Crystalline silica exposure in platinum mining: A task based approach

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Authors Contribution

This study was planned and executed by a team of researchers. Table 1 depicts the contributions of each of the researchers.

Table1: Research team

NAME	CONTRIBUTION
Mr. A. Breedt.	• Personal dust sampling at the platinum mine • Literature research, statistical analysis and writing of article
Prof. F.C. Eloff	• Supervisor • Assisted with the design and the planning of the study, protocol approval, reviewing of the dissertation and documentation of the study, analysis and interpretation of the results
Mrs. A. Franken	• Assistant-supervisor • Assisted with the design and the planning of the study, protocol approval, reviewing of the dissertation and documentation of the study, analysis and interpretation of the results

The following is a statement from the supervisors that confirms each individual's role in the study:

I declare that I have approved the article and the role in the study as indicated in Table 1 is representative of my actual contribution and that I hereby give my consent that it may be published as part of Anton Breedt's M.Sc (Occupational Hygiene) dissertation.

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Prof. F.C. Eloff Miss. A. Franken

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Table of Contents

Chapter 3: Article

Crystalline silica exposure in platinum mining: A task based approach

List of Abbreviations

ACGIH	American Conference of Industrial Hygienists
BBD	Beroepsblootstellingsdrempel
CDC	Centre for Disease Control and Prevention
CEN	European Committee for Standardisation
CHAN	Chemical Hazard Alert Notice
COPD	Chronic Obstructive Pulmonary Disease
D50	Particle size distribution 50 %
EUR	European Commission
HSE	Health and Safety Executive
IR	Infrared
ISO	International Organization for Standardization
IUPAC	International Union of Pure and Applied Physics
LOD	Limit of Detection
LOQ	Limit of Quantification
MCE	Mixed Cellulose Esters
MEL	Maximum Exposure Limit
MHS	Mine Health and Safety Act
NIOSH	National Institute for Occupational Safety and Health
O	Oxygen
OEL	Occupational exposure limit
OSHA	Occupational Safety and Health Administration
PEL	Permissible Exposure Limit
RCS	Respirable Crystalline Silica
SANAS	South African National Accreditation System
Si	Silicon

SIMRAC	Safety in Mines Research Advisory Committee
SiO_2	Silicon Dioxide
SWEA	The Swedish Work Environment Authority
TBG	Tyd Beswaarde Gemiddelde
TLV	Threshold Limit Value
TWA	Time Weighted Average
UK	United Kingdom
WHS	Work Health and Safety
XRD	X-ray Diffraction

Preface

This dissertation is written in article format specifically for potential publication in Annals of Occupational Hygiene and therefore conforms to the requirements preferred by the journal. For the sake of uniformity the same reference style is used throughout the entire dissertation.

Chapter 1 contains an overview of silica exposure to workers in the platinum mining industry. It consists of the aims and objectives and the basic hypothesis. Chapter 2 consists out of the presence of silica in mining, chemical properties of silica, sources of airborne silica, control methods, problems with monitoring silica, legislation, physiological background and silicosis. Chapter 3 is written in article format to be submitted to the Annals of Occupational Hygiene for peer revision and publication. The article consists out of an abstract, introduction, methods, results, discussion and conclusions. Chapter 4 contains the final summary and conclusions along with recommendations for future studies.

For the purpose of this study the term silica will refer to crystalline silica throughout this dissertation.

Abstract

Background: Workers will be exposed to silica dust (SiO_2) in any working environment where mineral deposits or rock types are being processed contain silica as a component. To prevent the development of silica related disease, the exposure to silica dust should be kept as far below the time weighted average (TWA) occupational exposure level (OEL). Exposure below the TWA OEL is considered to be safe. The silica content of platinum ore is low and exposure below the TWA OEL (Stanton *et al.,* 2006), however studies have shown evidence of silicosis in workers that had no other exposure to silica outside of the platinum industry (Nelson and Murray*.,* 2012). **Objectives:** To evaluate the silica exposure levels of 4 different high risk tasks at a platinum mine. To evaluate the sufficiency of the current South African OEL. To compare the differences in protocols used by the mine to NIOSH method 7602. **Methods:** Dust sampling was conducted by means of two cyclone samplers (aspirated at 2.2 L/min) in the breathing zone of each of the 48 workers in 4 different areas. Two cyclone samplers were used to compare two different protocols. The first protocol reflected the method used by the mine and the second was done in accordance with the NIOSH method 7602 (NIOSH, 2003). Sampling was done in the vamping, development cleaning, belt attendant and grout plant areas. A 25 mm MCE filter was used to capture the respirable fraction. The quartz content of the filter was determined by a SANAS accredited laboratory using qualitative infrared spectroscopy in accordance with NIOSH method 7602. Additional bulk samples were taken to be analysed for silica as well. **Results:** Most of the samples were below the respective OELs of 0.1 mg/m^3 (MHS, 1996), 0.05 mg/m^3 (NIOSH, 2002) and 0.025 mg/m^3 (ACGIH, 2012). A single sample in the development cleaning area in the Merensky reef had a value of 0.032 mg/m^3. Nearly no significant differences were found in the exposure levels between the two protocols, the two reefs or the different underground areas. Although the differences in protocol are not statistically significant the protocol implemented by the mine yielded lower exposure values. The grout plant had the lowest silica exposure levels. **Conclusions:** Upon evaluating the silica exposures of platinum mine workers there does not seem to be a health or safety risk involved at these low levels. The implemented control measures are sufficient in preventing the development of applicable health and safety risks. However if any new cases of severe illness (e.g. silicosis) occur it may be necessary

to re-evaluate the risks involved with silica exposure. **Recommendations:** The goal of silica monitoring should be to obtain accurate data that represents the actual exposure levels experienced by a worker during a working shift. Accurate data gives insight into the safety of the worker. To achieve this, the monitoring should be done as accurately as possible to adhere to the prescribed methods. Employees/workers should be trained in order to assist in identifying and correcting problems that may occur during sampling.

Opsomming

Agtergrond: Werkers sal blootgestel word aan silika (SiO_2) stof in enige werksomgewing waar verwerking van ŉ mineraal neerlegging of rots tipe is waarvan silika ŉ komponent vorm. Om die ontwikkeling van siektes geassosieer met silika te voorkom moet die blootstelling aan silika stof so ver as moontlik onder die tyd beswaarde gemiddelde (TBG) beroepsblootstellingdrempel (BBD) gehou word. Blootstelling wat benede die TBG val word as veilig beskou. Die silika inhoud van erts in platina myne word verwag om laag te wees en benede die TBG BBD (Stanton *et al.,* 2006), maar daar is studies wat bevind het dat daar silikose ontwikkel het in werkers wat geen ander blootstelling aan silika stof buite die platina industrie gehad het nie (Nelson en Murray, 2012). **Doelwitte:** Om die silika blootstelling van 4 hoë risiko aktiwiteite in ŉ platina myn te evalueer. Om te evalueer of die huidige Suid Afrikaanse BBD voldoende is. Om die verskille in protokol te evalueer soos gebruik deur die myn met NIOSH metode 7602. **Metodes:** Stof monitering is gedoen deur twee sikloon monsternemers (geaspireer teen 2.2 L/min) in die asemhalings sone van elk van die 48 werkerste plaas in die 4 verskillende areas. Twee siklone is gebruik om die twee protokolle te vergelyk. Die eerste protokol reflekteer die metode wat deur die myn gebruik word en die tweede was gedoen volgens NIOSH metode 7602 (NIOSH, 2003). Bykomende grootmaat monsters is ook geneem en geanaliseer vir silika. **Resultate:** Byna alle monsters was benede die respektiewelike BBD's van 0.1 mg/m^3 (MHS, 1996), 0.05 mg/m^3 (NIOSH, 2002) en 0.025 mg/m^3 (ACGIH, 2012). ŉ Enkele monster in die ontwikkelingsskoonmaak area in die Merensky rif het ŉ blootstelling gehad van 0.032 mg/m^3. Amper geen beduidende verskille was gevind tussen die blootstellingsvlakke van die protokolle, die twee riwwe en die verskillende areas nie. Alhoewel die verskille nie statisties beduidend was nie het die protokol wat deur die myn gebruik is laer blootstellingsvlakke gegee. Die sement werke het die laagste silika blootstelling ervaar. **Gevolgtrekking:** Evaluering van die silika blootstellings in ŉ platina myn het getoon dat die werkers nie ŉ gesondheidsrisiko aan die vlakke van blootstelling betrokke ervaar nie. Die geïmplementeerde beheermaatreëls is dus voldoende om die geassosieerde gesondheid en veiligheidsrisiko's te voorkom. Indien daar enige nuwe gevalle van ernstige siektes (bv. silikose) gerapporteer word sal dit nodig wees om die risiko's geassosieer met silika blootstelling te herevalueer. **Aanbevelings:** Die doel van

silika monitering moet wees om akkurate data te kry wat die ware blootstelling weerspieël van die werker gedurende ŉ werkskof. Akkurate data gee insig in die veiligheid van die werker in. Om dit te bereik moet die monitering so na as moontlik aan die voorgeskrewe metodes gedoen word. Lei werkers op om te assisteer met die identifisering en regstelling van probleme wat tydens monitering kan plaasvind.

CHAPTER 1: INTRODUCTION

General introduction

1.1 Introduction

Underground mining activities where the mined rock contains silica and occupations where cement is used (Calvert *et al*., 2003) exposes workers to crystalline silica dust which could cause silica related illnesses such as silicosis. To minimize the exposure to silica dust and risk of the workers developing silica related illnesses the generation of airborne respirable silica dust should be kept below the occupational exposure level (OEL) as far as possible (Stanton *et al*., 2006). The South African OEL is set at 0.1 mg/m^3 (MHS, 1996) but health risks have been reported for lifetime exposures at levels lower than that (ACGIH, 2010). Other countries have set OELs and TLVs that are significantly lower than South Africa's for example ACGIH (2012) 0.025 mg/m^3 and NIOSH (2002) 0.05 mg/m^3.

The crystalline silica content of the mined ore body in platinum mining is expected to be low, less than 1 %. Much less than when compared to gold and coal mines which has a silica content of 40% to more than 50 % (Stanton *et al*., 2006). Silicosis and other disease associated with silica exposure are to be expected in gold mines and coal mines more than what is found in platinum mines due to the higher silica content in the rock (Nelson *et al*., 2010).

Various sources in a platinum mine generate dust. The largest amounts of dust are generated by blasting, crushing and drilling. Engineering controls are needed to control the dust exposure efficiently (Kissell, 2003). Problems with monitoring silica exposures exist because of differences in sampling equipment (Pretorius, 2011) and analytical methods (NIOSH, 2003).

