Exposure to respirable crystalline silica amongst stope employees in an underground gold mine between July 2008 and June 2010

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Declaration

I, Senki Benjamin Kesilwe declare 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.

Signed at Johannesburg on this 7th day of May 2012

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ABSTRACT

Introduction

The aim of the study was to determine if the gold mine under study achieved the 2008 elimination of silicosis occupational hygiene milestones as set out by the South African mining industry in 2003.

Objectives

To identify high risk quartz exposed occupations within the conventional stope and TM^3 stope employees of an underground gold mine between July 2008 and June 2010; to describe the personal quartz exposure of conventional stope and TM^3 stope employees in an underground gold mine between July 2008 and June 2010; and to compare the time weighted average (TWA) quartz exposures between the conventional stope and TM^3 stope to the Department of Mineral Resources-Occupational Exposure Limit (DMR-OEL) of 0.1 mg/m^3, the National Institute of Occupational Safety and Health-Recommended Exposure Limit (NIOSH-REL) of 0.05 mg/m^3 and the American Conference of Government Industrial Hygienists-Threshold Limit Value (ACGIH-TLV) of 0.025 mg/m^3.

Methodology

To address objective one, a risk rating matrix was used to determine which occupations had the highest risk of exposure to respirable quartz. In order to address objective 2, the Microsoft Office Excel 2007 descriptive statistics function was also used to analyze the respirable quartz concentrations. In order to address Objective 3, the respirable quartz concentrations were compared to the following safe limits: the DMR-OEL of 0.1 mg/m^3, the ACGIH-TLV of 0.025 mg/m^3 and the NIOSH-REL of 0.05 mg/m^3. The percentage exceeding these safe limits was determined from both the conventional stope and the TM^3 section of the mine.

Results

The miner`s assistant was rated low risk, stope team leader at Shaft C was rated significant risk and all other occupations were rated medium risk. Rock drill operators at shaft A and at shaft B measured the highest respirable quartz concentration (RQC) with median of 0.03 and 0.01 respectively (range 0.0 mg/m^3 to 0.65 mg/m^3). At shaft C the stope team leader had the highest RQC with median of 0.14 (range 0.0 mg/m^3 to 1.22 mg/m^3). The dump truck drivers had the highest respirable quartz concentration (RQC) with median 0.1 (range 0.00 to 0.68 mg/m^3).

Discussion

The miner`s assistant was rated to be a low risk, stope team leader at Shaft C was rated significant risk and all other occupations were rated medium risk. This study indicated that the respirable quartz concentration (RQC) across all measurements ranged from 0.0 mg/m^3 to 1.2 mg/m^3. The highest percentage of measurements that exceeded the DMR-OEL was 88 percent (%) at Shaft C in 2009 as compared to the milestone target of 95% of measurements below the DMR-OEL (0.1mg/m^3). The conventional stope employees were at lesser risk than the TM^3 section employees.

Conclusion and Recommendations

The percentage of samples exceeding the safe limits is tabulated in table 13. This indicates that the mine under study failed to reach the occupational hygiene milestone from 2008 to 2010. There is a significant improvement for 2010. When the exposure was compared to the ACGIH-TLV (0.025 mg/m^3) and NIOSH-REL (0.05 mg/m^3) the exposure is worsened.

This study highlighted the need for the DMR to establish a quartz exposure data base that will make it simple for the mining houses to benchmark themselves within the industry.

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ABBREVIATIONS

ACGIH	American Conference of Government Industrial Hygienist
COM	Chamber of Mines
COPD	Chronic Obstructive Pulmonary Diseases
COSATU	Congress of South African Trade Unions
DMR	Department of Minerals Resources
FEDUSA	Federation of Unions of South Africa
GPES	Global Programme for Elimination of Silicosis
ILO	International Labour Organisation
IR	Infrared spectrometry
LHD	load haul dumper
MHSA	Mine Health and Safety Act
NACTU	National Council of Trade Unions
NPES	National Programme for Elimination of Silicosis
NIOH	National Institute for Occupational Health
NIOSH	The National Institute for Occupational Safety and Health
OEL	Occupational Exposure Limit
PMF	Progressive Massive Fibrosis
RCS	Respirable Crystalline Silica
REL	Recommended Exposure Limit
RH	Relative humidity
RQC	Respirable Quartz Concentration

