Respirable dust and quartz exposure of Rock Drill Operators in two Free State Gold mines

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A research report to the Faculty of Health Sciences, University of the Witwatersrand, in fulfillment of the requirements for the degree of Master of Public Health, Occupational Hygiene

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I, Daniel Michel Kemsley declares that this research report is my own work. It is being submitted for fulfillment of the requirements for the degree of Master of Public Health, Occupational Hygiene at the University of the Witwatersrand, Johannesburg. It has not been submitted previously for any degree or examination at this or any other University.

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……06th…………….day of………………… March, 2009

Dedication

Dedicated to Him who makes everything possible, our Lord Jesus Christ.

Abstract

Introduction

It is well established that gold mine dust is a major cause of pneumoconiosis and other lung diseases. The main sources of dust in gold mines are well documented. Rock drill operators using pneumatic percussion rock drills are at the sharp end of exposure due to the very nature of the drilling process in that rock is pulverized and liberate large amounts of dust even with the addition of copious amounts of water. Historically it has been found that the gold bearing rock formations in South Africa typically contain about 30% quartz. (1) Keeping this in mind, the potential for overexposure is obvious. The actual exposure of rock drill operators to dust and quartz is not well documented and for this reason this research focuses on this particular occupation.

Objectives

To measure the respirable dust and quartz exposure of Rock Drill Operators in two typical gold mines in the Free State province of South Africa in 2007.

Methods

This study is a descriptive, cross sectional, rapid assessment based on the findings of gravimetric sampling results taken at Rock Drill Operators working underground on two different gold mines. The actual gravimetric sampling was done in accordance with NIOSH methodology. The study population consisted of 30 Rock Drillers on one mine and another 30 on a second mine. The Rock Drill Operators was randomly selected using their company numbers and selected by the "Excel" program random number selection function. Ordinary gravimetric sampling, using Gillair pumps, was used and weighing done on the mine by a qualified and well experienced Air Quality Analyst using an appropriate methodology compatible with international best practices. Quartz analysis was done at the National Institute for Occupational Health (NIOH) in Johannesburg using a Phillips X-Ray diffraction. (Photo 2). The methodology used by the laboratory technician is conducted strictly according to the manufacturer's specifications and in line with international best

practices. This laboratory participates in quality assurances programmes and is highly regarded internationally.

Results

The initial hypothesis that exposure underestimation in the past in terms of this particular occupation is confirmed and could be contributable to the difficulties typically experienced when using the traditional gravimetric sampling method. The average quartz percentage was determined to be 25.45% for mine 1 and 38.49% for mine 2 giving an average of 30.67% for both mines. The Total Mass means was 0.73 and 0.23 mg for mine 1 and 2 respectively with an average for the two mines being 0.49 mg. Results for Time Weighted Averages revealed values of 0.69 and 0.22 mg/m^3 for mine 1 and 2 respectively with an average of 0.46 mg/m^3 for both. In terms of Air Quality Index (AQI) the values were 1.4 and 0.6 for mine 1 and 2 respectively with an average for both mines therefore being 1.1. A comparison with the South African OEL for quartz showed overexposure on 32% of all rock drill operators sampled. When using the NIOSH OEL that figure is even worse at 72%. Based on these results it would thus be fair to conclude that Rock drill operators working without appropriate respiratory equipment will be overexposed and therefore potentially suffer ill health as a result.

Discussion and conclusion

Rock drill operators are potentially exposed to high levels of harmful dust and quartz in their normal daily work if not adequately protected using good, effective appropriate and comfortable respiratory protective equipment (RPE) and additionally having proper ventilating velocity. At an average Air Quality Index (AQI) of 1.1, it would require the mine Occupational Hygienist to immediately institute remedial action in conjunction with an investigation to determine the reasons for such overexposure. The AQI of 1.46 and 0.6 for Mine 1 and 2 respectively curiously beg the question as to why there is a difference. The answer unfortunately is not clear at first glance as both mines wetted the stope working faces equally well, ventilates the faces with similar velocities which in turn alludes to similar dilution factors but the only reasonable deduction that could be made is that high TWA respirable quartz pollutant concentrations (mg/m^3) values in lots of cases corresponded with low actual quartz values. This could be co-incidental but in fact caused the TWA graph to be inversely proportional to the AQI graph. Couple this to the fact that the actual dust burden is lower in Mine 2 compared to Mine 1 as confirmed by the TWA values obtained, then the results becomes easier to interpret. However, the assumption is made that the TWA values should enjoy more preference in the analytical sense as it could be compared directly to OEL's which serves to highlight the hypothesis very clear in that rock drill operators are over exposed to a high degree of certainty which in turn concurs with other research done in the past.

The fact that the methods used to drill holes in order to be charged up with explosives has largely remained unchanged for more decades in the mining industry with no viable alternative on the horizon, emphasizes the fact that focused attention and proper risk assessment is called for to protect rock drill operator from harmful exposure. That said the normal paper dust mask cannot in all good conscience be regarded as appropriate RPE for this occupation. The aforementioned risk assessment must determine and ultimately classify which occupations would benefit from "upgrading" to better quality dust masks. To accept only one type of dust mask on a mine would be considered a travesty and contrary to the application of all good occupational hygiene principles. Failing to expedite the aforementioned risk assessment on RPE per occupation will result in failure to place effective safeguard measures in place to protect rock drill operators from harmful dust and will mean that their health will be compromised in time. The development of air line fed type hard hats incorporating a face shield, harness fitted with moisture trap, filter and a snap fit attachment to a compressed air line is likely to be the ultimate solution provided that it is light, comfortable and the introduction is done in a manner that will ensure the understanding in the benefits to be derived from using such a device in the place of ordinary dust masks by Rock

Drill Operators. Ultimately, using the Occupational Hygiene hierarchy of control that dictates the first consideration of such control being elimination, coupled with the horrendous ergonomic problems faced by rock drill operators, the solution seems to point inevitably towards meganisation.

Using a person in the same homogeneous exposure group (HEG) as that of the rock drill operator as a forced alternative is not advisable as the exposure of a rock drill operator is very unique and certainly not comparable to that of a winch driver for example. The wet environment certainly warrants the investigation into alternative methods for sampling as normal, traditional methods proved to be inconsistent, unreliable and often unusable.

Acknowledgements

The content of this research report is the result of collaborative research where the author of this research report served as the principal researcher and having persons assisting in gravimetric weighing as well as X-Ray diffraction analysis. In particular a word of thanks to specific personnel at NIOH for their assistance. Jonas Shai for his professional assistance in analyzing the gravimetric samples sent to his laboratorium using their excellent and very accurate X-Ray diffraction equipment, Kevin Renton and Rob Ferrie in providing such valuable advice and encouragement. Professor David Rees for his patience, advice and open door philosophy to assist me at a moments notice. A special word of thanks to the friendly staff of the excellent reference library that had endless patience and assisted in the search for suitable and often very rare but pertinent and informative articles on the chosen subject.

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Abbreviations

ACGIH:	American Conference of Governmental Industrial Hygienists
AQI:	Air Quality Index
COPD:	Chronic Obstructive Pulmonary Disease
COAD:	Chronic Obstructive Airway Disease
CEN:	Committee on European Standardization
DME:	Department of Minerals and Energy
HEG:	Homogeneous exposure group
ISO:	International Organization for Standardization
ILO:	International Labour Organization
IPM:	Inhalable Particulate Mass
IARC:	International Agency for Research in Cancer
MSHA:	Mine Safety and Health Administration
NIOSH:	United States National Institute for Occupational Safety and Health
NIOH:	National Institute of Occupational Health
OEL:	Occupational Exposure Limit
OSHA:	Occupational Safety and Health Administration
PTB:	Pulmonary Tuberculosis
PMF:	Progressive Massive Fibrosis
PPE:	Personal protective clothing
RPE:	Respiratory Protective Equipment
RR:	Rate Ratio
RPM:	Respirable Particulate Mass
SAMOHP:	South African Mines Occupational Hygiene Programme
TLV:	Threshold Limit Value
TLV-TWA:	Threshold Limit Value - Time Weighted Average
TWA-CONC:	Time Weighted Average – Respirable Quartz Concentration
TPM:	Thoracic Particulate Mass
WHO:	World Health Organization
XRD:	X-Ray Diffraction

Symbols

10^{-9}m:	Particles in the nanometer particle range and < 1 µm i.e. (10^{-9}m or 10 -3 µm)
µg/m^3	Micrograms per cubic meter
L/min:	Liter per minute. A measure of flow rate per unit time for a gas or liquid.
mg/m^3	Milligram per cubic meter. A measurement term used to indicate the airborne concentration of a substance.
µm:	Micrometer, unit of measurement equal to one millionth of a meter. It is used to measure extremely small dust particulate or aerosols.
m/s:	Meters per second.
m^2	Square meter.

Glossary

Alveoli: Gas exchange region of the lung. (About 500 million in an adult)

Ambient: This describes the surrounding air in a working place at a specific time.

Bronchial tubes: Branches or subdivisions of the trachea. The bronchiole is a branch of a bronchus which in turn is a branch of the windpipe.

Cilia: (Includes ciliated cells) Minute hair like structures found in the bronchi and other respiratory passages that facilitates the capture and removal of dust.

Cyclone: Used as part of the sampling train in gravimetric sampling in order to remove coarse or non-respirable dust. This dust is then deposited in the grit pot.

Cytotoxic particles: Toxic to cells, cell – killing.

Cytotoxic therapy: Chemotherapy and radiotherapy are forms of cytotoxic therapy. They kill cells.

Carcinogen, Carcinogenicity, Carcinogenic: A substance known to cause cancer or capable to cause cancer. Carcinogenicity therefore alludes to the potential cancer producing characteristics of a substance.

Dose: The amount of a pollutant to which an employee is exposed.

Dust: Solid particles generated by handling, grinding, rapid impact, detonation and decrepitation of organic or inorganic materials such as rock, ore etc.

Fibrosis: A condition associated with the increase of interstitial fibrous tissue.

Fibrogenic dust: A biologically active dust that leads to the development of masses of inactive fibrous tissue that slowly replaces active lung tissue.

Field blanks: These are filters cassettes actually taken to the sampling site and are treated the same way as the media used to collect samples but no air is drawn through them. The intention of field blanks is to identify errors in analysis caused by contamination of sampling media during handling, processing, transporting and storage before analysis. It is expected that these cassettes will show very little if anything in terms of contamination but if it does, the results from the sampling could then be questioned.

Gravimetric: Relating to measurement by weight.

Gravimetric pump: A vacuum/suction pump with built-in flow rate compensation and pressure adjusting capability to within 5% of the calibrated airflow rate over a full shift.

Interstitium: Refers to the underlying cellular layer that surrounds blood vessels

Occupational Disease: An occupational disease may be defined as a disease caused, or made worse, by exposure at work.

Occupational Exposure Limits: This is defined as a time-weighted average concentration for an 8-hour workday and a 40-hour workweek to which nearly all workers may be repeatedly be exposed without adverse health effects.

Occupational Exposure Limit – Time Weighted Average (OEL-TWA): The time weighted average concentration for a normal 8-hour workday and a 40-hour work week, to which nearly all workers may be repeatedly exposed, day after day, without adverse affects.

Occupational Exposure Limit – Short Term Exposure (OEL-STEL): Defined as a 15 minute Time Weighted Average which should not be exceeded at any time during a workday even if the 8-hour TWA is within the OEL-TWA.

Occupational Exposure Limit – Ceiling limit (OEL-C): It is an instantaneous value which must never be exceeded during any part of the working exposure.

Parenchymal airspaces of the lung: This would include the respiratory bronchioles, alveolar ducts, alveolar sacs, atria and alveoli.

Phagocytosis: The process by which a cell engulfs a foreign particle and could include cells such as neutrophils and/or monocytes (these are types of white blood cells). (*Phago* – Greek meaning, to eat).

Phagocytes: Cells that engage in phagocytosis.

Pneumoconiosis: A lung disease simply defined by the International Labour Organization as "the accumulation of dust in the lungs and the tissue reactions to its presence".

Progressive Massive Fibrosis (PMF): As the number of nodules in the lung increase they may agglomerate to form the early lesions of Progressive Massive Fibrosis. The lesions may appear throughout the lungs and can appear at any time after exposure. However, this will not occur immediately but usually and often only after many years of exposure. PMF will increase gradually in size and will do so even after cessation of exposure.

Quartz: Vitreous, hard, chemically resistant, free silica. The most common form in nature and is the main constituent in sand, sandstone and igneous rock.

Respirable dust: Airborne dust that is capable of reaching the gas exchange regions of the lung.

Respiratory system: Consist of (in descending order) nose, mouth, nasal passages, nasal pharynx, pharynx, larynx, trachea, bronchi, bronchioles, alveoli.

Rotameter: A secondary standard, calibrated to a primary standard, variable area flow meter giving easy to read and accurate flow values.

Silicoproteinosis: *Acute silicosis*

Sampling train: The complete assembly of hardware required to perform dust sampling. Typically this would include the calibrated and self regulated pump, tubing sampling cassette (cyclone) and filter media within the cyclone.

Silicosis: This is a fibrotic disease that is attributable the inhalation of crystalline Silica. Silica is usually in the form of quartz but could also occur albeit less commonly as cristobalite and tridymite.

Threshold Limit Value (TLV): The maximum concentration of an air contaminant to which an employee can be safely exposed for an eight hour period in one workday over a normal work life. These are general terms assigned to an apparent safe concentration of exposure to a chemical substance. Commonly used in America (ACGIH). South African legislation refers to Occupational Exposure Limits (OEL's).

Thoracic particulate: Particulate matter capable of reaching the lung airways.

Time Weighted Average Concentration (TWA): Time – weighted average concentration of an air pollutant measured in a working place for the duration of a shift, usually 8-hours or 40-hour workweek to which basically all workers may repeatedly be exposed to without adverse health affects.

Chapter 1 Introduction

This chapter describes the history and awareness of the fact that dust is an occupational hazard, the common problems associated with dust, its properties and the presence of free crystalline quartz in the dust and the associated dangers in the inhalation of the dust. A brief discussion on international as well as South African perspectives sets the scene with regards to silicosis as a mining related disease. Particle deposition behavior as well as the structure of the lung and airways is briefly discussed together with the body defense mechanisms with regards to dust exposure.

It further states the reason for this research and the need to measure exposure to dust in an accurate manner in order to obtain relevant data that will ultimately provide the occupational hygienist with an understanding in how to proceed in eliminating or minimizing the exposure to levels below Occupational Exposure Levels in compliance with legal requirements.

1.0 The history and awareness of dust as an occupational hazard

It is a well known fact that dust in gold mines are a major cause of pneumoconiosis and other lung diseases. Pneumonokoniosis (later shortened to pneumokoniosis), (Greek, *pneuma* = air and *konis* = dust) was a term that was coined by Friedrich von Zenker in 1866 to describe lung diseases following the inhalation of mineral dusts. Exactly four years later in 1870, Dr Adolf Kussmaul affirmed the presence of silica in a lung. Thereafter a French Doctor, Visconti coined the term Silicosis for the first time. (2) The actual root of the word stems from the Latin word silex which means flint. It is meant to describe the character of quartz dust. Elaine Katz describes silicosis as “white death, more dangerous than war”. (3) The International Labour Organization (ILO) simply defines pneumoconiosis as “the accumulation of dust in the lungs and the tissue reactions to its presence”. (4) This term for example would include silicosis (silica), siderosis (iron) and asbestosis (asbestos).

The main sources of dust in gold mines are well documented. Rock drill operators using pneumatic percussion rock drills are at the sharp end of exposure due to the very nature of the drilling process in that rock is pulverized and large amounts of dust are liberated even with the addition of copious amounts of water.

Although there have been a few research papers written on dust exposure and silicosis covering basically the whole spectrum of the underground labour force, this research was focused on the actual exposure of rock drill operators to dust and quartz. The reason why rock drill operators were not actively researched might well be due to the inherent difficulty of getting useable results from gravimetric sampling on said rock drill operators. Their working environment is probably the worst imaginable. The mere combination of possible hazards will frighten the unwary visitor into disbelief and ensure a very short stay in the vicinity. It is wet, uncomfortable, dimly lit and claustrophobic. Couple that to the omnipresent threat of rock falls, pressure bursts and explosive gas and it makes this an occupation suitable only for the daring, super fit and very courageous worker. The monitoring and execution of remedial action for this particular occupation serves as an enormous challenge to the Occupational Hygienist in terms of environmental control and the application of ergonomic principles.

In the past the assumption was made that miners doing the same work on different mines will be exposed to the same dust levels. This has been proven incorrect as this research has determined that factors such as the difference in the type of reef being mined would present different percentages of quartz. Couple this to different approaches of combating dust per mine and the results show a wide range of dust levels per occupation, work place, ventilating districts and of course different mines. The extent of the difference will be shown later on in this report.

1.1 Silica Dioxide (SiO_2)

Silica as a mineral dust can be divided into various groups as defined in the Occupational Hygiene Regulations under the Mine Health & Safety Act, [5] all of which is classed as Silica Dioxide ($Si\ O_2$). Firstly there is Silica, in an amorphous state (non-crystalline) being divided into inhalable (OEL = 6 mg/m^3) and respirable particulate (OEL = 3 mg/m^3), then Silica, crystalline (respirable and OEL = 0.1 mg/m^3) divided into Cristobalite, Quartz, Tridymite and Tripoli, then Silica fume (respirable particulate, OEL = 2 mg/m^3) and lastly Silica, fused (respirable particulate, OEL = 0.1 mg/m^3). Of these, Quartz is the most commonly found substance in nature and when heated to between 860 and 1470 ^0C is transformed into Tridymite and if subjected to even higher temperatures it is transformed into Cristobalite. Tridymite and Cristobalite are known to be more fibrogenic than Quartz. [6] Quartz (CAS No 14808-60-7) is a colourless, odourless non-combustible solid with a molecular weight of 60 with a boiling point of 2230 ^oC and melting point of 1610 ^oC.

Prolonged exposure to dust containing free crystalline silica will cause silicosis and has been recognized as an occupational disease in miners as far back as 1912. Silicosis is seen as one of the most severe occupational diseases in the mining industry and in South Africa contributes to approximately 2000 new cases every year. [7] Cognizance must also be taken to the other occupational disease in relation to dust exposure namely chronic obstructive lung disease (also known as chronic obstructive pulmonary disease –COPD) which was accepted as an occupational disease in 1973. This disease is not included in the previously mentioned term pneumoconiosis and so too hypersensitivity pneumonitis. There is a definite dose-response relationship between chronic obstructive lung disease and dust exposure when considering South African gold miners but that it is not dependant on the presence of silicosis. [8] Respirable quartz may also cause lung cancer and Chronic Obstructive Pulmonary Disease. Progressive Massive Fibrosis (PMF) is described as the presence of nodules that has been agglomerated to form early lesions and may appear throughout the lung. PMF will increase in size even after the cessation of exposure to quartz containing dust. It also increases the risk of contracting PTB. In addition to these diseases, quartz exposure has also been linked as the cause of scleroderma (systemic sclerosis) and Peripheral Thrombosis. In 1997 the International Agency for Research on Cancer (IARC) categorized crystalline silica as a human carcinogen. It therefore stands to reason that effective control and prevention of exposure, is vital. Furthermore, the accompanying necessity for measurement, analysis and comparison to OEL's is critical. Continuous measurement will assist the Occupational Hygienist in determining the effectiveness of current or recently adopted preventative measures as well as prompt further action to eliminate, minimize or improve controls based on the date and results of said measurements.

Epidemiological studies of populations are capable of determining whether disease is attributable to a particular type or level of exposure. However, for an individual person this is not clear. Court judgments about the possible exposure likely to be causal may be made in medico legal cases or claims for compensation but these decisions have little value in determining the true extent of disease caused in the working environment. This is particularly applicable in the South African context because of the absence of reliable exposure data. Information about the incidence and distribution of such diseases is thus far from complete.

To this extent, an understanding of the all possible causes of occupational diseases requires the application of both good epidemiology and detailed knowledge of the nature of exposure and the susceptibility of those exposed.

The measurement of dust and quartz pertaining to this research report was firstly sampled under strict supervision using Gillair Gravimetric sampling pumps. The samples were then weighed as per normal NIOSH requirements where after the samples were X-Ray analyzed at NIOH for percentage quartz. The greatest measure of care was applied throughout to ensure quality and accuracy taking care not to deviate from the NIOSH sampling protocol.

This study is a descriptive, cross sectional, rapid assessment that is based on the findings of gravimetric sampling results taken at Rock Drill Operators working underground on two different gold mines. The study population consisted of 30 Rock Drillers on one mine and another 30 on the second mine. The Rock Drill Operators was randomly selected using their company numbers and selected by the “Excel” program random number selection function. The two mines on which the research was done were selected purely on the bases that they represent typical Free State gold mines. One is rather shallow and the other deep. This is to cater for and include any possible variance in rock type, which may impact on the percentage quartz present in that particular rock type. That said, the manner in which the rock drills are used is virtually identical on all mines with the exception of some mines that use hydro powered rock drills and the recently introduced electrically powered Hilti Rock Drills. However, these two types of drills are still in the minority and in most cases used in an experimental manner. That said the method of drive of the drill rod is not of any importance as the basic rod remains the same with water being force fed through the middle in order to allay the dust being generated during the drilling process.