Important factors that determine the health risk involved in underground platinum mining is the efficiency of the control methods implemented by the workers to minimize the volume of dust that is generated and made available for inhalation as well as the efficiency of the lungs to eliminate the particles from the lungs (NIOSH, 2002).

Silicosis develops when silica particles are retained in the lungs. Silica particles are retained when the lungs are overburdened because the lungs are exposed to excessive amounts of silica or the capability of the lung to remove even a moderate amount of silica particles (Oberdörster, 1995).

1.2 Objectives

- To evaluate the silica exposure levels of 4 different high risk tasks in a platinum mine.
- To compare the mine respiratory dust sampling protocol with NIOSH method 7602.
- To evaluate the sufficiency of the South African exposure limit (OEL) and the risk of workers when exposed to low levels of airborne silica dust.

This will be achieved by:

a) Continuous full shift monitoring of workers in accordance with two protocols and determining as well as comparing the workers time weighted average exposures (TWA).
b) Comparing South African OELs to other international standards.
c) Recommendations given with regard to more accurate silica monitoring.

1.3 Hypothesis

It is proposed that:

a) The silica exposure levels of underground workers in a platinum mine and grout plant workers are below the current South African OEL of 0.1 mg/m^3 as listed in the MHSA.

1.4 References

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CHAPTER 2: LITERATURE STUDY

Literature study

A literature review was completed investigating the conditions and circumstances of silica exposure in a platinum mine.

In the mining industry the workers are exposed to various levels of dust which could contain silica as a constituent of the total dust. Physiological mechanisms are responsible for evacuating the harmful dust from the body to maintain homeostasis. These mechanisms will be discussed along with the possible health effects.

Different sources of dust exposure, the control of dust exposure sources and difficulties in controlling dust exposure will be discussed as well as the legislation associated with silica dust.

2.1 Presence of silica in mining

South Africa is the largest producer of platinum in the world and the platinum deposits found in the Bushveld Complex which is a volcanic intrusion containing many other minerals. Despite of working in such a mineral complex environment there has been very little research conducted and little is known about the health risks of platinum miners' (Nelson and Murray, 2012).

Crystalline silica is a component of almost every mineral deposit and rock type. This means that silica exposure is predominant in mining operations. Levels of silica in minerals sources vary and the material with the highest silica content usually produces the highest exposure levels. Correct assessment can only be ascertained by respirable dust and crystalline silica measurement (Stanton *et al.,* 2006; Greenberg *et al.,* 2007)

The SIMRAC Project GAP 802 (Biffi and Belle, 2003) reported that in platinum mining operations the quartz content of the ore is usually low. The exposure measurements in South Africa indicate a low exposure to respirable crystalline silica and that the analysis of stope rock samples in some platinum mines indicate an inherent silica content of less than 1%. Airborne respirable dust samples that were collected in platinum mines contained a silica content of less than 0.2%. In gold mines the exposure measurements varied between 9% and 39% and for airborne respirable dust from the collected samples varied between 5% and 57%. Respirable dust in gold mining often has a higher quartz content because of the gold bearing reef which has a hard conglomerate of quartz pebbles cemented together by an equally hard siliceous matrix (Stanton *et al*., 2006)

Coal dust contains different elements and their oxides and varies in mineral content from seam to seam. Coal dust is composed essentially of carbon, hydrogen and oxygen with smaller quantities of nitrogen and sulphur and, in all cases, mineral matter that remains as ash when the coal is burnt. GAP 802 (Biffi and Belle, 2003) reported that the average measured silica content of South African coal seams was 3.5%. Respirable coal mine dust usually contains less than 5% quartz (Stanton *et al.*, 2006).

Silica can also be present in the raw materials mines utilize for cement mixing. Various purposes and occupations that are involved in producing or mixing cement may potentially be exposed to silica dust (Calvert *et al.,* 2003).

2.2 Chemical properties of silica

Silica is a compound that is formed from silicon (Si) and oxygen (O) atoms to form silica dioxide (SiO_2). SiO_2 is present in the earth's crust as the second most abundant element and occurs in two specific forms namely: Crystalline silica and amorphous silica. Crystalline silica implies that the orientation and relation of each of the silicon and oxygen atoms are in fixed patterns whereas amorphous silica implies that the orientation and relation to each silica and oxygen atom is random (Stanton *et al.*, 2006; Greenberg *et al.*, 2007)

Amorphous silica exposure in animal inhalation studies showed partially reversible inflammation, granuloma formation, emphysema but no progressive fibrosis of the lungs. Epidemiological studies indicate no proof that amorphous silica induce fibrosis with high occupational exposure however due to the limitations of the data thus far the risk of developing chronic bronchitis, chronic obstructive pulmonary disease (COPD) or emphysema cannot be excluded. Currently there is no classification for amorphous silica concerning its carcinogenicity (Merget *et al*., 2002)..

Naturally occurring polymorphs of crystalline silica exist in a polymerized tetrahedral framework. These polymorphs are a function of temperature and pressure. The most common these polymorphs are alpha quartz, tridymite and cristobalite. Alpha quartz is stable when exposed most pressures and temperatures found in the earth's crust, whereas tridymite and cristobalite are stable at high temperatures and low pressures. There are other polymorphs of silica such as coesite and stishovite which occurs at a wide range of temperatures but only in high-pressure environments and may therefore be created in various industrial processes (Stanton *et al.*, 2006; Greenberg *et al.*, 2007).

2.3 Sources of airborne crystalline silica in mining

2.3.1 Hard rock mines e.g. platinum and gold mining.

Common sources of airborne dust in hard rock mining include:

- blasting
- blast hole drilling and blast hole cleaning
- support and rigging hole drilling
- barring down of loose rock
- face cleaning
- sweeping of fines
- ore tipping
- ore transport and handling
- re-entrainment of dust in dry intake airways owing to increased intake airway velocities and vehicle movement
- transfer and movement of ore in ore-passes and from chutes
- the movement of people and rolling stock along haulages, travelling ways and production areas liberating settled dust

- rock crushing
- backfill placement.
- screening, grinding, milling and pulverising of the ore during processing (Stanton *et al.*, 2006).

The largest quantities of dust are produced by blasting operations and mechanical operations such as those mentioned above. Ventilation is responsible for removing some of the fine dust, however a large amount of dust is trapped under blasted rock. Coarse particles settle out of the air onto surfaces such as footwalls. Finer particles that collide aggregate and form larger particles and can then settle out of the air. Precautions need to be taken to ensure that the settled dust particles do not become airborne again due to activities performed during a working shift and cause secondary exposure. All the workers in a mine are potentially at risk off inhaling airborne dust. Some workers, especially underground workers in the following categories are at a potential higher risk:

- mining crews in stopes and development
- team leaders
- drill operators
- scraper winch operators
- tip/loader operators
- locomotive drivers and crew (Stanton *et al.*, 2006).

2.3.2 Coal mines

Dust in coal mines can be generated by:

- blasting
- drilling
- cutting and transportation (Stanton *et al.*, 2006).

Silica in coal mines may be present as an inherent constituent of the coal itself, usually not a significant source, but in the underlaying or overlaying rock which is frequently removed with the coal produce significant amounts of dust containing silica. In addition, significant amounts of silica exposure occur in rock inclusions known as partings within the coal seam (NIOSH, 1997; Page, 2006). Cutting and blasting in conventional coal mining are the highest sources of generating dust. Roof drilling for support can also be a major dust generating activity if there is no suppression of the dust generated. Primary areas generating dust that is not at or near the coal face area are conveyor belts, coal haulage transfer points and haulage roads. Dust can adhere to the surface of the conveyor belt and can then be made airborne by the vibration of the belt as it passes over the rollers of the belt. Dust adhering to the bottom belt, when returning, can be crushed and pulverised creating an important source of respirable dust. In longwall mining the major dust sources are the shearer/plow, stage loader/crusher and the movement of roof supports. The amount of airborne dust produced by the shearer depends on the seam conditions, the operational parameters and the types of internal and external water sprays in operation. The amount of airborne dust generated by the support advance depends on the immediate roof conditions which vary with the support advancing operation as well as the setting and yielding loads of the supports. As the setting and yielding loads increase, greater amounts of dust are generated (Stanton *et al*, 2006).

2.4 Control Methods

2.4.1 NIOSH recommends the following measures to reduce exposures to respirable crystalline silica in the workplace and to prevent silicosis and death in various industries including, but not specific to, mining and construction. Some of the control measures cannot be practically implemented, for example in an underground mining environment the substance cannot be substituted and therefore other methods of controlling the exposure levels are necessary and will be discussed subsequently:

- crystalline silica materials must be replaced with safer substitutes, if possible.
- engineering or administrative controls should be provided where feasible, such as local exhaust ventilation, and blasting cabinets.
- protective equipment or other protective measures should be used where necessary to reduce exposures below the PEL.

- water sprays which are available for work practices to control dust exposures should be used.
- If respirator protection is required, only a N95 NIOSH certified respirator should be worn.
- the respirator should not be altered in any way. A tight-fitting respirator should not be worn with a beard or moustache that prevents a good seal between the respirator and the face
- a CE abrasive-blast supplied-air respirator should be worn for abrasive blasting.
- disposable or washable work clothes should be worn and a shower facility should be made available if possible
- dust should be vacuumed from clothes or workers should change into clean clothing before leaving the work site.
- participation in training, exposure monitoring, and health screening and surveillance programs should be used to monitor any adverse health effects caused by crystalline silica exposures.
- workers should be aware of the operations and job tasks that create crystalline silica dust that could expose them in the workplace environment. Workers should also know how to protect themselves from silica dust.
- workers should be aware of the health hazards related to exposure to crystalline silica.
- workers should not eat, drink, smoke or apply cosmetics in areas where crystalline silica dust is present.
- hands and face should be washed outside dusty areas before performing any activities (CDC, 1996).

According to Kissell (2003) engineering controls are an important and efficient form of dust control and are designed to suppress dust depending on various factors. Assorted methods for extracting ore exist but there are a lot of common sources of dust exposure and dust control needs.

Kissell (2003) also suggests the following engineering controls for the following tasks:

- ore pass dust control
- drill dust control
- blasting dust control
- conveyor belt dust control
- transfer point and crusher dust control
- roadheader dust control
- the volume of ventilation air to use

(1) Large quantities of airborne respirable dust is produced in ore and waste passes. Any broken rock that is delivered to the passes contains considerable amounts of dust on the rock itself which comes from preceding operations like blasting and loading. The design of the ore and waste pass can help in suppressing dust.

