulate Mass TLVs (RPM-TLVs)* for those materials that are hazardous when deposited in the gas exchange region.

Collection efficiencies representative of several sizes of particles in each of the respective mass fractions are shown in Tables 3.6a, b and c and are shown pictorially in Figure 3.6.

Table 3.6a
Inhalable Particulates

Particle Aerodynamic Diameter μm	Inhalable Particulate Mass (IPM) (%)
0	100
1	97
2	94
5	87
10	77
20	65
30	58
40	54.5

Table 3.6b

Thoracic Particulates

Particle Aerodynamic Diameter μm	Thoracic Particulate Mass (TPM) (%)
0	100
2	94
4	89
6	80.5
8	67
10	50
12	35
14	23
16	15
18	9.5
20	6
25	2

Table 3.6c

Respirable Particulates

Particle Aerodynamic Diameter μm	Respirable Particulate Mass (RPM) (%)
0	100
1	97
2	91
3	74
4	50
5	30
6	17
7	9
8	5
10	1

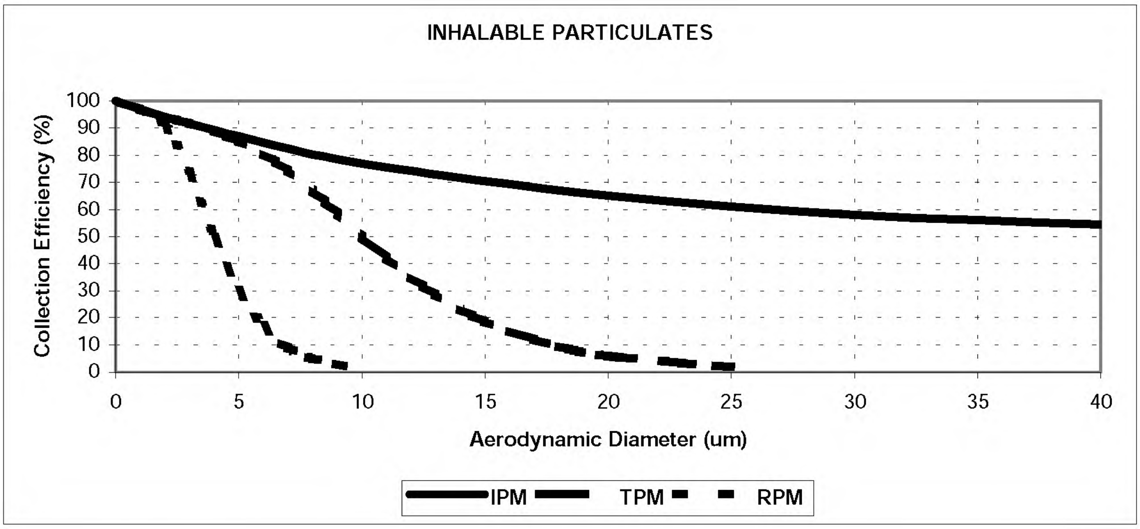


Figure 3.6: Summary of collection efficiencies in all particle size ranges

The particles are collected according to defined efficiencies for their respective masses. The most significant difference from previous definitions is the increase in the median cut point for the respirable particulate matter sampler from 3.5 μm to 4.0μm. This is in accord with the International Organization for Standardization/European Standardization Committee (ISO/CEN) Protocol (ACGIH, 1997).

The application of information on how the aerodynamic size of aerosols determines the inhalability, i.e. the fraction of airborne mass that actually enters the nose or mouth during inhalation, and the regional deposition of particles within the respiratory tract can lead to acquiring size-selective samples that more closely relate to aerosol inhalation hazards. Size-selective aerosol samples may be defined as reliably collected aerosol fractions that are expected to be available for deposition in the various sub regions of the respiratory tract (ACGIH, 1997).

Because the criteria for TPM and RPM are designed to overestimate the actual inhalation exposure of the average worker, they have built-in protection factors. Although this conservatism is desirable from an occupational hygienist's point of view, it does not necessarily serve the purposes of the epidemiologist. In an epidemiological study of hazardous aerosols, it is often desirable to determine the effect of aerosol particle size on risk. Ideally, the actual size distribution of the airborne material or the actual deposition in the exposed individuals is directly determined or otherwise estimated. However, being able to collect TPM and/or RPM in an epidemiological investigation could reduce the uncertainties in estimating the actual particulate exposures.

Several classes of aerosol particles do not behave in the simple aerodynamic manner that has been assumed in recommended in size-selective sampling procedures. Examples are aerosols that are highly electrically charged, aerosol particles that may be either rapidly growing or (hygroscopic) or rapidly decreasing (volatile) in size during inhalation. Aerosol particles that have extreme shapes, (e.g. fibres and thin plates) also behave in complex aerodynamic manner. Aerosols of these types must be considered as special cases in hazard evaluation, and the applicability of particle size-selective sampling recommendations must be evaluated on a case-by-case basis. (Phalen, 1990)

Sampling cyclones will be well placed to aid in exposure - response studies. Only once the pathology and the disease producing mechanism of how precisely inhaled dust reacts with the human body is better understood.

There are suggestions in the literature that the "breathing zone" i.e. the zone where personal monitors should be situated to secure representative samples of airborne contaminants, be defined as a zone of air 30.5 cm radius about the head of the individual being sampled. However, this has been found to be a non-homogeneous space. At the present state of the art, samplers can be located anywhere in this zone and adhere to accepted practice. As more is learnt about variations in contaminant concentration in the breathing zone, practice may change to more definite sampler location. (Rappaport, 1991)

Unsted (1996) reported that variations in dust concentrations were possible in samplers suspended 150 mm apart. Especially surprising were the significant variations in the quartz concentrations of the airborne dust. These results tend to support the above claims. Kielblock (1998) provided more support for this claim.

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

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

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

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

Engineering Sampling: An engineering sample is the dust sample taken at the continuous mining machine operator's position, which is not defined in any of the previous literature. An engineering sample is the dust sample taken to determine the dust concentration near machinery, tipping points, air filters, etc. to characterize the emission source or suppression effectiveness of dust suppression or control measures. The engineering sampler is switched at the face area in the beginning of the shift where cutting machine is standing and is switched off before leaving the face area at the end of the shift. The engineering sample will enable to determine the effectiveness of dust control and ventilation systems in the section. Further it aims at evaluating both the management (administrative effectiveness) of the dust control system as well as effectiveness of the dust control system (engineering).

Studies have indicated that personal sampling provides the best estimate of worker exposures and of the temporal and spatial variability in those exposures (Vincent, 1994). In nearly all the studies where personal and area sampling were compared with clinical measures of occupation-related adverse effects, the personal exposure measurements provided the best correlations (Stopford et al., 1978; Linch et al., 1970; Linch and Pfaff 1971). Also, the personal exposures are frequently higher than the exposures measured by area sampling (Niven et al., 1992; Cinkotai et al., 1984; Yoshida et al., 1980; Tomb and Ondrey 1976). Single dust measurement reading using spot samples from a real-time measurement instrument is insufficient to determine whether the TLVs have been exceeded. The variability associated with the dust samples collected by means of various methods will be discussed in Section 3.7.9.2.

3.7 Review of Routine Dust Sampling Protocols And Procedures

The instruments currently used for dust sampling give the details of respirable and total dust fractions through mass dust concentrations. However, the mineralogical composition and physical properties of the dust samples collected, such as size, number and shape of particle, could be determined at a later stage in the labs. The flow rate employed by dust samplers worldwide varies considerably between 0,4 l/min to 50 l/min.

Several types of dust samplers have evolved through the years and vary widely in nature and concept of operation (e.g., cyclones and spectrometers). In dust spectrometers, the determination of the dust concentration in each fraction is carried out by determining the particle aerodynamic size distribution for the sampled dust first and then by calculating numerically the size (frequency) distribution of the fraction of interest. The area under the curve generated by this numerical manipulation is indicative of the mass sampled in the size fraction of interest, and is hence indicative of the airborne concentration of the sample. In general, spectrometers need greater operator skill. Generally, the choice of instrument employed for sampling relates to the purpose of the sampling task.

The methods used for the mineralogical assessment of the dust are usually based on infrared spectro-photometry and X-ray diffraction. The latter requires the collection of a larger dust sample for more accurate assessment of the concentration. The minimum mass of dust required to carry out a satisfactory analysis depends on the analytical instrumentation available. For assessing quartz content, current rule-of-thumb is that a minimum mass of 0.1 mg of mixed dust is needed (Vincent, 1997).

The dust measurement strategy in various countries are discussed in the following subsections:

3.7.1 Measuring strategy in Federal Republic of Germany (FRG)

According to the measuring strategy effective in the FRG since 1954, the respirable dust concentration must be measured in a location within a working area where the maximum dust concentration is expected (Prinz, Stolz and Essen, 1998). The sampling location is generally set up in the return airway or tailgate, 50 m from the production area or longwall coal face as the case may be. Under normal operating conditions, measurements are taken once a month. The measurement period corresponds to the time spent by the miners at their workplaces. It should be noted that one monthly measurement over a five-year period is deemed statistically sufficient to determine the exposure of miners with sufficient accuracy. Compensation levels are based on these estimates.

3.7.2 Measuring strategy in Great Britain

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

In 1970, the standard average dust concentrations set by NCB for longwall coal faces in UK for an 8-hr working shift was set at 8 mg/m^3, based on measured dust concentrations and progression of CWSP (Jacobsen et al., 1971). In 1977, the dust standard for British coal mines was reduced to 7 mg/m^3, measured at a fixed point in the return roadway of longwall faces. In the 1980s, results derived from extended research confirmed the earlier dose-response curve with a small underestimate of risk at lower concentrations (Hurley et al., 1982).

Most of the coalmines in the UK are longwall mines. To assess the dust conditions at the workface, measurements were carried out using fixed-point sampling located in the return airways approximately 70 m out bye the face. The reason for selecting this sampling location is that at this distance the results deemed to be no longer influenced by the coarse dust or the unequal distribution of the respirable dust in the air. Measurements are taken in monthly intervals for a sampling period corresponding to the time the miners stay at the workplace. At values less than 15 mg/m^3 one measurement per month is deemed sufficient. At values greater than 8 mg/m^3, the average value must be calculated from up to five subsequent measurements in one week. The partial deposition of dust between the face and the measuring point is considered by introducing correction factors. Application of similar correction factors can be questioned. The development of similar correction factors in South Africa requires the definition of different sets of factors distinguishing bord and pillar and longwall mining methods.

3.7.3 Measuring strategy in USSR

The main objective incorporated in the measuring strategy adopted in USSR mines is the assessment of dust suppression that occurs in the face. When cutting the coal with shearers, the airborne dust concentrations with sizes of up to 74 μm without pre-separator (cyclone) is sampled directly behind the shearer while the coal is cut. Sampling is performed only while coal cutting is taking place. This implies that the sampling time per measurement lasts a few minutes only. The measurements are repeated in monthly intervals when concentration values are less than or equal to 10 mg/m^3. At higher concentration values the measurement is repeated directly after improving dust suppression. This way of dust measurement strategy can be linked to estimation of maximum health risk assessment.

3.7.4 Measuring strategy in USA

In the USA, the federally mandated respirable coal dust standard has been set to 2.0 mg/m^3 since 1969. For the purpose of dust sampling, respirable dust is defined as the fraction of dust recommended by British MRC and adopted by the Johannesburg Pneumoconiosis conference in 1959. MSHA data shows that average dust levels for an 8-hr period in most mines have been reduced from 8,0 mg/m^3 to below the current standard of 2,0 mg/m^3.

In the USA, measurement of the respirable dust concentration is by means of "personal dust samplers" placed directly on the employee. There are two types of sampling methods, namely personal (breathing zone) sampling and area sampling. The dust samples collected through these processes are categorized as personal samples and area samples respectively. *Personal or breathing zone* sample is collected within a few centimetres of the worker's face for the purpose of determining the amount of respirable dust to which the worker is exposed during the working shift. *Area sampling* is conducted by placing samplers at strategic locations in the workplace to measure the concentrations of dust in the air of the general work environment.

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

The sampling flow rate for all the sampling devices is set at 2,0 l/min (± 0,1 L/min), as the sampling cyclone used are Dorr-Oliver type cyclone. The sampling train is normally mounted on the miners (worker's) prior to the start of the shift and removed after the shift is finished, which is usually 8 hours. Because the 2,0 mg/m^3 dust standard is based on measurement data obtained with an instrument that sampled in accordance with the BMRC selectivity curve, respirable dust concentrations determined from measurements obtained with the personal coal mine dust sampler must be multiplied by a factor of 1,38 before the measurements are used to determine compliance.

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

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

If the average concentration determined from the five samples is below 2,0 mg/m^3 but one or more of the five collected samples registers a concentration greater than 2,0 mg/m^3, then sampling continues on all five occupations on subsequent production shifts. In this case sampling is continued until all individual samples and average are less than 2,0 mg/m^3. No more than five production shifts are sampled. Samples that are selected for quartz analysis are the designated occupation sample, all roof bolter samples and any other sample that may be suspected of having a high quartz contamination.

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

In the USA, the MSHA utilizes an infrared spectrophotometer to measure the absorbance of infrared energy by quartz in a dust sample to determine the quartz content of the sample. This analysis is conducted following the destruction of the combined sample and filter matrix by a low temperature ashing process and subsequent filter re-deposition of the ash containing the quartz. Since the mineral kaolinite interferes with the quartz determination, a correction is made to the results obtained (Parobeck, Ainsworth and Tomb, 1997).

3.7.5 Measuring strategy in France

According to French regulations, the level of coal dust exposure in each underground working must be measured by static sampling (using CIP10 samplers), i.e., positioning the samplers in the return air. It is assumed that the measurements in France could be in underground bord and pillar as well as longwall mines. The concentrations measured by CIP 10 in a national survey through more than 5000 measurements in 194 jobs were showed a time-weighted average (TWA) of 0,64 mg/m^3 respirable dust. The strategy for sampling is based on five successive days of measurements, eventually repeated following the results' dispersion and their extreme values (Zitter, et al., 1998). For the CIP10 dust sampler, selectivity matches the BMRC-definition quite well except at small particle sizes where the finest particles are not collected by the porous foam in the final collection stage of the instrument and are thus lost. Therefore, this instrument would thus tend to under-sample in atmospheres that are characterized by ultra-fine dust particulate. In the light of this influence, the instrument may not be used to sample the true exposure (Vincent, 1997). A similar result has been encountered in South African mines (Unsted 1998). It may be argued that the sampled used by Unsted for comparison may have contained ultra-fine particles that would have escaped the sponge-type rotating filter thus giving rise to the discrepancies and under-estimation of dust concentrations.