1.2 Background Information

Respirable dust seen in the context of past South African mining history is responsible for many deaths. Gold mining and in particular the occupation of rock drilling is known as primary dust generators. According to Geologist in the Free State Gold Fields, the rock formations that these rock drillers drill into in order to extract the gold bearing reef consist of 30% [(9)] on average of crystalline quartz (silica). Tests done regularly by mines to confirm actual crystalline quartz for gravimetric sampling purposes usually using Infra Red Spectrometry analytical methodologies, often reveal results varying between 5 and 32 %.

The International Agency for Research in Cancer (IARC) declared silica dust as being carcinogenic to humans in 1997 [(10)]. Silica can also be described as being cytotoxic particles because of its capability to cause macrophage injury.

Because of the drilling the silica is grounded into extremely fine particles to the extent that they become respirable. Although measures to combat dust at source have been practiced for quite a number of decades, the effectiveness is questionable. Quarterly airborne pollutant reports to the DME show regular overexposure in terms of respirable dust.

Not a lot of studies in this field exist in South Africa but good examples would be: "Estimating the Quartz Exposure of South African Gold Miners" [(9)] , "Risk of Silicosis in a Cohort of White South African Gold Miners" [(11)] and "Silicosis prevalence and exposure-response relations in South African goldminers" [(12)]

There is a great amount of confusion among mine occupational hygienists as to what must be done to improve on dust allaying and the feeling generally is "We have been doing it forever, what else must we do and where must we start?" Hopefully the results and recommendations of this study will provide some answers.

Currently, dust allaying methods would include the use of water, dilution through ventilation and dust capturing methods such as Rabson filter bags, etc. The latest trend is to have a primary filter medium such as a cyclone to separate the course media (and capture it) from the fine and a secondary filter such as Rabson bags to capture the remaining fine to super fine particles. The use of electrostatic filters also seems to be on the increase again. The current method used by all mines in South Africa to monitor exposure to dust is gravimetric sampling and the methodology is stipulated in the Guideline for the compilation of a mandatory code of practice for an occupational health programme on personal exposure to airborne pollutants [(13)], issued by the DME with an effective implementation date of 1 August 2002. The Occupational Exposure Limit (OEL) of 0.1 mg/m^3 in combination with the percentage quartz determined through either Infrared or X-ray diffraction analysis is used in a formula to determine the Air Quality Index (AQI) and should not exceed 1. However, despite this monitoring program and the measures taken in the past to prevent respirable dust exposure, the incidence of respirable dust-related illnesses persists.

The elimination of silicosis is a global program launched by the ILO and WHO in 1996. Britain and Australia claim to be well on track in succeeding therein.

There is concern that although the "elimination of silicosis campaign" was launched early in 2003, many of the mines especially small mines, have not yet embarked on an active participatory programs to ensure success in this regard.

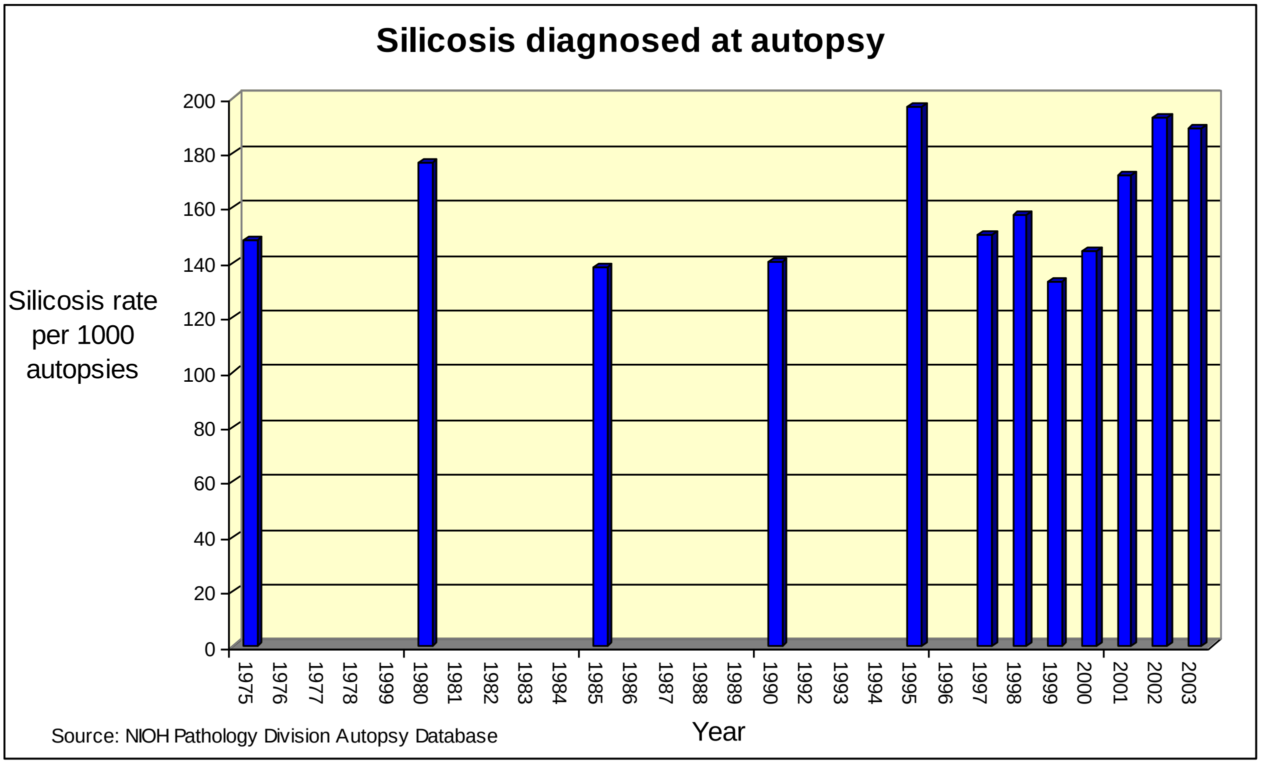
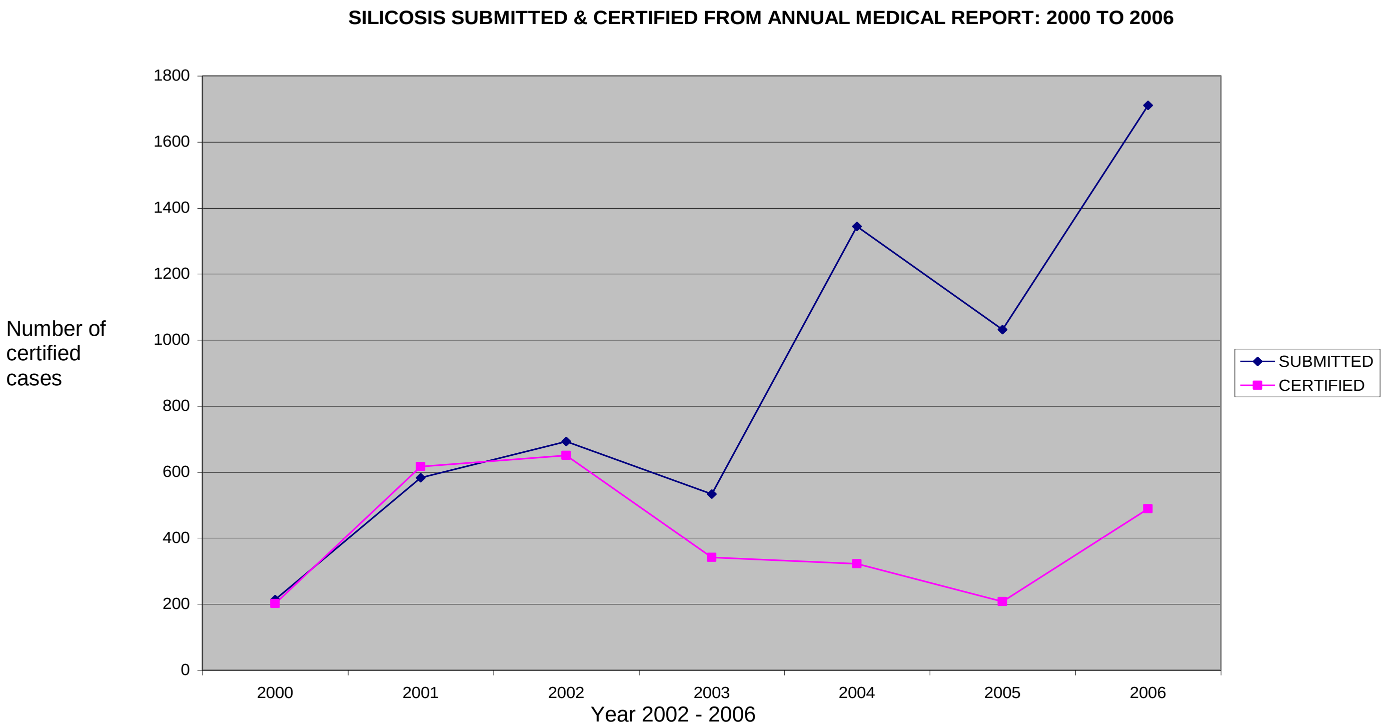


Fig 1.1 Silicosis rate per 1000 autopsies, NIOH pathology Division Autopsy Database 1975 – 2003.

As can be deducted from this graph (courtesy NIOH) there is still a slight upward tendency in silicosis diagnosed per 1000 autopsies since 1997. Due to the lag time for the onset of silicosis, only time will tell whether what industry is doing now to combat dust and indeed, all the effort expended currently to eradicate Silicosis, have been successful.

Eradication of silicosis and noise induced hearing loss milestone workshops/meetings are held on a monthly basis on the larger mines in the Free State Region and as this is a tri-partite endeavour, it is hoped that with the application of constructive decisions made, the success of the milestones will be achievable.

Fig 1.2 Certified silicosis taken from the DME annual medical report :2000 - 2006



This graph is taken from the DME annual medical report (14) emphasizes the concern with regards to the amount of silicosis cases submitted for certification per annum. As can be seen, around 500 are indeed certified as having confirmed silicosis annually.

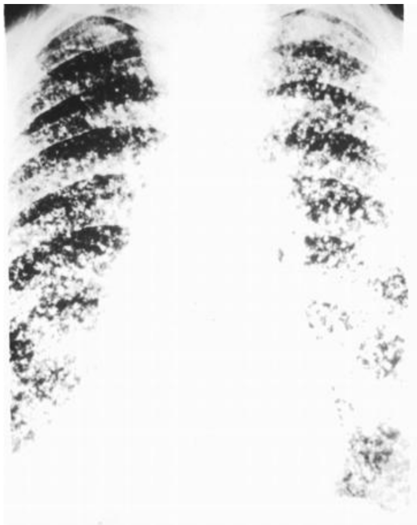


Figure 1.3 An X-Ray showing simple extensive silicosis .[15]

1.3 Literature survey

1.3.1 International Perspective

United Kingdom

In Britain there has been a sharp drop in the prevalence of silicosis. [15] The reason for the decline is two fold. Firstly, stricter law enforcement in the prevention of silicosis and secondly and probably the main reason, is the fact that coal mines have been closing down markedly over the past two decades. As a matter of fact the past forty years has seen a gradual move away from manufacturing industries as a whole and includes coal mining which historically has been the source of silicosis amongst miners in the UK. The decline in silicosis however, went hand in hand with a rather sharp increase in occupational asthma. The awareness and understanding of occupational lung diseases in the UK was brought about by the SWORD (surveillance of work related and occupational related diseases. Figure 1.4 explains how SWORD fits in with the United Kingdom Occupational disease surveillance scheme project [16] that was launched in 1989 by the Health and Safety Executive.

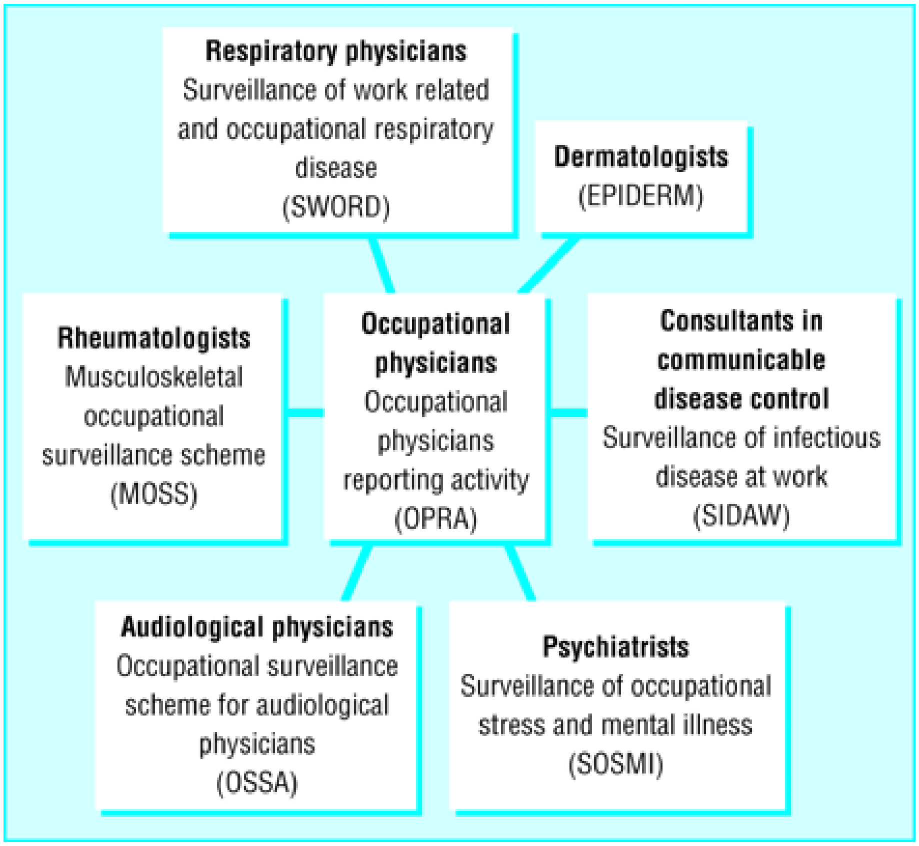


Figure 1.4 United Kingdom Occupational disease surveillance schemes in Occupational Disease Intelligence Network .[16]

Physicians specializing in occupational and respiratory diseases were invited to submit any newly diagnosed cases together with the suspected causal agent and/or occupation. Data was then frequently analyzed and conclusions drawn with respect to the prevalence of these diseases and subsequently publicized. Information relating to this data can be found at the Department of Occupational and Environmental Medicine, National Heart and Lung Institute, London.

United States of America

To get a feeling of where the USA is in terms of silicosis, one should read the document “Deadly Dust” by the authors David Rosner and Gerald Markowitz”. [17] The authors realized that silicosis became the “forgotten disease” after World War 2 and in 1991 brought this disease and its crippling effect to the fore. Organisations such as the Occupational Safety and Health

Administration (OSHA), National Institute of Occupational Safety and Health (NIOSH) and the Mine Safety and Health Administration (MSHA) took notice of the contents of the book and started referring to silicosis as a target disease. “Deadly Dust” was called a paradigm for its historical research done on silicosis. The authors was called upon as expert witnesses on the disease in several court cases involving the disease and they soon realized that far from being a disease perceived to have been cured, the opposite was true in that silicosis as an occupational disease was rife and extensively causing the death of thousands upon thousands of silica exposed workers across America.

Actual mortality data in terms of silicosis related deaths for the USA seems to be not readily available. However, it is noteworthy that 16% of all silicosis related deaths in the USA is associated with mining rock drill operators. [18]

It is reported that the USA has been able to reduce the incidence of silicosis with intervention and preventative programmes as initiated by OSHA, NIOSH and MSHA.

Australia

Australia is one of the countries that claim they were successful in reducing the incidence rate of silicosis with the implementation of preventative programmes.

In order to get a clear picture of where they stood in terms of Pneumoconiosis, they gained trends over a 24 year retrospective analysis of the national mortality data spanning from 2002 till 1979. During this time there was reportedly over 1000 pneumoconiosis related deaths 56% of which was caused by asbestos**,** 38% by silicosis and 6% by CWP (Coal Worker Pneumoconiosis). However, the figure of silicosis related deaths between 1979 and 1980 stood at 60%. By 2002 this was overtook by asbestosis as the number one killer in the country. The decline in silicosis related deaths since 2002 reflects back to intervention strategies imposed through legislation in the 1980's to address the incidence of silicosis. The figure (1.4) below , [19] serves to show the occupational respiratory disease claims for 2001 – 2003 but of real interest here is the fourth set of columns depicting the Pneumoconiosis – silicates related claims which seems to suggest that this country has either solved their dust problem or is fast tracking towards it.

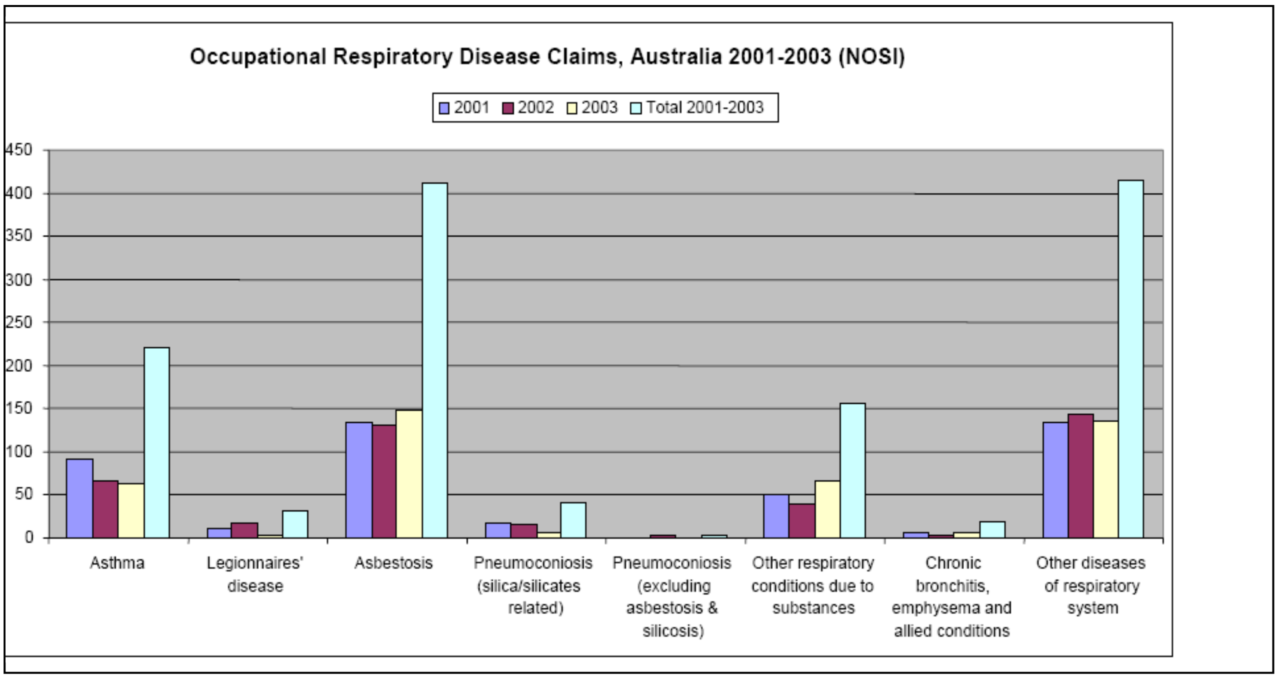


Figure 1.5 Occupational Respiratory Disease Claims in Australia 2001 – 2003.

Australia runs two SABRE (Surveillance of Australian workplace –based Respiratory Events) programs, one in Victoria and one in NSW from which data can be collected as well as the Dust Disease Board and Workers Compensation Board.

1.3.2. <u>South African perspective</u>

Mining activities in South Africa can be traced back to 1886 with quite a number of large and small, shallow mines being developed around the Witwatersrand area. The method of ventilating these mines depended entirely on natural ventilation pressure (NVP) and dry mining was used quite commonly as regulation as it stood then, did not require it. The lack of regulation also meant that dust was not deemed as hazardous but in 1902 the Government Mining Engineer of the Transvaal Mine Department declared dust to be hazardous to health. By the end of the same year, Lord Milner convened the Weldon commission with the intention to investigate the causes of and extend of silicosis.

The Leon Commission of Inquiry of 1994 [(20)] as the most recent commission to examine occupational health in the South African mining industry recommended the following;

- drafting of a new Mine Health and Safety Act (MHSA, 1996) to provide the comprehensive legal framework for creating a health and safe working environment
- restructuring of the enforcement agency
- promulgating of regulations on rock falls and rock bursts
- promulgating of regulations and protective measures to protect the health of workers including occupational hygiene and medical surveillance programmes with specific reference to tuberculosis
- restructuring of research institutions and health information systems
- ensuring appropriate training and certification of all workers in the industry

After extensive consultation between representatives of government, employers and trade unions, The Mine Health and Safety Act (Act 29 of 1996) was promulgated to effectively replace Act 50 of 1991 to effectively regulate occupational health and safety on South African Mines. Due to a high level of active participation amongst all stakeholders, this Act enjoys substantial legitimacy and is said to be consistent with ILO standards.