A vital step in controlling the dispersal of dust is to prevent its escape into working areas. This can be accomplished by confining the dust through a system of stoppings and airtight doors over the ore and rock pass tipping locations.

Wetting the rock before it is delivered to tipping sites can reduce dust dispersal.

(2) To minimize the dust generated from drilling, water is injected through the drill steel. This reduces the generation of respirable dust by 95% or more. During initial collaring when the drill hole is started and some dust is generated which is not yet able to be efficiently suppressed by the injection of water.

(3) Water and ventilation are necessary, but the most significant reduction of dust exposure is blasting off-shift. Wetting the area surrounding the blast with water thoroughly beforehand will reduce and prevent dust that settled out from previous operations from becoming airborne again.

(4) Conveyor belts potentially generate large amounts of respirable dust from more than one source, for example, unclean belts, dust that is knocked from the belt when passing over idlers. To reduce this dust source, belt scraping and washing will help

and in case the belt is dry wetting it can help. A great deal of respirable dust arises at belt transfer points.

(5) Transfer points: Traditionally transfer point dust control is done by tightly enclosing the transfer point and exhausting the dust-laden air from the enclosure through a duct. Removing the dust from the air by way of a dust collector or discharging the dust to a return airway.

Crushers: Water sprays and local exhaust ventilation from the crusher enclosure will provide sufficient dust control.

(6) Dust control methods for machines like roadheaders generally depend on a level of dust cloud confinement. Methane that is released along with the dust in mines could by confining the dust cloud, raise the methane concentration.

Ventilation-based controls: Controlling dust via ventilation requires adequate air volume by using an exhaust duct with the duct inlet located close to the face. A second important component in dust control via ventilation is the location and use of water sprays to minimize turbulent air at the face.

Machine-based controls: The most significant dust suppressing method is to control the machinery remotely. This in conjunction with the ventilation-based control methods, allows the machine operator to separate and distance himself from the dust cloud at the cutting face and therefore reduce dust exposure. Another control strategy is to use a wet-head machine with low-pressure sprays to reduce dust exposure; however this is not as effective as remotely controlling the machine.

Lastly an air curtain can be used to hold the dust cloud against the cutting face and away from the operator.

2.4.2 Difficulties in controlling silica exposure

According to Kissel (2003) the lack of dust control programmes or improper implementation of the above mentioned dust control methods may cause unnecessary exposure to the workers. The sources that produce the most dust in hard rock mines are drills, blasting and crushers.

Factors that can lead to high dust levels on drill operators:

- lack of proper maintenance
- failure to use water
- inadequate quantities of water
- plugged water holes in drill steels
- dull drill bits
- dry collaring
- poor maintenance on dust collector systems

Crushers need great amounts of water and air due to the fact that it breaks a lot of rock, which generate large amounts of dust. Water and ventilation are necessary to aid in dust control during blasting operations, but the most significant reduction of dust exposure is blasting off-shift. The quantity of the water spray and the pressure at which it operates as well as the configuration of the water sprays are important for efficient dust control (Kissell, 2003).

2.4.3 Other sources of dust which increase worker exposure unnecessarily include.

Workers who operate mobile equipment that operate with enclosed cabs are potentially exposed to respirable silica dust because the equipment is old and may not provide the operators the desired protection. The older enclosed cab's gaskets and seals deteriorate to a point where it no longer provides adequate sealing. Older cabs may lack filtration and pressurization systems, or poorly designed systems are installed that are incapable of maintaining acceptable air quality within the cab. Minimizing time working downwind from continuous mining machines and the maintenance of dust control systems could decrease the dust exposure (Colinet *et al.,* 2007).

Dust-soiled work clothes are potentially a substantial source of personal dust exposure. Current method of cleaning the clothes (vacuuming) of the workers are difficult and time-consuming, some workers choose to use compressed air to blow dust from their contaminated clothing. Using compressed air to clean clothes is not an approved method, but for either method it is a difficult task to clean the worker's back and legs effectively (Colinet *et al*., 2007).

2.5 Problems with monitoring silica exposures

2.5.1 Samplers.

There is not a standardised sampler for respirable dust because there are different samplers used in South Africa. During 2007/2008 a pilot study was conducted in a South African platinum mine, in which the particle size distribution, expressed as D50, for samples taken was evaluated (Pretorius, 2011). The D50 values of the dust collected on the filters were scattered between 2 and 42 μm, when the expected cut-point for these respirable samplers should be at approximately 4 μm.

It is recommended that a quality assurance test protocol be developed by independent parties other than the manufacturers themselves. The samplers should be tested and approved before it is made commercially available. The samplers should be standardised so that all mines sample with the same respirable dust sampler and subsequently all laboratories must use the standardised sampler to calibrate their methods. This will improve consistency and reliability for dust and silica results (Pretorius, 2011).

2.5.2 Analytical methods.

The NIOSH Analytical Method 7500 most likely underestimates the silica content of an airborne respirable dust sample by only 5–10 %. The results of a study done by Page (2006) suggested that any changes that may have occurred in the median respirable size of airborne coal mine dust are not significant enough to cause any appreciable error in the current methods used for respirable crystalline silica analysis.

X-ray Diffraction (XRD) can distinguish between the three types of silica polymorphs and silica interferences can be wiped out by treating the sample with phosphoric acid. Infrared (IR) methods can also quantify quartz, cristobalite and tridymite when amorphorous silica and silicates are not present in large amounts. Sensitivity can however be reduced if multiple polymorphs are present and secondary peaks are therefore needed. Crystalline silica can also be determined by visible absorption spectrophotometry, but silica polymorphs cannot be distinguished by this technique. Visible absorption methods also have larger laboratory-to-laboratory variability than

XRD and IR methods and are therefore recommended for research use only according to NIOSH method 7602 (NIOSH, 2003).

2.6 Legislation

2.6.1 Background

The Health and Safety Executive (HSE) introduced a Maximum Exposure Limit (MEL) for respirable crystalline silica (RCS) of 0.4 mg/m^3 for an 8-hour time weighted average (TWA) in 1992. In 1997, the MEL was reduced to 0.3 mg/m^3 following the adoption of the ISO/CEN sampling convention for respirable dusts. The HSE issued a chemical hazard alert notice in 2003 (CHAN 35) on RCS that stated that current evidence then indicated workers exposed to 0.3 mg/m^3 on a regular basis had much higher risk of lung damage than previously believed. The HSE believed it should be reasonably practicable for all industry sectors to reduce RCS control limits to 0.1 mg/m^3 for an 8-hour TWA (Stanton *et al.*, 2006).

In 1995 the South African Department of Labour based its OELs on the HSE's OEL of 0.4 mg/m^3. In 2002 the Department of Energy and Minerals set an OEL of 0.1 mg/m^3 for RCS. In 2005 the Department of Labour planned to reduce its crystalline silica OEL-Control Limit from 0.4 mg/m^3 to 0.1 mg/m^3 in 2006 (Stanton *et al.*, 2006). Only in 2008 did the Department of Labour amend the occupational exposure limit from 0.4mg/m^3 to 0.1 mg/m^3 (SA, 2008).

2.6.2 South Africa vs. International Standards

Table 1: South African OEL vs. International standards

Standard	(mg/m^3)
MHS:Mine Health and Safety Act (1996) (South Africa)	OEL - 0.1
ACGIH: American Conference of Industrial Hygienists (2012) (United States)	TLV - 0.025
SWEA: The Swedish Work Environment Authority (2011)	OEL - 0.05
NIOSH: National Institute for Occupational Safety and Health (2002)	OEL - 0.05
Work safe Australia (WHS) (2011)	OEL - 0.1

Judges in the Constitutional court ruled on a case in 2011 that lung-diseased employees in South African mines can now sue the employers for damages directly. If a class action suit against the mines is successful it could cost the mining industry billions of dollars (Cropley, 2012).

When comparing South Africa's OEL value for silica exposure of 0.1 mg/m^3 (MHS, 1996) against the NIOSH OEL of 0.05 mg/m^3 (NIOSH, 2002) and the ACGIH already recommending values of half that at 0.025 mg/m^3 (ACGIH, 2012) workers in the future could argue that the Department of Minerals and Resources and the mines themselves were aware that the South African OEL was not safe and could therefore be held accountable for the negative health effects.

2.7 Physiological background

2.7.1 Background

The environmental particles are deposited in the different anatomic structures of the human lung depending on the size of the inhaled environmental particles. The lung acts as a serial filter system during inhalation and removes environmental particles from the inhaled air with large particles effectively deposited in the extrathoracic region (nose, larynx) and in the intrathoracic airway bifurcations due to impaction. At the airway bifurcations the particles do not follow the airstream because inertia causes the larger particles to deposit on the airway epithelium. This mechanism is effective for high inhalation flow rates. Penetration of air into deeper parts of the lung causes the air velocity to decrease rapidly. For this reason there is a second mechanism that causes the particles to fall out of the airstream and deposit on the wall of small airways and in the alveoli called sedimentation (Möller, 2004; Greenberg *et al.*, 2007).

Depending on the mechanism of deposition and thoracic region where the particles deposit, which is dependent on the aerodynamic fractions, there will be differing mechanisms of particle clearance (Greenberg *et al.*, 2007). To maintain homeostasis in the lungs the airways are covered by a mucus layer that is transported out of the lung by ciliary beating which results in fast removal of deposited particles where the airspeed is high. In the lung periphery where the airways bifurcate and air flow is low there is no mucus to transport these particles out of the lungs, therefore alveolar macrophages phagocytise any foreign particles and digest it. Particles of low solubility can be retained for long times within the lungs and are digested within macrophages (Möller, 2004).

Aerodynamic fractions are defined as follow*:* Inhalable fraction (particles with a 50% cut-point of 100μm), the fraction of airborne material that can be inhaled by the nose or mouth, and can deposit anywhere in the respiratory tract. Thoracic fraction (particles with a 50% cut-point of 10μm), the fraction of airborne material particles that passes the larynx. Respirable fraction (particles with a 50% cut-point of 4μm), the fraction of particles that penetrate the gas exchange region of the of the lung (EUR, 2002). Some countries (e.g. Britain, Australia and Finland) have adopted these criteria in their standards for occupational aerosol exposure. There is only a small number of occupational exposure limits (OEL) subscribed to the respirable fraction (e.g. crystalline silica and copper fume). There are no OELs based on thoracic exposure (Linnainmaa *et al*., 2007).