3.7.6 Measuring strategy in Sweden

Swedish Standard Method (SSM), which meets criteria for the method 0500 in the NIOSH manual of analytical methods (NIOSH, 1993) is the commonly used sampling method in Sweden. With this method, air samples are collected during a full shift (5-8 hours) on Millipore AAWP cellulose-acetate filters with a pore size of 0,8 microns. The filter is mounted on open-face cassettes (SKC) with a diameter of 25 mm. The sampling rate is maintained at 2,0 L/min, which is equivalent to a sampling velocity of 0,07m/sec over the filter. The Swedish method is designed to give one sample during a full shift.

3.7.7 Measuring strategy in Estonia

The Estonian Standard Method (ESM), is a method developed originally in Russia and has been adopted by Estonia and other former East Block countries since the early 1950's (Kask and Uibo, 1963; SUSC, 1988). With this method, dust samples are taken for 10 minutes every hour over a full shift of 8 hours. The sampling pump used, Migunov model 822, is a pump developed and manufactured in Russia. The sampling filters used are PVC-fibre filters AFA 201 in a 45 mm diameter cassette. The sampling flow rate is 20,0 L/min, which results in a sampling velocity of 0,21 m/sec. As described above, the ESM requires approximately five to eight samples during a full shift.

3.7.8 Measuring strategy in Australia

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

3.7.9 Measuring strategy in South Africa

Worker exposure limits are becoming stringent in South Africa. It is therefore increasingly necessary to measure the dust concentrations as accurately as practicable to assess the dust exposure, by using personal sampling techniques. Currently, in South African mines, workers' exposure to dust is assessed by using various air samplers such as Casella 10 mm cyclone, Gilian cyclones, MSA cyclones, and CIP10 samplers. All these units are designed for monitoring dust and are approved by the Department of Minerals and Energy (DME) at a conventional flow rates of 1,9 l/min, except for CIP-10, the flow rate is 10,0 l/min. Mines are also obliged to submit "engineering samples" to the DME, where gravimetric samples are collected at continuous mining machines. Apart from this, the DME separately collects bi-yearly "personal samples" from all controlled mines for risk determination purposes.

In most of the South African underground mines, dust samplers (both mine operator and DME) are currently being operated at a flow rate ranging from 1,9 l/min to 10,0 l/min in agreement with the BMRC respirable convention (BMRC, 1952). However, according to the new ISO/CEN/ACGIH respirable dust curve with a 50% cut point (d_{50}) of 4 μm (previous 5,0 μm) the recommended flow rate is 2,2 l/min (Kenny, Baldwin and Maynard, 1998). The new flow rate confers an immediate advantage in sensitivity since, presently, South African cyclones sample 16 % less air per minute. At present, no change is being recommended by the ACGIH for measuring respirable dust using a 10-mm nylon cyclone at a flow rate of 1,7 l/min. Measurement of the size-selection characteristics of the South African cyclones confirmed that they are similar to the Higgins-Dewell designs commonly used in the UK and Europe. Hence they are suited for sampling in accordance with the new ISO/CEN/ACGIH respirable convention with a 50 % cut-point (d_{50}) of 4 μm. It should be noted, however that a flow rate of 2,2 l/min is recommended (Kenny and Maynard, 1995).

The strategy used in South Africa consists of sub-dividing exposed workers in working categories (referred to as statistical populations) and working areas typifying the geographic difference of different mining sections and nature of ventilation systems within these. Typically operators are required to analyse the samples collected for quartz concentration at least once annually. Such an analysis is carried out for samples collected in each statistical population as defined in each mine's own sampling strategy (which must be approved by the DME). The quartz levels are combined with the average duct concentration in each sampling area to determine the air quality index in each area and for each statistical population.

3.8 Databases

In 1980 the U.S. Bureau of Mines developed the Mine Inspection Data Analysis System. It is a computerized industrial hygiene database capable of statistically analysing Mine Safety and Health Administration compliance data collected in coal and non-coal mines and mills. Data are collected by inspectors and mine operators, and are provided to the Bureau annually on magnetic tape. The Bureau extracts, merges and edits these data to reduce storage requirements and to facilitate analysis. The database contains approximately 1.5 million records of respirable coal mine dust samples collected since 1981, and about 45 000 records of respirable coal mine dust samples analysed for quartz. Another 6 million records of respirable coal mine dust samples dating from 1970 are archived on magnetic tape. The database also contains records of approximately 750 000 personal and area samples collected at metal and non-metal mines and mills from 1972 to 1992. These samples were collected to determine the concentration of about 130 different substances and noise in non-coal mines and mills. In addition, there are approximately 4000 records of samples collected from 1976 to 1978 for a variety of contaminants at 22 non-coal mines using diesel powered equipment. Analyses of data have shown which commodities, locations and job categories have the highest exposures. These analyses have assisted the Bureau in planning, prioritising and conducting industrial hygiene research activities at surface and underground mines and mills. The Mine Safety and Health Administration have used these to assess the potential impact of proposed changes in occupational health standards and to evaluate compliance sampling strategies.

3.9 Surveillance

Whatever the underlying mechanisms of the tissue-damaging reactions in the lungs of workers with pneumoconiosis, the method of prevention is clear. It is known that the risks of developing simple pneumoconiosis in coal miners and of developing asbestosis in asbestos workers are related to the subject's cumulative exposure to dust particles in the respirable range. However, the attributes and properties of the inhaled dust that causes disease, the particles of interest within the respirable size range and the age of the dust is largely unknown. Prevention, therefore, depends upon reduction of the levels of dust to which these workers are exposed. Even though there are differences in the ways individuals respond to the same dust and, indeed, to similar dusts generated in different industries, no useful method has yet been devised of screening out susceptible individuals. Prevention relies on the application of measures of dust control and should ideally be guided by the results of epidemiological studies.

A mean exposure-response curve conceals much variability in the data, and adherence to any dust standard does not guarantee that no miner will get disease. Mineralogical variation, individual susceptibility, failure to adhere to standards, variations in exposure levels on a shift-to-shift basis, sampling inconsistencies and variations in airborne quartz content mean that these diseases will occur so long as men (and women) mine. Therefore, any programme of dust control must be backed by a programme of worker surveillance in order to pick out the disease at the earliest and, hopefully, the least progressive stage and thus prevent or at least minimize further dust exposure in the victim. Neither of the two dust sampling programmes (i.e. dust control and surveillance), should be regarded as optional and both should be implemented concurrently.

There is still insufficient evidence on exposure-response relationships for quartz, asbestos, many silicates and the new fibres for confidence in a strategy for prevention of pneumoconiosis. Where the problems of lung cancer or chronic airway disease arise, there is almost no information on which to base risk analyses in any industry other than asbestos or coal mining. Much more epidemiological research is needed in these areas, concentrating especially on accurate estimates of dust exposures.

From the point of view of understanding the mechanisms of the pneumoconioses, emphysema and lung cancer, not much progress has been made thus far. It is reasonable to suppose, however, that a dramatic increase in understanding will soon occur with the application of biochemical and immunological techniques to patients and to animal and cellular models. Such studies may have far-reaching consequences in the prevention or treatment of many non dust-related lung diseases. Their contribution to the prevention of dust-related disease is, however, likely to be small compared to those of the epidemiologist and, especially the dust control engineer.

Most of the available health effect (exposure) data on (these) pollutants are for the single-pollutant case rather than the more realistic multiple-pollutant case, and the data were obtained at pollution concentrations above those found in even heavily polluted areas (Burling, 1991). Obviously, the effects of synergism are far more complicated to study and far more complex to evaluate, although many studies have tried to take into account the effects of smoking, but until synergism is fully accounted for sampling efforts and epidemiological conclusions will be hampered.

Rappaport (1991) made an appeal to analytical chemists and designers of instruments to develop methods and devices that can significantly reduce the unit costs of measurements. It was felt that inexpensive, direct reading, personal monitors which require a minimum of calibration and maintenance and which individuals without professional qualifications can use. Since measurement error is almost always a small component of the total variation in exposure, analytical precision can be traded off against cost to increase sample size greatly at a given investment. Attention should also be paid to devices that can be worn over periods of weeks or months so that true long-term monitoring can be achieved.

In South Africa, the National Centre for Occupational Health (NCOH) is responsible for the pathological analysis of a deceased miner's lungs to determine the possibility of the presence of occupationally related diseases. The analyses are done at State cost and in accordance with the *Mine, Health and Safety Act*. However, the usefulness of the analysis outside the realm of compensation is doubtful as the historical exposure of the deceased is not available and the cause-effect relationship may not be established. However, the pathologist performing the analysis and the results of the analysis captures the results on computer and the information relating to the presence of an occupational disease and the possible grade of the disease are recorded.

The results of work performed (Trapido, 1999) show a high prevalence of radiological pneumoconiosis in a random sample of ex-mineworkers in South Africa. It has also been demonstrated that there is a statistically significant association between total length of service and pneumoconiosis. This research shows that the probability of developing pneumoconiosis after ten years of service could be 30% and after 20 years service it increases to 44%. An important methodological issue regarding the ILO codes was also shown up by the reader variation found in the study by Trapido (1999). The reader variation relates to the problems of diagnosing pneumoconiosis in the presence of tuberculosis. This indicates further that from a perspective of medical studies, a clear problem associated with the accurate radiological assessments of chest diseases in communities exposed simultaneously to both occupational respiratory diseases and tuberculosis.

3.10 Inferences from global dust measurement variability studies

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

- A Government Accounting Office report to US Congress (1975) indicated that under certain conditions the error associated with the respirable mine dust samples could be as great as 50 %.
- The US National Bureau of Standards (1975) submitted an investigation report to Senate Committee on Labour and Public Welfare studying respirable mine dust sampling and analysis. The study focused specifically on gravimetric sampling and analysis and examining each step of the sampling process, such as dust weighing, pump flow variation, and others. It was concluded that under tightly controlled conditions with a "well-trained" technician, the average standard deviation associated with the process was ± 0,39 mg/m^3, or 19 % (at the 2,0 mg/m^3 standard dust concentration).
- NIOSH (1976) found that in high-risk mine sections, which failed to comply with the 2,0 mg/m^3 standard, the coefficient of variation in dust measurements was 91, 6 %.
- The National Research Council in USA (1980) concluded that uncertainties associated with spatial and temporal variation in dust estimates from machine mounted samplers precluded this method for estimating personal exposures.
- A study by Page and Jankowski (1984) comparing dust measurements of paired RAM-gravimetric sampler results in longwall mining operation expressed dust ratios of 0,41 to 1,63. The authors attributed this variation to differences in the aerosol cloud being sampled, air flow velocity at the face and cyclone orientation.

- A comparative study of personal and fixed-point (area) samplers by Breslin, Page and Jankowski (1983) reported the coefficient of variation of measured mine dust concentration to be typically less than 20 %.
- In 1986, a study by Kissell, Ruggier and Jankowski reviewed several factors contributing to the measured dust concentration variability. They concluded that sampler position, geological variation in composition of coal (for variability in measured free silica), production factors such as deep or continuous cutting and failure to control known sources, such as shuttle car loading, play an crucial role in dust concentration sample results.
- Sampling and laboratory variability for respirable mine dust was studied using 23 and 20 pairs of dust samples from coal and non-coal mines respectively (Hall, Corn and Zeger, 1997). In coalmines, mine dust ratios (larger to smaller values) exceeded 1,5 in half of the paired samples and 2,5 in 10 % of the pairs. The variability of mine dust was somewhat less in coalmines with 50 % of the samples having ratios greater than 1,13. 10 % of samples demonstrated ratios of 6,19. Discussions indicated that in coalmines, sampler location was an important contribution to the variability. Machine mounted samples showed an improvement in variability for all measured parameters. The improvement in variability for machine-mounted samples when compared with personal samples was 40 %.
- Parallel measurements taken at a cement plant with ESM and SSM indicated the differences between two methods. The study illustrated the importance of comparing and evaluating different sampling and analytical methods (Berg, Jaakmees and Bodin, 1999).

In South Africa, a comparative study (Belle, 1999) on the differences in measured dust concentration levels obtained by independent parties showed a very poor correlation (r = 0,34)

4 Discussion and conclusions

4.1 Status Quo

During the late 1950's and 1960's considerable work was performed in South Africa to ameliorate conditions leading to the excessive exposure of mine workers to respirable dust. South African researchers such as Beadle, du Toit and Kitto have contributed to different degrees and in different areas. At the time of these developments, there were no computers, integrated circuit technology for continuous monitoring equipment was in its infancy and communications systems were rudimentary by today standards. In addition medical research techniques were just as antiquated by today's standards.

The principles behind some of the recommendations made at the 1959 Johannesburg International Conference on pneumoconiosis are still valid today (4). Some of them regarding the field of dust and engineering are listed here:

- "That measurement of dust in pneumoconiosis studies should relate to the 'respirable' fraction..."
- "That in the light of present knowledge, dust measurements to assess the health hazard should be expressed as the average level of dustiness over an appropriate period of sampling, such as a shift... Exceptional peaks of dust concentration may also be recorded"
- "That in the light of the present available evidence, the best single descriptive parameter to measure be considered
  (a) in the case of coal dust to be the mass concentration of the respirable dust,
  (b) in the case of quartz dust to be the surface area of the respirable dust."

- "That wider use be made of long period dust sampling instruments."
- "That more attention should be paid to designing correct dust sampling strategy bearing in mind the difference between sampling for purposes of dust control and sampling in order to determine the health hazard."
- "That further studies should be made of the quantity and character of the dust produced by various mining operations."
- "That further studies should be made of the dust exposure in different occupational groups."