SAMOHP	South African Mines Occupational Hygiene Programme
SiO_2	Silicon Dioxide (Silica)
TB	Tuberculosis
TLV	Threshold limit value.
TM^3	Trackless Mechanised Mining Method
TWA	Time Weighted Average
WHO	The World Health Organisation
XRD	X-ray diffraction

GLOSSARY

90^{th} percentile	Means the value which must be used to determine when the HEG needs to be re-classified
Alveoli	Gas exchange part of the lung.
Airborne particulates	Are particles that are so small that they remain airborne for a considerable period of time before they settle on the ground.
Ascentional ventilation method	Is the method of ventilation whereby fresh air is taken through the downcast shaft, directly to the bottom levels of the mine and then allowed to ascent through the workings to the up-cast shaft.
Conventional stope	An underground excavation where the reef bearing rock is extracted at an average height of 1m and using hand held rock drill machines.
Crystalline silica	Is formed when silica molecules are lined in order and in crystal form
Dust	Solid particle generated by handling, grinding, rapid impact, detonation of organic or inorganic materials such as rock or ore.
Exposure	means the subjection of a person to an airborne pollutant in the course of employment through any route of entry (e.g. inhalation, ingestion, skin contact, or absorption);

Gravimetric	Relating to measurement by weight.
Homogeneous Exposure Group (HEG)	Means a group of employees who experience pollutant exposures similar enough that monitoring exposures of any representative sub group of employees in the group provides data useful for predicting exposures of the remaining employees.
Inhalable dust	Dust particles less than 50 microns which can be inhaled, but will precipitate on the mucous membranes of the nose, throat and windpipe.
Occupational exposure limit (OEL)	Time-weighted average concentration of an air pollutant at the workplace for a conventional 8-hour workday and a 40-hour workweek, to which nearly all workers may be repeatedly exposed without adverse health effects
Personal sampling	Dust sample collected in the breathing zone of the worker performing occupational duties during a work shift. The worker wears the sampling train (cyclone, pump, tube and sample filter) for the entire shift.
Quartz	Vitreous, hard, chemically resistant, free silica. The most common form in nature and is the main constituent in soil.
Recommended	Has a similar definition to Occupational Exposure Limit (OEL).

exposure limit

Relative humidity	The ratio of actual vapour pressure to saturation vapour pressure at a given dry-bulb temperature, expressed as a percentage.
Respirable dust	Particles are those particles small enough to reach the alveoli of the lung.
Risk	Combination of the likelihood and consequences of a specific hazardous event occurring
Stope	An underground excavation where the reef bearing rock is extracted.
Silicosis	The fibrotic tissue disease attributed to the inhalation of crystalline silica.
Threshold limit value (TLV)	Has a similar definition to Occupational Exposure Limit (OEL).
TM^3	Trackless Mechanised Mining Method. The mining method where machinery is used for mining as compared to the conventional mining method.
XRD	A Bruker D4 XRD instrument equipped with a LynxEye detector is used. A 2.7 kW fine focus copper anode X-ray tube is utilised as X-ray source and operated at 40 kV and 40 mA. Filters are back-mounted on special sample holders with an aluminium backplate.

CHAPTER 1: INTRODUCTION

This chapter presents the background information, aim of the research, the objectives and the literature review. The global and local initiatives to prevent silicosis are discussed under the background information. The health effects associated with quartz exposure and quartz exposure in the gold mining are discussed under the literature review.