When the above mentioned removal mechanisms are overburdened or the lungs are impaired due to smoking, the removal of the silica particles are not as efficient or the lungs are then incapable of removing the deposited silica particles thus leading accumulation of excessive lung burden(Oberdörster, 1995). A possible association exists between the increasing cumulative weight of retained silica in the lung (the pulmonary silica burden) and the subsequent development of silicosis and this could also increase the severity of silicosis. Other minerals are also important in the development of silicosis. When dealing with relatively pure silica, such as in gold mines, the total amount of retained dust amounting to 1- 3 grams could be sufficient enough to develop silicosis. Sequent exposure to other, relatively non fibrogenic dust such as in coal mines will produce little silicosis with the same weight of dust (Mossman and Churg, 1998; Greenberg *et al.*, 2007).

2.7.2 Health effects

Occupational exposures to respirable crystalline silica (SiO_2) are associated with various diseases which include the development of silicosis, lung cancer, pulmonary tuberculosis and airway diseases. These exposures may also be related to the development of autoimmune disorders, chronic renal disease and other adverse health effects. Recent epidemiologic studies demonstrate that workers have a significant risk of developing chronic silicosis when they are exposed to respirable crystalline silica over a working lifetime at the current OEL of 0.05 mg/m^3 recommended by NIOSH (NIOSH, 2002). Reports done for the ACGIH show that a lifetime exposure to silica at an OEL of 0.06 mg/m^3 has a significant increase in developing silicosis which suggests that an OEL of 0.05 mg/m^3 is not sufficiently protective (ACGIH, 2010).This could pose a problem in the South African mining industry as the OEL value for crystalline silica is set at 0.1 mg/m^3 which is four times the level in question by the ACGIH. (MHS, 1996) The ACGIH is already recommending a TLV of 0.025 mg/m^3 however NIOSH still continues to recommend an exposure limit of 0.05 mg/m^3 as a time-weighted average (TWA) for up to a 10-hr workday during a 40-hr work week until improved sampling and analytical methods are developed for respirable crystalline silica overexposure to crystalline silica could cause silicosis which in severe cases can be disabling or even fatal and there is no cure for silicosis. It affects lung function and makes workers more susceptible to lung infections like tuberculosis. (NIOSH, 2002).

The IDLH (immediately dangerous to life or health concentrations) is set at 25 mg/m^3 for cristobalite and tridymite and set at 50 mg/m^3 for quartz. This is based on being 500 times the 1989 OSHA PELs of 0.05 mg/m^3 and 0.1 mg/m^3 respectively. Available toxicological data contain no evidence that an acute exposure to a high concentration of crystalline silica would impede escape from the working area or cause any irreversible health effects within 30 minutes of exposure. (CDC, 1994)

2.8 Silicosis

2.8.1 Background

In gold mines the crude proportion of silicosis for Caucasian miners was six times that of Black miners in 1975. By 2007, it was 1.5 times higher for black miners. The proportion of miners with silicosis increased from 0.03 to 0.32 for black miners and from 0.18 to 0.22 for Caucasian miners. Although it must be mentioned that time of employment and age may be the reason for this increase (Nelson *et al.,* 2010).

2.8.2 Silicosis is classified in three types namely:

Acute silicosis occurs after a few weeks or months of extremely high exposure or up to 5 years of extremely high exposure to crystalline silica. Symptoms include shortness of breath, weakness and weight loss and death (OSHA, 2002; NIOSH, 2002).Hypertrophic pneumocytes are present in the acute setting and may produce excessive amounts of proteinaceous material and surfactant protein which may fill the alveoli with protein-containing material.In the acute setting formation of excessive free-radicals may also contribute to the development of silicotic lung disease. (Greenberg *et al,* 2007)

Chronic or classic silicosis is the most common form of silicosis and occurs after many years (between 15 to 20 years) of moderate to low exposure to respirable crystalline silica. Progressive silicosis symptoms include shortness of breath when exercising as well as poor oxygen and carbon dioxide exchange. Later on the worker may experience fatigue, severe shortness of breath chest pain and respiratory failure (NIOSH, 2002). The exact mechanisms has not yet been elucidated but the theory behind it is that fine particles of silica dust are inhaled and deposited in the lungs where macrophages ingest the dust particles in an attempt to clear the silica particles. If the burden on the macrophages are to big it may become damaged and it is the damaged macrophages that will set off an inflammation response by releasing tumour necrosis factors, interleukin-1, leukotriene B4 and other cytokines. In turn, these stimulate fibroblasts to proliferate and produce collagen around the silica particle, thus resulting in fibrosis and the formation of the nodular lesions (Greenberg *et al.,* 2007).

Accelerated silicosis occurs after 5 – 10 years of high exposure to respirable crystalline silica. Symptoms are shortness of breath, weakness and weight loss. It takes longer for the symptoms to appear than in the case of acute silicosis (OSHA 2002; NIOSH 2002).

2.8.3 Pathological Mechanisms in Silicosis

There are various clinical and pathological types of silicosis that include simple or nodular silicosis, acute silicosis (silicoproteinosis), complicated silicosis (progressive massive fibrosis) and interstitial fibrosis.

The pulmonary tissue of silicotic lungs suffering from simple silicosis presents itself as darkened and in conjunction with associated enlarged and fibrotic hilar and peribronchial lymph nodes. Pulmonary nodules in the lung parenchyma are present in most cases and are usually located in the upper lobes. Lesions that characterize this condition may vary in degree of calcification and could be only a few millimetres to more than a centimetre in diameter.

Complicated silicosis develops when the lesions of simple silicosis coalesce and form pulmonary masses of 2 cm or larger. Complicated silicosis may progress to a stage of central necrosis with cavitation. Secondary infections may develop with a variety of mycobacterial organisms including: *Mycobacterium tuberculosis, Mycobacterium kansasii,* and *Mycobacterium intracellulare*.

On examining microscopic sections it may reveal silica-containing macrophages and reticulin fibers which could then organize and form the classic silicotic lung nodules which consist of a hyaline centre and collagen fibres concentrically arranged around the centre. The periphery of these areas consist of varied inflammatory cells such as macrophages and lymphocytes that progress away from the centre. This outward configuration induces a fibrous reaction in normal vessel, airway and pleural structures (Greenberg *et al*., 2007, NIOSH 2002).

Removing a worker from a working area to eliminate silica exposure does not stop the development or progression of chronic silicosis. This means it is not guaranteed that a worker will not develop silicosis or silicosis diseases or that the impaired worker’s condition will stabilize (NIOSH, 2002). Even in the absence of silicosis and after exposure to silica dust ends, silica dust exposure is a risk factor in the development of pulmonary tuberculosis and the risk of pulmonary tuberculosis increases with the presence of silicosis (Hnizdo and Murray, 1998).

When considering the problem that silica poses to the health of mine workers and the challenges faced when monitoring the workers, it is imperative to obtain data that accurately represents silica dust exposure to protect the workers from risk.

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Jones and Brown (1995) observed total breakdown of control..., or

Total breakdown of control has sometimes been observed (Jones and Brown, 1995; Horspath *et al*., 2006). At the end of the paper, references should be listed in alphabetical order by name of first author, using the Vancouver Style of abbreviation and punctuation. ISBNs should be given for books and other publications where appropriate. Material unobtainable by readers should not be cited. Personal Communications, if essential, should be cited in the text in the form (Professor S.M. Rappaport, University of California). Internet material can be referred to if it is likely to be permanently available; the date on which it was last accessed should be given. References will not be checked editorially, and their accuracy is the responsibility of authors.

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CHAPTER 3: ARTICLE

Crystalline silica exposure in platinum mining: A task based approach

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3.1 Abstract

Keywords: Silica, silicosis, OEL, protocols, platinum, personal samples.

Background: Platinum mine workers are considered to be exposed to silica levels that are low enough to be of no safety or health concern. New studies however have found evidence of silicosis in workers that had no apparent exposure to silica outside of a platinum mine. **Objectives:** To evaluate the silica exposure levels of 4 different high risk tasks at a platinum mine. To evaluate the sufficiency of the South African exposure limit (OEL) and to evaluate the risk to workers at these expectedly low levels of airborne silica dust. To compare the differences in protocol due to practical reasons used by the mine to NIOSH method 7602. **Methods:** Dust sampling was conducted by means of 2 cyclone samplers (aspirated at 2.2 L/min) in the breathing zone of each of the 48 workers in 4 different areas. The use of 2 cyclone samplers was used to compare 2 different protocols. The first protocol reflected the method used by the mine and the second was done in accordance with the NIOSH method 7602. Sampling occurred in the vamping, development cleaning, belt attendant and grout plant areas. A 25 mm MCE filter was used to capture the respirable fraction. The quartz content of the filter was determined by a SANAS accredited laboratory using qualitative infrared spectroscopy in accordance with NIOSH method 7602. Additional bulk samples were taken to be analysed for silica as well. **Results:** All but one sample were below the respective OELs of 0.1 mg/m^3 (MHS, 1996), 0.5 mg/m^3 (NIOSH, 2002) and 0.25 mg/m^3 (ACGIH, 2012). A single sample in the development cleaning area in the Merensky reef had a value of 0.032 mg/m^3. No significant

differences were found in the exposure levels between the two protocols, the two reefs or the different underground areas. The grout plant had the lowest silica exposure levels. **Conclusions:** Upon evaluating the silica exposures of platinum mine workers there does not seem to be a health or safety risk involved at these low level exposures. The implemented control measures are therefore sufficient in preventing the development of applicable health and safety risks. However if any new cases of severe illness (e.g. silicosis) occur it may be necessary to re-evaluate the risks involved with silica exposure.

3.2 Introduction

South Africa is the largest producer of platinum in the world and the platinum deposits are found in the Bushveld Complex which is a volcanic intrusion containing many other minerals (Nelson and Murray., 2012).Platinum workers are becoming one of the largest workforces in the mining industry and in spite of working in such a mineral complex environment there is not much existing data and insufficient information concerning the respiratory health of platinum miners (Haskins, 2008). Historical occupational hygiene data indicate a low to absent risk involving silica exposure in platinum mines because silicosis is not expected to occur in platinum mines due to the low silica content of the mined rock (Haskins, 2008;Nelson and Murray, 2012). Autopsies of mine workers that had no exposure to silica dust outside of the platinum mining industry had shown cases of fibrotic nodules in the lymph nodes and silicosis (Nelson and Murray., 2012). It is therefore necessary to investigate the possibility of overexposure due to task based exposure and also to assess the sufficiency of the current OEL. This is important for both the health and safety of the workers in platinum mines and also holds financial and legal implications for the mining industry. The mine selected for sampling was identified by the historical occupational data as having the highest risk concerning silica exposure and the tasks selected by the occupational hygienist of the particular mine.