- "That epidemiological studies to determine the dose-response relationship in man should be continued and expanded."
- "That individual cumulative dust exposure records should be kept for men working in dusty occupations...showing their hours underground and their dust exposure...Their medical data should be specially recorded."
- "That further studies should be made of pulmonary retention of particles..."
- "That detailed studies should be made of the size distribution composition and amount of dust found in the lung tissues of miners..."
- "That the composition of sub-microscopic particles which occur in mines and dusty industries should be studied in more detail".
- "That more effective liaison and co-operation should be established between the various disciplines involved in the study and control of pneumoconiosis."

The epidemiological studies carried-out in South Africa principally by Beadle (5), were designed primarily to investigate the link between cause and effect in miners suffering from pneumoconiosis from the early 1930's to the late 1950's. The results showed that exposure to dust could be linked to pneumoconiosis and that workers exposed to high levels of dust for a longer period of time were at greater risk than workers who are exposed to lower dust levels for shorter period of times.

Although limited in some aspects, Beadle's work provided a first insight into the problem of pneumoconiosis. As the result of the limited service history available, Beadle's cohort groups were drawn only from white miners. Statistical considerations resulted in Beadle dividing the cohort groups into eleven occupational categories rather than in occupations. In addition, measurements are based on the exposure of "observers" that followed the cohorts in the work places. Despite these and other limitations, Beadle's work is still recognized today as being pioneering in nature and responsible for a quantum leap in knowledge around dust exposures in South African Mines.

The introduction of gravimetric dust sampling in South Africa heralded the abolishment of official dust sampling for control purposes. Each mine conducts gravimetric dust sampling solely for the calculation of a levy. Although full shift personal samples are collected the results are not used to determine occupational related dust exposure levels nor to compare dust concentrations for different occupations, and different risks are not assigned to different occupation groups (Unsted, 1995).

Past dust measurements were by konimeter, and extensive simultaneous konimetric and gravimetric sampling was carried out to derive a curve for conversion to gravimetric exposure units. A curvilinear relationship was found, but the plots furnished do not inspire confidence in conversions at low gravimetric levels i.e. $< 100\mu g/m^3$. The small number of cases, and the imprecision in converting particle counts to gravimetric levels, should be kept clearly in mind. (Weill, 1994)

When gravimetric dust sampling was introduced into gold and platinum mines (1992) all official sampling with konimeters ceased since mines were unwilling to conduct surveys using two different types of instrument and to implement different sampling strategies and techniques. The "snap" konimeter samples were used to give an indication of the dustiness of working places, or whether remedial measures were needed to reduce or control dust levels and the effectiveness of such measures. By taking samples at specific time intervals, decay patterns of a dust cloud such as in a development end or a stoping section after a blast, could be determined.

The konimeter was unsuitable for studies of exposure over a shift. By contrast, gravimetric samplers are designed specifically to determine personal exposures over a full shift but, in the South African mining context, have only been used to calculate a mine risk on which a compensation levy is then based.

A research study indicated large intra and inter- shift differences in dust concentrations for a given employee. Peak dust concentrations and their duration and very high dust concentrations during the full shift measurement cannot be identified and therefore remain undetected and not dealt with. Because of the extreme averaging system used to arrive at a mine risk even high 8-hour Time Weighted Averages become masked. Even if these high dust concentrations are noted very soon after their measurement, the reasons for the elevated levels and places where high dust concentrations may have been encountered cannot readily be identified. If any high dust concentration is detected in the mine's report at the conclusion of a sampling cycle (every six months), the possibility of locating the person and retracing his movements for that particular shift to try and establish reasons for the high dust concentration must be regarded as remote and meaningless since there would be little relevance in doing so. It was concluded that shift-long samples were of little use for determining the levels of dustiness in workplaces or processes where unsatisfactory amounts of dust are liberated. This must be regarded as a serious flaw in a single system of dust sampling, which is in essence aimed only at personal sampling and which cannot provide useful data, as may have been conceived, with regards to workplace or process emissions.

It also became clear that when large numbers of samples are collected, any efforts to reduce dust levels on a mine are unlikely to be detected in present sampling strategies. The situation is exacerbated for risk determination by the considerable variations in both dust and quartz concentrations that can be encountered on a shift-wise basis. This sort of occurrence was also noted by Corn (1990): "Air contaminant concentrations will vary with time, and estimated exposures will vary between workers doing the same or similar tasks. Although part of this variation will be systematic and part random, it will seldom be possible to distinguish these by air sample results.

Day to day variations of occupational exposures have important implications for the Industrial Hygienist trying to assess compliance with an occupational exposure limit. (Burling et al, 1991)

In some countries such as the United States, compliance testing can result in legal sanctions against the employer when evidence indicates that employees are overexposed. However, even in countries where the legal basis for monitoring is unclear, compliance testing is still commonly practiced owing both to a strong historical precedent and to a seductive simplicity which is appealing to the practitioner. A decision is made regarding exposure merely by comparing the largest of a set of measurements with the operative OEL. Thus, compliance testing should be viewed as a general mechanism for assessing exposure that transcends the legal milieu in which air sampling is conducted. The decisions arising from compliance testing would be reasonable if the airborne concentration experienced by a worker or group was constant. Unfortunately, exposures vary to such an extent that a person found to be exposed at, say, half of the OEL on one day might be exposed at twice the OEL on the next day. This variability and the lack of guidance for dealing with it, greatly complicates the assessment of occupational exposure.

Since the durations of measurements are sometimes different, the question logically arises as to the impact of averaging time on the exposure distribution. Are the mean and variance of the distribution of 15-minute averages, for example, the same as those of eight-hour averages when sampling the same environment? Experience and common sense suggest that this is not the case and that the variance, in particular, decreases with increasing time. This was indeed found to be the case by Unsted (1996) when 15-minute samples were compared with 2-hour samples. Another example of these variations can be found in real-time traces of pollutant concentrations when second-to-second variations are readily apparent. This indicates that exposure distributions change with averaging time even when all measurements come from the same environment.

Of particular concern are the questions of when to sample and how many samples to collect. Attempts were made to address these concerns in South Africa through the Guidelines for Gravimetric Dust Sampling which requires mines to sample five percent of the workforce over each six month cycle, covering all shifts and all Statistical populations. Given the magnitude of the workforce of the mining industry it became obvious during the research investigation (Unsted, 1995) that too few samples were being collected. No follow-up samples are collected unless samples have to be discarded for whatever reason. No system is prescribed that will determine the minimum number of samples necessary for any given individual to determine exposure levels with any confidence.

Many officially recommended monitoring strategies fail to address the subject of selecting appropriate time intervals between individual measurements (Burling, 1991)

The small number of samples usually collected during surveys leads to biased estimates of the variance of the exposure distribution.

As noted above occupational exposures to toxic chemicals vary considerably from day to day, from shift to shift and even from hour to hour. Villnave offered the explanation that these variations in time arise from changes in the emissions of pollutants, the degree of ventilation, and mobility, as well as different tasks and work practices of the worker.

These are all-important considerations for meaningful sampling to take place and will need to be addressed in a practical manner to improve epidemiological analyses.

Ulfvarson (1983) also reported variations in measurements and added that almost no efforts have been made to develop sampling strategies that would permit the true uptake pattern of substances in the bodies of exposed employees to be determined. The reasons claimed were:

i. the ethical problem involved in prospective epidemiological studies and,
ii. the prohibitively high costs in for measurements when future use of the measurements is unknown.

An examination of a trace of real-time dust concentrations from a real-time monitor such as a tyndallometer confirms substantial second-by-second fluctuations in dust levels. In the past, fluctuations in successive konimeter samples were ascribed to instrument error but real-time readings largely refute this criticism.

The deployment of modern, internationally accepted dust sampling equipment, as used at present, has not assisted with the investigation or determination of risk.

Recent research has shown that it is possible to determine different exposure levels for different occupations. Even though the differences may appear to be small, the differences may be very significant in exposure/dose-response relationships and hence in risk determination for given occupation groups. The introduction of multi-skilling labour groups could complicate occupational dust sampling and also the reconciliation of present dust exposure measurements with previous work experience and would need careful handling (Unsted, 1996).

The research findings also indicate that short duration samples, i.e. 10 to 15 minute samples, can successfully be used to determine workplace dust levels, which can then be used to determine workplace risk. The risks of the various workplaces can be used to compile, finally, a mine workplace risk. While this would not be worker risk it can reasonably be argued that if workplace exposure levels are controlled then, in turn, worker exposure levels will be controlled. This approach by no means proposes abandoning personal dust sampling, but supports personal dust sampling as well as workplace dust sampling. This approach was clearly mooted in the 1959 Johannesburg Pneumoconiosis Conference.

There are major disagreements as to sampling strategies. One most important factor is the selection of a guideline to be used. Without some guideline, it is not possible to define "exposed" or to decide what is "trivial" exposure so that a reasonable sampling strategy may be applied.

A major defect in some strategies is that they suggest the same strategy for all situations.

The strategies tend to fit a common situation where routine operations are performed at the same location for most of the shift. Other common situations include the roving worker who works at any part of a process and another situation involves work where the emission of pollutants is controlled but which has occasional fugitive emissions. With the routine operation the exposure may be relatively continuous, if variable throughout the shift. With the roving worker the exposure may occur at only one point or at one time during the day. At the controlled process exposure may be negligible. Issues to be resolved are:

1) Whether an air sample will yield information enabling the prediction of exposures in the future - assuming no major changes in the nature of operations.
2) Whether an air sample will yield information, which will assist in controlling the operation.
3) Whether the information will be of value in protecting his (or her) health considering that the only purpose of the air sample is to estimate the exposure of the worker on the day and at the time sampled.

It will often be necessary to take more than one personal sample on a worker, or to sample more than one worker, in order to estimate the hazard, if any. (Corn, 1990). Villnave et al (1991) reported on the MSHA strategy for regulation in the context of respirable free crystalline silica and dust data. They concluded that deficiencies of the strategy include the same enforcement efforts regardless of compliance history, inappropriate treatment of data, and emphasis on short-term variability of silica content.

It was noted that the determination of the respirable dust standards in each working section of each mine is made by MSHA. The validity of setting any standards without due recognition for influencing factors must be queried.

Corn (1985) noted that the MSHA strategy is completely regulatory and represents a scientifically indefensible strategy*. **It is strongly recommended that cognisance be taken of this very considered remark.*** The sampling strategy is considered to be a guess at true conditions that does not provide any meaningful long-term data for exposure or trends.

Villnave also conducted tests on 25-paired samples and found differences of percentage of silica values ranging from less than 0.1 to 19.2. The magnitude of percentage of silica content of samples collected from the same section ranged from differences of 7.5 to 88. Unsted (1995 and 1996) reported very similar findings with paired samples, but the differences in percentage ranges were even higher than those reported by Villnave.

The silica content of the dust from a section is determined once a year or every six months. Yet, as demonstrated, even paired samples often do not have silica contents that agree within 2%.

Given the variability of silica content in respirable dust samples, there appears to be no justification for a mechanism that allows for a respirable standard to be set based on the analysis of only one sample. The position is greatly exacerbated when, as is permitted in South Africa, five samples may be combined for a single analysis and analyses are only required once per year.

4.2 Uncertainties

Because airborne exposure varies greatly over time and between individual workers, occupational hygienists should adopt sampling strategies that recognize the inherent statistical nature of assessing exposure. Rappaport, (1991) proposed to change the traditional practice of testing compliance with occupational exposure limits in favour of a system whereby acceptable exposures are defined with analyses of exposure distributions. Biases are often introduced since much of the official, regulatory sampling effort is directed towards "worst case" scenarios, where workers are engaged in activities that are expected to produce the highest airborne concentrations of the pollutant.

It can be confirmed in the literature that at the turn of the last century the contraction time for silicosis amongst gold miners on the Witwatersrand was phenomenally high (less than five years service). Various measures were introduced to improve the situation and monitoring of the air supply to the workings was introduced. The manner of monitoring was, at the various progressions of mining, considered to be according to the best available knowledge and equipment at the time. Dust sampling moved from mass determinations using a sugar tube to a konimeter for particle count assessment. Particle determination in the working air was practiced for over 70 years as a measure of conditions to which workers were being exposed. The postulation was that if the dust levels in the workplace could be controlled then worker exposure would also be controlled. Without the means of determining personal exposure levels this appeared to be a very acceptable approach. The only shortcoming was that this method of monitoring could not provide much, if any, information that could be used in epidemiological studies.

Since x-rays of lungs were mainly assessed on opacities in the evaluation of lung impairment the next development was the determination of the respirable surface area of dust in airborne samples. The logic here was easy to understand.

Occupational hygienists, on a global basis and in conjunction with medical opinion, however, decided that the mass of dust inhaled was the important parameter in assessing the quality of air in the workplace. Accordingly, dust sampling was changed to incorporate this concept. The concept of mass concentration as an indicator of personal exposure soon evolved. However, as has been seen, both from the literature and from research, there are many shortcomings in the sampling strategy introduced to determine personal exposures, risk and possible compliance with a preset limit.

An examination of the findings presented above shows that there is great uncertainty in what parameters to measure/monitor to determine risk. Equally, the concept of one single sampling strategy to determine health risk and also to be used to assess the effectiveness of engineering controls appears more to be a matter of expediency rather than one of practical possibility or merit.

The arguments advanced in this report indicate that much research is still needed. When the concepts of TLVs and TWAs are challenged and the importance of ultra fine particles, age of the dust, synergism, the role of peak concentrations and variations of dust levels in the breathing zone is shown then questions have to be asked on what needs to be monitored. The effect of variations in pollutant concentrations over short time periods, between shifts and between workers doing the same work in the same workplace on sampling requirements also needs to be addressed. Only when answers to the findings of epidemiological studies on the critical parameters of disease formation and progression are available can meaningful sampling strategies be developed.

The use of TWA and TLV (or OEL) in determining risk or for compliance testing is seen to be a matter of concern. Also, single samples have been shown to have little or no value in the estimation of exposure for compliance testing. The value of single samples in medical surveillance can also thus be questioned.

It has been shown that particulates and aerosols can exhibit very unpredictable behaviour patterns. These factors tend to complicate any efforts to sample these airborne contaminants in a meaningful or realistic manner. Although considerable efforts have been dedicated to developing size-selective samplers, there is still uncertainty as to the correct criteria to apply. Repeatability of results is not reported in the literature.