The Mine Health and Safety Council, operating as an advisory body to the Minister (Minerals & Energy) made certain commitments during a biennial summit in 2003 and in particular to reduce accidents and to eliminate silicosis and reduce the prevalence of noise induced hearing loss. Particular to the eradication of silicosis the requirements are;

- By the year 2008, 95% of all exposure measurements will be below 0.1 mg/m^3 (these results are for individual readings and not averaged)
- From the year 2013, using present diagnostic techniques, no new cases of silicosis will occur among previously unexposed individuals.

The Department of Minerals and Energy issued the "Guideline for the compilation of a mandatory code of practice for an occupational health programme on personal exposure to airborne pollutants" (21) in February 2002. Under the auspices of the Mining Occupational Health Advisory Committee (MOHAC) a tripartite sub committee drafted this guideline which became effective in August 2002. It comprehensively addresses the way to approach the Occupational Hygiene and Medical Surveillance in order to ensure compliance with the guideline and also uniformity to the required standards.

The ILO/WHO Global Programme for the Elimination of Silicosis (GPES) has stated as their objective that silicosis must be eliminated as an occupational disease by the year 2030. Many countries have stated that they have been successful in reducing the incidence of this disease but South Africa it seems is still a long way off from making similar claims.

In response to the Global drive for the eradication of silicosis as launched by International Labour Organization (ILO) and the World Health Organization (WHO) in 1995, the Minister of Labour, Mr Membathisi Mdladlana launched the National Programme for the Elimination of Silicosis in South Africa (NPES) on 28 June 2004. Subsequently the Department of Labour (DoL) established a National Working Group to serve as the "guardian" to develop and manage NPES the tri-partite working group consists of government, organized labour and other interested parties.

1.4 Pneumoconiosis and Silicosis

A brief look of what pneumoconiosis and silicosis is will be appropriate at this stage. Pneumoconiosis and silicosis are diseases caused by exposure to dust and quartz. It has been said that deciding to work underground is to except the fact that it is a dangerous working environment that might cause a short life expectancy. The only unknown factor is the difference in the size of the rock that could kill you, microscopic or one ton. This is probably a very negative and fatalistic outlook on underground work because in both cases, if proper care is taken, the risk can be greatly reduced. However, there is a distinct difference in combating the tendency of rock to fall and combating something that cannot be seen by the naked eye.

Dust can be described as dry particle aerosols that is created during rock breaking procedures typically found underground but will also be found in significant quantities in the reduction plants on mines where grinding and pulverizing occurs. In essence dust will be created whenever broken rock is handled, for example when it is moved from one position to another (i.e. loading, conveyor belt, ore passes etc). Dust particles in approximation are generally described as being spherical in shape. The behavior of dust particles and more particularly the deposition characteristics thereof depends largely on the size, geometrical and aerodynamic properties of it. The dust encountered in the underground working environment is never of uniform size (monodisperse) and because of this there will be different deposition methods.

Silicon dioxide (SiO_2), also more commonly referred to as Silica and also sometimes referred to as simply quartz can be found in crystals of several centimeters in diameter down to microscopic level. In crystalline form the oxygen and silicon atoms are arranged in a very ordered lattice which extends infinitely in every direction.

In 1997, the International Agency for research on Cancer (IARC) undertook a review of literature on studies conducted on quartz and cristobalite (22) and their findings could be summarized as follows;

- There is sufficient evidence that inhaled crystalline silica show carcinogenic reactions in humans as proven in studies
- Animal studies have shown sufficient evidence of the carcinogenic nature of quartz ad cristobalite
- Little evidence of carcinogenic nature on animals in terms of tridymite
- Inadequate evidence of carcinogenic nature on humans due to amorphous silica
- Inadequate evidence of carcinogenic nature on animals due to synthetic amorphous silica

There are basically three clinicopathologic types of silicosis and they are:

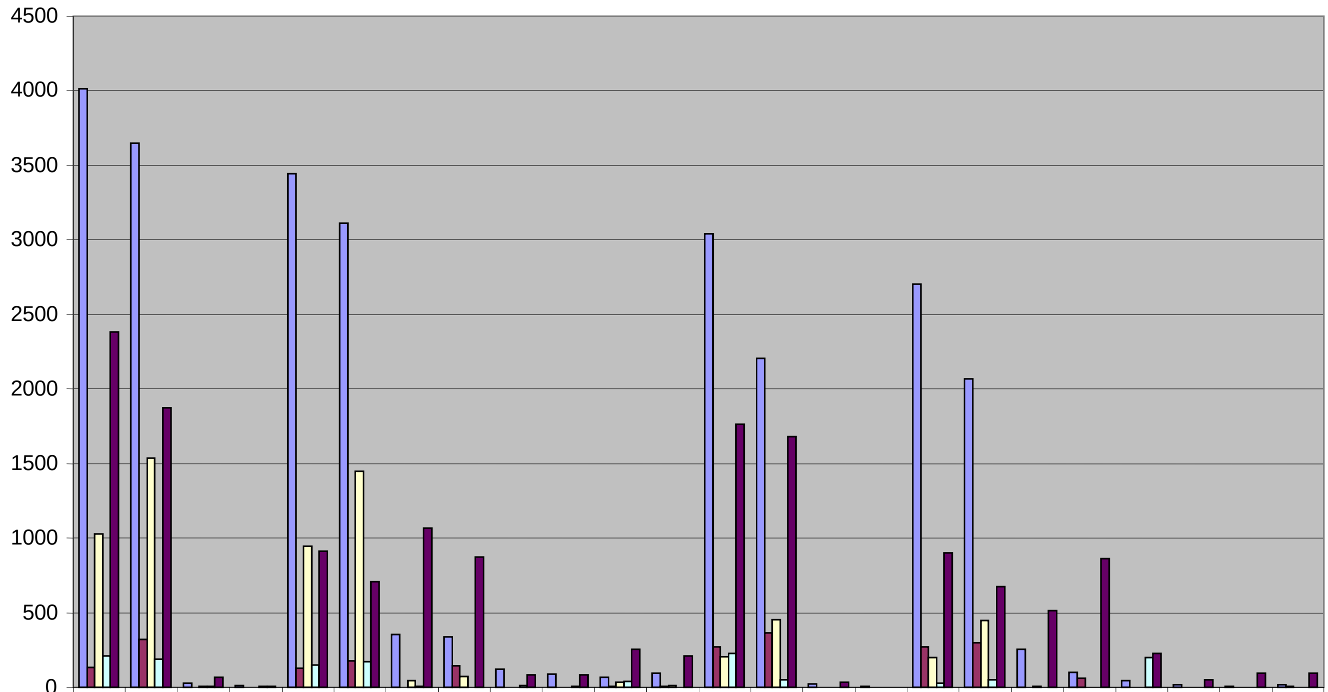
- Chronic silicosis, results from exposure to silica over decades instead of mere years.
- Accelerated silicosis, resulting from short periods of heavy exposure
- Acute silicosis (silicoproteinosis), resulting from intense exposure to very fine silica dust more often associated with sand blasting operations.

Needless to say the more commonly encountered disease is chronic silicosis, identified by the silicotic nodule as seen on radiological examinations.

1.5 <u>The relationship between silicosis and pulmonary tuberculosis</u>

The fact that there is a strong association between silicosis and pulmonary tuberculosis has been known for a considerable time in that epidemiological and case studies have proved that workers that are exposed to dust containing silica (SIO_2) have an increased morbidity and mortality rate when suffering from PTB. Furthermore, studies have shown that there is an increased susceptibility to myco-bacterial infections.

Figure 1.6 Annual medical report on occupational diseases, Department of Minerals and Energy, (2005-2006).



	SUBMITTED												CERTIFIED											
	Total 2005	Total 2006	Diamonds 2005	Diamonds 2006	Gold 2005	Gold 2006	Platinum 2005	Platinum 2006	Coal 2005	Coal 2006	Others 2005	Others 2006	Total 2005	Total 2006	Diamonds 2005	Diamonds 2006	Gold 2005	Gold 2006	Platinum 2005	Platinum 2006	Coal 2005	Coal 2006	Others 2005	Others 2006
Pulmonary Tuberculosis	4015	3648	30	12	3442	3115	355	338	121	88	67	95	3039	2204	23	3	2705	2067	257	102	46	15	8	17
Silico-Tuberculosis	132	320	0		126	175		141	1	1	5	3	272	363			272	299		60	0			4
Silicosis	1031	1536	5		944	1450	45	74	2	2	35	10	207	452	0		201	450	5	2	0		1	
Obstructive Airways Disease	208	186	4	8	148	169	8	1	11	7	37	1	225	52	0	0	25	51	1		199	1		
Noise Induced Hearing Loss	2380	1875	66	3	911	705	1065	874	85	83	253	210	1763	1681	34	2	899	675	513	861	225	47	92	96

The attention of the reader is directed here to the Silico –Tuberculosis (maroon bar) statistics for the 2005 – 2006 periods in that the most cases are prevalent in the gold mining sector having 272 and 299 certified respectively.

From research done by Eva Hnizdo and Jill Murray, “Risk of pulmonary tuberculosis relative to silicosis and exposure to silica dust in South African gold miners” [23], it was concluded that exposure to silica dust is indeed a risk factor for the development of PTB in the absence of silicosis even after exposure to silica dust has ended. Of importance here is that the risk of PTB increases with the presence of silicosis. PTB was diagnosed on average about 7.6 years after the exposure to dust at approximately the age of 60. Radiological silicosis onset preceded the diagnosis of PTB in 90.2 % of the cases. The risk of PTB also increases significantly with the increasing severity of silicosis in a patient. Silicosis is a progressive disease and unfortunately only becomes known through radiology several years after exposure and even after exposure has ceased.

The prevalence of silicosis can also be confirmed at necropsy even though not diagnosed through radiological means. Silica dust that has found its way to the deepest parts of the lungs will remain there and the accumulation thereof even without the development of radiologically confirmed silicosis will remain a risk for the development of PTB and holds true long after exposure to silica dust has ended. It therefore goes without saying that workers that have had exposure to silica dust must maintain medical surveillance and particularly be on guard for the onset of PTB. This fact should be emphasized and brought to the attention of primary care workers in an attempt to further enhance the effectiveness of the ongoing battle against the proliferation of this disease. Where possible, the supply of prophylactic antituberculous treatment should be made available to such workers.

The association between PTB, dust and silicosis and in particular radiologically diagnosed silicosis brought researchers to the conclusion that with the presence of silicosis the risk of PTB is increased about 4 times (RR 3.96). The risk of contracting PTB also increases with the increased severity of silicosis. The unknown factor mentioned in the research is whether there is increased risk of PTB to subjects who is exposed to silica dust but does not have silicosis. Worth noting is that the risk of PTB is also increased when a person is exposed to dust and being a smoker at the same time.

The question as to why PTB is considered to be an increased risk in the presence of silica dust might be explained by the results and findings done *in vitro* and in animal experimentation where silica dust were seen to have detrimental effects on pulmonary macrophage.

The actual mechanism by which silica particles have an effect on the macrophage is entirely dependant on the dose relationship. The higher the dose, the higher the probability of mycobacterial infection. High doses of silica can cause destruction of pulmonary macrophage but in lower doses might still cause alteration and function which in turn increases the likelihood for effective antibacterial defense.

The presence of silica dust in lungs invariably also have the capacity to alter cell mediated immunity (24). There are two possible but debatable opinions as to how PTB susceptibility is made probable. One school of thought points to the possibility that the PTB bacilli could be encapsulated in the silicotic nodule and is reactivated some time later or secondly, that immunologically compromised individuals with silicosis might actually be predisposed to PTB infection.

Besides the risk of contracting PTB, there is also the increased risk of contracting scleroderma (systemic sclerosis) and Peripheral Thrombosis. In his research, Robert Cowie found that the incidence of scleroderma in the age group 33-57 was estimated to be 81.8 per million (25).
The approximate number of infected individuals in the general population with this disease normally is about 3.4 per million. In other studies the percentage of individuals diagnosed with silicosis and having scleroderma ranged from 13, 32, and as high as 42% but in this particular study, 6 out of 10 individuals were positively identified with the disease. The conclusion is that mere exposure to silica would constitute an increased risk of scleroderma. Autoimmune diseases as well as PTB are known to be more prevalent in subjects with silicosis. It is also mentioned that the

association of autoimmune diseases with PTB may cause the acceleration of silicosis [(26)]. Scleroderma is an occupation associated disease in individuals exposed to silica dust. In terms of peripheral thrombosis it is said the relationship with inflammation, leukocytes, the vasculature and the coagulation system, there is a confirmed interaction with each other. [(27)] The true mechanisms of these interactions are unfortunately not well understood. Results from this research indicated that silica particles induce lung inflammations and enhanced peripheral thrombosis.

Intratracheal instillation of silica particles in hamsters lead to significant dose dependant increases of macrophage and neutrophils numbers in the bronchoalveolar lavage (BAL) and subsequently cause the development of a prothrombotic tendency in recirculating blood. Worth noting is that through exposure (long term) to silica, extrathoracic structures such as the liver and spleen may also be affected adversely. Extrathoracic silicosis is usually associated with pulmonary silicosis and is believed to be metastatic by means of possible lymphatic spread.

The main phagocytes that mediate and bring about degradation of organisms in the lungs is alveolar macrophages. Not only does resident infiltrating macrophage bring about locomotion, phagocytosis and microbiocidal activities, it also secretes a variety of chemokines and cytokines that in turn is responsible for polymorhonuclearneutrophils (PMN) recruitment. Experimentation with the use of mice showed that lung macrophage depletion of liposome-encapsulated clodronate suspension (CL) as conducted by Koay and co-workers [(27)] causes selective depletion of pulmonary macrophage and also causes considerable inhibition of monocytes and PMN influx upon the administration of silica. This then serves to indicate the primary role for the macrophages in the PMN recruitment.

By using cyclophosphamine pre-treatment (CP) to deplete circulating PMN and monocytes, the role of lung macrophages could be further assessed. It was determined that CP did not affect the composition or the number of cells which includes macrophages in the bronchoalveolar lavage (BAL) of control hamsters, nor could any change be noted in the number of circulating platelets. Through the use of saline treated hamsters the degree of thrombosis was not affected by the use of CP. This serves to show that the acute thrombotic response during photochemical injury is quite independent of the interactions of leukocyte activation and platelet-leukocytes. The result obtained from these experiments agrees with similar studies in mice, hamsters and pigs done by other researchers.

With CP, the depletion of monocytes and neutrophils brought about a strong inhibition of the silica particle-dependant peripheral thrombosis. This proves that lung macrophage activation in the presence of silica, is a prerequisite to initiate peripheral thrombogenicity, however, simple macrophage activation is incapable to do so in the absence of more macrophage-mediated influx of monocytes as well as PMN in the lung. Together, these results indicate the primary role of lung macrophages in that it causes PMN influx in the lung and the important role of PMN itself, being responsible for additional monocytes infiltration. Through the depletion experimentation it was revealed that the macrophage- PMN interaction is an important element in the development of peripheral thrombotic action upon instillation of silica particulate.

Macrophage-neutrophil interaction can thus conclusively be regarded as critical for the formation of lung inflammation and that it subsequently leads to neutrophil elastase release into the systemic circulation. The priming of platelet activation that could be caused by neutrophil enzymes contribute to the onset of thrombotic tendencies, especially when these primed platelets come in contact with a mildly injured vessel wall.

1.6 Particle deposition and behavior

The main deposition mechanisms are gravitational settling (sedimentation), inertial impaction, diffusion, electrostatic attraction and interception. Also to be considered with particle deposition is the electrostatic charge of the particle. This characteristic is particularly useful when therapeutic aerosols are developed. However, this will not be considered in this report.

1.6.1 Gravitational settling *(sedimentation)*

Any dust particle has a settling velocity due to gravity and will accelerate according to Newton's Second Law. Obviously the larger and heavier the particle, the greater the settling velocity i.e. the settling velocity is directly proportional to the mass of the particle. The actual rate will largely depend upon the size, mass, shape and orientation of the particle as well as the air density.
The term sedimentation is used to describe the movement of an aerosol particle through a gaseous medium while under the influence of gravity. The following sketch depicts typical particle behavior when traveling in an airway. (28) The gaseous medium represented in this scenario is inhaled air.

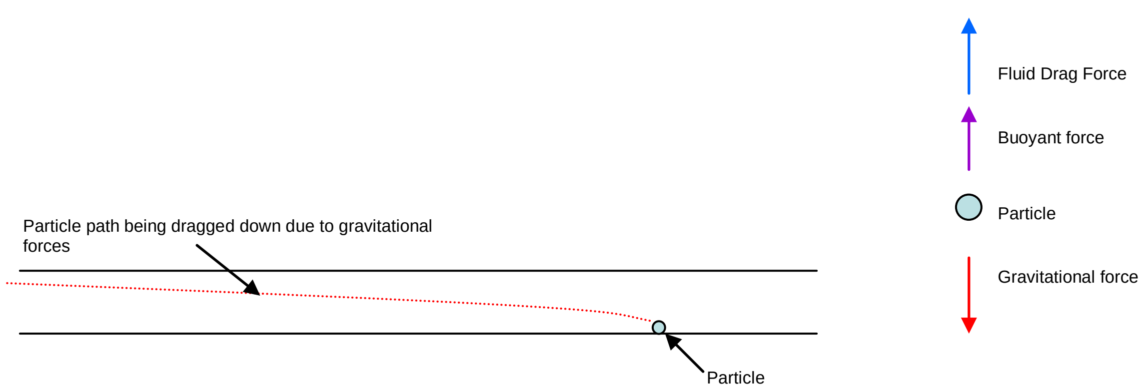


Figure 1.7 Illustration of sedimentation (Adapted from Schaper M)

This form of deposition is important especially in the distal region of the bronchial airways but is equally important in the pulmonary deposition role when breathing takes place through the mouth.

1.6.2 Impaction

Any body, object or particle has a tendency to want to travel in a straight line.

This tendency can also be described as inertial resistance to change in direction. With particles this is regarded as an important deposition mechanism. Newton’s First Law of Motion states that any particle, while traveling through a fluid will attempt to travel in a straight line unless it is been acted upon by an external force. When a particle is in motion within an aerosol and that aerosol is forced to change direction, inertia will attempt to force the particle in a straight line until such time as the momentum in that direction is bled off by fluid drag. However, if that particle should come into contact with a surface during this forced change of direction, chances are good that impaction will occur.

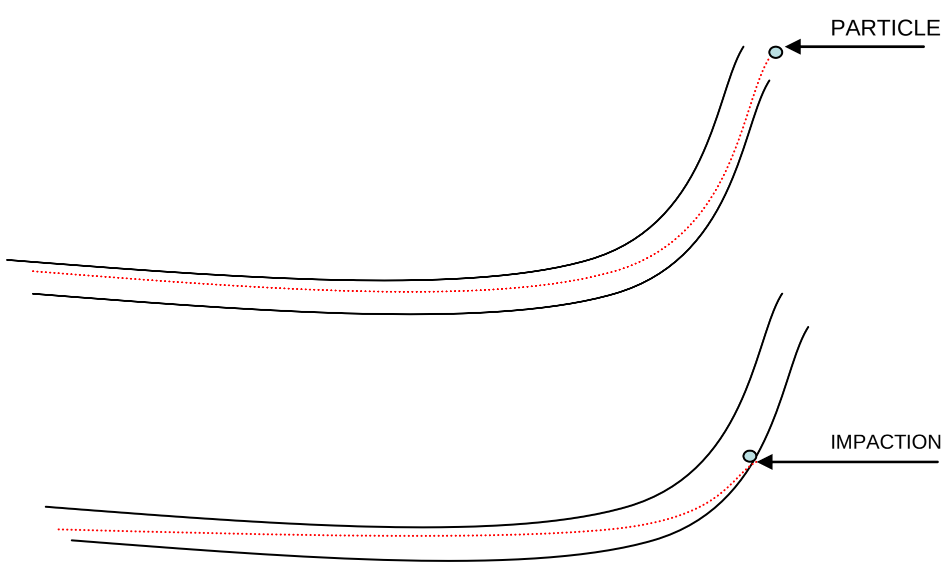


Figure 1.8 Illustration of Inertial impaction.

Obviously the sharper the bend and the more the mass and velocity of the particle, the more the likelihood of impaction.

1.6.3 Diffusion

Diffusion as a deposition mechanism can be described as particles suspended in a gaseous medium that is being bombarded by individual molecules that are in what is known as Brownian motion. Because of Brownian movement a certain measure of displacement will take place in a random fashion and this is known as diffusion. Simply put, the smaller the particles (diameter) and the higher the concentration differences, the more likely the possibility of diffusion taking place. Stokes-Einstein developed an equation for particle diffusivity but will not be elaborated upon in this paper.