1.1. Background information

Occupational lung diseases are a major cause of premature retirement and death among people working in the South African mining industry. Total direct cost of occupational diseases in the gold mines were estimated around R 343 million in 1996 (Guild *et al.,* 2001*).*

The National Program for the Elimination of Silicosis (NPES) was launched during 2004 in South Africa under the leadership of the Department Labour (DoL). This was in line with the International Labour Organization (ILO) and the World Health Organization's (WHO) Global Programme for Elimination of Silicosis (GPES). The programme united government agencies such as the Department of Mineral Resources (DMR); the Department of Health (DoH), the Chamber of Mines (CoM), three major trade unions and federations (Congress of South African Trade Unions (Cosatu), Federations of Unions of South Africa (Fedusa) and National Council of

Trade Unions (Nactu)), the National Institute for Occupational Health (NIOH) and academic and research institutions (WHO, 2007).

To achieve the above mentioned objective, the occupational health and safety targets and milestones were agreed to at the 2003 Mine Health and Safety summit. Two occupational hygiene milestones were set by the South African mining industry with regard to the elimination of silicosis (Chamber of mines, 2008):

- By December 2008, 95% of all exposure measurements results will be below the occupational exposure limit (OEL) for respirable crystalline silica of 0.1 mg/m^3 (these results are individual readings and not the average results) (Chamber of mines, 2008).

- After December 2013, using present diagnostic techniques, no new cases of silicosis will occur amongst previously unexposed individuals. (Previously unexposed individuals mean individuals previous unexposed prior to 2008, i.e. equivalent to a new person entering the industry at 2008 (Chamber of mines, 2008).

1.2. Aim of the research

The aim of this study was to determine if the gold mine under study achieved the 2008 elimination of silicosis occupational hygiene milestones as set out by the South African mining Industry in 2003.

1.3. Study objectives

- To identify high risk occupations within the conventional stope employees and trackless mechanized mining method (TM^3) stope/ section employees of an underground gold mine between July 2008 and June 2010.

- To describe the quartz exposure of conventional stope employees and TM^3 stope employees in an underground gold mine between July 2008 and June 2010.

- To compare the time weighted average (TWA) quartz exposures between the conventional stope and TM^3 stope to the Department of Mineral Resources-Occupational exposure Limit (DMR-OEL) of 0.1 mg/m^3, the American conference of Government Industrial Hygienists threshold limit value (ACGIH-TLV) of 0.025 $mg/m^3$and the National Institute of Occupational Safety and Health - recommended exposure limit (NIOSH-REL) of 0.05 mg/m^3.

1.4. Literature review

1.4.1. Health effects associated with quartz exposure

The mineral dust diseases are caused by dust particles that are small enough to enter the alveoli (Guild *et al.,* 2001). The quartz particles are toxic to macrophages and results in cell death. The damaged lung tissue forms nodules (Guild *et al.,* 2001).

The adverse effects associate with exposure to respirable crystalline silica includes silicosis, tuberculosis, chronic obstructive pulmonary diseases (COPD), and lung cancer (Guild *et al*., 2001*)*. Many studies have been conducted in South Africa that indicated that silicosis is the most serious occupational disease in South African hard rock mines. Gold mines are mostly affected considering high silica content of the ore body (Biffi and Belle, 2003).

The prevalence of silicosis was found to be 18.3 percent (%) among black gold miners in 2000. This was despite the fact that these employees` exposure was below the DMR-OEL (0.1mg/m^3). These findings highlight the research need to determine the safe level of respirable crystalline silica. Silicosis rate reported at autopsy since 1975 is 17.2% (Stanton *et al.,* 2006*).* For any quartz increase of mg.year/m^3 the prevalence of silicosis increases 3.2 times (Churchyard *et al.,* 2003*).*

Silicosis is incurable, irreversible disease caused by breathing dust containing quartz particles that are tiny, less tha10 microns (µ) in diameter, as illustrated in figure 1 below. Silicosis progresses after removal from exposure (Stanton *et al.,* 2006*).*