If sampling instrument uncertainties are coupled to uncertainties in disease-producing mechanisms it must be concluded that there is still a great deal of research necessary before exposure levels can be determined in a fully representative way so that predictions of pollutant exposures can be reliably related to dose and disease progression, which could also aid in timeous medical intervention.

Previous researchers in pollutant hazard measurements and epidemiologists tended to investigate dust properties in isolation. Risks were described in terms of particle concentrations or mass concentrations but not in terms of both parameters.

Further inaccuracies in the collected samples have been introduced in the assessment of exposure levels. All samplers collect airborne particulates at a fixed flow rate yet people change inspiration rates throughout the working day due to exertion or heat factors. There are also individual differences, which are not taken into account. Modern technology could help address this anomaly and assist in providing variable sampling rates based on, for example, heart rates.

The value of a central data base on exposure levels, even if not very valuable to determine risk, has been reported and should be borne in mind when the matter of reporting is considered.

4.3 Generic conclusions

Conditions that are peculiar to the South African mining industry require a differently focused approach and application of monitoring techniques and standards. The characteristics of some South African mining operations that require consideration from a dust sampling perspective are listed below:

- South African metal mining techniques and ventilation systems are employed in narrow, tabular ore body operations differ radically from typical American, Australian or European mines.
- Some of the inherent features of South African coalmines are: long headings (up to 35 m allowed), the increased use of highly mechanized equipment and inherently high dust generation potential of coal seams (Srikanth and Ramani, 1996; Belle, 1997).

- Country rock formations in South African metalliferous mines are significantly harder. This requires the use of considerable energy, usually through blasting, to break the rock. This implies the creation of more dust than might be the case in softer rock environments.
- The most commonly used ventilation and dust-control systems in South African coalmines are on-board scrubbers, external spray systems and auxiliary ventilation devices such as jet fans and force fans.
- Long headings and the rate of advance per shift in headings in South African collieries are comparatively greater than those in European or US mines.
- The mining of narrow tabular ore bodies is very labour intensive in comparison to other mining countries. This means that the number of workers at risk is significantly higher.
- Ventilation system design of narrow tabular ore bodies is done on a series flow basis. The levels of contamination are therefore additive as the air moves from the inlet to the return airways.
- Dust control systems (in gold mines) consist mainly of water sprays used at different stages of the production cycle and, in places at rock transfer points. The effectiveness of such dust control system is erratic and very much a function of diverse variables such as the water pressure, condition of nozzles and jet gaps (drills) and the proficiency of operators in watering-down effectively.

In a global analysis of the information presented in this report, the following conclusions are made:

1) The main purpose of this newly proposed gravimetric sampling programme is the determination of worker exposure to dust.
2) Given this requirement and the characteristics of South African mines listed above, personal sampling is the more likely method of dust measurement that will indicate workers' exposure with a reasonable degree of confidence. However, machine-mounted samples showed an improvement in variability for all measured parameters. The improvement in variability for machine-mounted samples when compared with personal samples was 40 %.
3) Area sampling is deemed not to be suited as a surrogate measurement of workers' exposure since the correlation between area measurement and workers' exposure is not possible.
4) There is a lot of work required to improve the relationship between a gravimetric personal sample to an exposure or even a dose. Any prospective system must take

cognisance of this and of the fact that dust concentration may not be an accurate representation of the cause of occupational respiratory diseases.

This aspect was found to be a major stumbling block in arriving at the definition of new criteria. There is a real danger that by employing a certain set of criteria based on the measurement of dust concentration, the purpose of the measurement (i.e. for epidemiological purposes) may not be valid as the outcome could be as the result of exposure to a number of dust characteristics (size, surface area, peaks, polarity). The synergism that may occur between exposure to dust and other airborne pollutants (diesel exhaust particulate, radon gas, etc.) may also not be considered by this system.

It is therefore recommended that the system proposed be structured in a flexible manner in order to allow for data "adjustments" further down the road. At the same time it is suggested that a wide-ranging project be considered to address issues relating to the causes of respiratory occupational diseases with the view of pinpointing the causal properties more accurately. This information should be used to refine the sampling system and to make it more representative of the relationship between dust exposure and pathogenesis.

In order to do this, the following are suggested:

1) Any sampling criteria put forward for South African mining conditions must take due cognisance of requirements and limitations that may be imposed by mining techniques and operations.
2) The sampling methodology should be based on un-ambiguous and well-defined goals. Any such methodology should also be part of a greater, co-ordinated strategy aimed at improving the level of knowledge about the causes of occupational respiratory diseases.
3) The new system(s) should eventually replace the existing system, which suffers from the following draw-backs:
   - It is not used to determine workers' exposures
   - It has not been reviewed and upgraded in the last decade.
   - It does not focus on actual exposures but rather on shift exposures (all samples being related to an eight hour equivalent shift irrespective of shift length)
   - It cannot correlate the exposure to the occupation of individuals sampled.
4) A new system should be structured so that the information gathered is analysed regularly and used to benchmark progress in limiting the exposure of workers to dust.

This information should be summarised by a central monitoring body who will make summary and detailed information available for further analysis and as part of other work planned in parallel with the monitoring.

5) The system should also lend itself to upgrades. Concurrent with this, regular reviews of advances made in the area of dust sampling should be monitored with the view of adapting these to the system with minimal disruption and loss of data.

5 Recommendations

5.1 Generic issues

In order to assess peak exposures, considered as a very real necessity by some experts, real-time monitoring will assist in establishing the magnitude and frequency of peaks. Although some instruments may be capable of this, real- time monitors may have to conform to ISO standards for particulate collection i.e. to discern between respirable, thoracic or inhalable particles. The suggestion of a sampler to provide true long-term data on exposures should be given serious consideration.

Equally, and perhaps even more importantly, it appears that the determination of the ultra fine fraction of dust being inhaled is highly significant. This can only be ascertained from an actual physical sample and therefore, in addition to a real-time sample, a physical sample is needed for size distribution analyses. Present microscopic techniques do not permit examination of dust particles less than 0.2μm in diameter and studies of the ultra fine particle content will require a different analytical technique, possibly electron-microscope analysis.

To date, all influencing factors appear to have been studied in isolation. Therefore, in conjunction with epidemiological studies, all possible dust parameters should be measured for inclusion in these evaluations. These would embrace mass concentration, particle concentration, surface area and size distribution, particularly of the ultra fine range, and even the age of the dust.

The above parameters should be evaluated at major dust-producing sources to determine differences, if any, in the characteristics of the airborne dust at the sources or operations.

It is likely that the answers being sought could be provided by a highly modified real-time sampler or, more importantly, from a novel instrument developed to specifically address all the shortcomings found in present generation sampling instruments.
Various attempts have been made to determine risk based on data, which are 30-40 years old (Fitsimons et al, 1999). In order to do this an expedient conversion had to be made to convert results of particle counts to mass of dust. However, recent research has confirmed that the correlation between particle concentration and mass concentration is very poor, as can be expected since different parameters are being evaluated. Instead of using "old" data, however useful it appeared to be, the latest data from mines in all mining sectors could be analysed and relevant exposure levels, trends and other matters of concern compiled.

The deployment of modern, internationally accepted dust sampling equipment, as used at present, has to date not assisted with the investigation into and the determination of risk. Research is needed into devising an acceptable dust sampling strategy, which will produce workplace, and hence mine, risk and occupational risk, taking into account the many variables involved, including variable respiration rate.

The use of Threshold Limit Values and Time weighted Averages should be very carefully considered in any attempts to assign "risk" to the results of eight-hour sampling. Risk should take into account both exposure and response and its definition in these terms would need to be researched.

Cognisance should be taken of short exposure peaks in deciding the extent of risk. The method to do this and the sampling technique would also need to be researched as will reporting results in a format meaningful to epidemiologists and mine management.

Airborne dust concentrations can vary from minute to minute, hour to hour and day to day. Airborne quartz concentrations vary similarly, but are not related to dust concentrations. There are no clear indications on how to deal with this variableness with regard to either compliance testing or risk determination. Before any meaningful sampling strategy can be devised these factors will have to be addressed.

In view of the large number of variables and confounding factors involved, which may take too long to resolve to develop a dust sampling strategy that will satisfy epidemiologists and occupational hygienists as well as mine management, a radical change in approach could be considered. As part of this ***alternative approach***, it is suggested that "occupational" dust sampling in workplaces should be discontinued, as it appears to serve no purpose in any case. Instead, workplace sampling should be reintroduced along very structured lines. Every effort must be made by organizations to ensure that these levels are kept as low as possible and such levels can be set in "Codes of Practice." This practice would allow comparison of dust levels in individual workplaces as well as between organizations to be made, if necessary. Unsted (1996) has proposed a technique that could be deployed in this regard.

Furthermore, as part of this alternative, in order to study epidemiology of workers exposed to different workplace pollutants, several cohorts, embracing different occupations, should be selected throughout the industry and sampled on a daily basis - if possible and if considered desirable. As far as possible, all influencing factors e.g. size distribution, peak levels, age of dust, silica content, etc should be included in these measurements.

It is obvious that the long-term sampler proposed above could find a definite use in such an investigation but would take some time to develop and any investigation should not be delayed waiting for such a sampler.

This alternative approach, if accepted, would provide the means to judge how well dust is controlled in the workings and therefore how well exposure is controlled and at the same time invaluable epidemiological data can be accumulated. These data may indicate modifications to workplace sampling strategies with the passage of time.

5.2 Proposed rational criteria for routine sampling

5.2.1 The criteria

Given the foregoing discussion, the criteria proposed here are part of a sampling/surveillance programme that designed to:

- Collect data pertaining to the exposure of mine workers to dust.
- Record all necessary data to be able to assign exposures to different work categories.
- Produce reports that will assist medical practitioners in the monitoring of patients
- Produce information that will result in the assignment of a life-long dust exposure levels to workers within the mining industry.

In order to explain this further, this section is sub-divided into three sub-sections: The sub-division of the worker population, the collection of data and the management of data and creation of information.

These criteria are proposed despite the fact that there is no firm knowledge of the dust parameter(s) that require measuring to represent a surrogate dose measurement. For the sake of illustrate the criteria, it is assumed that mass per unit volume, obtained through gravimetric sampling, will be the accepted dust parameter. This aspect and it relationship within a much wider monitoring programme will be covered later in this section.

The basic principles of these criteria are that any type of sampling will be representative of worker exposure. This therefore means that all samples must be *personal samples collected over a full shift*. In addition, information regarding the type of work performed during the shift must also be recorded for later analysis. Certain items of information are mandatory for each sample. These are:

- The surrogate dust exposure measure.
- The shift duration – irrespective of whether a short-shift or overtime are worked.
- The actual nature of the work and location.

5.2.2 Worker population sub-division

The brief for this project is to provide sampling criteria that will suit all sectors of the South African Mining Industry. To this end it is therefore desirable that the first sub-division be made along the lines of the mineral mined. This will allow the separate study of the different sectors and avoid the overwhelming of the results of one particular sector by another or of a number of sectors by a single one (e.g. Gold when compared to Platinum, Coal, Diamonds and others). Further sub-division may be considered depending on the type of mining operation performed in each sector. For example, in coal mining a distinction could be made between mechanized and explosive mining operations. However, confirmation of this will be obtained only once preliminary data is analysed. The proposed sub-divisions are shown in Appendix A.

Each mining sub-sector is sub-divided further in accordance with the perceived level of risk. These sub-divisions are made based on the current knowledge of mining activities in each sub-sector and the grouping of these together in what are perceived to be (at this stage) equivalent levels of exposure and possibly risk. Initially this classification is purely arbitrary. However, as information relating to exposure and occupations becomes available and is analysed, re-classification may be necessary. Each sub-sector is divided further in a set of broad occupational activities – each of which will be monitored separately. This was a pragmatic aspect of the strategy aimed at reducing the number of different categories to be monitored.

Further sub-divisions into geographical areas within the same operations are ignored. At this stage it is thought to be expedient to do this as the sampling is primarily aimed at investigating occupational exposure and not to compare dust levels from different mine ventilation districts or zones. This presumes also that workers may move from section to section in a specific mine within the same occupational activity – often resulting from economic considerations. The variability arising from this assumption is discussed later.

It is necessary that, in preparation for the sampling, the mine's worker population be sub-divided in each of the occupational activities listed below. Although it is important to sample a statistically representative number of workers in each category, the acceptability criterion is based on the numbers actually sampled in relation to the variance of samples within the parent population.

5.2.3 Sector sub-division

5.2.3.1 Gold Mining

The Gold mining sector can be divided into three sub-sectors: ore production, shaft sinking and metallurgical extraction. It is assumed that further sub-division of this sector is not necessary as the vast majority of mining operations consist of underground blasting or underground digging. Opencast operations will be handled as a separate sector.

Sub-Sector: Gold Mining - ore production

This sub-sector is divided into the following occupational activities:

a. Face area activities including: stoping and development, drilling and blasting, boring, cleaning, loading (fully and semi-mechanized), support, face preparation and charging-up.

b. Horizontal transport activities include: tramming, tipping, loading, haulage maintenance remote pump stations.
c. Vertical transport activities include: hoisting, transfer level activities, main pump stations.
d. Boring and exploration activities in established mines.
e. Supervisory and service activities (hoist drivers, survey, sampling, geology, rock mechanics, ventilation).
f. Maintenance activities (all engineering staff employed underground).

Sub-Sector: Gold Mining - shaft sinking

This sub-sector is divided into the following occupational activities:

a. Shaft sinking activities including: sinking, primary station development, all stage work, all boring and exploration performed during sinking operations.
b. Maintenance and service activities (permanently allocated to sinking) : Underground hoist staff, engineering, survey, etc.).
c. Shaft sinking supervision.

Sub-Sector: Gold Mining - Metallurgical Extraction

This sub-sector is divided into the following occupational activities:

a. Crushing, screening, assaying, grinding.
b. Filtration.
c. Smelting and refining.
d. Transport and ore movement (conveyor belts, loaders).
e. Maintenance.
f. Supervision (management and security).