Crystalline silica poses a health risk to workers in the mining industry because silica exposure is prevalent in mining operations. Crystalline silica is a component of almost every mineral deposit and rock type and the amount of silica in mineral sources may vary. The material with the highest silica content usually produces the highest exposure levels. Platinum baring ore usually has a quartz content which is low and the exposure measurements in South African platinum mines indicate a low level of exposure to respirable crystalline silica which is less than 1%. Airborne respirable dust samples in platinum mines contained a silica content of less than 0.2% (Stanton *et al.*, 2006). These low exposures are expected in both the Merensky and the UG2 reefs even with the reefs differing in composition (Schouwstra& Kinloch, 2000). In gold mines the exposure measurements vary between 9 % and 39 % and for airborne respirable dust from the collected samples vary between 5 % and 57 %. Coal dust contains different elements and their oxides and it varies in mineral content from seam to seam. The average measured silica content of South African coal seams is 3.5% with the respirable fraction of mine dust that usually contains less than 5% of quartz (Stanton *et al.*, 2006).The sources that produce the most airborne dust in hard rock mines such as platinum and gold mines are drills, blasting and crushers (Kissell, 2003). Occupations associated with cement production or mixing have the potential of being exposed to silica dust as well (Calvert *et al*, 2003).

Lack of a dust control programme or improper implementation of dust control methods may cause unnecessary dust exposure to the workers. Other sources of dust which increase worker exposure unnecessarily may include workers operating mobile equipment with enclosed cabs that are not properly maintained. These workers are potentially exposed to respirable silica dust because the equipment is old and may not provide the operators the desired protection. Dust-soiled work clothes are another potentially substantial source of personal dust exposure. Since the ideal method of cleaning the clothes (vacuuming) of the worker is difficult and time-consuming, some workers choose to use compressed air to blow dust from their contaminated clothing (Colinet *et al*., 2007).

Some difficulties exist in obtaining the most accurate data and this is due to the different cyclone samplers being used in South Africa because there are no standardised samplers for respirable dust. The manufacturers specify a specific flow rate so that the cut-point for a sampler is 4 μm. The D50 (50 % of the particles collected are below a specified value in μm) values of the dust collected on the filters of the different samplers were scattered between 2 and 42 μm, when the expected cut-point for these respirable samplers should be at approximately 4 μm (Pretorius, 2011).

Silicon (Si) and oxygen (O) atoms form silica dioxide (SiO_2) which is present in the earth's crust as the second most abundant element. Silica occurs naturally in two specific forms namely: Crystalline silica and amorphous silica. Crystalline silica implies that the orientation and relation of each of the silicon and oxygen atoms are in fixed patterns whereas amorphous silica implies that the orientation and relation to each silica and oxygen atom is random (Stanton *et al.*, 2006; Greenberg *et al.*, 2007).Occupational exposures to respirable crystalline silica (SiO_2) are associated with various diseases which include the development of silicosis, lung cancer, pulmonary tuberculosis and airway diseases. These exposures may also be related to the development of autoimmune disorders, chronic renal disease and other adverse health effects (NIOSH, 2002). Animal inhalation studies of amorphous silica exposure showed partially reversible inflammation, granuloma formation and emphysema but no progressive fibrosis of the lungs. Epidemiological studies report no proof of amorphous silica inducing fibrosis associated with high occupational exposure. The risk of developing chronic bronchitis, chronic obstructive pulmonary disease (COPD) or emphysema cannot be excluded. There is no classification for amorphous silica concerning its carcinogenicity (Merget *et al*., 2002).

Depending on the mechanism of deposition and thoracic region where deposition takes place, there will be different mechanisms of clearance (Greenberg *et al.*, 2007). To maintain homeostasis in the lungs the airways are covered by a mucus layer which is transported out of the lung by ciliary beating that results in fast removal of deposited particles where the airspeed is high. In the lung periphery where the airways bifurcate and air flow is low and there is no mucus to transport these particles out of the lungs, the alveolar macrophages phagocytise any foreign particles and digest it. Particles of low solubility can be retained for long times within the lungs and are digested within macrophages (Möller *et al.*, 2004). When the removal mechanisms are overburdened or impaired, the removal of the silica particles are not as efficient or the lungs are incapable of removing the deposited silica particles. The volume of particles phagocytized by the alveolar macrophage is the most critical for causing impairment. A possible association exists between the increasing cumulative weight of retained silica in the lung (the pulmonary silica burden) and the subsequent development of silicosis and could also increase the severity of silicosis (Oberdörster, 1995).

Overexposure to crystalline silica could cause silicosis which in severe cases can be disabling or even fatal and there is no cure for silicosis. It affects lung function and makes workers more susceptible to lung infections like tuberculosis (NIOSH, 2002; Greenberg *et al.,* 2007).

Silicosis is classified in different types namely:

Acute silicosis: Occurs after a few weeks or months and up to 5 years of extremely high exposure to crystalline silica. Symptoms include shortness of breath, weakness and weight loss and death (NIOSH, 2002;OSHA, 2002).

Chronic or classic silicosis: The most common form of silicosis and occurs after long periods of moderate to low exposure to respirable crystalline silica (between 15 to 20 years). Symptoms: shortness of breath when exercising and poor oxygen and carbon dioxide exchange. Later on the worker may experience fatigue, severe shortness of breath chest pain and respiratory failure (NIOSH, 2002).

Accelerated silicosis: Occurs after 5 – 10 years of high exposure to respirable crystalline silica. Symptoms: shortness of breath, weakness and weight loss. It takes longer for the symptoms to appear than in the case of acute silicosis (NIOSH 2002; OSHA 2002).

If a worker is removed from a work area to eliminate the silica exposure it does not stop the development or progression of chronic silicosis (NIOSH, 2002).Even in the absence of silicosis or even after exposure to silica dust ended, silica dust exposure is still a risk factor in the development of pulmonary tuberculosis and the risk of pulmonary tuberculosis increases with the presence of silicosis (Hnizdo& Murray, 1998).

Despite silica exposure that is expected to be low there may still be a risk involved at or even below the levels that are considered to be safe. It is therefore important to ascertain an accurate and true representation of the actual silica exposure to workers in the platinum industry.

Epidemiological studies demonstrate that workers have a significant risk of developing chronic silicosis when they are exposed to respirable crystalline silica over a working lifetime at the current OEL of 0.05 mg/m^3 recommended by NIOSH

(NIOSH, 2002). Reports done for the ACGIH show that a lifetime exposure to silica at an OEL of 0.06 mg/m^3 has a significant increase in developing silicosis which suggests that an OEL of 0.05 mg/m^3 is not sufficiently protective (ACGIH, 2010).This could pose a problem in the South African mining industry as the OEL value for crystalline silica is set at 0.1 mg/m^3. (MHS, 1996) The ACGIH is already recommending an TLV of 0.025 mg/m^3, however, NIOSH still continues to recommend an OEL of 0.05 mg/m^3 as a time-weighted average (TWA) for up to a 10-hour workday during a 40-hour work week until improved sampling and analytical methods are developed for respirable crystalline silica (NIOSH, 2002). Additionally Sweden recommends an OEL of 0.05 mg/m^3(SWEA, 2011)and Australia still recommending an OEL of 0.1 mg/m^3 (WHS, 2011).

3.3 Methods

3.3.1 Selection of work areas and tasks

Dust sampling was conducted by means of cyclone samplers on 48 (24 in the UG2 reef and 24 in the Merensky reef) high risk workers in 4 different working areas in a platinum mine in the North West province, South Africa. The mining site that was sampled was identified as a site with a high silica exposure by the mines occupational hygienist. High risk workers were identified depending on the task that was performed in conjunction with a hygienist on site. The 4 tasks that were identified were: Vamping, development cleaning, belt attendants and grout plant workers. Workers in the vamping area are equipped with shovels to scrape the ore into the side gullies. The ore in the side gullies are then scraped clean with a scraper winch into the centre gully. Development cleaning occurs after blasting. The blasted rock is loaded into trains by a loader. Belt plant workers operate the conveyor belts and control the loading of the rock into appropriate containers which then travel to the crushers. Grout plant workers are responsible for mixing and preparing cement for various applications. The mixing is controlled from an enclosed control booth.

3.3.2 Sampling and analyses of samples

During sampling the personal sampling pump was mounted on a belt attached to the cover all designed to hold the pump. The belt would allow for the pump to be held in place without causing discomfort to the worker and the sampling head was placed on the collar of the worker’s cover all within the breathing zone of the worker. Each pump was calibrated beforehand with a representative sampler in line and calibrated again at the end of the 8 hour shift. If the flow rate of the pre-and-post calibrations differed by more than 5% the specific filter was not used for analyses. The sampling pumps were calibrated with a soap bubble burette. A filter cassette holder with the filter and cyclone sampler was connected to the calibrated personal sampling pump. Dust was collected by drawing ambient air through the filter of the cyclone sampling head at a constant air flow rate of 2.2 L/min as stated by the cyclone manufacturer (SKC) and NIOSH method 7602 (NIOSH, 2003). A 25 mm MCE filter was used to capture the respirable fraction.

Two sampling pumps were attached to each worker for conducting sampling according to two differing protocols. The first protocol (P1) was done in accordance to the mines protocol where the pump was attached and started at the lamp house, which is located above ground, before going underground and working a full shift and then stopped sampling only when the workers got back to the lamp house. The second protocol’s (P2) pump was attached and started at the start of actual work underground and stopped at the end of shift before leaving the work area.

After sampling the cassette filter holder containing the filter, it was transported in a rubber foam lined carrier case to avoid the loss of dust from the sample filter back to the lab where the survey filters were acclimatized for 24 hours and then weighed. Filters with sufficient dust were analysed by a SANAS accredited laboratory to determine the alpha quarts content by qualitive infrared spectroscopy of the respirable fraction in accordance with NIOSH method 7602. For quality purposes the analysis results were then verified by a second accredited laboratory. Within the four identified areas, two workers were monitored twice on consecutive days.

Seven additional dust bulk samples were collected from overhead structures in the monitored areas and analysed for silica.

For the purposes of this study each sample that was measured below the detection limit (BDL) was treated in accordance to the limit of detection (LOD) and limit of quantification (LOQ) IUPAC methods (Thomsen *et al.,* 2003). This method yields heterogeneous values which can be compared to each other. Other methods of treating data below the BDL such as beta substitution yields homogeneous values for all samples taken and therefore would have been incomparable.

3.3.3 Environmental Factors

The condition of the dust and the effectiveness of the watering down process were noted as it could have a significant influence on the amount of dust release and subsequent exposure during mining activities.