Smaller particles as mentioned have larger diffusion coefficients mainly because of the fact that they have less inertial or aerodynamic resistance to the impact of gas molecules. This unique property can best be described in terms of aerodynamic or diffusive diameter and is particularly useful for particles < 0.5 µm with a physical density of approximately 1 μ/cm^3.

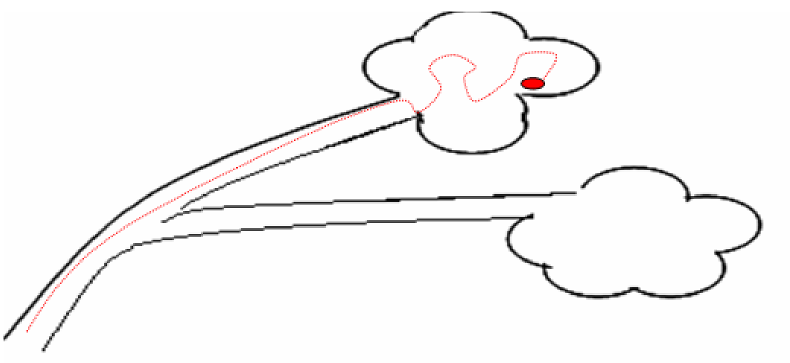


Figure 1.9 Brownian diffusion.

The influences of inertial properties and diffusional properties in lung deposition terms are deemed to be about equal.

1.6.4 *Interception*

This deposition type describes the incidental impaction of a particle with lining of the airway. However, this is one of the more unlikely scenarios for particle deposition and could be more applicable for fibers such as asbestos.

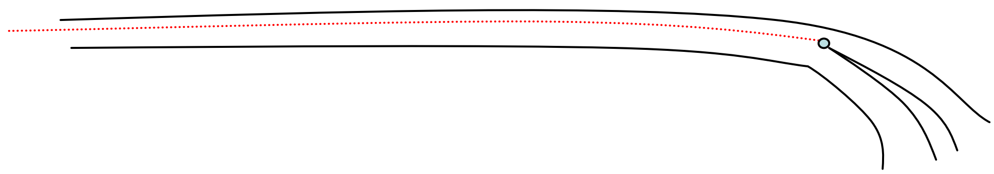


Figure 1.10 Illustration of Interception.

1.6.5 *Electrostatic attraction*

This method of deposition is thought to be of lesser importance but should it occur it would probable do so in the mouth and throat or even the tonsils that is naturally charged to do so. Airways in humans are covered by an electrolytic conductive liquid that probable inhibits powerful electric field buildup. It would then seem that charged particulate matter could be attracted primarily by image charging as they approached the wall of the airway or even by mutual repulsion from a unipolarly charged collection or concentration of particles. That said it is assumed that this form of deposition plays a small role.

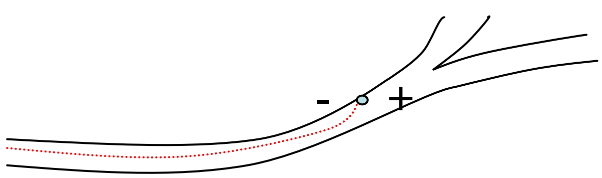


Fig 1.11 Electrostatic attraction.

The deposition of inhaled particulate matter and airborne liquid, sometimes also referred to as aerosols in any portion of the respiratory tract that would include the nasal –pharyngeal region as well as the oral pharynx, the tracheobroncial and pulmonary regions, will invariable lead to various types of biological responses and this could include irritation as well as injury. The actual outcome of the response depends largely on the nature of the inhaled particle. Other factors that plays a role in this outcome is clearance, resident time, deposition and deposition site as well as the eventual biochemical, cellular and tissue interaction that might occur. Also, as discussed previously, the actual deposition of the inhaled particle will depend of the aerodynamic properties of that particle, the anatomical features of the reparatory tract and the eventual deposition mechanism that will occur.

The three terms applicable in this section is deposition, clearance and retention. Deposition is basically means the inhalation of particles and the eventual resting place of that particle through whatever deposition mechanism. Clearance on the other hand refers to the translocation of a particle either to another organ or to the removal of particles out of the respiratory tract or from the body. Retention is the temporal distribution of uncleared particulate matter.

1.7 Particle retention relative to particle size

Larger, coarser particles of 10 µ or more will tend to be captured through impaction, gravity settlement and centrifugal precipitation at almost 100% by volume. However, particles smaller than 0.05 µ will almost always be exhaled completely due to the extremely low diffusion velocity. Particles of 0.05 µ sizes have up to 63% retention as determined by Morrow and associates. However, Dautrebande *el al* [(29)] also found that "alveolar air" is essentially void of any retained dust particles.

It should also be kept in mind that breathing through the mouth will have much lower retention values [(30)] compared to breathing through the nose due to the protective action of the nasal chamber.

Total retention respiratory curves drawn by Findeisen and Landahl [31] based on their calculations, serves to demonstrate consensus of several researchers in terms of predicted values. The particular sites where actual deposition occurs will not be expanded upon in this report but what will be discussed is what fractions of inhaled particles of varying sizes actually manage to penetrate and is retained in those pulmonary spaces where silicosis and other pneumoconiosis are known to develop. There are basically three factors to be considered when the aforementioned retention phenomena are analyzed;

a. The percentage removal of particles captured before entering the pulmonary lobules
b. The fractional quantity of tidal air reaching the pulmonary spaces
c. The ability of the pulmonary spaces to efficiently collect dust

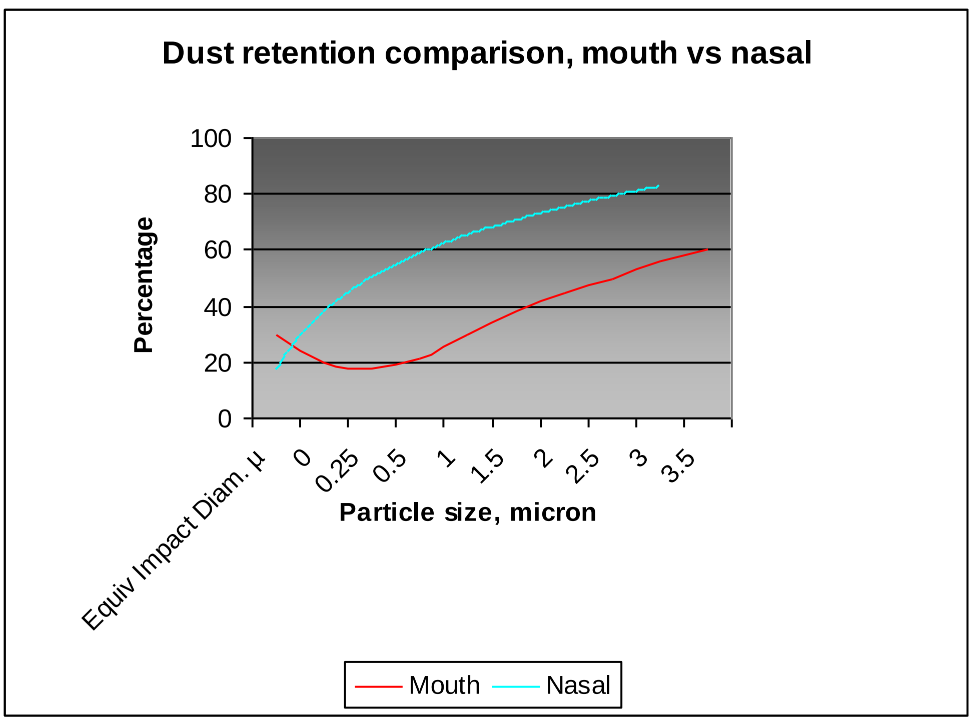


Figure 1.12 Dust retention comparison, mouth versus nasal breathing. [31]

By means of theoretical calculations Landahl concluded that the nasal chamber manages to capture 90% of particles of 10 μ but at 5 μ this efficiency drops to around 70% and at 1 μ, virtually nil. Watkins-Pitchford and Moir [32] reports that through research they concluded that particles of sizes larger than 3-4 μ have little bearing on the development of silicosis because they tend to be trapped before it reaches the pulmonary spaces. However, at sizes of 1-2 μ they found deposition exclusively in the pulmonary lobules.

1.8 Dust defined

In the late 1970's there was consensus that the multiple definitions that existed at that time for respirable dust was not acceptable seen in the light that an international agreement on the control of dust was called for and this task was given to ISO and CEN.[33] Some time afterwards it was decided that *inhalable dust* is that fraction of airborne particles that enter the nose and/or mouth during normal breathing whereas *thoracic* would be that fraction of inhalable particles that would be capable of reaching the larynx and *respirable* would be regarded as that fraction of inhaled particles capable of penetrating the alveolar region (gas exchange region) of lungs. These definitions were published in the European Standard EN 481 in 1993 and the International Standard IS 7708 of 1996.

The expression of the three forms of Particle Size-Selective TLVs are as follows:

I. **Inhalable Particulate Mass** TLVs (IPM-TLVs): Used to describe the particulate matter that are hazardous when deposited anywhere within the respiratory tract.

II. **Thoracic Particulate Mass** TLVs (TPM-TLVs): Used to describe the particulate matter that are hazardous when it is deposited anywhere within the lung airways and gas exchange region.

III. **Respirable Particulate Mass** TLVs (RPM-TLVs): Used to describe the particulate matter that is hazardous when deposited in the gas exchange region of the lung.

In terms of determining the potential hazard of chemical substances in inhaled air as particulate matter, one needs to consider the actual particulate size as well as the mass concentration because of the following reasons;

- The particulate size will determine the site of deposition as well as the subsequent effects,
- Depending on the site of deposition certain occupational diseases will interact with the particulate matter

The American Conference of Governmental Industrial Hygienists (ACGIH) recommended certain size –selective TLVs for crystalline silica for quite some time now due to the fact that they identified the apparent association between silicosis and respirable mass concentrations.
The ACGIH committee is currently examining other chemical substances that can occur in particulate form especially when encountered in the occupational working environments with the objective of defining:

- the health effect proportional to the size fraction
- the mass concentration within that size fraction expressed as the TLV.

The following graphs represents several sizes of particulate matter is association with mass fractions. [34]

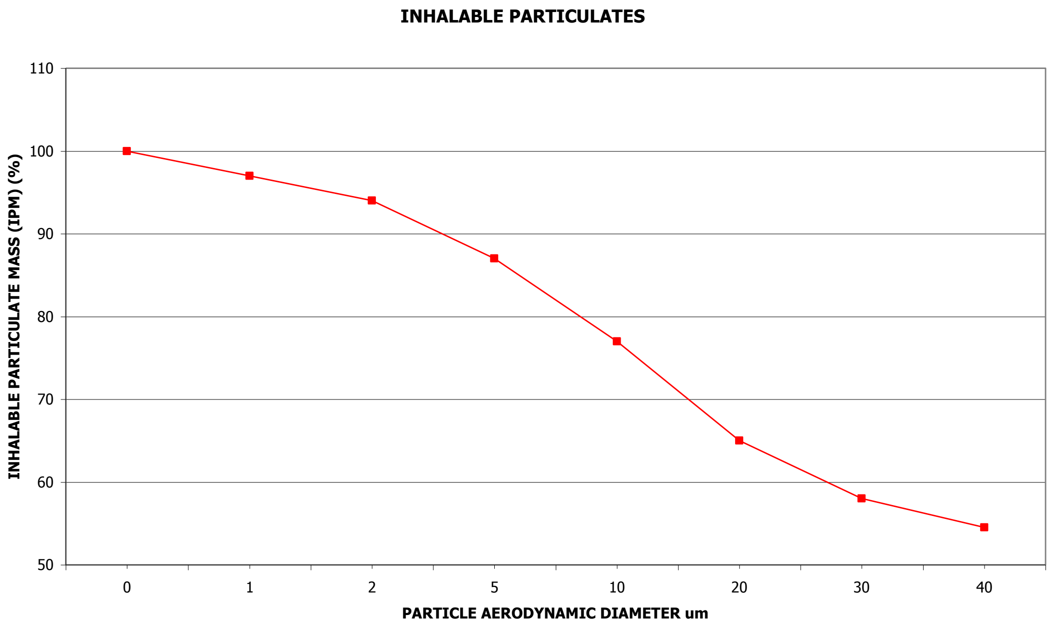


Figure 1.13 Particulate matter in micrometer compared to that fraction capable of entering the nose and/or throat.

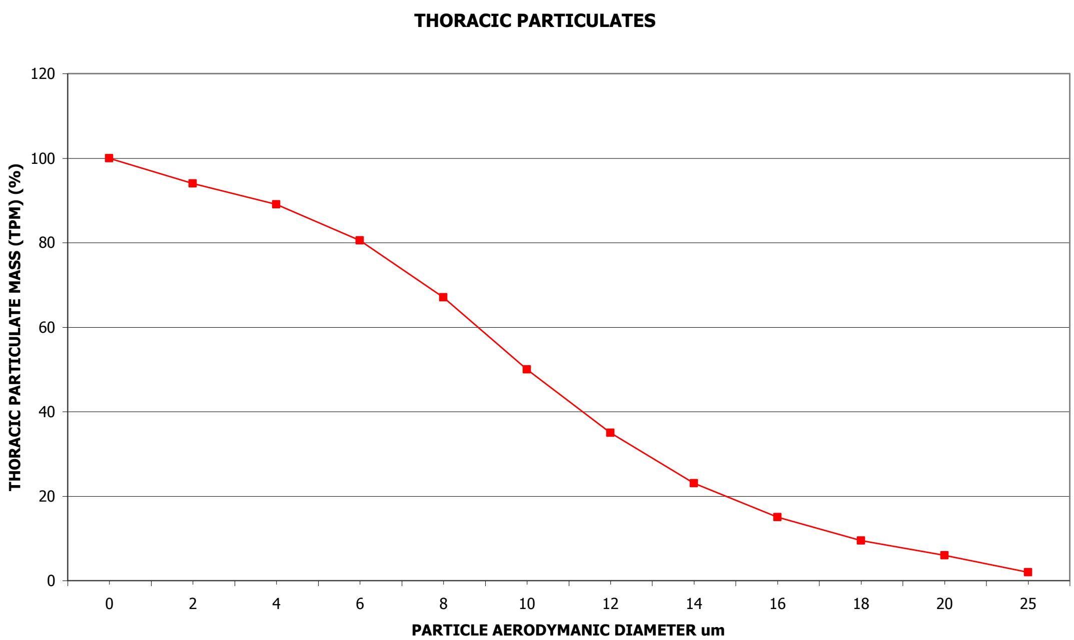


Figure 1.14 Particulate matter in micrometer compared to that fraction of inhalable particles that would be capable of reaching the larynx.

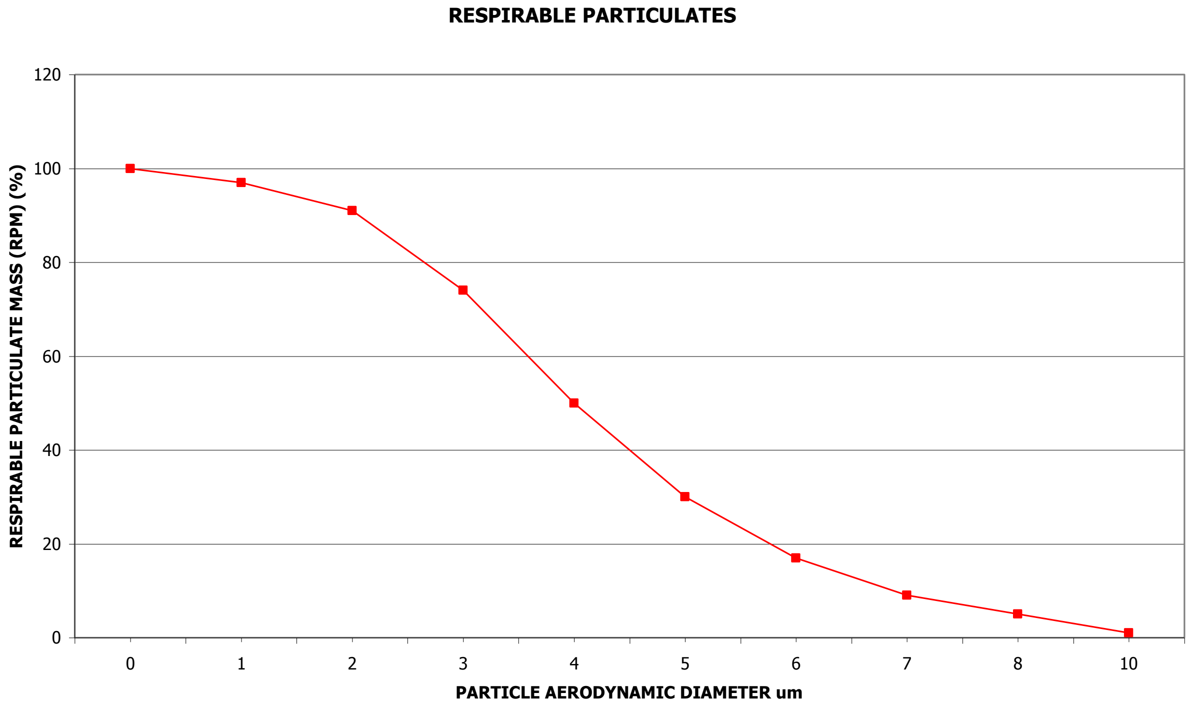


Figure1.15 Particulate matter in micrometer compared that fraction of inhaled particles capable of penetrating the alveolar region (gas exchange region) of lungs.

1.9 <u>The structure of the airways and lungs</u>

A brief discussion on the respiratory structure will touch on the upper airways, primary airways, alveolar region as well as a phenomenon known as clearance. [35] The intention here is the realization of how delicate the respiratory system really is and thus perhaps endorses the fact that care should be taken to maintain the health thereof as best one can. The diseases this organ attains through exposure to dust and in particular quartz is irreversible, further emphasizing the importance of preventative measures pertaining to dust exposure.

The nasopharynx as part of the upper airways plays an important role in humidifying inhaled air as well as in clearing particles together with any reactive substances that may be contained in those gasses. As the turbulent gas flow, brought about by the nasal turbinates, reach the right-angle turn of the posterior pharynx, most of the larger sized particles are removed by means of impaction. From there, the air flow path next enters the trachea.

The nasopharynx plays a vital role in virtually removing almost all of the very highly soluble or reactive gases. Also, situated at the posterior pharynx is lymphoid tissue that processes the incoming gasses and serves a critical role as part of the immune system at the border region of the internal body and that of the external environment.

The trachea as part of the primary airway is about 25 cm long in an adult with a diameter of approximately 2.5 cm. There is between 15 and 20 horseshoe-shaped cartilaginous rings that serve to reinforce this airway and prevent it from collapsing when a considerable negative pressure is brought about during the inhalation phase of the lung.

There is a membranous portion of the cartilaginous rings situated at the posterior portion of the trachea that contains the trachealis muscle. On the way towards the lungs the trachea now splits into two main-stem bronchi where after there is a rapid division into smaller airways in an irregular dictomous pattern into increasingly and progressively smaller bronchi.

The cartilaginous support previously mentioned is continuously found in a supporting role until the bronchioles are reached. The medium sized bronchi are believed to be the significant site of bronchoconstriction. However, the closer to the bronchioles, the lesser the smooth muscle until the virtual absence thereof at the terminal bronchioles.

The shortest pathways from the trachea to the terminal bronchioles consist of about seven divisions with an approximate length of between 7 – 8 cm. The longer pathways in contrast consist of about 25 divisions with an approximate length of 22 cm. As the smaller pathways are reached and due to the numerous divisions, the sum total cross-sectional area is actually increased causing the airflow velocity to decrease and causing the flow to become less turbulent and thus more laminar.

The terminal bronchioles are about 250 µm in internal diameter and are void of smooth muscle. The airways make up about 10 % of the lung substance but about 25% of the lung cells. What makes the lung so unique is that about 40 different cells are found in its makeup and nearly every class of tissue. The most common type of cell in the lung is capillary endothelial. The lung consists of three lobes on the right and two on the left. The right lobes consist of ten segments while the left only eight. The smallest unit of the lung is the lobule and is separated by fibrous septa. This lobule is about 2 cm in size and within this lobule there are approximately 4 – 8 terminal bronchioles.

The alveolar region is best described as a branching system of alveolar ducts of which the walls consist of alveoli. The human lung consist of about 500 million alveoli, each being spherical in shape and approximately 225 µm in diameter. Gas exchange takes place across the alveolar walls. The capillary blood is separated by a 0.5 µm thin and very fine tissue. For an oxygen molecule to penetrate the alveolar wall it must first of all traverse a highly attenuated epithelial cell, then a basement membrane together with a highly attenuated endothelial cell that forms the constituents of the tissue barrier. Now in the capillary, it must cross the plasma and finally penetrate the red cell where it will bind to hemoglobin. At any one time there is about 200 ml of blood in the lung.