5.2.3.2 Platinum metals mining

The Platinum Metals mining sector can be sub-divided into the following activities: ore production, shaft sinking and metallurgical extraction. It is assumed that further sub-division is not necessary as the vast majority of mining operations consist of underground blasting or underground digging. Opencast operations will be handled as a separate sector.

Sub-Sector: Platinum Metals - ore production

This sub-sector is divided into the following occupational activities:

a. Face area activities include: stoping and development, drilling and blasting, boring, cleaning, loading (fully and semi-mechanized), support, face preparation and charging-up.
b. Horizontal transport activities include: tramming, tipping, loading, haulage maintenance remote pump stations.
c. Vertical transport activities include: hoisting, transfer level activities, main pump stations.
d. Boring and exploration activities in established mines.
e. Supervisory and service activities (hoist drivers, survey, sampling, geology, rock mechanics, ventilation).
f. Maintenance activities (all engineering staff employed underground).

Sub-Sector: Platinum Metals - shaft sinking

This sub-sector is divided into the following occupational activities:

a. Shaft sinking activities include: sinking, primary station development, all stage work, all boring and exploration performed during sinking operations.
b. Maintenance and service activities (permanently allocated to sinking) : Underground hoist staff, engineering, survey, etc.).
c. Shaft sinking supervision.

Sub-Sector: Platinum Metals - Metallurgical Extraction

This sub-sector is divided into the following occupational activities:

a. Crushing, screening, assaying, grinding.
b. Filtration.
c. Smelting and refining.
d. Transport and ore movement (conveyor belts, loaders).
e. Maintenance.
f. Supervision (management and security).

5.2.3.3 Underground Coal Mining

The underground coal-mining sector can be divided into a number of sub-sectors. It is assumed that whether the coal is cut or blasted, the face area represents a similar level of risk in terms of exposure to respirable dust. Coal washing operations are analysed separately. Opencast operations will be analysed as a separate sector.

Sub-Sector: Coal production

This sub-sector is divided into the following occupational activities:

a. Face area activities include: seam cutting, road heading, blasting, stone-dusting, loading, face preparation and charging-up (where done).
b. Feeder breaker: coal transfer and loading
c. Roof bolting.
d. Transport.
e. Supervisory activities and services (survey, geology, rock mechanics, ventilation, etc.).
f. Maintenance (all engineering staff employed underground).

Sub-Sector: Coal processing plant

This sub-sector is divided into the following occupational activities:

a. Crushing.
b. Washing.
c. Transfer, transport and storage (including at harbour bunkers under the responsibility of the mine).
d. Maintenance staff allocated to the plant.
e. Plant supervisory staff.

5.2.3.4 Base metals and diamond mining

These mining sectors are grouped together given similarities between diamond and base metal mining operations involving vertical crater retreat (VCR) or cut-and-fill mining using machinery. In general it is assumed that the exposure as the result of the mining method is similar. However the information obtained for different minerals should be kept separate particularly that pertaining to dry drilling operations. Opencast operations will be analysed separately.

Sub-Sector: Ore or mineral production

This sub-sector is divided into the following occupational activities ;

a. Face area activities include: Drilling, charging, blasting, cleaning, support.
b. Transport activities (horizontal, vertical and incline).
c. Development and exploration activities.
d. Maintenance and service activities.
e. Supervisory activities.

Sub-Sector: Diamond and base metal surface beneficiation plants.

This sub-sector is divided into the following occupational activities:

a. Crushing and sorting.
b. Transfer, transport and storage (including harbour bunkers and storage areas under the responsibility of the mine).
c. Metallurgical processing (where applicable)
d. Maintenance staff allocated to the plant.
e. Supervisory.

5.2.3.5 Opencast operations

Given similarities between different opencast mining operations using similar types of machinery to a varying degree, these are grouped together. However the information obtained for exposure to different minerals or ores having different toxicity should be recorded separately.

Opencast operations are sub-divided into the following activities:

Sub-Sector: Ore or Mineral Production:

a. Drilling and blasting operations.
b. Face loading (mechanical shovels).
c. Transport (conveying, trucking, transfer and loading points) and storage (including harbour bunkers and storage areas under the responsibility of the mine).
d. Remote loading (drag-lines).
e. Maintenance.
f. Supervisory.

Sub-Sector: Mineral or ore beneficiation:

a. Crushing and sorting.
b. Transfer, transport and storage (including harbour bunkers and storage areas under the responsibility of the mine).
c. Metallurgical processing (where applicable)
d. Maintenance staff allocated to the plant.
e. Supervisory.

5.2.4 Data management

As stated previously, it is assumed that a suitable singular dust parameter (or combination of a number of these) can be used as surrogate exposure. For the purpose of the following discussion, it is assumed that gravimetric dust samples are such surrogate.

5.2.4.1 Sample Numbers

To ensure that the samples collected are statistically representative of the exposures experienced by the workers, samples numbers from each sub-sector have to be determined from a prior pilot study based on the same sub-division. It is suggested that such study be based firstly on the gravimetric sampling data presently archived by the DME. Should this data be found unsuitable, it is suggested that specific pilot studies be commissioned to arrive at statistically satisfactory sample numbers.

The pilot study proposed here must be aimed at establishing the variance of scattered data within each occupational group of each sub-sector. The scatter of such data will be used to determine the number of samples deemed to be representative

5.2.4.2 Frequency of sampling

The purpose of this measurement is to estimate worker exposures on an annual basis. For this reason it is suggested that the sampling period be defied as one calendar year. A period of contingency should be included in the twelve-month sampling window to ensure that sampling is accurate and that sampling errors and shortcomings are recognised discarded and rectified. The data thus gathered will be used to arrive at a surrogate annual exposure in each occupational group of each sub-sector.

Careful and structured sub-division of the parent worker population in each operation is required to ensure that sampling is representative of all activities over seasonal as well as diurnal cycles – with all shifts being represented in balanced proportions. At the same time the sampling methodologies must take into account the geographical distribution of the workers in relations to different surface locations, shaft systems and ventilation districts.

5.2.4.3 Collected data

The data collected and used for analysis will consist of primary samples – in this case the gravimetric samples – as well as any ancillary data that may be stipulated by the monitoring protocol – in the case of gravimetric sampling it may be the chemical analysis of the dust collected indicating the concentration of toxic material contained in the sample.

The data thus collected should be recorded in a manner that will facilitate storage, handling,, reporting and retrieval. Primary and ancillary data will be grouped to reflect a mean and variation (range) of exposure for each activity within each operation. The variance introduced by this will be used to verify whether the initial assumptions that were made in sub-dividing the sub-sector into the various occupational groups is valid. This information can be used to re-structure these if so required – bearing in mind the criterion of the data being easily traced.

It is expected that this data handling process will facilitate the assignment of a pseudo-exposure to each worker annually. The pseudo-exposure assigned will be a function of the work performed and the period of time spent by each worker in different occupations and in different mines or part of the same mine. For this reason, it is important to link this data to the attendance record of workers by means of a data management system.

5.2.4.4 Data management

The data collected and stored in accordance with the prescribed monitoring protocol should be pooled in a centralised system designed to:

- Produce ad-hoc reports analysing the data collected over specified periods of time for each mining operation. These reports will indicate typically the exposures in the individual activities within each operation.

- Produce annual reports for each operation indicating the exposure levels for each occupational activity. This information may be used to identify high risk groups, monitor these as well as monitoring the overall mine dustiness as represented by the total exposures for the mine.

- Produce annual surrogate exposure figures for each occupational group for each mine in each sub-sector. This is intended to assign a "life-time" dose to each worker in the Industry for medical surveillance purposes as well as for epidemiological studies.

- Produce annual reports for different sub-sectors of the Industry that can be analysed for trends and progress in ameliorating exposures.

- Produce exposure profiles for different activities across the same mining sub-sector. Researchers in epidemiological studies could use this data.

The data management system must be aimed to assist in assigning a surrogate exposure to each worker in the industry given that worker's employment history during the year. This information will be produced and recorded by such a system and made available to users.

To this end it is suggested that the system be maintained by a central agency that would be tasked with the data management and creation of an electronic information centre that would make relevant information available to interested and authorised parties via the Internet or by means of a web site. The site could also be the hub of communication for a number of interested parties. This could include a chat line, information bulletin board and calendar of events pertinent to the study of respirable dust in the Mining Industry.

At this stage it is envisaged that such a system will be of use to a number of stakeholders as shown in Figure 5.2.4. The primary target audience is the operations who may use the feedback to structure campaigns to highlight problem areas and take appropriate corrective action. Another target audience is SIMRAC who may be in a position to make generalised formats of the information available to researchers in the future. It is expected that the DME may also benefit from such information in the drafting of legislation and regulations as well as in setting surveillance and action limits which would suit different sectors of the Industry more appropriately.

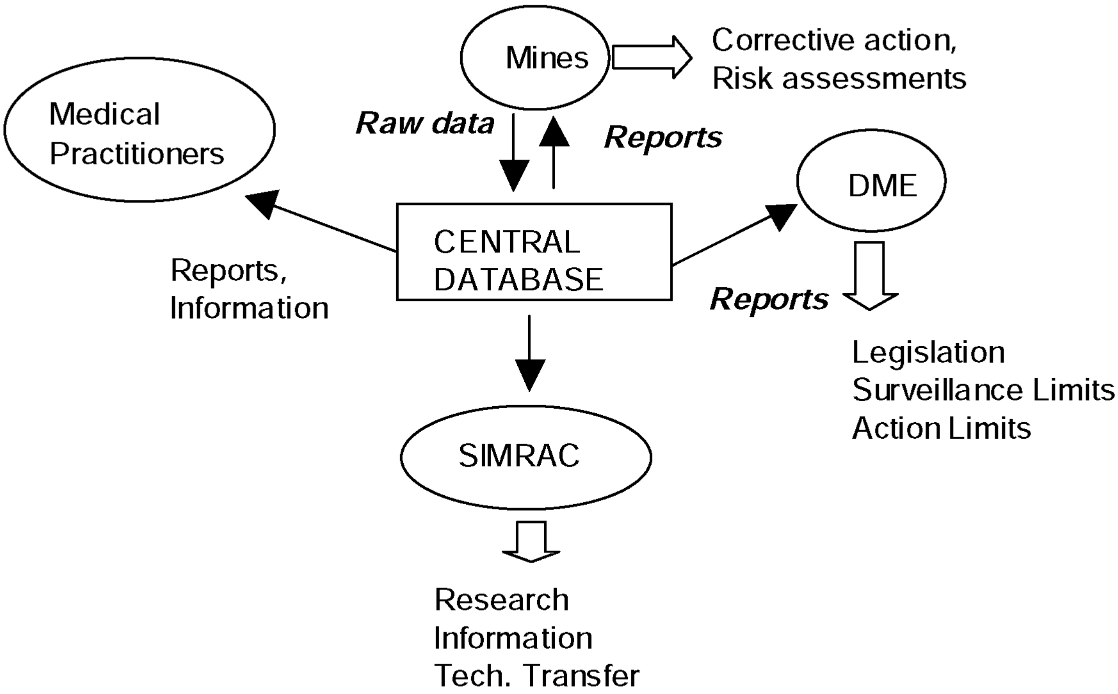


Figure 5.2.4: Information and data flow for proposed Management System

Medical practitioners operating from mines or as part of a follow-up in diagnosing occupational diseases would find the information useful in assessing the past exposure of patients to various dust levels in different stages of their occupation – given their occupational history. This link is perhaps the most significant since it embodies the link between occupational medicine and occupational hygiene purported in the Mines Health and Safety Act.

5.2.5 Other aspects

Other aspects need to be considered in the definition of the criteria. These are of a complementary nature but are deemed to be necessary to meet the proposed objectives.

Some of these aspects are linked directly to the proposed criteria while others relate to a much broader initiative and to a wide-encompassing system designed to make the data collection more streamlined and the generation of information more accurate and accessible.

5.2.5.1 Parallel pilot studies

In view of the fact that there are a number of uncertainties in what has to be measured, it is recommended that all the parameters be considered and included in a monitoring programme. This monitoring could be introduced on a trial basis in a representative number of mines and all results compiled in a central database. After one or two years the data can be fully evaluated (although this should be done in an ongoing basis) and significant trends or patterns determined. These findings should be at all times be evaluated in terms of medical surveillance.

For this proposal, gravimetric sampling is used initially as a surrogate measure of the exposure of workers to respirable dust, it is desirable to define a series of parallel pilot studies, forming part of this programme, aimed at "fingerprinting" the gravimetric dust samples taken on specific operations. Some of these studies have been mentioned above and should be aimed at confirming statistical distribution of data to validate the number of samples in each occupational group.

Other studies may be required to "fingerprint" dust samples as a function of gravimetric measurements as described below. Sampling in each of the pilot studies would be taken in parallel with the gravimetric samples and the aim would be to characterize:

- Particle size distribution;
- Collected sample surface area;
- Electrical charges (if any) of the respirable dust;
- Occurrence of peaks during the sampling interval. These should be analysed in terms of magnitude and duration

as a function of the gravimetric sample taken.

The collection of this data may be useful to further knowledge into the dust properties or combinations thereof that are causal to silicosis and other respiratory occupational diseases. Having categorized a number of gravimetric samples in this manner, it may be possible, at a later stage, when relationship between the cause and effect are better defined, to convert the surrogate exposures obtained from gravimetric sampling to more accurate indications of the actual exposure.

This approach is aimed at making the gravimetric sampling data thus gathered available for future reference. The system will be revised once the actual individual dust property or combination of different properties is positively identified as being causal to silicosis. However the data gathered up to that point will be available and will have some relevance.

5.2.5.2 Involvement by an external agency

Given the importance of maintaining a large database that requires frequent updating, regular reporting and ad-hoc, on-line access, it may be desirable to allocate the management of the data to one or more agencies. It may be also advantageous to use more than one agency to facilitate and expedite the flow of information within large or widely spread sectors. However, all data needs to be managed ultimately in one centre to facilitate analysis.

Similarly, it may be desirable to assign the assessment of the samples collected by one or more specialised, suitably accredited agencies. This may complicate the sampling process – by involving another link in the chain - but may improve its accuracy and management.