3.3.4 Statistical Analysis

An independent t-test was used to determine if significant statistical differences in exposure were present between the two protocols as well as between the Merensky reef and the UG 2 reef. A three way ANOVA determined if the average exposure differences were statistically significant for all 4 areas. For both the t-test and the ANOVAs a statistically significant value was indicated by a p-value ≤ 0.05.

3.4 Results

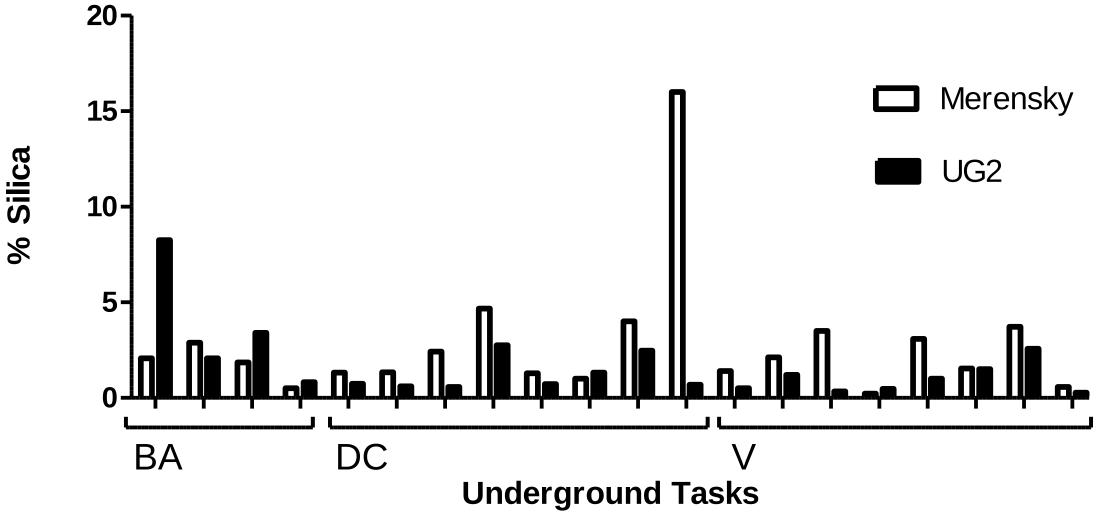

Figure 1: Percentage silica of airborne dust for all underground tasks in Merensky and UG2 reefs (BA: Belt attendants, DC: Development cleaning and V: Vamping).

Figure 1 compares the percentages of respirable silica dust in personalised samples for the three different underground work areas on both the Merensky reef and the UG2 reef. The three different areas are represented on the x-axis.. The silica content for most samples were well below 5 % with two high values of 8 and 16 %.

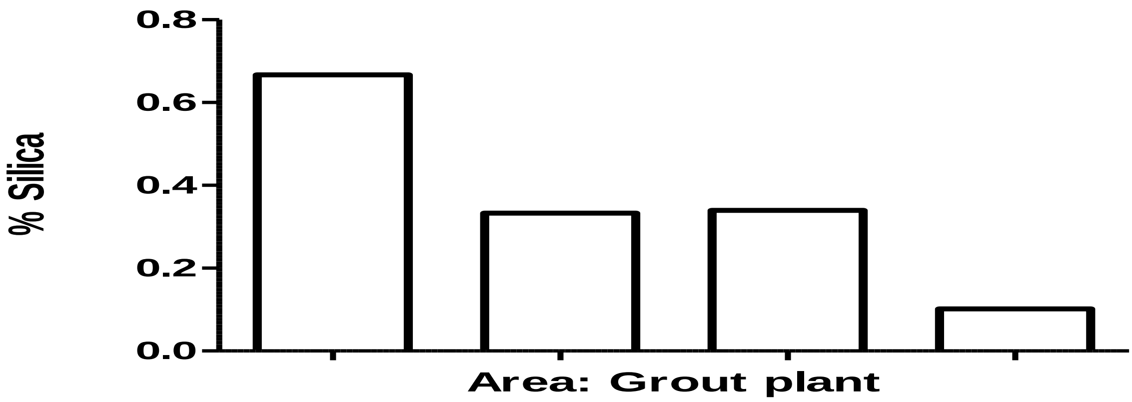

Figure 2: Percentage silica in airborne dust at the grout plant

Figure 2 indicates the percentages of the 8 respirable silica dust personal samples at the grout plant area. Four of the eight samples returned a zero result with the highest silica content of a sample of less than 0.7 %.

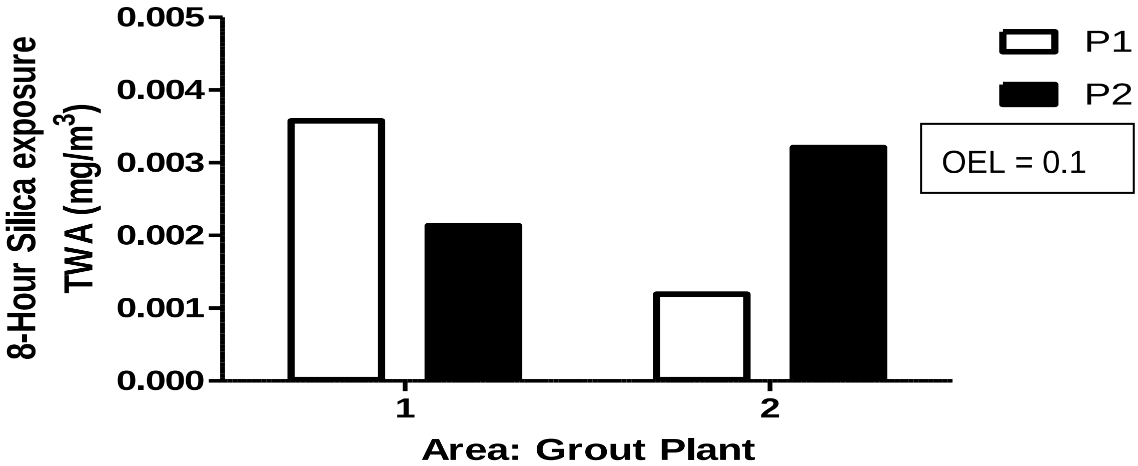

Figure 3: Silica exposure of grout plant workers (P1: Protocol 1 and P2: Protocol 2).

Figure 3 indicates the TWA exposure levels compared to each protocol of the grout plant workers to respirable silica dust. Four samples were taken according to each protocol. Out of the eight samples taken four samples returned a zero result. The highest exposure measured was less than 0.004 mg/m^3. The exposure levels experienced by the workers were below the respective OELs of 0.1 mg/m^3 (MHS, 1996), 0.05 mg/m^3 (NIOSH, 2002) and 0.025 mg/m^3 (ACGIH, 2012).

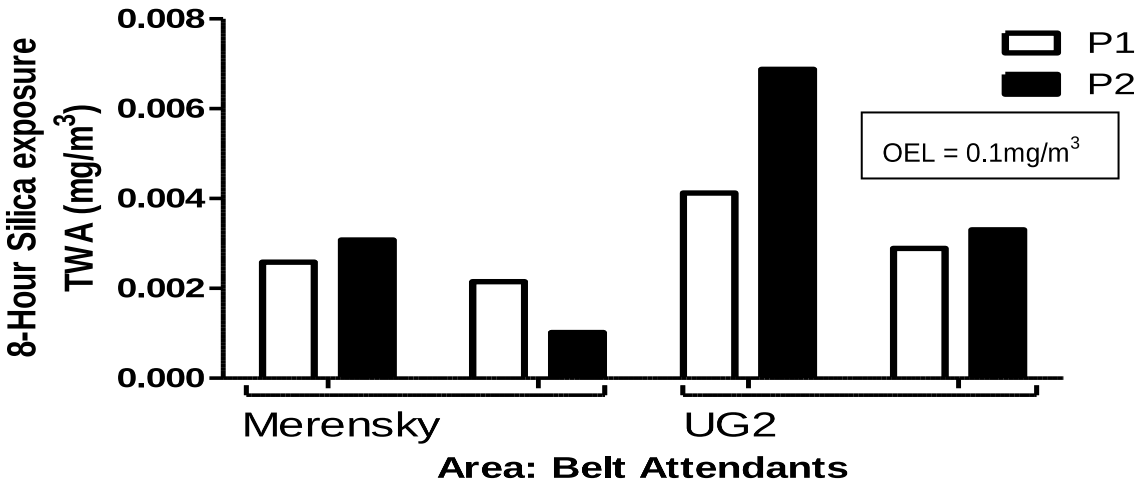

Figure 4: Silica exposure of belt attendants (P1: Protocol 1 and P2: Protocol 2).

Figure 4 indicates the TWA exposure levels of the belt attendants to airborne silica dust. Two samples were taken according to protocol 1 (P1) on both the reefs. Two samples were taken according to protocol 2 (P2) on both reefs. A total of 8 samples were taken. Protocols (P1 and P2) are grouped next to each other for comparison within the associated reefs. The exposure levels experienced by the workers were below the respective OELs of 0.1 mg/m^3 (MHS, 1993), 0.05 mg/m^3 (NIOSH, 2002) and 0.025 mg/m^3 (ACGIH, 2010).

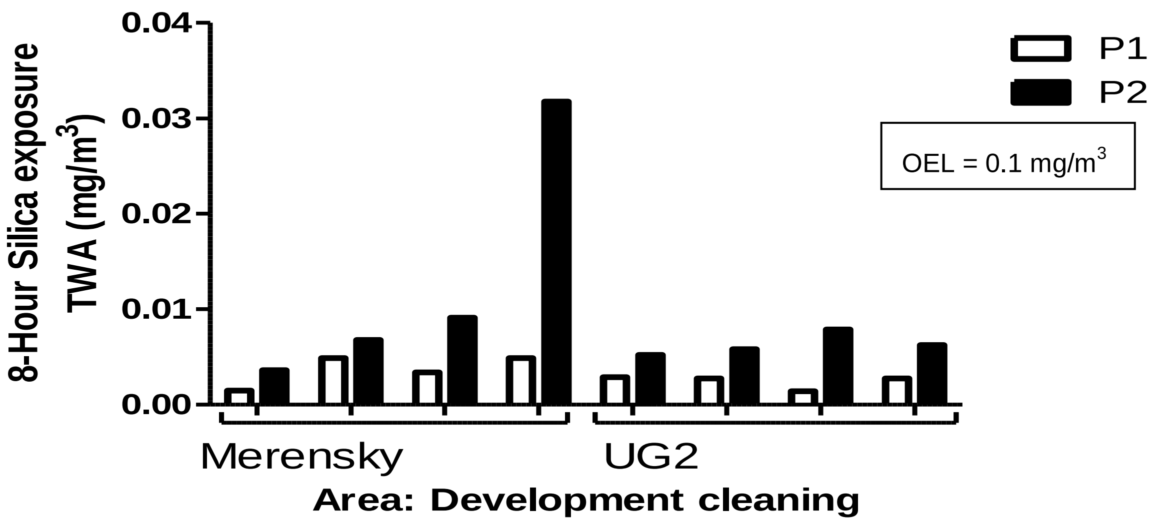

Figure 5: Silica exposure of belt attendants (P1: Protocol 1and P2: Protocol 2).