Clearing of fluids in the lung and the pleural space is done by an extensive system of lymphatic's. However, should the permeability barrier created by the pulmonary capillary walls get affected by disease, it will lead to pulmonary lymphatic drainage disturbance or alternatively increase the pulmonary hydrostatic pressure the ultimately leads to a rapid accumulation of pleural effusions and in severe cases cause alveolar flooding. The method of clearance of inhaled particles is nothing short of miraculous. About 99% of all inhaled particles are exhaled. This is done primarily in the nasopharynx and larger airways. Those particles trapped through impaction are cleared by means of the epithelial mucociliary escalator. The epithelial cells being covered in a mucous coat in the airways becomes increasingly thicker as it moves upwards and proximally by ciliated cells when this mucous substance reaches the posterior pharynx it is normally swallowed and can amount to about 1 liter per day. The unfortunate ability of particles less than 10 µm to reach the alveolar region is the main cause for concern particularly when that particle consists of quartz.

In each alveoli there are usually about 12 macrophages. They are free moving cells on the alveolar surface and their primary task is to process inhaled particles, bacteria and even viruses by means of phagocytosis. The aim is to do so without causing a stimulated or amplified immune response. It is likely that disorders in these immune regulatory pathways may be the cause of hyper immune or inflammatory lung diseases.

Inhalation of 10 µm or less sized particles is of most concern as the primary sites of lung injury are the small airways as well as the most proximal portions of the alveolar gas-exchange region. Keeping in mind that the smallest particle that can be seen by the naked eye is about 50 µm, one can imagine how much small and dangerous particles are present when dust is seen in the underground environment.

Clearance from the human respiratory tract depends on several factors such as chemical composition of the particle, the actual site of deposition, macrochemical form, particulate size as well as the mucociliary transport situated in the tracheobroncial tree and includes macrophage phagocytosis and numerous other cellular interactions situated in the deepest regions of the lung. [36]

Studies conducted by King, Naglesschmidt and associates[37] revealed that quartz clearance on rats showed an irregular exponential removal pattern. Results showed an initial rapid removal within 2-3 months with no real drop over the remainder of the year. 50% of the original deposited lung burden was found to have been cleared. The clearance in humans in terms of silica dust on the other hand cannot be related to that of rats. The assumption is being made that clearance is exponential and that the day-today retention value of say 30% can be extrapolated to a half life residual lung storage value of 5%. As an example say the dust concentration amounts to 1 mg/m^3 , the total amount of dust from 10 m^3 of air deposited in the lungs will be equal to 3mg and the remaining 7mg will subsequently be exhaled almost immediately or cleared within a couple of days from the upper respiratory tract. Taking the assumption further in that should we regard 5% (or 3500mg) of lung storage in a typical silicotic lung to represent the potential equilibrium level of this lung, it would equate to a clearance period of 38 months which is obviously very slow. In turn this would mean that the lung would reach equilibrium status after about 15 years.

The following figure (1.16) is quite interesting as it serves to show the fate of particles in the lungs as described by Theodore Hatch. [30]

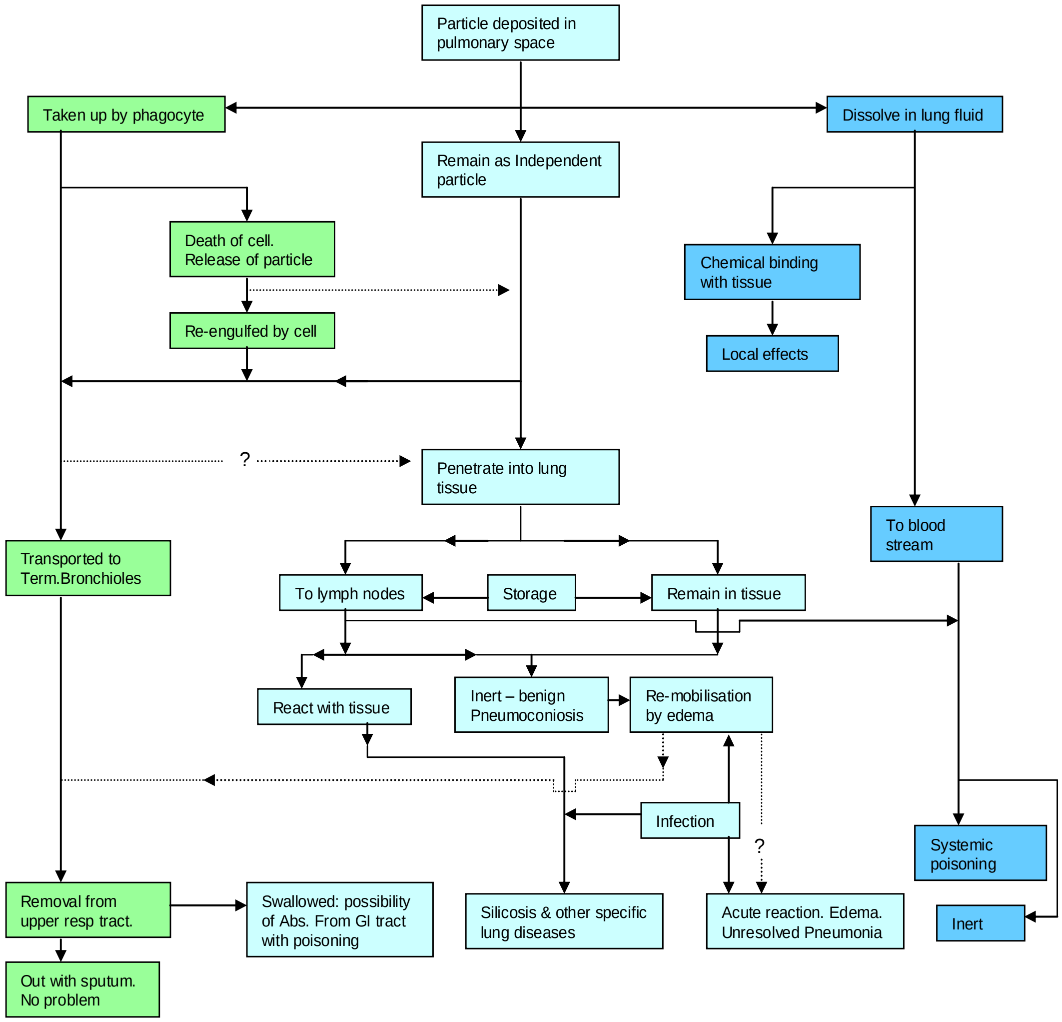


Figure 1.16 Adapted from Theodore Hatch [30] showing the fate of particles in lungs.

1.10 <u>Human body defense mechanism</u>

The human body has to its benefit certain defense mechanisms to prevent harmful particles to cause damage to lungs but unfortunately it is not perfect. Particulate matter that is deposited anywhere in the respiratory tract will most probably be removed by the tracheobroncial ciliary escalator in a continued upward movement towards the throat where it is usually swallowed or expectorated. Of particular note should be the warning that this epithelial mucociliary escalator is paralyzed for a considerable length of time (approx 10 minutes at a time) each time a cigarette is smoked with eventual total destruction of the cilia after approximately 20 years of smoking (depends on the frequency/quantity of cigarettes smoked/day) The inability of this natural removal of particulate matter in association with the toxic properties nicotine might then expedite the onset of illnesses such as emphysema.

The pathogenic effect that dust has on the lungs is directly attributable to the retention times involved. [(34)] The inability of lung scavenger cells as well as alveolar macrophages to rapidly clear intrusive toxic or even non toxic particulates may result in the migration of that particulate from the lung epithelium to the interstitium. At this site there is the distinct possibility of causing inflammation and in some cases may lead to fibrosis. In severe cases this might even lead to cancer. Particulate matter such as silica that ends up in the interstitium and causes irritation has been found to alter the bloods ability to coagulate and also initiate heart failure. The irritation caused by deposition of dust and in particular silica particulate in the alveolar region results in fibrogenic tissue formation. In turn this causes irreversible damage in terms of the elasticity of the lung as well as reduced capacity for oxygen absorption.

Particulates not cleared by the tracheobroncial ciliary escalator (also sometimes referred to as a mucus blanket) may also be absorbed and cleared by the lymphatic system that is then ultimately transferred to the blood. A particle that enters the pulmonary region is usually engulfed by phagocytic cells and through this process will discourage their entry into lung tissue. Particles that are thus phagocytosed are unable to participate in pneumonoconiotic activities. It therefore becomes obvious that phagocytosis can thus be regarded as an excellent defense mechanism as it encourages the removal of said particles from the lung by way of the ciliated airways. Phagocytosis may be stimulated more by one type of substance than compared to another and thus have a direct reflection on the rate of clearance. The actual manner in which the mentioned particulate matter is cleared will largely depend on the physicochemical characteristics of the particulates, the respiratory physiology and of course the site of deposition. Inert and insoluble particulate matter of microscopic size is of most concern as they are tenaciously retained in the pulmonary region of lungs. On the other hand one finds that soluble particles that are usually trapped in the nasal turbinates may be absorbed into the blood stream. The accumulation of dust in the lungs depends largely on clearance and deposition. [(28)] The actual nature of the dust combined with the amount and duration of accumulation will determine the biological response of the dust. Silica dust for instance tends to become entangled due to the very fibrous nature engendered to it. Some dust particles are capable of biological activity. The silica dust particle can be described as a potent biological active and cytotoxic particle, known for its ability to cause macrophage injury. Being cytotoxic it is characterized by the fact that quartz elicits the simultaneous release of lysomal and cytoplasmic enzymes. A coal dust particle on the other hand appears to be relatively inert and requires a considerable amount to be present for a rather minimal response by the native tissue. The cumulative lung dust burden relates to the severity of the lung tissue response. This holds true for basically any dust exposure. Typical responses to exposure of silica are nodular fibrosis a.k.a. silicotic islets.

Upon contact with body tissue certain airborne particles will initiate toxic effects.
The quantity of the physiologically active toxicant otherwise known as the dose, when coming into contact with the tissue will depend on the aerosol's physical properties i.e. the size of the particle, the shape, density as well as the hygroscopicity. These properties will also determine the behavior of the particle while being airborne and how easily it will be inhaled and subsequently be deposited in the respiratory tract. These properties will therefore also determine how it will interact with the tissue it comes into contact with.

Previous studies done by Robert L.Cowie alluded to the fact that the cumulative risk of developing silicosis compared to cumulative exposure to respirable silica dust lagged by approximately 5 years in terms of hard rock miners. The risk of silicosis is strongly dose dependant [(11)] and increases exponentially with cumulative dust dose. Eva Hnizdo et al, found that the highest exposure levels of 15 mg/m^3 – years which on average is comparable to a 37 year underground mining career with exposure to respirable dust in concentrations of 0.4 mg/m^3 the cumulative risk for contracting silicosis is 77%. Of particular interest is that she determined that in 57% of persons diagnosed radiologically with signs of silicosis the latency period was about 7.4 years after their mining exposure had ceased.

Research done by Theodore Hatch[(30)] suggest that only a small portion, about 5% of the total amount of mineral dust inhaled is retained in the lungs. This suggests that the retained dust possible possesses some rather special characteristics. The remainder is usually exhaled from breath to breath within a relatively short period of time. Some will be removed at a slower pace through the normal tracheobroncial ciliary escalator action.

The actual dose can therefore be regarded as a very important factor in determining the clinicopahological type of silicosis diagnosed in the exposed person. The first being what is commonly referred to as *chronic silicosis*. The onset of chronic silicosis may entail clinical diagnoses measured in decades rather than years after exposure and may thus be associated to respirable dust with typically containing quartz measured to be less than 30% by content. *Accelerated silicosis* will by implication be likely to occur after much shorter albeit more intense exposure, usually 3 – 10 years of exposure. *Acute silicosis* (silicoproteinosis) may result when a person is intensely exposed to very high levels of silica with associated high (pure silica such as that used in sand blasting) silica content. The most likely form of silicosis in the mining industry is *chronic silicosis* and is identifiable radiologically by identification of the typical silicotic nodule and is one of the few agent-specific lesions in terms of pathology.

Silicotic nodules initially develop in the hilar lymph nodes and may remain confined in this particular area. These nodules become encased through calcification and may impinge or even erode into the airways. The next step will involve the lung parenchyma, usually located bilateral and involving mainly the upper zones where the appearance is grayish black, palpable and discreet. Nodules of similar appearance and type may also be found in the lymphatic drainage channels of the lung, more particularly the perivascular sheath. With accelerated silicosis the occurrence is notably more cellular than fibrotic but interstitial pulmonary fibrosis may also develop. Chronic and accelerated silicosis share commonness in that with natural progression of the disease the nodules may become confluent which in turn may develop into progressive massive fibrosis (PMF). These lesions typically 1cm in diameter or even larger can obliterate the lung structure and in some cases even lead to cavitations i.e. holes in the lung.

Acute silicosis on the other hand has all the features of pulmonary alveolar proteinosis.
Persons so exposed may show virtually the same signs as that of chronic bronchitis and emphysema. Abnormalities typically may include fibrosis and pigmentation of respiratory bronchioles. Also particular to acute silicosis is the development of nodules in the cervical and abdominal lymph nodes and also, but less frequently, in the liver, spleen and even in the bone marrow.
For clarification purposes, figure 1.7 illustrates the respiratory system in detail [38] starting at the nasopharynx down to the alveoli.

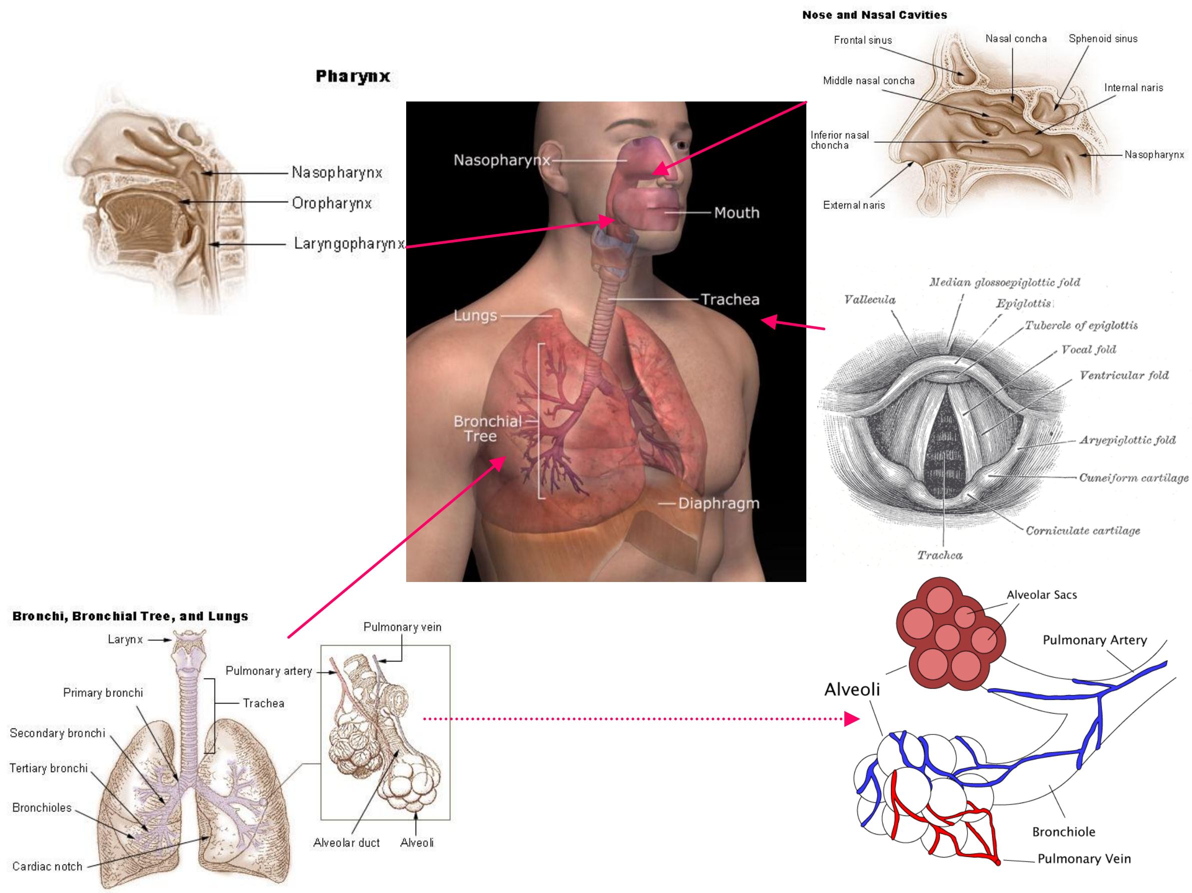


Fig 1.17 The respiratory system.

1.11 Objectives

To measure the respirable dust and quartz exposure of Rock Drill Operators in two typical gold mines in the Free State province of South Africa in 2007.

There is a paucity of published data on respirable dust and quartz exposure of underground gold miners in South Africa and rock drill operators in particular. Because of the serious diseases associated with silica exposure and the fine dust generated in drilling rock, rock drill operators are an important group in whom to quantify exposure. Hence this project on rock drills operators.

Chapter 2 Methods

This chapter will describe the methodology used starting with the type of study that was done, the population selection , sampling strategy, measuring methods and the manner in which the data was captured.

2.1 Study Design

The study is a descriptive, cross sectional, rapid assessment study that is based on the findings of gravimetric sampling results taken at rock drill operators working underground on two different gold mines in the Free State.

2.2 Study work place & population

The working places used for this study were stopes. A stope is where the actual gold bearing ore is found in what is known as the reef. The extraction is done by means of drilling a hole with a percussion compressed air driven drill, charged up with explosives and blasted. Removal of broken ore is done by using scrapers. These activities all generate dust.

As mentioned earlier, two mines have given their permission to have this study done on their premises. On President Steyn Gold Mine, there are 614 rock drill operators and on Beatrix Gold Mine, 1328. There are three different mining houses in the Free State but only two were used in this study for practical reasons.

2.3 Sampling strategy

According to the NIOSH sample size selection method (appendix 2) and aiming for the top 10% with 95% confidence level, the minimum sample size should be 29. (This means that at least one of the top 10% of exposed workers will be sampled). For this study however, 30 rock drill operators will be sampled per mine.

There are different options available to randomly select numbers. One of these is the Random Number Table as recently published in the Mine Health and Safety Council's "Handbook on Mine Occupational Hygiene Measurements" [39] and works fine but for this research report however, the rock drill operators was selected using the "Excel" program's random selection function and was paraded and told about the study and invited to participate in the study as well as requested to read and sign the consent form. Both mines only have one drilling cycle and that is during the morning shift. Seeing that only 30 samples were required at each mine, different rock drill operators was sampled (i.e. not one person was sampled twice).

Each rock drill operator was required to wear the gravimetric pump for the entire duration of his shift. At the end of the shift, the employee that wore the gravimetric pump handed it in at the lamp room where it was collected and taken to the Air Quality Analyst laboratory.
The researcher accompanied the sampler and monitored the way in which the instrument was treated and transported.

Labeling: All the air sample filter cassettes were pre-labeled with an indelible marker on a sticky label. The label itself was given a unique number that started with a symbol depicting the particular person i.e. R, for **r**ock drill operator.

Storage: Filters was stored in Millipore filter holders until such time as they were analyzed.

Strategy: Everything possible, meaning lengthy explanations, was done to ensure that the person being sampled performed his work normally i.e. they were requested to perform their normal tasks and ignore the fact that they were being observed.

2.4 <u>Measurement methods: - Gravimetric sampling</u>

All mines in the Free State use Gillair pumps and are calibrated before use with a rotameter (as well as afterwards to ensure accuracy).

Use of the Platon Rotameter Calibrator will be done only with the assurance that in itself it has been calibrated against a primary standard (annually) and having a certificate as proof.

The rotameter calibrator is checked once a month against a bubble meter calibrator for confirmation of calibration accuracy, and is regarded as a secondary standard check.

The dust samples were collected on 25 mm 5.0 micrometer pore size PVC, silicon-free filters, in a SKC cyclone sampling at a flow rate of 2.2 l/min. The samplers were calibrated prior to issue by a Platon Rotameter calibrator, an airflow-measuring device that is traceable to a primary standard. Filters were weighed before and after sampling according to the NIOSH method ID 142.

Each sample, after being processed and weighed at the mine laboratory, was then taken to the National Institute of Occupational Hygiene (NIOH) in Johannesburg for quartz analysis. Transportation of these samples was done using personal transport in an effort to further assure adherence to the intended quality control.

Frequent visits to the facility and more especially, the XRD laboratory have confirmed that they participate in a comprehensive quality assurance programme.

The method of preparing and using the sampler is as follows: (from NIOSH Pocket Guide to Chemical Hazards)

Samples were pre- and post-weighed on a scale by the Air Quality Analyst (AQA) at the mines gravimetric laboratory. The net sample weight provides additional information to the Air Quality Analyst as well as the analytical laboratory. The amount of respirable dust was determined for the sample.

For samples weighed by the Air Quality Analyst:

1. Desiccate and then weigh the PVC filter before sampling.

2. Place the PVC filter and a cellulose backup pad in a two- or three-piece cassette.

3. Attach the cassette, which is preceded by a 10-mm nylon cyclone, to a calibrated personal sampling pump using flexible tubing.

4. Place the sampling assembly in the breathing zone of the worker or sampling area and place the pump in an appropriate position. Pass 1056 L of air through the cassette at approximately 2.2 L/min. Do not allow the cyclone to be inverted during or after sampling.