5.2.5.3 Assistance for smaller operations

The involvement of a centralised monitoring agency may also be extended to be of assistance to the smaller mining operations that do not have access to full-time occupational hygienists and use contract professionals for this purpose. The centralized database would complement the monitoring done on these operations by private consultants and assist in the benchmarking of results from similar sites. The expansion of the service to exchange a wider range of information may also be advantageous to the smaller operators offering the opportunity to communicate and share information with other mines experiencing similar conditions.

5.2.5.4 Co-ordinated research programme

The criteria for routine sampling discussed in this report are but a part of the efforts necessary to reduce workers' exposure to dust and ultimately reduce the incidence of occupational lung diseases. The strategy proposed here is supportive of a hitherto not specified overall direction aimed at achieving these objectives. The creation of a managed centre of data and information as proposed here, should be seen as the nucleus for much broader research efforts and intervention activities. Within an industry that experiences a high incidence of occupational respiratory diseases (Tuberculosis and Silicosis) superimposed to a high incidence of HIV/AIDS amongst mineworkers, it is felt that this wider, more co-ordinated and revitalized research programme will address the impact of these diseases. This data management system could be expanded to form the nucleus of such a co-ordinated initiative. It is important therefore that the creation of such a system not be seen in isolation and should therefore be structured to allow for the expansion necessary to accommodate the need of future initiatives.

It is essential, however, that strategies, leadership and co-ordination be sourced from a central body representative of all stakeholders. Furthermore, although important, the determination of workers' exposure is not comparable in effectiveness to a properly structured and effective drive designed at characterizing the emission of dust from a number of mining activities and at designing effective suppression methods that will eventually reduce workers' exposure anyway.

5.3 Recommendations

The principle criterion of the proposed system is based on continuous sampling over a full shift. The sample thus collected must be associated to an occupation group in order to facilitate data analysis.

It is suggested that the worker population within the Mining Industry be sub-divided into a number of sectors – each sector representing similar types of mining activity or mineral/ore production. Each sector is sub-divided into sub-sectors that relate to various, broadly similar mining operations. This similarity is based on the area within the mining activity that certain group of workers is active and which is deemed representative in terms of dust exposure.

It is recognised that gravimetric sampling alone is not the most accurate surrogate for dust exposure. However, using this method to gather data on the respirable fraction of the dust inhaled by workers may be useful and could be used to validate assumptions made at this stage. This information, together with the "fingerprinting" of samples done in parallel with the gravimetric sampling, is required to provide a meaningful base from which data may be used in the future.

It is proposed that all data collected from each mine be stored in (preferably) a single data management system. This system will analyse the data and produce a series of reports that will reflect trends of exposures for mines, mining sectors and the Mining Industry as a whole.

More importantly, however, the management system will enable medical practitioners and researchers to assign a surrogate exposure levels to every worker given the worker employment history.

It is proposed that the data management system be run by a central agency that will be responsible to the individual operations as well as other stakeholders in managing, updating and upgrading all information.

It is recommended that the criteria be encompassed into a detailed set of guidelines that will facilitate the implementation of a new sampling strategy on every operation. The procedures should also assist operations in a gradual and systematic transition from the existing sampling methodology to the new.

It is stressed that a group representative of all stakeholders in the Mining Industry be instituted to guide the implementation and development of this new methodology. The group should also be tasked with other coordinated and strategically compatible initiatives formulated designed and executed to address the problem posed by occupational respirable disorders. It is stressed that looking at the problem of dust exposure in isolation may not achieve adequate results given the postulated synergism between dust and other agents (radiation and diesel exhaust particulate and fumes) and opportunistic diseases such as HIV/AIDS.

It is recommended further that the criteria proposed here and incorporated in new guidelines be supported by a series of pilot studies running in parallel with the main sampling programme. These studies should be aimed at "fingerprinting" sample data and facilitate future research. In this respect it is recommended that the dust sampling data already in the DME's possession be scrutinized with the objective of identifying sections that could be of use in this respect – thus reducing time frames and avoiding repeating work.

The generation of information about exposures to respirable dust will be the basis on which knowledge linking exposure to outcome can be established. However, a process designed at studying and minimizing emission of dust into the environment must complement any initiative that may arise from this work.

6 References

Gürtünca, R. G., 1997. *Identification of safety and health hazards and quantification of risks in the South African mining industry with time.* Final project report, SIMRISK 401, SIMRAC..

Kielblock, A.J., Franz, R.M., Unsted, A.D., van der Linde, A., Ashworth, S.G.E., 1997. *Quantification of occupational health risks in the South African mining industry and assessment of the sources of uncertainty in the estimates.* Final project report, SIMRISK 401, SIMRAC.

NCOH/SORDSA, 1999. *Crystalline silica: Health hazards and precautions.* SORDSA Alert.

Orenstein, A. J., Editor, 1960. *Proceedings of the pneumoconiosis conference.* J. & A. Churchill Ltd., London.

Beadle, D. G., 1967. *An epidemiological study of the relationship between the amount of dust breathed and the incidence of silicosis in South African Gold Mines.* Proceedings of an International Symposium organized by the British Occupational Hygiene Society. Cambridge, 28 September – 01 October 1965. Pergammon Press, C. N. Davies Editor.

8 Bibliography

Advances in air sampling, ACGIH, 1990. Lewis publishers. pp 17-24 and pp 337-352.

Atherley, G. A critical review of Time-Weighted Average as an Index of exposure and dose, and of its key elements. Am Ind. Hyg Assoc. J (46) September 1995 pp 481-487

Attfield, M.D., Seixas, N.S., (1995): Prevalence of pneumoconiosis and its relationship to dust exposure in a cohort of U.S. bituminous coal miners and examiners. Am. Journal Ind. Med 27:137-151.

Attfield, M.D., Morring, K., (1992): An investigation into the relationship between CWP and dust exposure in US coal miners. Am. Ind. Hyg. Assoc J 53(8):486-492.

Attfield et al. (1995): The Prevalence of Pneumoconiosis and its Relationship to Dust Exposure in a Cohort of U.S. Bituminous Coal Miners and Ex-miners, Journal of American studies.

Althouse, R.B., Bang, K.M., Castellan, R.M., (1995): Tuberculosis co-mortality with Silicosis-United States, 1979-1991. Appl. Occup Environ Hyg 10(12):1037-1041.

American Conference of Governmental Industrial Hygienists (ACGIH), (1998): 1998 Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices, American Conference of Governmental Industrial Hygienists, USA.

ASTM Standard E1156-87, (1987): Health Requirements for Occupational Exposure to Synthetic Amorphous Silica. American Society for Testing and Materials, Philadelphia.

Bell S. L., and Lynch, P.J., (1997): A Respirable Dust Survey of Various Metalliferous Mine Sites in Queensland, Australia, Sampling and Control of Mine Dust, pp 1019-1024.

Belle, B.K., (1999): Personal Communications, CSIR, South Africa.

Bedford, T. and Warner, C. G., (1943): Chronic Pulmonary Disease in South Wales Coal Miners, II. Environmental Studies. Spec. Rep. Ser. Med. Res. Coun. pp 244.

Berg, P., Jaakmees, V., and Bodin, L., (1999): Comparison of Dust Sampling Methods in Estonia and Sweden-A Field Study, Applied Occupational and Environmental Hygiene, Volume 14 (9): 592-597.

Bowie, D., St. J., (1978): Ferro Alloy Workers Disease. Cent. Afr. J. Med. 24:81-86.

Breslin, J.A., Page, S.J., Jankowski, R.A., (1983): Precision of Personal Sampling of Respirable Dust in Coal Mines, USBM RI 8740.

British Medical Research Council (1952): Recommendations of the M.R.C. Panels Relating to Selective Sampling, Extracted from the Minutes of a Joint Meeting of Panels 1, 2 and 3 held on 4th March 1952, quoted by Hamilton, R. J., and W. H. Walton in Inhaled Particles and Vapours, p. 475. C. N. Davies, Ed. Pergammon Press, Oxford (1961).

Burling, Eltjo and Lanting, Exposure variability in the workplace: its implications for the assessment of compliance. AM Ind Hyg Assoc J (52) March 1991 pp 6-13

Busch, K. A. and Taylor, D. G., (1981): Statistical Protocol for the NIOSH Validation Tests, In: Choudhary, G, ed. "Chemical Hazards in the Workplace - Measurement and Control, Washington DC: American Chemical Society, ACS Symposium Series 149.

Caplan, A., (1960): Rheumatoid disease and pneumoconiosis. In: (Ed. King and Fletcher), Industrial Pulmonary Diseases.

Casswell, C., Bergman, I., and Rossiter, C.E., (1971): The Relation of Radiological Appearance of CWSP to the Content and Composition of the Lung. In: Inhaled Particles III (Ed. W. H. Walton), Unwin Bros. 713-724.

Castronova et al. Enhanced pulmonary response to the inhalation of freshly fractured silica compared with aged dust exposure. Appl. Occup. Environ. Hyg. 11(7) July 1996

Chen, G.X., Burnett, C.A., Cameron, L.L., et al., (1997): Tuberculosis Mortality and Silica Exposure: A Case-Control Study Based on a National Mortality Database for the Years 1983-1992. Int. Journal of Occupational Health 3:163-170.

Cherrie, J., W. (1998): Particulate size and health". Croner's Occupational Hygiene Magazine, pp 15-19.

Cherry, N.M., Burgess, G.L., Turner, S., et al., (1998): Crystalline Silica and Risk of Lung Cancer in the Potteries. Occup Environ Med 55779-55785.

Corn, Morton. Sampling strategies for prospective surveillance; overview and future directions. Advances in air sampling, ACGIH, 1990. Lewis publishers. pp 17-24.

Costello, J., Castellan, R.M., Sweeker, G.S., et al., (1995): Mortality of Cohort of US workers Employed in the Crushed Stone Industry. A J Ind Med 27 (5):625-640.

CEN (Comité European de Normalisation), (1992): Workplace Atmospheres - Size fraction definitions for measurement of airborne particles, Brussels, Belgium: Comité European de Normalisation, Central Secretariat, European pre-standard EN/232.

Cinkotai, F. F., Gibbs, A. C. C., Sharpe, T. C., (1984): A Comparison of Exposure to Airborne Dust in Cotton Processing Plants Estimated From Personal and Workzone Samples, Ann. Occup. Hyg. 28(3): 347-352.

Croner's occupational hygiene magazine, (1999).

Davies, C. N., (1952): Dust Sampling and Lung Disease, Br. J. Ind. Med., v. 9, p. 120.

Davis, J.M.G., (1979): Autopsy studies of miners lungs, Final Report (TM/79/9), Edinburgh, Institution of Occupational Medicine, UK.

Douglas, A.M., (1986): Dust Exposure, Dust Recovered from the Lung and Associated Pathologyin a group of British Coal Miners, British Journal of Industrial Medicine.

Dyer, C., (1998): Miners win Historic Battle for Compensation, BMJ: 316:327, UK.

Evelyn, J. Fumifugium (1961), London.

ECSC Research Project Final Report, (1997): No. 7263-02/101/08.

Fitzsimons, P. and Johnston, J. Personal Communication (1999).

General Accounting Office, (1975): Improvements Still Needed in Coal Mine Dust Sampling Program and Penalty Assessment and Collection, Report RED-76-56.

Gibson, M. (1833-34): On the phthisis melanotica (so-called) of coal miners. Lancet, 1833-34, ii: 838-9.

Goldstein, B., and Webster, I., (1966): British Journal of Ind. Med., v. 23, p. 71.

Gregory, J. C. (1831): Case of peculiar black infiltration of the whole lungs, resembling melanosis. Edinburgh Medicine and Surgery Journal, 36, pp. 389.

Groth, D.H., Moorman, W. J., Lynch, D. W., Stettler, L.E., Wagner, W.D., Hornung, R. W., (1981): Chronic Effects of In haled Amorphous Silica's in Animals, In Health Effects of Synthetic Particulates, ASTM STP 732, Dunnom, D. D., Ed. ASTM, Philadelphia.

Guidelines for gravimetric dust sampling. Department of Minerals and Energy (1990).

Hadden, G. C., Jones, C. O., and Morgan, D. C., (1966): A Study of Volumes of Respired Air in Relation to Dust Exposures of Coal Miners, Inhaled Particles and Vapours II: Proceedings of the 2nd International Symposium, Ed. C. N. Davies.

Hall, T. A., Corn, M., Zeger, S., (1997): respirable Dust and Free Silica Variation in Mine Environments, Strategies for Mine Dust Measurement.

Hamilton, R. J., G. D. Morgan, and W. H. Walton, (1967): The relationship Between Measurements of Respirable Dust by Mass and by Number in British Coal Mines, Inhaled Particles and Vapours II, ed. By C. N. Davies, p. 553.

Hnizdo, E., Sluis-Cremer, G.K., (1991): Silica Exposure, Silicosis, and Lung Cancer: A mortality Study of South African Gold Miners. Br. J Ind Med 48:53-60.

Hnizdo, E., (1990): Combined Effect of silica Dust and Tobacco Smoking on Mortality from Chronic Obstructive Lung Disease in Gold Miners. B J Ind Med 47:656-664.

Hurley, J.F. et al. (1982): Coalworkers simple pneumoconiosis and exposure to dust at ten British coalmines, British Journal of Industrial Medicine, 39, 120-127.

Hurley, J.F., Maclaren, W.M., (1987): Dust-related risks of radiological changes in coal miners over a 40-year working life: report on work commissioned by NIOSH, Edinburgh, Scotland, UK: IOM, Report No. TM/87/09.

International Agency for Research on Cancer (IARC), (1997): IARC monographs on the Evaluation of Carcinogenic Risks to Humans: Silica, Some Silicates, Coal Dust and Para-aramid Fibrils. World Health Organization (WHO) Ed, Lyon 68.

ISO (International Organization for Standardization), (1993): Air Quality - Particle Size Fraction Definitions for Health-Related Sampling, Geneva, Switzerland: ISO Report No. ISO 7708.

Jacobsen, M., Rae, S., Walton, W. H. and Rogan, J. M., (1970): New Dust Standards for British Coal Mines, *Nature,* Vol. 227, pp 445-447.