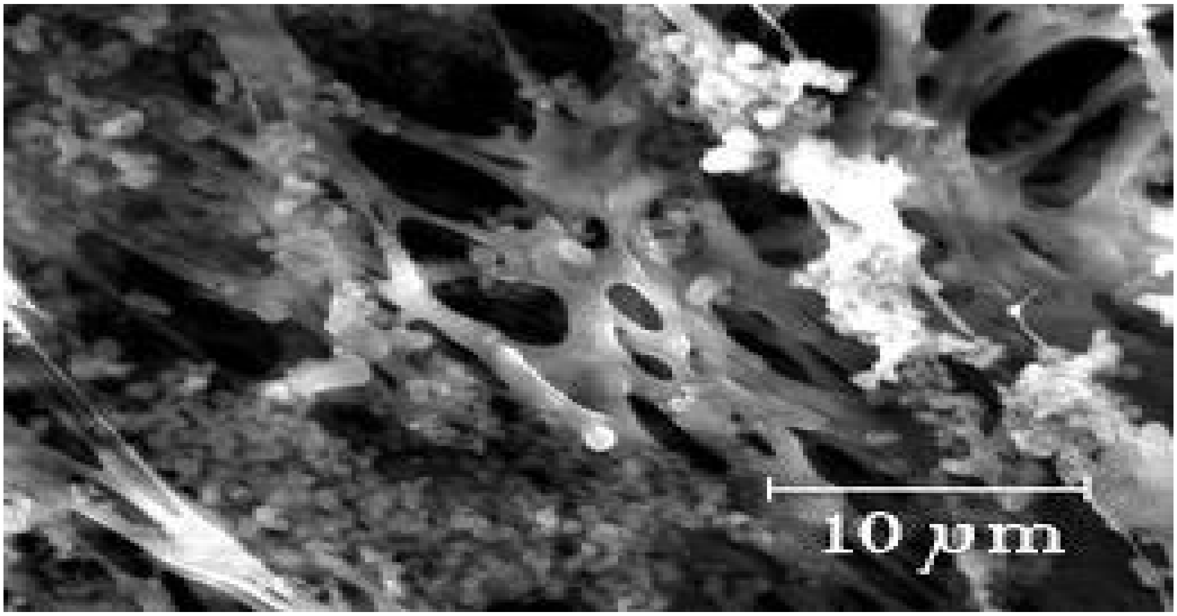

Figure 1 A microscopic illustration of a crystalline silica dust particle (source: http://www.osha.gov)

There are three types of silicosis:

- Chronic silicosis (most workers who develop this silicosis do not show any symptoms for 10 or more years. Their exposure to silica dust are a fairly low but frequent);
- Accelerated silicosis (workers who develop this silicosis show features within 5-10 years of exposure. Their exposure to silica dust levels are increased); and
- Acute silicosis (workers who develop this type of silicosis show the features within a few weeks after initial exposure. Their exposure to silica dust level is very high. This can occur in miners who are exposed to very high dust levels like sand blasters, tunnelers and rock drill operators) (Stanton *et al.,* 2006).

Progressive massive fibrosis (PMF) can develop and results from severe scarring and is more common in the accelerated silicosis (Stanton *et al.,* 2006).

Increased dust lung burden causes an increased risk of pulmonary tuberculosis (PTB). The risk is highest with confirmed silicosis (Guild *et al.*, 2001*)*. Pulmonary tuberculosis is epidemic in the South African gold mines and is associated with HIV infection and silicosis. The presence of silicosis increases the risk of tuberculosis (TB) (teWaterNaude *et al.*, 2006*).*

Silica is a risk factor for PTB even in the absence of silicosis. The high prevalence of PTB was reported in the rock drilling (27 percent) and winch operating (25 percent) occupations in the gold. This high prevalence was found to be associated with the reported high quartz and dust concentrations (teWaterNaude *et al.*, 2006).

COPD develops in people who smoke but silica dust increases the damaged caused by smoking. Non smokers rarely develop COPD (Stanton *et al.*, 2006). COPD results as combination of environmental exposures and genetic susceptibility (Guild *et al.*, 2001*)*.

Lung cancer occurs in the air tissue where there is highest exposure to noxious environmental agents. There is a link between silica dust, silicosis and lung cancer. Exposure to radon gas and diesel engine emissions are possible causes of lung cancer in the underground environment (Guild *et al.*, 2001*)*.