5. Check the pump and sampling assembly periodically to verify performance and to monitor particulate loading on the sample filter. If the filter becomes overloaded (>3 mg) during the sampling interval, replace it with another filter.

6. Terminate sampling at the predetermined time and record the pump flow rate and collection time. Carefully remove the filter, desiccate, and then weigh to determine the net weight gain. Carefully replace the filter and firmly seal the cassette by placing plastic plugs in both the inlet and outlet ports.

7. Record on the sample information form all pertinent sample data. Also indicated on the form was the request for analysis for quartz.

8. Identify and submit an appropriate blank filter from each lot of filters used.

9. Seal each filter cassette and identify it with the information form mentioned in 7. Transport samples to the laboratory in a suitable container designed to prevent damage.

As mentioned previously, alpha quartz analysis was done at NIOH using X-Ray diffraction.

The membrane was scanned by XRD giving a series of diffraction peaks (lines) occurring at different angles relative to the sample and X-ray source. The X-ray technique is based on the Bragg equation: $n\lambda = 2d \sin\theta$

2.5 <u>Data analysis</u>

The data were entered on standard occupational hygiene sampling sheets (appendix 1) from where it was entered onto an Excel spreadsheet. The results were shown using simple graphs, generated by the Excel program.

Data analysis was done using means, standard deviation and “box and whisker” plots.

Air Quality Index (AQI) Calculation

The following table (taken from SAMOHP codebook) show how the calculation is done for Time Weighted Average (TWA) as well as how to calculate the Air Quality Index (AQI)

Table 2.1 Calculation of results/particulate concentrations

Calculation of results/particulate concentrations		
	Steps	***Example***
1	**Note the average flow rate and sample time**	
	Obtain the calibrated pump flow rate Determine the total sample time Convert total sample time to minutes	2,2 Liters per minute 8 Hours 20 minutes ∴ Minutes = (8 x 60) + 20 **= 500 minutes**
2	Determine the sample volume	
	Results must be expressed in mg/m^3 ∴ Volume of air through the sample pump = Flow rate x time Convert liters to m^3 (1000 liters of air = 1 m^3)	Volume = Flow Rate (l/min) x time (minutes) = 2.2 x 500 **= 1100 liters of air** = 1100 ÷ 1000 **= 1.1 m^3** sucked through pump
3	**Determine the correction filter mass (correction factor)**	
	Determine the average of pre and post weighed control filters by: • weighing pre weighed control filters three times consecutively when weighing sample filters, and • weighing post weighed control filters three times consecutively when weighing exposed sample filters - add together and divide by 3 If weighed in gram multiply by 1000 to convert to milligram	Post filter mass: 20,16 mg; 20,18 mg; 20,17 mg; = 60.51 ÷ 3 **= 20,17 mg** Pre filter mass: 20,10 mg; 20,11 mg; 20,09 mg; = 60,30 ÷ 3 **= 20,10 mg**
	Subtract the pre weighed blank filter mass from the post weighed blank filter mass.	Correction factor = Post filter mass - Pre filter mass = 20,17 - 20,10 = **0.07 mg** Heavier, picked up moisture
	If this is + **subtract** as a correction factor. If this is – **add** as a correction factor.	As this is positive subtract it from the sample filter mass.
4	**Determine the sample mass**	
	Subtract the pre weighed sample filter mass from the post weighed sample filter mass. Also weighed in the manner described in step 3	Post weight sample mass - Pre weight sample mass 20,78 - 20,66 **= 0.12 mg**

5	**Determine the corrected sample mass**	
	Subtract the correction factor from the sample mass (point 4 – 3) Add if mass loss occur	Corrected sample mass = Sample mass - Correction factor = 0,12 mg - 0,07 mg **= 0,05 mg**
6	**Determine the concentration**	
	Divide the corrected sample mass by the volume of air sampled.	Concentration = mass ÷ volume (mg/m^3) = 0.05 ÷ 1.1 **= 0,045 mg/m^3**
7	**Determine the TWA dust concentration as applicable**	
	Multiply the concentration with a time correction factor to obtain the E8hEV	TWA = concentration x (total sample time in minutes ÷ 480)
	Time correction factor = actual sample time in minutes ÷ 480	= 0,045 mg/m^3 x (500 ÷ 480) = **0,047 mg/m^3**
	Therefore: Airborne dust concentration in the working area = dust (in mg) for each cubic meter (m^3) of air.	

TWA = TWA dust concentration x **Quartz %**

AQI = TWA / OEL (0.1)

Chapter 3 Results

This chapter reveals the results from the gravimetric sampling taken on the two mines at Rock Drill Operators working in stopes. The results have been tabulated according to the corresponding sample number. Samples results with values below the detectable range of the X-Ray diffraction analysis instrument is indicated as such but has been left out in the graphs that follow thereupon. Box and whisker graphs are used to clearly show the difference between the two mines.

3.1 Tabulated Results

The following two tables represents the values & results of the Gravimetric samples taken at two mines selected as previously mentioned.

Table 3.1 Respirable dust and quartz concentrations and Air Quality Index for Rock Drill Operators on Mine 1.

Mine1

Sample No.	Result (microgram ug)	Mass of respirable dust (milligram, mg)	Total mass (mg)	%Quartz	Pollutant Conc.	TWA (mg/m3)	Air Quality Index
BXR5	20	0.019	0.267	7.154	0.254	0.018	0.18
BXR 6	178	0.17	1.056	16.098	1.005	0.162	1.62
BXR7	100	0.096	0.457	20.897	0.435	0.091	0.91
BXR 7	393	0.375	1.279	29.344	1.217	0.357	3.57
BXR 8	150	0.143	0.58	24.698	0.553	0.137	1.37
BXR 9	85	0.081	0.633	12.824	0.603	0.077	0.77
BXR 14	295	0.282	0.568	49.599	0.539	0.267	2.67
BXR 15	190	0.181	0.918	19.766	0.871	0.172	1.72
BXR 17	61	0.058	0.218	26.722	0.207	0.055	0.55
BXR 18	74	0.071	0.348	20.307	0.331	0.067	0.67
BXR 19	156	0.149	0.714	20.866	0.679	0.142	1.42
BXR22	505	0.482	0.841	57.345	0.799	0.458	4.58
BXR24	167	0.159	0.401	39.772	0.382	0.152	1.52
BXR27	444	0.424	3.057	13.87	2.902	0.403	4.03
BXR28	141	0.135	0.923	14.589	0.877	0.128	1.28
BXR29	79	0.075	0.3	25.148	0.285	0.072	0.72
BXR32	348	0.332	1.449	22.936	1.38	0.317	3.17
BXR33	69	0.066	0.349	18.881	0.331	0.062	0.62
BXR34	81	0.077	0.176	43.952	0.167	0.073	0.73
BXR35	59	0.056	0.282	19.98	0.267	0.053	0.53
BXR45	29	0.028	0.072	38.465	0.069	0.027	0.27
BXR46	39	0.037	0.272	13.693	0.258	0.035	0.35
BXR47	62	0.059	0.341	17.364	0.324	0.056	0.56
BXR55	<19	Below detectable limit		Below detectable limit	0		Below detectable limit
BXR50	258	0.246	1.732	14.226	1.648	0.234	2.34
BXR51	49	0.047	0.32	14.623	0.304	0.044	0.44
BXR52	260	0.248	0.39	63.667	0.372	0.237	2.37
BXR53	97	0.093	0.626	14.798	0.596	0.088	0.88
BXR54	236	0.225	0.339	66.484	0.323	0.215	2.15
BXR56	109	0.104	0.987	10.547	0.935	0.099	0.99
BXR57	104	0.099	2.003	4.959	1.899	0.094	0.94

Table 3.2 Respirable dust and quartz concentrations and Air Quality Index for Rock Drill Operators on Mine 2.

Mine 2

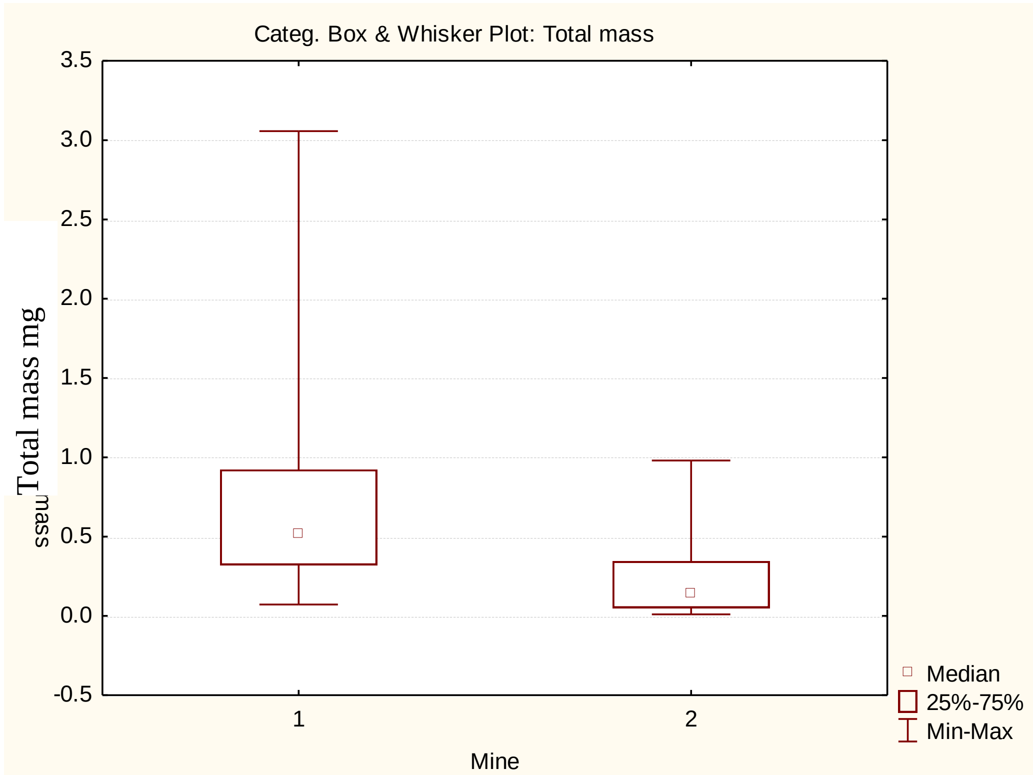
Sample No.	Result (microgram ug)	Mass of respirable dust (milligram, mg)	Total mass (mg)	%Quartz	Pollutant Conc.	TWA (mg/m3)	Air Quality Index (AQI)
SRD1	135	0.129	0.37	34.845	0.347	0.121	1.21
SRD2	50	0.048	0.23	20.761	0.215	0.045	0.45
SRD3	64	0.061	0.43	14.214	0.404	0.057	0.57
SRD4	77	0.074	0.9	8.171	0.849	0.069	0.69
SRD5	77	0.074	0.09	81.706	0.082	0.067	0.67
SRD6	41	0.039	0.33	11.865	0.309	0.037	0.37
SRD7	74	0.071	0.09	78.522	0.088	0.069	0.69
SRD8	82	0.078	0.17	46.065	0.158	0.073	0.73
SRD9	<19	Below detectable limit		Below detectable limit	0.347		Below detectable limit
SRD10	96	0.092	0.34	26.965	0.319	0.086	0.86
SRD11	103	0.098	0.16	61.478	0.148	0.091	0.91
SRD12	<19	Below detectable limit	0.02	Below detectable limit	0.016		Below detectable limit
SRD13	30	0.029	0.05	57.3	0.044	0.025	0.25
SRD14	44	0.042	0.37	11.357	0.347	0.039	0.39
SRD15	<19	Below detectable limit	0.01	Below detectable limit	0.006		Below detectable limit
SRD16	97	0.093	0.98	9.453	0.93	0.088	0.88
SRD17	164	0.157	0.25	62.648	0.24	0.150	1.5
SRD18	47	0.045	0.38	11.812	0.363	0.043	0.43
SRD19	35	0.033	0.35	9.55	0.335	0.032	0.32
SRD20	<19	Below detectable limit	0.32	Below detectable limit	0.306		Below detectable limit
SRD22	21	0.02	0.03	66.85	0.032	0.021	0.21
SRD23	95	0.091	0.02	453.625	0.022	0.100	1
SRD24	20	0.019	0.05	38.2	0.05	0.019	0.19
SRD25	21	0.02	0.1	20.055	0.097	0.019	0.19
SRD27	37	0.035	0.03	117.783	0.032	0.037	0.37
SRD26	41	0.039	0.04	97.888	0.041	0.040	0.4
SRD28	<19	Below detectable limit	0.06	Below detectable limit	0.06		Below detectable limit
SRD29	<19	Below detectable limit	0.12	Below detectable limit	0.117		Below detectable limit
SRD30	<19	Below detectable limit	0.07	Below detectable limit	0.069		Below detectable limit

Note: **SRD 23** and **SRD 27** are regarded as outliers (faulty/suspect) and are not considered in the analysis.

AQI > 1 =	Any value > 1 is regarded as unacceptable, prompting investigation by the mine's Occ Hygienist and the DME
AQI < 1 =	Any value < 1 is regarded as fair

3.2 Box and Whisker Graphs

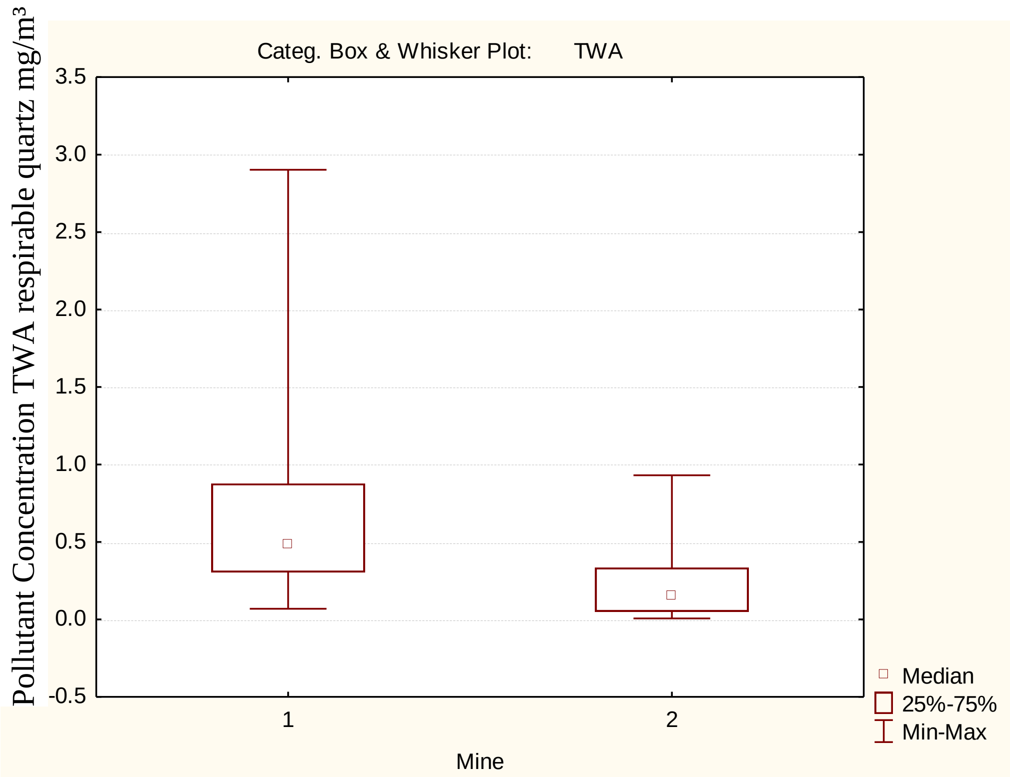
Figure 3.1 Total mass in mg comparison between mine 1 and 2.



Mine	2-Way Tables of Descriptive Statistics Smallest N for any variable: 58									
	Total mass Means	Confidence -95.000%	Confidence +95.000%	Total mass N	Total mass Std.Dev.	Total mass Minimum	Total mass Maximum	Total mass Q25	Total mass Median	Total mass Q75
1	0.729933	0.489155	0.970711	30	0.644815	0.072000	3.057000	0.320000	0.512500	0.923000
2	0.227143	0.132556	0.321730	28	0.243932	0.010000	0.980000	0.050000	0.140000	0.345000
All Grps	0.487207	0.342244	0.632170	58	0.551324	0.010000	3.057000			

The total mass mean for both mines were 0.487 mg but mine 1 had a significant higher value of 0.73 mg (Std Dev 0.64) compared to mine 2 at 0.23 mg (Std Dev 0.24). Perhaps of significance here is that the range spread in mine 1 is much bigger for mine 1 compared to mine 2 and is contributable to the fact that on mine 1, the number of samples in the 0 – 0.99 mg range amounted to 79.3% of all the samples taken with 4 samples (13.8%) in the 1.0 – 1.99 mg range, 1 sample in the 2.0 – 2.99 mg and lastly 1 sample measured in the 3.0-3.99 mg range. With mine 2 all the values fell between 0 -0.99 mg. If one could exclude the 6 sample with values > 1.0 mg on mine 1 then the comparison between the two mines would have appeared almost identical.

Figure 3.2 Time weighted average respirable quartz (mg/m^3) – Pollutant concentration comparison between mine 1 and 2.

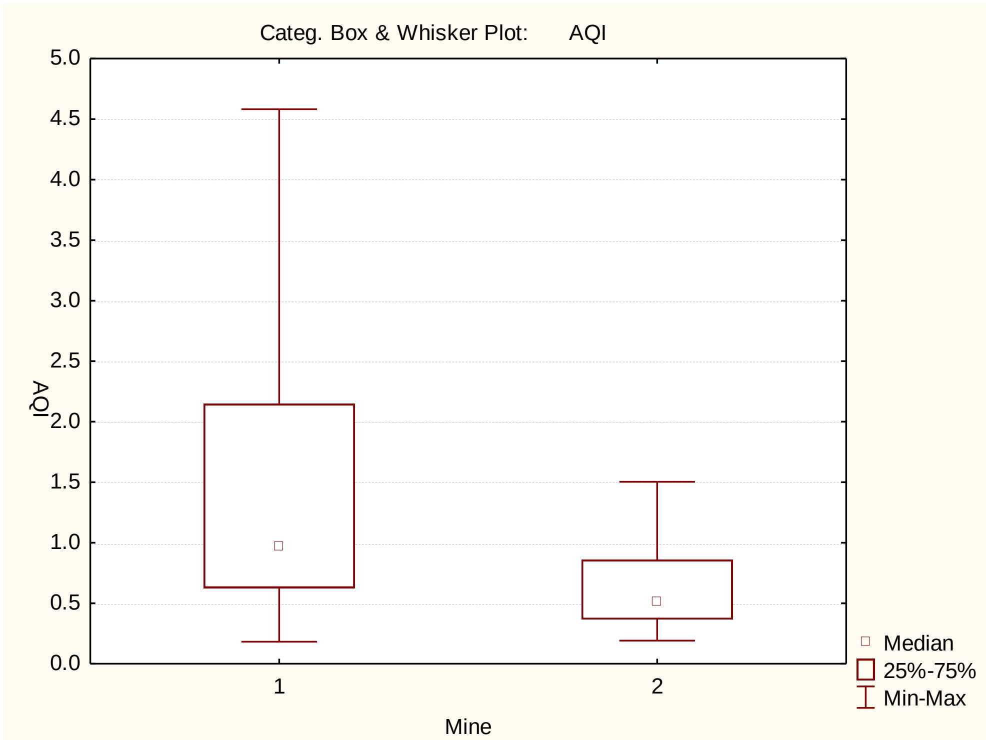


Mine	2-Way Tables of Descriptive Statistics Smallest N for any variable: 59									
	TWA Means	Confidence -95.000%	Confidence +95.000%	TWA N	TWA Std.Dev.	TWA Minimum	TWA Maximum	TWA Q25	TWA Median	TWA Q75
1	0.693733	0.465109	0.922358	30	0.612268	0.069000	2.902000	0.304000	0.487000	0.877000
2	0.219755	0.133181	0.306328	29	0.227598	0.006310	0.930000	0.050000	0.148360	0.334600
All Grps	0.460761	0.325459	0.596063	59	0.519191	0.006310	2.902000			

Let’s consider the Box and whisker graph of both mines with regards to Time Weighted Average Respirable Quartz, pollutant concentration. Mean values were calculated to be 0.69 mg/m^3 (Std Dev 0.61) for mine 1 and 0.22 mg/m^3 (Std Dev 0.23) for mine 2. The median value of mine 1 is 0.487 and for mine 2 it is 0.148. This graph is almost a copy of the Total Mass version and the comments in this regard is also applicable.

Time Weighted Average Concentration (TWA) for respirable quartz: Time – weighted average concentration of an air pollutant measured in a working place for the duration of a shift, usually 8-hours or 40-hour workweek to which basically all workers may repeatedly be exposed to without adverse health affects.

Figure 3.3 Air Quality Index (AQI) comparison between mine 1 and 2.