Jacobsen, M., Rae, S., Walton, W. H. and Rogan, J. M., (1971): The Relationship between Pneumoconiosis and Dust Exposure in British Coal Mines, In: Walton W.H., ed, "Inhaled Particles III", Vol. 2, Surrey, UK, Unwin Brothers Ltd, Gresham Press, pp 903-919.

Jacobsen, M., (1973): Progression of Coal Workers' Pneumoconiosis in Britain in Relation to Environmental Conditions Underground, In: "Proceedings of Conference on Technical Measures of Dust Prevention and Suppression in Mines", Luxembourg, October 11-13, Luxembourg: Commission of the European Communities, pp 77-93.

Jacobsen, M., (1979): Effect of Further Dust Exposure among Men with Early and More Advanced Signs of Simple Pneumoconiosis, Edinburgh Institute of Occupational Medicine, Final Report on CEC Contract 6244-00/8/107, Report No. TM/79/16.

Jacobsen et al. (1980): New Data on the Relationship Between Simple Pneumoconiosis and Exposure to Coal Mine Dust, Chest 78, Supplement 408.

Jurinskl, J.B., and Jurinski, N.B., (1997): A proposed control limit for exposure to airborne erionite fibers, Applied Occupational Environmental Hygiene, Vol. 12 (6), pp. 429-434.

Kask, M., Uibo, M., (1963): Practical Hygiene, Government of Estonia (in Estonian), pp. 71-73.

Kenny, L. C., Baldwin, P. E. J., and Maynard, A. D., (1998): Respirable Dust Sampling at Very High Concentrations, *IR/L/A/98/01, Health and Safety Laboratory, UK*, p 12.

Kenny, L. C., and Maynard, A. D., (1995): Performance Assessment of Three Personal Cyclone Models using an Aerodynamic Particle Sizer, *Journal of Aerosol Science*, Vol. 26, No. 4, pp 671-684.

Kielblock, (1998) Private communication.

King, E. J., Mohanty, G. P., Harrison, C. V., and Nagelschmidt, G., (1953): The Action of Different Forms of Pure Silica on the Lungs of Rats, Br. J. Ind. Med., v. 10, pp. 9-17.

Kissell, F. N., Ruggier, S. K., Jankowski, R.A., (1986): How to Improve the Accuracy of Coal Mine Dust Sampling, Am. Ind. Hyg. Assoc. J. 47 (10): 602-606.

Klosterkotter, W., Zur Frage der silikogenen Wirkung des amorphen Siliciumdioxide in Jotten, K.W. Klosterkotter, W. (1954): Die Staublungenergrankungen, Vol. 2., pp 73-84, Steinkopf, Darmstadt.

Koskela, R.S., Klockars, M., Laurent, H., et al., (1994): Silica Dust Exposure and Lung Cancer. Scan J Work Environ Health 20 (6): 407-416.

Laennec, R. T. G. (1819): Traite de l'ausculation mediate, ed. 4, Paris.

Le Bouffant et al. (1977): The therapeutic action of Aluminium compounds on the development of experimental lesions produced by pure quartz or mixed dust. (Ed. Walton), Inhaled Particles IV, 389-400.

Leidel, N. A; Busch, K. A. and Crouse, W. E.. Exposure measurement action level and occupational environmental variability. U S Department of Health and Welfare. National Institute for Occupational Safety and Health. 1975.

Linch, A. L., Wiest, E. G., Carter, M. D., (1970): Evaluation of Tetraalkyl Lead Exposure by Personnel Monitor Surveys, Am. Ind. Hyg. Assoc. Journal, 31: 170-179.

Linch, A. L., Pfaff, H. V., (1971): Carbon Monoxide-Evaluation of Exposure Potential by Personnel Monitor Surveys, Am. Ind. Hyg. Assoc. Journal, 32: 745-752.

Lippman, M. et al., (1973): The prevalence of circulating anti-nuclear antibody and rheumatoid factors in U.S. coalminers. Annual Internal Medicine, 79, 807.

Maclaren, W.M., Hurley, J.F., Collins, H.P.R., and Cowie, A.J., (1989): Factors associated with the development of PMF in British coalminers: A case/control study. British J. of Ind. Med. 46, pp. 597-607.

Makellor, A. (1845): Black phthisis, or ulceration induced by carbonaceous accumulation in the lungs of coal miners, Monthly Journal of Med. Science, 5, 645-653.

Malmberg, P., Hedenstrom, H., Sundblad, B.M., (1993): Changes in Lung Function of Granite Crushers Exposed to Moderately High Silica Concentrations: A 12 Year Follow-Up. Br. J Ind Med 50 (8): 726-731.

Marple, V. A., Rubow, K. L., and Zhang, Z., (1997): Experimental and Theoretical Measurement of the Aerodynamic Diameter of Irregular Shaped Particles, Dust Measurement, pp 663-667.

Martinson, M J. Sampling pathogenic airborne particles. Environmental Engineering in South African mines. The Mine Ventilation Society of South Africa. 1982. Cape and Transvaal Printers. pp 357-378.

Melandri, C., Tarroni, G., Podi, V., De Zaiacomo, T., Formignani, M., Lombardi, C.C., (1983): Deposition of charged particles in the human airways, Journal of Aerosol Science, I4 (15): 657-669.

Minter, Stephen G. The changing face of respiratory illness. Occupational Hazards pp 43-44 February 1995.

Mitchell, William J. U.S. Standards for air sampling of environmental contaminants: current basis and future options.

National Bureau of Standards, (1975): An Evaluation of the Accuracy of the Coal Mine Dust Sampling Program Administrated by the Department of Interior, Final Report to the Senate Committee on Labor and Public Welfare, Washington, D.C., USA.

National Resource Council, (1980): Measurement and Control of Respirable Dust in Mines, USA.

NIOSH, (1976): Statistical Analysis of (Mining Enforcement Safety Administration) Respirable Dust Data, USA.

NIOSH, (1993): 0500 NIOSH Manual of Analytical Methods, 4th ed., USA.

NIOSH, (1995): Criteria for a Recommended Standard: Occupational Exposure to Respirable Coal Mine Dust, NIOSH, USA, pp 336.

Niven R. M., Fishwick, D., Pickering, C. A. C., Fletcher, A. M., Warburton, C. J., Crank P., (1992): A Study of the Performance and Comparability of the Sampling response to Cotton Dust of Work Area and Personal Sampling Techniques, Ann. Occup. Hyg. 36(4): 349-362.

Particle size-selective sampling for airborne particulate matter. American Conference of Governmental Industrial Hygienists. 1997 TLVs and BEIs. pp 47- 50.

Organiscak, J.A., and Page, S.J., (1998): Investigation of coal properties and airborne respirable dust generation, RI 9645, NIOSH, USA.

Oudiz, J., (1986): Silica Exposure Levels in United States Foundries. Silica, Silicosis and Cancer. Edited by Goldsmith, D.F., Winn, D.M., Shy, C.M., pp. 21-28.

Page, S., Jankowski, R., (1984): Correlations Between Measurements with RAM-1 and Gravimetric Samplers on Longwall Shearer Faces. Am. Ind. Hyg. Assoc. J. 45(9): 610-616.

Parkes, W.R. (1982): Occupational Lung Disorders, 2nd Edition, pp. 138 and 158-159.

Parobeck, P., Ainsworth, S. and Tomb, T., (1997): Analysis of Respirable Coal Mine Dust Samples by Infrared Spectroscopy, Strategies for Mine Dust Measurement, pp 1142-1147.

Pearson, G. (1813): Phil. Trans. Royal Society, London, pp. 103.

Phalen, Robert F. Rationale for and implications of particle size-selective sampling.

Proceedings of Third International Conference of Experts on Pneumoconiosis, Sydney, March 1950.

Prinz, B., Stolz, R., and Ruhrkohle, A.G., Essen, (1998): Effect of the Measuring Strategy on the Determination of the Respirable Dust Concentration in the Breathable Air at Underground Workplaces, Strategies for Mine Dust Measurement, pp 1148-1151.

Rappaport, S M. Assessment of long term exposures to toxic substances in air. Ann. Occup. Hyg. Vol. 35 No 1 pp 61-121, 1991.

Rappaport, Stephen M. Biological considerations for designing sampling strategies.

Ratney, R. S., (1997): The Threshold Limit Value for Various Forms of Amorphous Silica, Strategies for Mine Dust Measurement, pp 1134-1135.

Ratney, R. S. The development of workplace exposure limits for toxic substances. Applied Industrial Hygiene. 12/89 pp 48-49.

Reisner, M.T.R. (1971): Results of Epidemiological Studies of Pneumoconiosis in West German Coal Miners. (Ed. Walton), Inhaled Particle III, Unwin Bros. Old Woking, Surrey, 921-931.

Reisner, M.T.R. (1977): Results of Epidemiological, Mineralogical and Cytological Studies on the Pathogenicity of Coal Mine Dust. (Ed. Walton), Inhaled Particle IV, Oxford, Pergamon, 703-715.

Rekus, John F. The real meaning of Threshold Limit Values. Occupational Hazards. June 1996. Pp 45-47.

Rivers, D., Wise, M.E., King, E.J. and Nagelschmidt, G. (1960): Dust Content, Radiology and pathology in simple pneumoconiosis of Coal Workers, Br. J. Ind. Med., 17, 87-108.

Rossiter, C.E. (1972): Relation between Content and Composition of Coal Workers Lungs and Radiological Appearances, Br. J. Ind. Med., 29, 31-44.

Roach, S. A., (1958): Counting Errors due to Overlapping Particles in Thermal Precipitator Samples, Br. J. Ind. Med., v. 15, pp. 250-257.

Sabastien, P. (1989): The scientific basis for controlling exposures to phyllosilicate dust at the workplace. In: (Ed. J. Bignon), Health Related Effects of Phyllosilicates.

Schroeder H. H. E., (1989): The properties and effects of dust, , Environmental Engineering in South African Mines, The Mine Ventilation Society of South Africa, J. Burrows Editor, SA.

Schroder, H H E. The properties and effects of dust. Chapter 12Environmental engineering in South African mines. The Mine Ventilation Society of South Africa. 1982 Cape and Transvaal Printers. pp 313-336.

Seaton, A., MacNee, W., Donaldson, K., Godden, D. (1995): Particulate air pollution and acute health effects, The Lancet. Vol. 345, pp176-178. 1995.

Seaton, Anthony. Respiratory diseases in miners. Ann. ACGIH Vol. 14, 1996 pp 21-25.

Skidmore, J. W., Morris, T. G., Nagelschmidt, G., and King, E.J., (1965): The Retention f High and Low Rank Coals in Rats, Ann. Occup. Hyg., v. 8, p. 183-192.

Srikanth, R., and Ramani, R.V., (1997): Personal Communications, The Pennsylvania State University, USA.

Soutar, C.A., Miller, B.G., Gregg, N., Jones, A.D., Cullen, R.T., Bolton, R.E., (1997): Assessment of human risks from exposure to low toxicity occupational dusts, Annals of Occupational Hygiene, Vol. 41, pp. 123-133.

Soderholm, S. C., (1989): Proposed International Conventions for Particle Size -Selective Sampling, *Ann. Occupational Hygiene,* Vol. 33, No. 3, pp 301-320.

Soderholm, S. C. Unstable aerosols. Advances in air sampling, ACGIH, 1990. Lewis publishers. pp 161-174.

Soderholm, S. C., (1991a): Why Change ACGIH's Definition of Respirable Dust? *Applied Occupational Hygiene,* Vol. 6, No. 4, pp 248-250.

Soderholm, S. C., (1991b): Correction, *Ann. Occupational Hygiene,* Vol. 35, No.3, pp 357-358.

Soderholm, S. C., (1995): Particle and gas phase interactions in air sampling, Chapter 4, "Air sampling instruments for the evaluation of atmospheric contaminants". ACGIH, 8th edition, 1995.

Stopford, W., Bundy, S. D., Goldwater, L. J., Bittikofer, J. A., (1978): Micro-environmental Exposure to Mercury Vapor, Am. Ind. Hyg. Ass. Jour., 39: 378-384.

Soviet Union Standard Committee (SUSC), (1988): General Sanitary Requirements for Working Zone Air, No. 12.1.005-88, Soviet Union.

Schepers, G.W., Durkan, T.M., Delahant, A.B., Credon, F.T., Redlin, A.J., (1957): The Biological Action of Degussa Submicron Amorphous Silica Dust. AMA Arch. Ind. Health 16:125-46, 203-244, 280-301.

Tickner, J., (1997): Dust Control and occupational Exposure to Silica in the United Kingdom, Sampling and Control of Mineral Dust, pp 1008-1010.

Tomb, T. F., Ondrey, R. S., (1976): Determining the Feasibility of Area Sampling to Enforce the Respirable Dust Standard in Underground Coal Mines, Pittsburgh, PA: Pittsburgh Technical Support Center, MSHA, IR 1037.

Tomb, T., (1997): Measurement strategies in US Underground coal mines, Strategies for Dust Measurement, 1124-1133

Trapido, A., (1999): Unpublished Report, Personal Communications, South Africa.

Ulfvarson, U. Limitations to the use of employee exposure data on air contaminants in epidemiological studies. Int. Arch Occup. Environ. Health (1983) 52: pp 285-300.

US Federal Register, (1995): Vol. 60, No. 20, Notices 1995, USA.

Unsted, A.D., (1998): Gravimetric dust sampling for control purposes and occupational dust sampling, Journal of Mine Ventilation Society of South Africa, Volume 51, Number 1, pp 24-27.

Unsted, A D. Gravimetric dust sampling and risk assessment. SIMRAC research report GAP046, Johannesburg, 1995.

Unsted, A D. Occupational dust sampling and sampling for control purposes. SIMRAC research report GAP 326. Johannesburg, 1996.

Villnave J, M; Corn M; Francis, M. and Hall, T.A. Regulatory implications of airborne respirable free silica variability in underground coal mines. AM Ind Hyg Assoc J (52) March 1991 pp 107-112.

Vincent, J. H., (1994): Measurement of Coarse Aerosols in Workplaces: a review, Analyst 119:13-18.

Vincent, J. H., (1997): Joint European Investigations of New Generations of Dust Sampling Instrument, Instrumentation for Dust Measurement, pp 618-624.