Figure 5 indicates the exposure levels of workers, working in the development cleaning area in both the Merensky and the UG2 reefs to airborne silica dust. Four samples were taken according to protocol 1 (P1) on both reefs. Four samples were taken according to protocol 2 (P2) on both reefs. A total of 16 samples were taken. Protocols (P1 and P2) are grouped next to each other for comparison within the associated reefs. A single sample in the development cleaning area in the Merensky reef had a value of 0.032 mg/m^3 putting it above the ACGIH's TLV of 0.025mg/m^3 (ACGIH, 2012). The exposure levels experienced by the rest of workers were below the respective OELs of 0.1 mg/m^3 (MHS, 1996), 0.05 mg/m^3 (NIOSH, 2002) and 0.025 mg/m^3 (ACGIH, 2010).

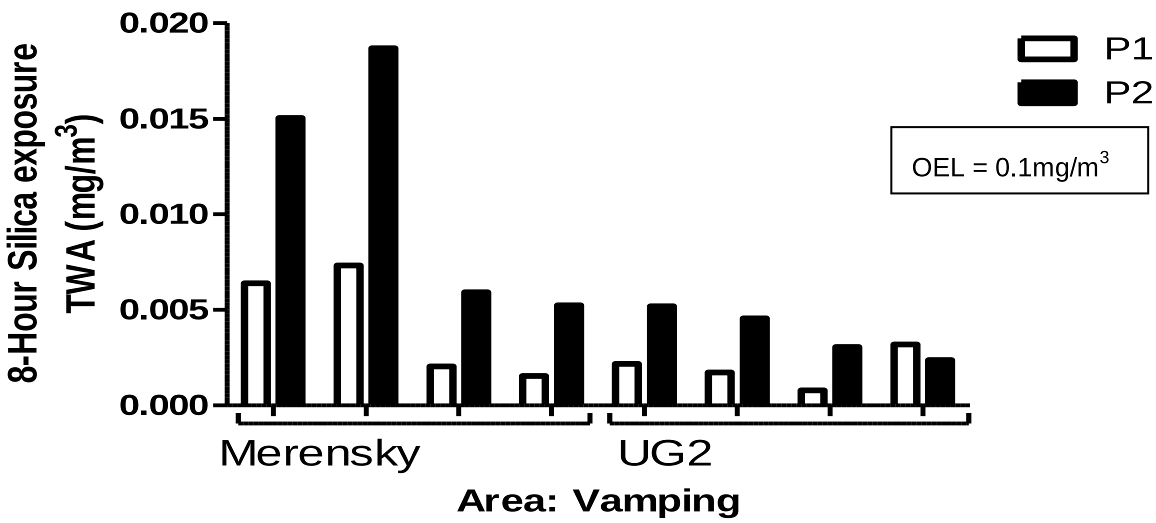

Figure 6: Silica exposures of vamping crews (P1: Protocol 1 and P2: Protocol 2).

Figure 6 indicates the exposure levels of workers, working in the vamping area in both the Merensky and the UG2 reefs to airborne silica dust. Four samples were taken according to protocol 1 (P1) on both reefs. Four samples were taken according to protocol 2 (P2). A total of 16 samples were taken. Protocols were grouped together for comparison within the associated reefs. Two workers were respectively exposed to 0.15mg/m^3 and 0.19mg^3 which are above the action level of the ACGIH's TWA TLV of 0.025 mg/m^3 (ACGIH, 2012). The exposure levels experienced by the rest of workers were below the respective OELs of 0.1 mg/m^3 (MHS, 1996), 0.05 mg/m^3 (NIOSH, 2002) and 0.025 mg/m^3 (ACGIH, 2010).

Table 1 indicates the statistical significance by way of 3 way ANOVA of the worker's silica exposure in the two reefs, the 3 underground working areas and the 2 different protocols. A p-value of less than 0.05 for protocol is indicated.

Table 1: Statistical analysis by three way ANOVA for all underground tasks.

	All undergroundareas
Reef	**p = 0.188**
Area	**p =0.374**
Protocol	**p =0.027**

Table 2 indicates that the statistical difference (p-value less than 0.05) calculated in protocol is only found in the vamping area and not found in the other two areas.

Table 2: Statistical analysis of unvariate significance for all underground tasks comparing p-values for reef and protocol for areas vamping, development cleaning and belt attendant area.

	Vamping	**Development cleaning**	**Belt attendant**
Reef	**p = 0.022**	**p = 0.256**	**p = 0.125**
Protocol	**p = 0.038**	**p = 0.068**	**p = 0.590**

The silica content of the bulk samples taken in the 3 underground areas are shown in table 3. The bulk samples were all below the detection limit (BDL).

Table 3: Silica content of bulk samples taken in surface and underground areas.

Sample description	**Crystalline silica (mg/50 mg)**
Grout plant	<0.005
Development cleaning	<0.005
Vamping	<0.005

3.5 Discussion

Figure 1 and 2 indicates the silica content in percentages of the samples taken of the underground tasks (vamping, development cleaning and the belt attendants) and the above ground task (grout plant). This usually gives a good indication of where the highest silica exposure may occur (Stanton *et al*., 2006). From these figures we expect the highest exposure in the development cleaning and vamping areas. Comparing graphs 3 to 6, the time weighed average for alpha quartz in all 4 areas (below and above ground tasks) were below the South African TWA OEL of 0.1 mg/m^3 and below the action level of half the South African TWA OEL. These low levels of silica were confirmed by both the analysis laboratories. Legislatively the mine complies with the current TWA OEL set by the Department of Mineral Resources.

Even though the exposure levels comply legislatively, the safety of the workers could still potentially be at risk. Currently NIOSH has set a silica exposure limit of 0.05 mg/m^3 (NIOSH, 2002) and the ACGIH has set a limit of 0.025 mg/m^3 (ACGIH, 2012) both of which are substantially lower than the South African TWA OEL of 0.1 mg/m^3. When comparing the data with the two international standards set by NIOSH and the ACGIH it is observed that there is only 1 out of the 48 samples above ACGIH's TWA-TLV and 2 other samples above the action level of the ACGIH's TWA-TLV. During vamping (Merensky reef) the two workers were respectively exposed to 0.15mg/m^3 and 0.19mg/m^3 which are above the action level of the ACGIH's TWA TLV of 0.025 mg/m^3 (ACGIH, 2012). A worker in the development cleaning area (Merensky reef) was exposed to 0.032 mg/m^3 which is above the ACGIH's TWA TLV of 0.025 mg/m^3 (ACGIH, 2012) and above the action level of the NIOSH TWA OEL of 0.05 mg/m^3. These samples also had the highest percentage of silica content which supports the statement that silica content is a good indicator for determining where the highest exposures may occur. Considering the low levels of exposure experienced by the workers it can be assumed that, according to current knowledge, the exposed workers experience very low risk of developing illnesses associated with silica exposure.

Workers in the vamping area watered down the area sufficiently to suppress the airborne dust below the South African OEL and even the ACGIH's TWA-TLV except in one case in development cleaning. The two samples in the vamping area with exposures above the action level of the ACGIH's TLV could be a result of the watering down process of the area which only takes place once before the working shift starts. During the end of the shift most of the water has been scraped away by the scraper operated by the winch operator into the centre gully. This does not evacuate all of the water from the working area. The area is still wet but not as saturated with water compared to the start of the shift. This decrease in water could lead to higher levels of dust becoming airborne into the circulating air and therefore increasing exposure to silica dust. The higher exposure of the worker in the development cleaning area could be because the rock had a higher silica content (16%) and the material with the highest silica content usually leads to the highest exposure (Stanton *et al.*, 2006). The loader loads the rock into the locomotive with a lot of force and causes a large mechanical disturbance. If the rock is not properly wet or the ventilation duct is located too far from the working area more dust will become available for inhalation.

Workers associated with above ground tasks working in the grout plant had the lowest overall exposures. Large periods of time were spent working from the control room which is cordoned off from the main working area where the dust is generated. Workers only went outside for minor maintenance tasks which lasted for very short periods of time. The materials used for mixing the cement had the lowest silica content.

Table 1 indicates an overall statistical significant difference in the two protocols. Table 2 shows that this overall difference in protocol was caused only in one area and not the other two. This is due to the small sampling pool and the two samples that were substantially higher than the other samples taken, (figure 6) it could have influenced the calculation of the p-value giving misleading significant differences.

Table 3 indicates that the bulk samples taken had silica contents below the detection limit in the vamping, development cleaning and grout plant areas. Seeing as the belt attendants receive ore and waste rock from each of the vamping and development cleaning areas it is reasonable to assume that the silica content of the rock will also be below the detection limit for that task or area. If the silica content of the ore bearing rock underground and the raw material used in the above ground grout plant is low it is therefore a reasonable assumption that the exposure to airborne respirable silica will be low.

3.6 Conclusion

The alpha quarts exposure of all the workers did not exceed the South African TWA OEL. No significant differences in exposure were observed between the two reefs, Merensky and UG2. The differences in protocol are practically insignificant because of the very low exposure levels. From figure 5 and 6 it is visible that the differences in protocol are larger when the exposure is more substantial therefore different results could be obtained in a setting where higher volumes of dust are generated or the mined rock contains higher concentrations of silica within, such as in gold or coal mines. Upon evaluating the silica exposures of platinum mine workers there does not seem to be a health or safety risk involved at these low levels. The implemented control measures are therefore sufficient in preventing the development of applicable health and safety risks. If any new cases of silicosis are reported even at these low levels then the risk involving silica related illnesses and the control of silica dust in a platinum mining environment have to be reconsidered.

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CHAPTER 4: CONCLUDING CHAPTER

4.1 Conclusions

This study evaluated personal respirable silica dust exposure in underground workers and above ground grout plant workers at a platinum mine and compared the sufficiency of the current South African OEL to other international standards. The importance of this study is indicated in a study that found signs of silicosis in autopsies of platinum mine workers that were not exposed to silica in any other industry outside platinum mining (Nelson and Murray*,* 2012).