In combination the two mine's AQI mean is calculated to be 1.1. However, if one look at the mines individually in terms of AQI results then Mine 1 is higher than Mine 2 at 1.46 and 0.6 respectively. The effect size is calculated to be 0.44 which alludes to the fact that the difference is moderate. On closer examination one would find that mine 1 has some high values as outliers but that most values occur between the 25 – 75% quartile range and therefore serves as an example of how wide the values of quartz can range on a particular mine.

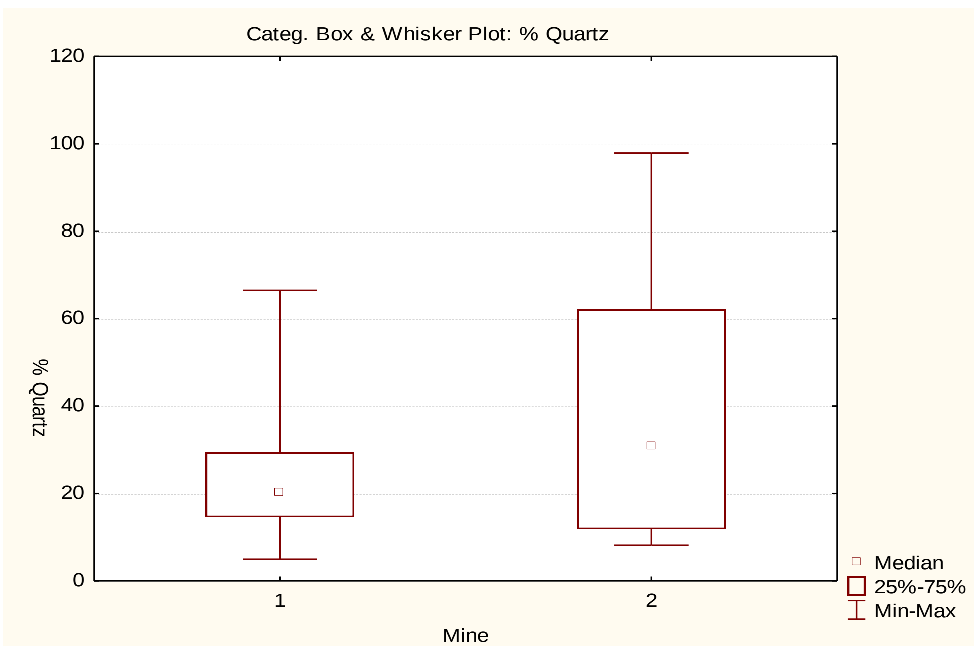
	2-Way Tables of Descriptive Statistics Smallest N for any variable: 52									
Mine	AQI Means	Confidence -95.000%	Confidence +95.000%	AQI N	AQI Std.Dev.	AQI Minimum	AQI Maximum	AQI Q25	AQI Median	AQI Q75
1	1.464395	1.030334	1.898455	30	1.162436	0.181700	4.581899	0.624964	0.963869	2.147426
2	0.604578	0.449917	0.759239	22	0.348827	0.191000	1.503552	0.366633	0.509966	0.859662
All Grps	1.100626	0.821883	1.379369	52	1.001225	0.181700	4.581899			

variable	Mann-Whitney U Test By variable Mine Marked tests are significant at p <.05000 Rank Sum Group 1	Rank Sum Group 2	U	Z	p-level	Z adjusted	p-level	Valid N Group 1	Valid N Group 2	2*1sided exact p
Total mass	1162.500	548.5000	142.500C	4.31805	0.000016	4.31845	0.00001E	30	28	0.00000E
% Quartz	716.000	662.0000	251.000C	-1.46321	0.143410	-1.46321	0.14341C	30	22	0.147061
TWA	1180.000	590.0000	155.000C	4.24535	0.000022	4.24566	0.00002:	30	29	0.00000S
AQI	968.000	410.0000	157.000C	3.20425	0.001354	3.20425	0.001354	30	22	0.00106:

	Effect size
Total mass	**0.57**
% Quartz	**0.14**
TWA	**0.55**
AQI	**0.44**

Total mass, TWA and AQI are in practice larger in mine 1 than in mine 2

Figure 3.4 Percentage Quartz comparison between mine 1 and 2. (without the two outliers)



The mean percentage quartz for both mines without the two outliers is calculated to be 30.67% and confirms the believe that for many years now, this figure represents the expected Free State Province average quartz percentage. Mean values for percentage quartz for mine 1 was determined to be 25.45 % (Std Dev 16.29) and 38.49% for mine 2 (Std Dev 28.54). The effect size is 0.14 and thus can be regarded as a rather small difference in comparison with each other. The median values for the individual mines are 20.1% for mine 1 and 30.9% for mine 2. The difference could be contributable to the different type of reefs being mined. The actual matrix make-up of certain types of reefs will determine the amount of quartz contained in that particular reef and can vary widely even in the space of one reef line. A valid comment here would be that the mine Occupational Hygienist should determine what the quartz mean value is on his/her mine and should any determination of exposure be made in terms of day to day gravimetric sampling, then either the highest analyzed result from a particular stope line but certainly not lower than the mean percentage quartz of that mine, must be used in calculating and determining exposure. That way one can err on the safe side rather than proclaiming a workers environment safe when indeed it is not.

Two way table without two outliers

	2-Way Tables of Descriptive Statistics Smallest N for any variable: 50									
Mine	% Quartz Means	Confidence -95.000%	Confidence +95.000%	% Quartz N	% Quartz Std.Dev.	% Quartz Minimum	% Quartz Maximum	% Quartz Q25	% Quartz Median	% Quartz Q75
1	25.45247	19.36993	31.53502	30	16.28935	4.958562	66.48378	14.58884	20.14398	29.34441
2	38.48510	25.12963	51.84058	20	28.53646	8.170556	97.88750	11.83850	30.90465	62.06306
All Grps	30.66553	24.21986	37.11119	50	22.68030	4.958562	97.88750			

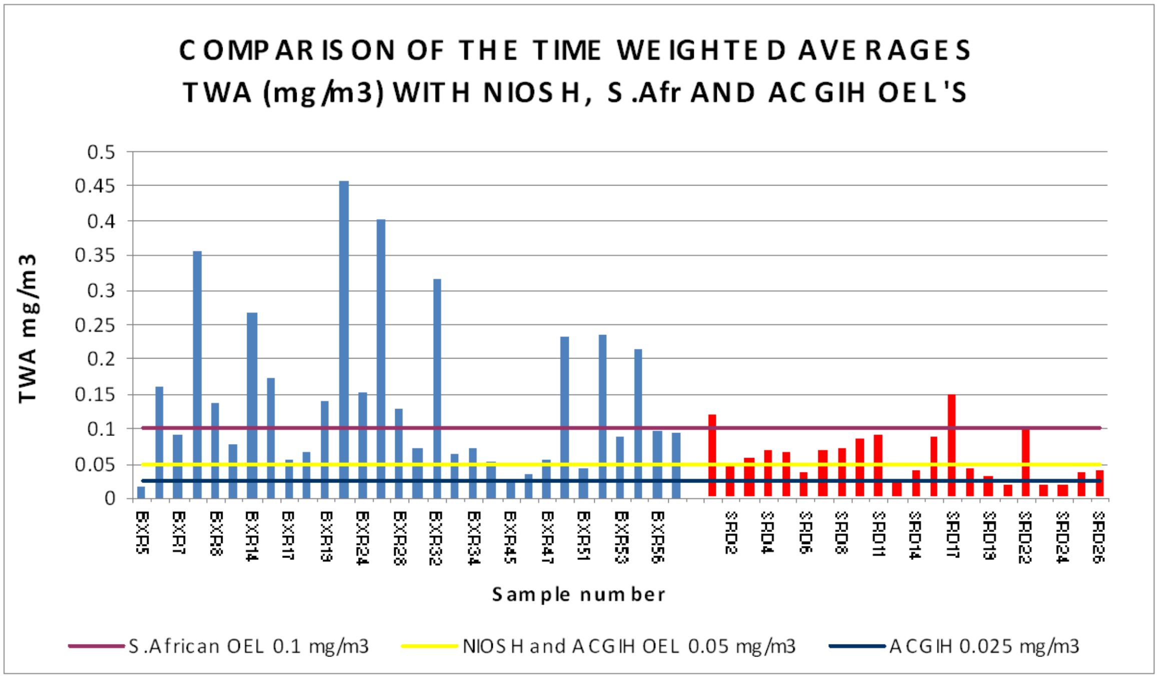
Mann Whitney U test without two outliers

	Mann-Whitney U Test By variable Mine Marked tests are significant at p <.05000									
variable	Rank Sum Group 1	Rank Sum Group 2	U	Z	p-level	Z adjusted	p-level	Valid N Group 1	Valid N Group 2	2*1sided exact p
% Quartz	716.0000	559.0000	251.0000	-0.970345	0.331876	-0.970345	0.331876	30	20	0.340086

Effect size=0.14

3.3 Comparison of TWA values with OEL's

Figure 3.5 A comparison of the TWA results with NIOSH, ACGIH and South African OEL's.



3.4 Results summary

The first question that might be asked is whether there is a significant difference between the two mines. This question will then also cover the aspects of whether the results may be generalisable for other gold mines. In short the answer is yes, there is a difference. A glance at the box and whisker graphs will confirm this. In comparison the significant difference between the two mines lies with the Total Mass, TWA and AQI, (effect size 0.57, 0.55 and 0.44 respectively) in that the values are higher with mine 1 than compared with mine 2. This emphasizes the fact that the results reflected in this report should not be regarded as hard and fast rules for every gold mine in the country and neither is any claim made that ultimately these results must be regarded as true for all rock drill operators *per se* but rather that it gives an indication that there is a fair chance that overexposure might exist on a mine where the quartz percentage in the reef being mined is comparable to the figures reflected on these two mines. The results show that overexposure to dust and SiO_2 did occur. The exposure refer to also points to the potential exposure of the Rock Drill Operator should he not wear RPE. What must be clearly understood however are that the findings revealed the apparent lack of appropriate RPE and the fact that rock drill operators opt to use material such as mutton cloth in place of the ordinary type of paper dust masks as it is perceived to be more appropriate (and comfortable) and that in itself could lead to this particular occupation from experiencing potentially overexposure.

From figure 3.5 it is easy to deduct that there are quite a few results (32%) above the South African Occupational Exposure Limit (OEL) of 0.1 mg/m^3 but if one would consider the NIOSH of 0.05 mg/m^3 and ACGIH OEL of 0.025 mg/m^3**,** the picture changes dramatically in that almost 72% of all the readings are above the NIOSH OEL and 97% above the ACGIH OEL. It also becomes quite clear that Mine 1 have values far in excess to that of mine 2. The problem with having the OEL at 0.05 is mg/m^3 is that the instruments currently available world wide is not capable of measuring such minute values. Seen purely from a practical viewpoint the 0.1 mg/m^3 OEL is regarded as lowest allowable limit compatible with the analytical instruments currently available but it is believed that as soon as this situation changes, legislation might well be adapted and brought down to equal that of NIOSH and ACGIH. Remember that when there is reference to overexposure the assumption is made for a worker not wearing appropriate and effective RPE.

At this stage it would serve well to remember that the requirement is to have medical surveillance programmes in place if 1/10th of the OEL is exceeded. (This also includes Occupational Hygiene Programmes).

3.5 Research limitations, difficulties and pitfalls encountered

As with every sampling strategy it would seem that there is always an element of the unforeseen that is bound to creep in. In preparation of this research a schedule was drawn up in order to plan for the actual commencement of the sampling strategy. In reality this schedule could not be kept because so much went wrong. There are various reasons for this. Of real concern is the health of the work force because on numerous occasions the person selected for sampling on a certain day would not pitch due to the fact that he has reported sick. Some forgot to report at the crush in order to collect the pump even though every effort was made to parade them timeously. Then there were cases where the pumps just failed. The reason was unclear as they are generally very reliable. Of course the real problem surfaced at the onset of sampling in that the Dorr-Oliver cyclone usually used by the mining community, delivered a soaked and ruined sample for quite a few consecutive days. Invariably the question arose as to how it was done by other people and the answer was surprisingly simple. Honest replies from several local Occupational Hygienists that sampling of rock drill operators is a nightmare for which there apparently seemed to be no easy solution.

Initial sampling revealed that every sample taken had the appearance of a wet rag. This resulted in lost time and effort. Pumps even got water logged and resulted in costly repairs. An urgent search for an alternative solution was pursued and the possibility of using the new SKC cyclone became a reality. (See photo 8) Tests done with it seemed promising and everything was back on track albeit that a month was lost. Needless to say the original schedule was regarded as obsolete. The process of updating the schedule was repeated time and time again.

Just when everything seemed to be going smoothly, another spoiled sample would appear. Even though there was strict supervision in terms of quality control to prevent “little accidents” or deliberate tampering with the samplers, every now and then there were still spoiled samples due to water ingress and so on. The fact that workers were randomly selected initially to wear these samplers meant that the same worker to should wear it again if it was determined that the original sample was spoiled for some reason. Even though the spoiled samples were questioned, no reason could be found other than speculation, to explain why it occurred. Suffice to say the sampling strategy concluded way beyond the expected and planned date.

The number of samples taken as previously mentioned, were determined by using the NIOSH sample size selection guide (see appendix 3). 30 Samples were taken at each mine. The one mine had 460 development as well as 868 Stope rock drill operators. The other mine has 614 in total.

It must be kept in mind that only stope rock drill operators were sampled. The results should therefore not be regarded as generally applicable to all type of rock drill operators. Furthermore, the fact that only 60 samples out of the total number of drillers were sampled, might be regarded as a too small sample and to some degree this might be true. However, the tasks of stope rock drill operators are almost identical by nature with the only distinguishable difference being variances in velocities at the time of measuring. This is definitely a limiting factor with regards to this research with the velocity envelope varying between 0.25 and 1.5 m/s. Obviously the higher the velocity, the better the dilution. However, since the rock drill operators were selected randomly, the results should indicate the average exposure that can be expected from this occupation. Ideally and given unlimited time and funds, a bigger sample size would have been preferable.

The question of whether the two mines selected can be compared to other gold mines is debatable as there is certainly going to be differences in the composition of the rock formations and more particularly to the reef being mined. It is generally known that the quartz content can vary considerably between one stope line and another and indeed even within the same stope from one panel to another. The research results reflected within this report should therefore not be regarded as applicable to each and every gold mine in South Africa but what it does show is that there is a high probability of overexposure to dust and quartz as measured on rock drill operators. Focused risk assessment on this occupation is regarded as critical and should not be included into a HEG during such risk assessment merely for the sake of convenience. The aforementioned risk assessment must as part of the remedial action also consider the appropriateness of the respiratory protection provided to this particular occupation.

The following problem was one that initially caused a lot of confusion as there was no straight forward answer for it. Upon much discussion and investigation it became clear that the cyclone was to carry the blame. This entailed the blotch effect seen one some of the rejected samples. Anybody that has done some spray painting will immediately identify with the common blocked nozzle problem. With reference to fig 3.6 and photo 1 (middle photo BXR 47), Air Quality Analysts should immediately recognize this irregular “spray” pattern and associate it with blockage in the cyclone nozzle. Hence, if found, such a sample should be rejected and the person that carried the gravimetric pump should be scheduled for re-sampling. The procedure for preparing the cyclone for use must include careful washing and inspection to ensure with absolute certainty that the nozzle is clear of any possible obstructions.

Reasons for the obstructions are multiple. However, the first possibility is that the cleaning procedure might be at fault, i.e. not done properly, particles of the cloth used in the cleaning of the cyclone/cassette itself might remain behind but the most probable reason might be because the cyclone is tilted during the sampling process. This is because the rock drill operator has to adopt such awkward body postures during his normal daily tasks and therefore it is impossible to expect such a person to be conscious of the orientation of the cyclone all the time. That said the theory is that some larger particles that should have remained in the grid pot might actually find its way back into the cyclone at certain stages of the sampling process (when accidentally turned on its side – horizontally or at worst, upside down) and subsequently cause a blockage at the cyclone nozzle.

Figure 3.6 Filter "spray" pattern indicating possible blockage and an unsuccessful sample.

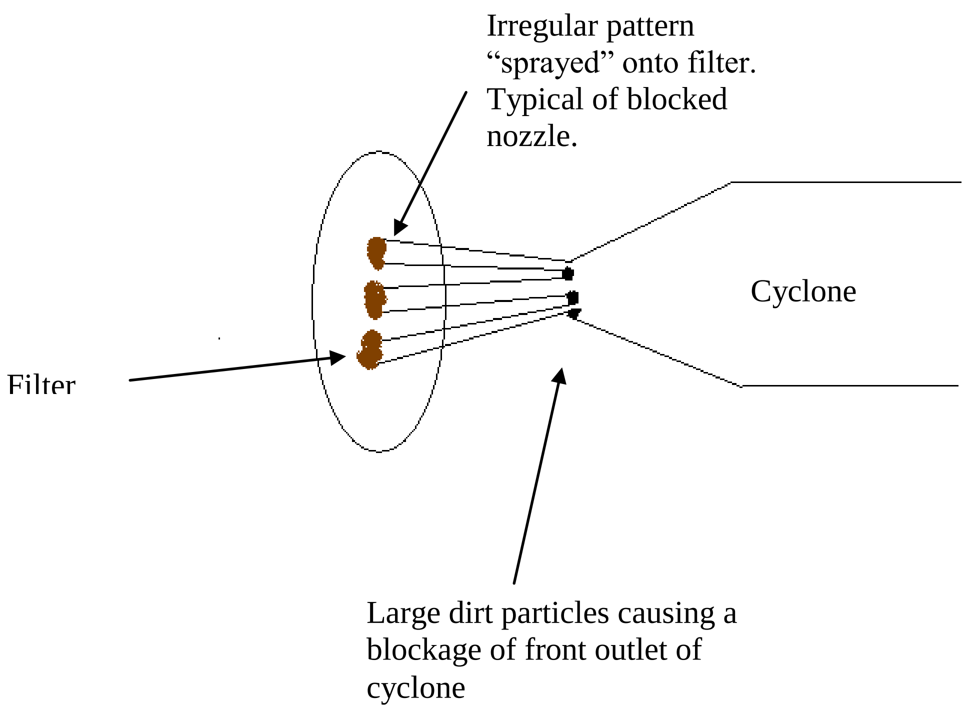
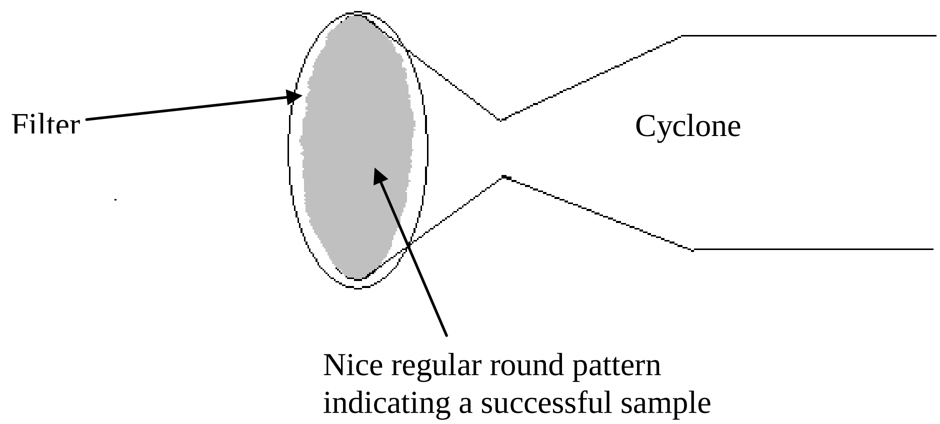


Fig 3.7 Filter “spray” pattern indicating a desired and successful result



The NIOSH guideline on gravimetric sampling refers to the fact that the cassette (cyclone) must be kept in an upright position for the entire duration of the sampling period. The obvious reason for this is because a cyclone operates on two important principles and is what makes a cyclone both unique and very efficient. Firstly there is the centrifugal effect, sometimes referred to as the cyclonic effect. This is brought about by the fact that air enters the cyclone at an angle (on the side) of the unit and “spins” the air around at relatively high speed. Secondly there is the gravitational effect and in combination with each other, course particles, being heavier, exits the cyclone at the bottom while finer particulate matter exits at the top. If however the cyclone is tilted on its side as is often the case with workers inside stopes, then the gravitational principle is effectively nullified and the very uniqueness of the cyclone is lost causing anomalies and inefficiencies that is contradictory to the very idea of obtaining meaningful data pertaining to actual and accurately measured exposure.

3.6 Possible other considerations not covered in this research

Rock drill operators are rarely placed in a stope on their own during a drilling cycle. If one then keep in mind the ventilation flows along the face continuously in a controlled manner (i.e. direction @ constant velocity) one will immediately recognize the fact that the dust generated at one position will flow along with the ventilation current and is added to the dust created by the second rock drill operator and so forth. (Fig 3.8) Obviously the situation gets worse the more rock drill operators there is. Often the ventilation flow from one stope panel flow to the next where even more rock drill operators are drilling and thereby increasing the dust burden even more. Consider the following sketch.