Walton, W.H., (1966): The airborne dust problems in coal mines in Great Britain, Mining Engineer, Vol 126, No 73-84, pp. 97-117.

Watts, W. F Jr., and Parker, D. R. Mine inspection data analysis system. Appl. Occup. Environ Hyg. April 1995. pp 323-330.

Weill, H.; Jones, R. N. and Parkes, W. R. Silicosis and related diseases. Occupational lung disorders. Third edition. W R Parkes (Editor) Chapter 16. Butterworth-Heinemann Ltd. Oxford, England. 1994.

Willams B., (1999): Epidemiologist, Personal Communications, CSIR-Miningtek, South Africa.

Wilson, R. K., Stevens, P. M., Lovejoy, H. B., Bell, Z. G., Richie, R. C., (1979): Effects of Chronic Amorphous Silica Exposure on Sequential Pulmonary Function, J. Occupational Medicine, v. 21, pp. 399-402.

Wright, B. M., (1953): Br. J. Ind. Med., v. 10, p. 235.

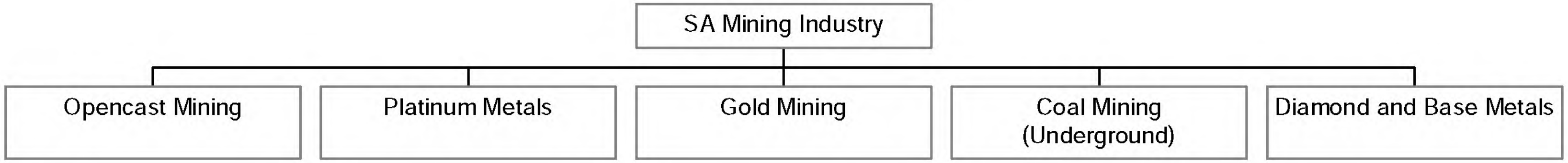
Yoshida, M., Yamauchi, H., Yamaura, Y., (1980): A Study of Mercury Exposure Monitoring-Comparison of Environmental and Personal Monitoring, Jpn J Hyg 35 (3): 543-549.

Zaidi, S. H., King, E. J., Harrison, C. V., and Nagelschmidt, G., (1956): Fibrogenic Activity of Free Silica of Different Particle Sizes, A. M. A., Arcs. Ind. Health, v. 13, pp. 122-132.

Zitter, M., Mahieu, B., De Surgy, D., Auburtin, G., Mas, A., (1998): Assessment of Personal Dust Exposure with the CIP 10 for a better medical Management of the Pneumoconiosis Risk in Coal Workers, HBL, France Instrumentation for Dust Measurement.

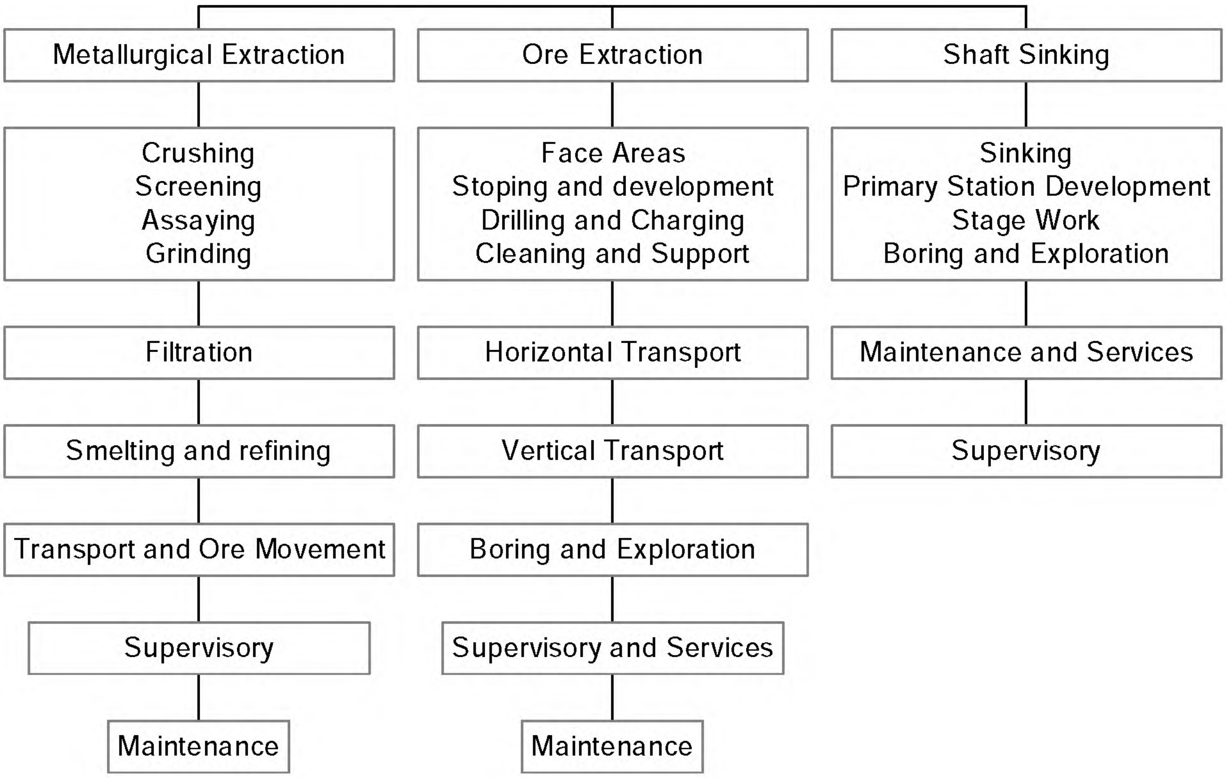
Appendix A : Mine Workers' Population Breakdown.

APPROACH PROPOSED



Appendix A : Mine Workers' Population Breakdown.

GOLD MINING



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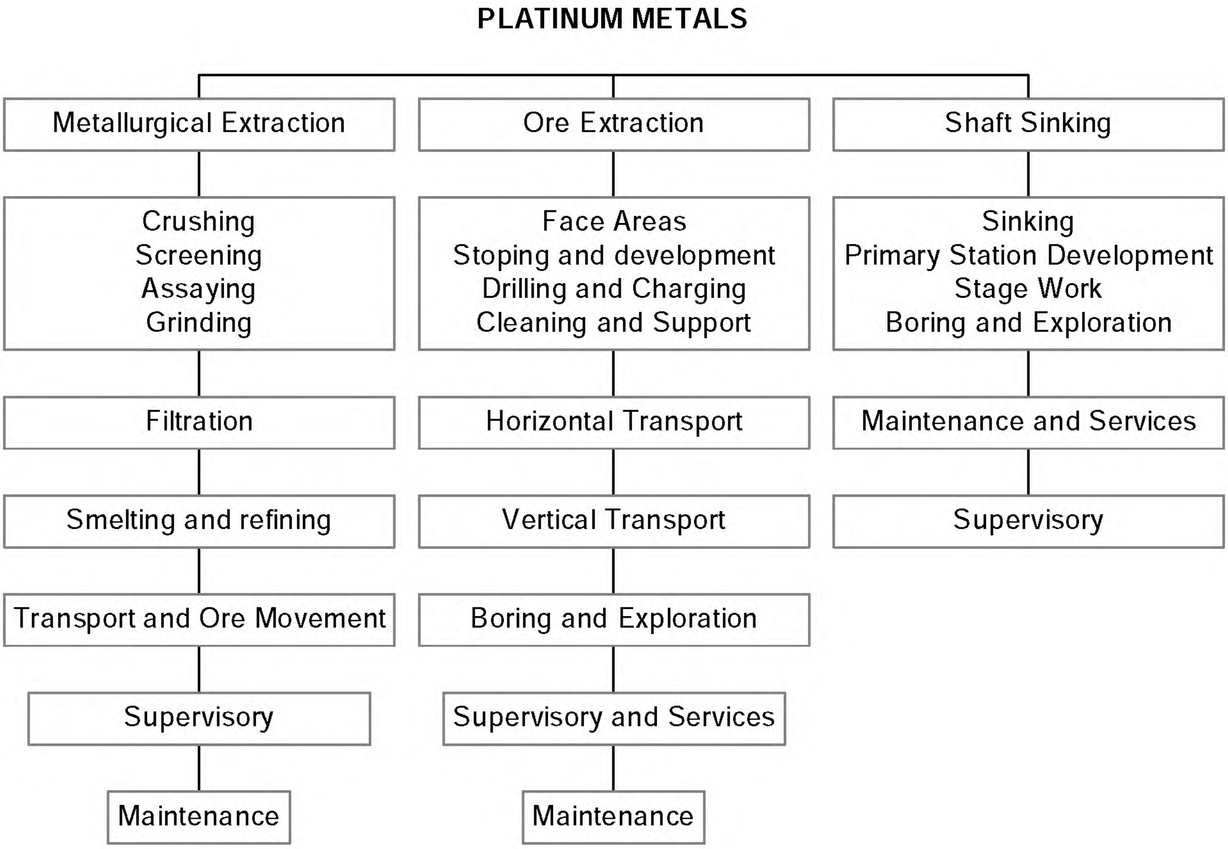
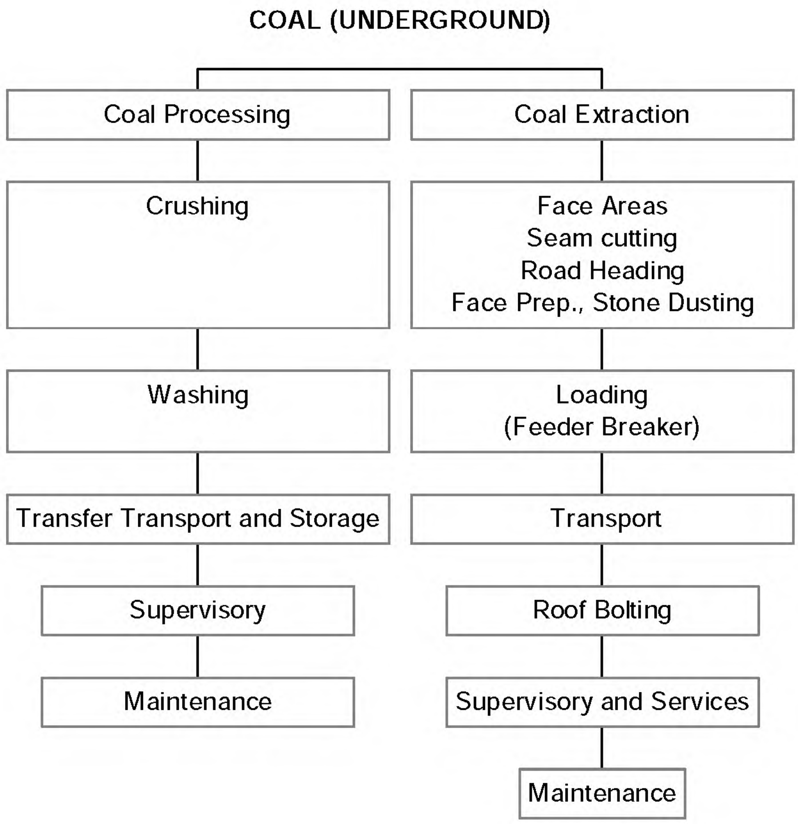
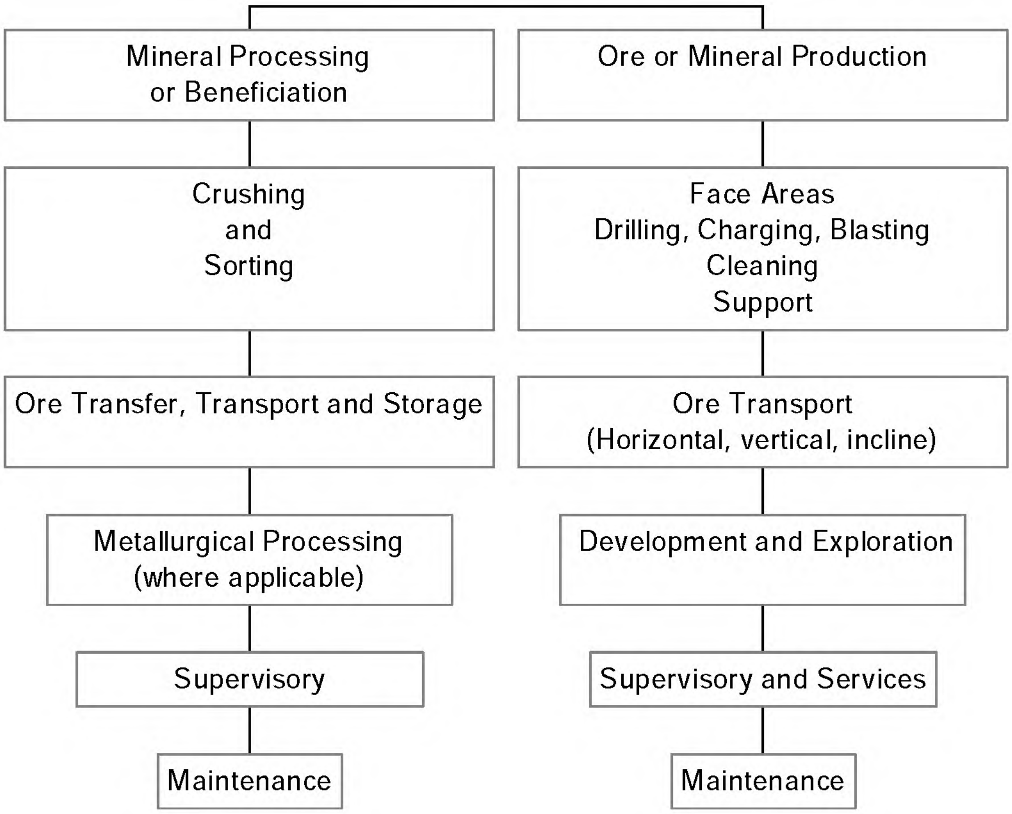


Appendix A : Mine Workers' Population Breakdown.



Appendix A : Mine Workers' Population Breakdown.

DIAMONDS AND BASE METALS



Appendix A : Mine Workers' Population Breakdown.

OPENCAST OPERATIONS