Crystalline silica and amorphous silica are prevalent in mining operations (Stanton *et al*., 2006) and in occupations working with cement (Calvert *et al.,* 2003). Silica is associated with respiratory health risks such as silicosis and various other illnesses (NIOSH, 2002). Amorphous silica poses no health risk to occupational exposures (Merget *et al*., 2002)., therefore this study concentrated on crystalline silica.

Low concentrations (< 1 % respirable) of crystalline silica dust are expected in platinum mines (Stanton *et al*., 2006). Despite the expectedly low levels of silica exposure in platinum mines, significant health risks have been found to be present even at a level of 0.06 mg/m^3 (ACGIH, 2010).

The control methods that reduce airborne respirable dust and the ability of the lungs to remove the particles from it are two important factors that determine the health risk that is present to the workers. Various engineering control methods which include using wet processes and adequate ventilation reduces the airborne dust that is generated and made available for inhalation (Stanton *et al*., 2006). Wet processes and adequate volumes of ventilation are the most effective dust control methods (Kissell, 2003).

Improper or a lack of a control programme may expose the workers to excessive volumes of silica dust (Colinet *et a*l., 2007). This increases the lung burden and the risk of developing silica associated diseases such as silicosis. The lung burden is determined by the efficiency to remove particles from the lungs which in turn determine the cumulative weight of the retained particles in the lung (Oberdörster, 1995). In the areas monitored during this study the control methods were implemented effectively by watering down the areas and using effective ventilation.

Two personal dust samplers that differed in protocol were placed on each worker and were worn for the duration of the shift. This made it possible to evaluate the sufficiency of the protocol the platinum mine uses and the control methods implemented to prevent health risks. For practical reasons the mine's method entails issuing and collecting the samplers and pumps at a central point at an above ground location at the lamp house. This made it easier for the worker to distribute and collect the sampler before and after the working shift. The pumps are started and shut off again at the lamp house. Dilution of the sample occurs because it measures the additional time where the worker is exposed to zero silica. This is because workers have to get to distant working areas at times and attend safety meetings before work and does not accurately represent the exposure of the actual work done by the worker. This time of zero exposure varies daily depending on the distance to the working area (up to 3 km), time spent waiting for safety meeting to begin and the length of the safety meetings as well as work delays that may occur.

Protocol in the vamping area showed a significant difference but not in the other areas. Due to the low exposure levels the difference in protocol seems insignificant; however this does raise uncertainty about the protocol. Exposure levels that are much higher than the levels experienced in this study may yield a larger difference between the protocols.

Results for this study indicated that the underground workers and grout plant workers experienced very low exposure levels to respirable silica dust during working activities. Most of the workers were exposed to levels below the OELs set by national and international governing bodies. One worker was exposed to levels of dust above the ACGIH's TLV of 0.025 mg/m^3 which potentially puts the worker at risk. Even though the South African OEL (0.1 mg/m^3) is higher than other governing bodies, the actual exposures of the workers are below the ACGIH's 0.025 mg/m^3 and NIOSH's OEL of 0.05 mg/m^3.

During the course of this study it has been found that the exposure levels of underground platinum mine workers and above ground grout plant workers were exposed to levels below the South African OEL of 0.1 mg/m^3. The levels of exposure present at the platinum mine do not pose a significant health risk. All but one worker was exposed to levels lower than the ACGIH's TLV of 0.025 mg/m^3. When the South African OEL is compared to other international standards it is evident that the South African OEL is not sufficiently protective.

The hypothesis is accepted that the exposure levels of the underground workers and grout plant workers at the platinum mine are below the OEL of 0.1 mg/m^3.

Limitations: The areas that were sampled had very low dust exposures, therefore making a comparison between the two sampling protocols difficult. If the dust content were to be more substantial a more significant difference could have been observed. Only a limited number of employees were monitored in the different work areas during the study.

4.2 Recommendations

4.2.1 Recommendations for further studies:

- This study did not consider effects of very low long term exposures on workers with impaired lungs and could possibly warrant further study.
- Conducting a study in an environment where significantly more dust is generated and an environment with a higher percentage of silica in the dust to compare the two protocols used in this study.

4.2.2 Recommendations for better silica dust monitoring:

To ensure that more accurate sampling data is obtained that represents the actual silica exposure to workers the following can be implemented:

- Train workers in a team to identify and correct problems that may occur with the sampling pumps as well as proper sampler handling.

- Let the wearer or a member of the mining team switch the sampling pump on and off at the appropriate times to obtain accurate data that represents the time of actual work till end of shift exposure.
- The monitoring of silica dust should be aimed at reflecting the actual working exposure levels of workers and not to simply comply with legislation.
- Ensure the sampler is calibrated with a representative sampler in line and that the flow rate is correct and specific as stated by the manufacturer.
- Do not allow the sampler to be inverted at any time when using the cyclone. Turning the sampler to anything other than vertical may deposit oversized material on the filter.
- During sampling ensure that the sampler is placed in the respiratory zone and not on the belt or any other area that is not in the breathing zone.

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Appendix A

HECS Laboratory Services cc.

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Att: Prof. Eloff

18 July 2012

Test Results
Report No. NWU 002

Test Item Description	*Test Item Condition*	*Date Received*	*Date of Analysis*
Milled Ore Samples	Sealed in Plastic Containers Received at ambient temperature	06/07/2012	18/07/2012

Pellet Number	*Sample Description*	** Crystalline Silica Final Result (mg)*
CS 2058 – CS 2062	Plant Assistant 12.04.14 Rosand G/P	< 0.005
CS 2063 – CS 2067	BS^{E}UG2 12.06.13 Winch	< 0.005
CS 2068 – CS 2072	Develop Clean 12.06.19 Merensky	< 0.005
CS 2073 – CS 2077	T 7^{W} ST7 BR UG2 12.06.13	< 0.005
CS 2078 – CS 2082	Merensky Vamping	< 0.005
CS 2083 – CS 2087	12.06.14 Winch Operator Rosand G/P	< 0.005
CS 2088 – CS 2092	Develop Clean 202.06.25 Lvl 6 UG 2	< 0.005

Specific Test Conditions	Samples stored at ambient temperature prior to analysis
Detection Limit	0.005mg
OEL Value	0.10mg/m^3 per sample
Deviations	None

Analyst | Laboratory Manager

Prof. Eloff | Mine/General Manager

Page 1 of 1

* Accredited.
SiO_2 measured according to SOP05/HECSLAB - Based on NIOSH 7602.
Note: Results relate only to samples being tested.
5 Duplicate samples to determine average.

HECS Laboratory Services cc.

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Att: Prof. Eloff

12 July 2012

Test Results
Report No. NWU 001

Test Item Description	*Test Item Condition*	*Date Received*	*Date of Analysis*
Filters	Sealed in Petri Slides Received at ambient temperature	06/07/2012	11/07/2012

Pellet Number	*Filter Number*	** Crystalline Silica Final Result (mg)*	*Actual Reading (mg)*
CS 1894	SP 6972	< 0.0050	0.0023
CS 1895	SP 6973	< 0.0050	0.0032
CS 1896	SP 6974	< 0.0050	0.0027
CS 1897	SP 6975	< 0.0050	0.0023
CS 1898	SP 6976	< 0.0050	0.0007
CS 1899	SP 6977	< 0.0050	0.0018
CS 1900	SP 6978	< 0.0050	0.0030
CS 1901	SP 6979	< 0.0050	0.0014
CS 1902	SP 6980	< 0.0050	0.0000
CS 1903	SP 6981	< 0.0050	0.0000
CS 1904	SP 6982	< 0.0050	0.0000
CS 1905	SP 6983	< 0.0050	0.0018
CS 1906	SP 6984	< 0.0050	0.0018
CS 1907	SP 6985	< 0.0050	0.0016
CS 1908	SP 6986	< 0.0050	0.0006
CS 1909	SP 6987	< 0.0050	0.0000
CS 1910	SP 7031	< 0.0050	0.0033
CS 1911	SP 7032	< 0.0050	0.0034
CS 1912	SP 7033	< 0.0050	0.0037
CS 1913	SP 7034	< 0.0050	0.0033
CS 1914	SP 7035	< 0.0050	0.0034
CS 1915	SP 7036	< 0.0050	0.0033
CS 1916	SP 7037	< 0.0050	0.0031
CS 1917	SP 7038	< 0.0050	0.0029
CS 1918	SP 7039	< 0.0050	0.0029
CS 1919	SP 7040	< 0.0050	0.0017

* Accredited.
SiO_2 measured according to SOP05/HECSLAB - Based on NIOSH 7602.
Note: Results relate only to samples being tested.

HECS Laboratory Services cc.

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Pellet Number	*Filter Number*	** Crystalline Silica Final Result (mg)*	*Actual Reading (mg)*
CS 1920	SP 7041	< 0.0050	0.0037
CS 1921	SP 7042	< 0.0050	0.0033
CS 1922	SP 7043	< 0.0050	0.0026
CS 1923	SP 7044	< 0.0050	0.0031
CS 1924	SP 7045	< 0.0050	0.0026
CS 1925	SP 7046	< 0.0050	0.0009
CS 1926	SP 7047	< 0.0050	0.0020
CS 1927	SP 7048	< 0.0050	0.0018
CS 1928	SP 7049	< 0.0050	0.0043
CS 1929	SP 7050	< 0.0050	0.0034
CS 1930	SP 7051	< 0.0050	0.0029
CS 1931	SP 7052	< 0.0050	0.0028
CS 1932	SP 7053	< 0.0050	0.0042
CS 1933	SP 7054	0.0096	0.0096
CS 1934	SP 7056	< 0.0050	0.0031
CS 1935	SP 7057	< 0.0050	0.0041
CS 1936	SP 7058	< 0.0050	0.0037
CS 1937	SP 7059	< 0.0050	0.0033
CS 1938	SP 7083	< 0.0050	0.0038
CS 1939	SP 7084	< 0.0050	0.0036
CS 1940	SP 7085	< 0.0050	0.0028
CS 1941	SP 7086	< 0.0050	0.0017

Specific Test Conditions	Samples stored at ambient temperature prior to analysis
Detection Limit	0.005mg
OEL Value	0.10mg/m³ per sample
Deviations	None

Analyst

Laboratory Manager

Prof. Eloff

Mine/General Manager

* Accredited.
SiO_2 measured according to SOP05/HECSLAB - Based on NIOSH 7602.
Note: Results relate only to samples being tested.

Appendix B

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT

November 15, 2012

To whom it may concern

I, Kalienka Marx (21276056), declare that I have done the proof reading as well as the grammar editing for Mr. A. Breedt (20696906) for his mini dissertation entitled **Crystalline silica exposure in platinum mining.**

Kalienka Marx

Interpreter and Translator (Physiology)

North-West University

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