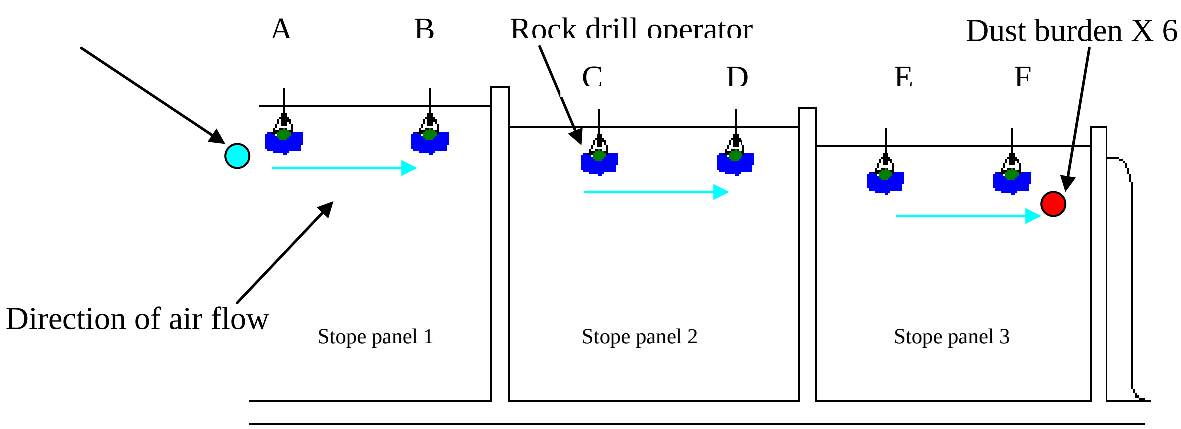


Figure 3.8 From this sketch it is plain to see that the dust burden at rock drill operator F will be approximately six times more than the exposure of rock drill operator A.

During this research project this fact was not taken into account as it was deemed too complicated to attempt given the allotted time but could be considered as an extremely interesting project for someone so inclined. However, the values obtained for this research project should serve as a good indicator as to the average exposure expected for a rock drill operator.

Gravimetric pumps sample at a constant flow rate but in reality the person sampled cannot breathe at a constant rate throughout his shift and this thus triggered considerable debated as to how representative the results are from such sampling compared to real life respiration rates and subsequent exposure. At some periods there may be strenuous tasks to be performed while at other times a more relaxed rate of work is required. The Gravimetric pump does not compensate for the "peaks" and the actual effect on results is unknown. However, if the forgoing text is taken into consideration with emphasis on the difference in mouth versus nasal breathing then there is certainly a good chance that once again the case of underestimation of actual exposure is possible. If technology could perhaps develop a gravimetric pump that could monitor either the breathing rate of the wearer and then adjust the flow accordingly, one might end up with something more suitable.

A further aspect not measured or accounted for in this research was the varying velocities of airflow along the working faces. It is therefore important to realize that the result obtained through gravimetric sampling in this research project refers to the average exposure of Rock Drill Operators to dust and SiO_2.

Chapter 4 Discussion, conclusion and recommendations

This chapter aims to describe the findings of the research, draw some conclusions based on these findings and provide practical recommendations. In order to measure the respirable dust and quartz exposure of Rock Drill Operators in two typical gold mines in the Free State province of South Africa, gravimetric sampling was used following the NIOSH methodology with great emphasis on quality assurance. The reason for conducting this research came about when the topic of dust exposure by underground workers were researched and it quickly became apparent that rock drill operators have not been singled out with a focused type of research in order to determine their actual dust and respirable quartz exposure. The hypothesis was formulated that there is a definite possibility that this particular occupation will be susceptible to potentially very harmful concentrations of dust. The research done by G.W.Gibbs and R.S.J Du Toit [(8)] alluded to the fact that measurements taken during their research showed that stopers in general are exposed to dust levels that exceed the current OEL's. Stopers used to be a generic term describing and included the miner, his assistant, the rock drill operators and basically any person working in the face of a stope. Prompted by this result it was felt that rock drill operators should be singled out for this research as they were deemed to be at the sharp end of dust generating activities. However, some aspects of the research turned out to be difficult to control in that dust generation elsewhere in the mine or section could have played a role on the overall dust burden of the person sampled on any particular day and as this was deemed to be beyond the control of the researcher and remains an uncertainty. That said, the varying conditions could be averaged and regarded as typical of the exposure to dust and SiO_2. In all cases there was watering down of the entire stope face and strike gullies prior to the commencement of drilling operations.

In conclusion it can thus be said that this research prove that the dust burden in the working environment of rock drill operators is high and certainly above the OEL for SiO_2. Keeping this in mind and reflecting upon the results that show overexposure to the extent of 32% over the South African OEL, then suffice to say that the danger of the failure of the noble campaign to eradicate silicosis as an occupational disease is a very real probability. Comparison to the OEL's of NIOSH (0.05 mg/m^3) and ACGIH (0.025 mg/m^3) paint an even darker picture. With the NIOSH OEL the overexposed percentage rises to 72% but with the ACGIH OEL the results indicates that 94% of the rock drill operators are overexposed.

As alluded to previously, there is scant literature on respirable silica exposure on rock drill operators in hard rock mining however, G.W.Gibbs and R.S.J Du Toit (8) in their research found that stopers, who can be closely related to rock drill operators in terms of their occupation, determined a mean respirable mass concentration of 0.37 mg/m^3. In the same research report the findings of other researchers on stoppers are quoted as being 0.37, 0.348 and 0.2 mg/m^3 (Hnizdo and SluisCremer, Du Toit and Beadle respectively). The results from this research for Mine 1 revealed a mean of 0.69 mg/m^3 and 0.22 mg/m^3 for Mine 2. The deduction is thus that Mine 2's result is directly comparable to these researchers' findings however the same cannot be said of Mine 1's results which are about three times higher. There might be an immediate forthcoming answer in that the one mine is doing better dust allaying through application of wetting down compared to the other but this was deemed important enough during the research as a point of interest in order to compare this function and it was concluded that both mines wetted down the stope working faces to an equal level of requirement. A glance at the quartz analysis comparison reveals that Mine 2 has a relatively higher percentage quartz than Mine 1 yet the AQI results for Mine 1 is higher than compared to Mine 2 and this seems to contradict each other. The fact of the matter is that the overall dust burden for Mine 2 is just lower than Mine 1. Another fact that becomes evident from studying the results is that lots of the high TWA respirable quartz pollutant concentrations (mg/m^3) values co-incidentally had low quartz content values and when taking the formula for determining AQI into account, it reveals a box and whisker graph that is inversely proportional to the TWA box and whisker graph. This is deemed insignificant and focus should rather be placed on the TWA values in comparison with the various OEL's. The bottom line is that if the rock drill operator occupation is considered without the use of RPE, overexposure is virtually certain.

The fact that Page-Shipp and Harris (1972) [(8)] made the assumption that miners performing the same kind of work in different mines could be considered as having the same level of exposure seems to be contradicted by this researchers findings. There appear to be distinct differences between mines and might be contributable to the type of reef being mined and having different percentages of crystalline quartz present in these ore bodies.

Recommendations

In occupational hygiene the hierarchy of control is 1) elimination, 2) substitution, 3) engineering controls, 4) isolation, 5) administrative controls and 6) personal protective equipment (PPE). If however one take the underground working environment into consideration specifically that of the rock drill operator, it becomes clear that exposure to dust can be reduced through the application of administrative controls, engineering controls and PPE. Substitution and elimination might also be possible should one consider automation but in the current economic state of the country this can be in direct contradiction to the objective of job creation thus proving to be unpopular. That said, the results are ample proof that given the fact that RPE equipment are heavily relied upon to safeguard rock drill operators from overexposure, then the onus lies squarely upon employers shoulders to ensure that the RPE issued to these workers are appropriate, correctly worn, comfortable and of correct protection factor. Ergonomic and vibration risk assessment will also in all probability indicate that automation of drilling should be considered as the next logical step and will undoubtedly contribute in reducing the dust burden of the rock drill operator.

D.G.Beadle stated in the late 1950's [40] that the objectives of dust sampling should be:

1. To identify working places where unsatisfactory dust conditions prevail
2. To investigate and determine the reason for the dusty conditions
3. To determine and implement the necessary control measures
4. To follow up and measure the effectiveness of the implemented control measures
5. To confirm compliance and that satisfactory conditions have been attained after remedial action has been taken
6. The provision of effective record keeping in order to provide trends
7. To correlate the data from dust exposure with the incidence of disease
8. To comply with the Law. (one should include OEL requirements here)

Keeping in mind the timeframe in which he made these statements it is quite commendable particularly when comparing it to what has been done since, one might say that not much has changed. It still is valid and any prevention strategy will include these objectives especially seen in the context of the new requirements to conduct ergonomic and vibration risk assessments.

Personal protective equipment in the form of respiratory protective equipment (RPE) will always depend on the human factor to be effective. This is of major concern to the occupational hygienist as experience has shown that respiratory protective equipment have always proved to be unpopular with underground workers, requiring vigilant supervision and constant threats of disciplinary action for refusal to wear it. Personal experience have shown that use of the ordinary paper dust mask (FF 2 with no non-return valve) in a environment that usually has a high humidity content (often completely saturated) is very impracticable as the mask becomes soaked after less than 15 minutes with inevitable collapse because of loss of rigidity. Should this occur it is usually discarded by the user in favour of mutton cloth worn around the face. Obviously this is useless considering the poor filter and retention ability of the material. Through observation of the randomly selected rock drill operators this became abundantly clear as being a definite and major concern. In this regard in is highly recommended that mine occupational hygienist conduct a thorough risk assessment in this regard with the main objective being the determination of which job category should be issued what type of respirator. To issue the aforementioned disposable paper dust mask for the entire underground work force is to invite failure of the objective of the eradication of silicosis. Surely it must be understood that certain job categories will have increased dust exposure (relates to dust burden per activity performed) compared to others and therefore require more substantial protection. In the case of rock drill operators the half face double cartridge type respirator must be considered a basic requirement. The fact remains, this particular occupation is performed in an environment that is extremely harsh and given all the stressors encountered must be placed high on the priority list of the Occupational Hygienist in order to find solutions, implement it and monitor the effectiveness of such remedial action and adjust and fine tune said remedial actions from time to time. Risk assessment and job observation must play a vital role here in order to safeguard rock drill operators from ill health. Reliance on respiratory protective equipment (RPE) in occupational hygiene terms is always the last resort and even when selected it must be revisited in order to find suitable alternatives as remedial action. The reason is straight forward in that RPE is only effective if used at all and more importantly, used correctly. This in real world terms is unfortunately seldom the case.

Perfect, ideal, practical and comfortable RPE for the Rock Drill Operator must still be designed and there is talk of continued work on this subject. It is probably going to be a forced (supplied-air respirator) fed system (uncontaminated air) that will include the hard hat, shield, harness to hold a moisture and particle trap and double up to ensure the ease of trialing the air supply hose behind the wearer and preferably be of lightweight construction. The challenge to suppliers in this regard is to manufacture such a device with all due haste as the replacement for ordinary paper dust masks and even PVC half face masks is long overdue and then for mine managers to implement such devices as standard equipment with equal urgency.

The fact that PPE is issued must never be regarded as a final solution. The occupational hygienist must always accept the issue of PPE as a temporary solution, seeking to find the permanent solution so as to ensure no exposure once the remedial action has been implemented with subsequent elimination of the use of said PPE. In the ideal world this is what we all strive for but in practical terms this is not always possible or practical, especially in the harsh underground working environment. That said there is still a lot that can be done to minimize exposure. Some considerations of what can reduce dust might be in order.

The very first tool to combat dust at source remains the use of water. Water had been used in the pneumatic rock drill for ages. The requirement of a minimum pressure of 150 kilopascals at the drill intake should be checked daily by the miner and confirmed by regular checks by the Shift boss, recording the results for the purpose of providing proof during audits. Watering down of the stope working face has been done probably since the beginning of gold mining. However, the watering down of the entire working area should include the foot, side and hanging walls (where ground conditions allow it) of intake airways, traveling ways, center gulleys, strike gulley's and face. There is a general believe that if the foot wall is wetted then all is well. Obviously this is not at all true. As was described previously, all dust particles will settle but keep in mind that larger particles will settle most probably to the foot wall first with the smaller particles settling on any surface and often on top of pipes, light fittings, sidewalls etc. In most instances these are the particles of most concern as they tend to be of the inhalable size. The solution is to properly wet down everything in sight and regularly during the shift. It has become common practice to redo the watering down procedure during the mid shift barring procedure. Of great importance here is the realization that a person performing this watering down must position himself in the up-wind position so that any dust liberated during the watering down process is not liberated into his breathing zone. Additionally, this person must make sure that no one is working on the return side of where he watering down. Everybody living in the Free State has experienced what happens before a thunder storm. First there is a dust storm followed by rain. The same happens when conducting watering down procedures underground. Although difficult to see, the water kicks up vast amounts of settled dust that can cause very high dust exposures for the unwary on the return side.

It would thus further appear that one cannot assume a general mean respirable quartz percentage for a province and indeed neither for a mine. That said and taking this thought further, it would be an error to use the average of the respirable quartz of a mine and apply that figure to all the sampled persons on that mine but rather to use the mean respirable quartz average of the working place where the person was sampled. The only other alternative is to use the highest value of all samples sent for analysis and use that as the respirable quartz value in all gravimetric result calculations. In this manner one would err on the safe side rather that using an average that if too low, would allow persons overexposed to continue working without requiring investigation or intervention.

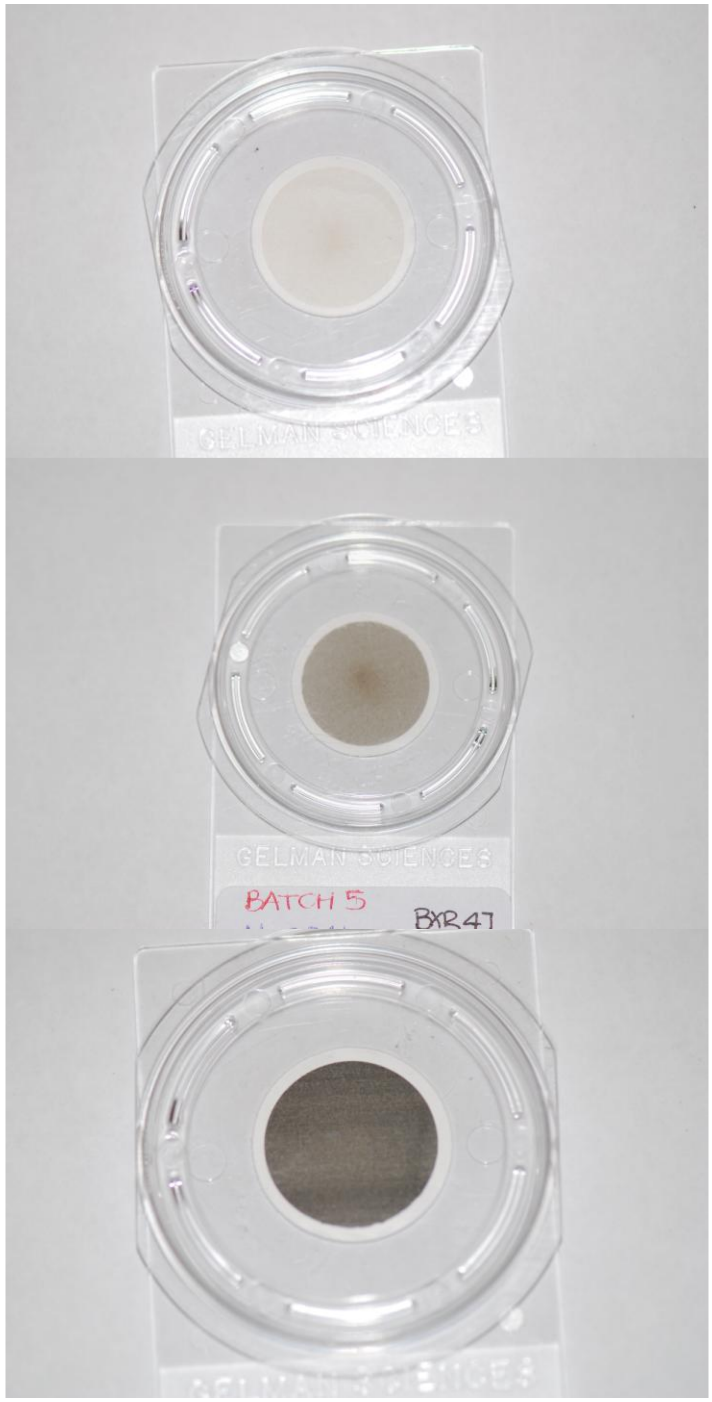
Ethical considerations

Informed consent was sought from each individual partaking in this study. There will be no negative outcome for anybody that participated in this study, in fact, it is foreseen that the results emanating from this study will only serve as a benefit to mine workers in the future. The sampling methods and equipment used for this study is currently routinely used by the mining industry as part of their compliance to the Codes of Practice on Airborne Pollutants.

However, Wits informed the researcher that permission need not be sought for ethical clearance with regards to this particular research. (See appendix 3)

Index to photos

Photo 1



Examples of samples of varying concentrations. The actual filter is kept in a Gelman Sciences holder for protection. All samples were also transported using these holders.

Photo2:

The NIOH Laboratory Philips XRD machine.

Photo 3

Photo 3: Typical underground stoping working environment

Photo 4

Photo 4: Typical underground stoping working environment

Photo 5

Clearly seen in this photo is the tube leading from the gravimetric pump to the sampler's cyclone. Note the cramped and difficult body posture of this rock drill operator. Also note how well wetted this immediate vicinity of the worker is.

Photo 6

Same worker as Photo 5. The ventilating air is supposed to flow along the face being drilled and the face of the rock drill operator (breathing zone) hence diluting or removing dust particles before reaching his nose. Also note that in this case the rock drill operator was not wearing any type of dust mask.

Photo 7

Of note here is the white cassette holder attached to the gravimetric pump. This is a sealed cassette with the field blank in it. The orange tube is the actual connecting tube to the cyclone fitted to the collar of the worker in order to access the breathing zone.

Photo 8. SKC cyclone.

SKC CYCLONE

SKC CYCLONE EXPANDED VIEW
Courtesy SKC

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Appendix 1

DATA CAPTURE SHEET

Research Project. Respirable dust and quartz exposure of rock drill operators in two Free State Mines

Data of Sampling :		
Company Number :		
Sample Number :		
Working Place :		
Modern & serial no. of pump:		
Calibration Date of pump:		
Description of work performed:		
Dust allaying effectiveness:		
Air velocity:		
Number of drillers per panel:		
Filter holder & sample No. :		
RPE used by worker?	Yes	No
Air flow rate at start of shift:		
Air flow rate mid shift :		
Air flow rate at end of shift :		
Ambient temperature :	(WB/DB)	
End of shift information:		
a) Record time of end of shift:		
b) Was the pump running?	Yes	No
c) Condition of sampling train:		
d) Check that present flow rate is still within 5%	Yes	No
GENERAL REMARKS		

Appendix 2

Sample Size selection (NIOSH)

Top 20% with 90% Confidence (Use n=N if N ≤ 5)		Top 20% with 95% Confidence (Use n=N if N ≤ 6)		Top 10% with 90% Confidence (Use n=N if N ≤ 7)		Top 10% with 95% Confidence (Use n=N if N ≤ 11)	
Size of Group (N)	No. of Samples required (n)	Size of Group (N)	No. of Samples Required (n)	Size of Group (N)	No. of Samples Required (n)	Size of Group (N)	No. of Samples Required (n)
6	5	7-8	6	8	7	12	11
7-9	6	9-11	7	9	8	13-14	12
10-14	7	12-14	8	10	9	15-16	13
15-26	8	15-18	9	11-12	10	17-18	14
27-50	9	19-26	10	13-14	11	19-21	15
51-∞	11	27-43	11	15-17	12	22-24	16
		27-43	12	18-20	13	25-27	17
		44-50	14	21-24	14	28-31	18
		51-∞		25-29	15	32-35	19
				30-37	16	36-41	20
				38-49	17	42-50	21
				50	18	∞	29
				∞	22		

Appendix 3

University of the Witwatersrand, Johannesburg – Human Research Ethics Committee clearance.

University of the Witwatersrand, Johannesburg

Human Research Ethics Committee (Medical)
(formerly Committee for Research on Human Subjects (Medical)

Secretariat: Research Office, Room SH10005, 10th floor, Senate House • Telephone: +27 11 717-1234 • Fax: +27 11 339-5708
Private Bag 3, Wits 2050, South Africa

Ref: **W-CJ-080613-2** 13/06/2008

TO WHOM IT MAY CONCERN:

Waiver: This certifies that the following research does not require clearance from the Human Research Ethics Committee (Medical).

Investigator: **Mr D M Kemsley**

Project title: **Respirable dust and quartz exposure of Rock Drill Operators in two Free State Gold Mines.**

Reason: This study deals with dust levels collected as an occupational health monitoring. No research on humans has been done.

Professor Peter Cleaton-Jones
Chair: Human Research Ethics Committee (Medical)

UNIVERSITY OF THE WITWATERSRAND
PROF PE CLEATON-JONES
HREC (MEDICAL)
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