1.4.2. Quartz exposure in the gold mining industry

The compound silica (SiO_2) is formed from Silicon (Si) and Oxygen (O). Quartz is the most common crystalline silica (Stanton *et al.*, 2006). The Department of Mineral Resources occupational exposure limit (DMR-OEL) for crystalline silica is 0.1mg/m³. The American Conference of Government Industrial Hygienist threshold limit value (ACGIH-TLV) is 0.025 mg/m³. The National Institute for Occupational Safety and Health recommended exposure limit (NIOSH-REL) is 0.05 mg/m³.

Main sources of dust are blasting and mechanical mining operations. The other sources like, barring, drilling (see table 1 below) produce additional dust. The dust produced by blasting is carried away by ventilation air stream and observing re-entry periods. The additional dust produced by other activities is controlled by watering down and water flow from the drill steel that captures dust at drilled holed (Guild *et al.*, 2001).

Table 1 Sources of airborne dust in a mine (Guild *et al.*, 2001).

Approximate severity	**Dust producing operation**
1	Blasting
2	Drilling
3	Crushing
4	Grinding
5	Scarping
6	Barring
7	Lashing
8	Tipping
9	Loading

When one looks at the table 1 above, all of the activities except three (crushing, grinding, loading) are associated with stope. This table highlights the risk of stope employee exposure to underground respirable dust and quartz.

The following mining crews are at risk of exposure to airborne dust, mining crews in stope and development; team leaders; drill operators; scraper winch operators; tip operators and locomotive drivers and crew (Stanton *et al.*, 2006).

In the study conducted by Kemsley he indicated that the rock drill operators (RDO) are at the sharp end of exposure due to high amount of dust (mean quartz concentration of 0.69 mg/m^3) that released during drilling process. The highest quartz content reported in this study was more than 100 percent, which is very concerning for a person`s exposure. Thirty two percent (32%) of the employees sampled by were above the DMR-OEL and the exposure was obviously worse when compared to the NIOSH-REL and the ACGIH-TLV safe limits (Kemsley, 2008).

Biffi and Belle conducted the study to identify main dust generation sources in the gold and platinum mines. They performed on site measurements of dust generation rates. These measurements were performed in activities which were assumed to be hazardous like, scrapping, drilling, tipping, crushing and rock transfer. The study highlighted that dust generation is activity dependent and silica content of the dust depend in the geological area. See table 2 below for the study findings.

Of the three activities assumed to be hazardous, the following are activities performed in the stope section, drilling, scraping and tipping. This indicate the necessity of conducted this project. The silica content according their study indicated that silica content in gold mines varied between 9 percent and 39 percent. The reported gravimetric respirable dust sample silica content was reported to be between 4.5% and 57%. (Biffi and Belle, 2003). The silica content at the other region, the Free State was report to be high than 100 percent. (Kemsley, 2008) this confirms the findings of Biffi and Belle that “silica content is dependent on the geological areas”.

When one do a calculation to determine the respirable crystalline silica with the given average dust levels and silica fraction at the gold mines as stipulated in table 2 above, stope face with silica content of 9.92% and average dust level of 0.89 mg/m³, the average respirable crystalline silica in that stope face will be 0.09 mg/m³. With the same silica content, the stope tip with an average dust level of 0.73 mg/m³, the average respirable crystalline silica content will be 0.07 mg/m³. The stope tip with silica content of 39.05 mg/m³ and an average dust level of 1.69 mg/m³ will have average respirable crystalline silica of 0.66 mg/m³. This indicates that the stope employees' respirable quartz exposure is below the DMR-OEL of 0.1mg/ m³ but above the ACGIH-TLV and the NIOSH-REL which are very stringent when compared to the South African safe limit for silica exposure.

Table 2 Summary of respirable dust levels in mg/m^3 in test mines (Biffi and Belle, 2003)

			Dust levels			Crystalline
Mine	Mine type	Dust source	Min	Max	Avg	silica %
1	Gold [West Wtis]	Intake	0.09	1.57	0.46	9.92
		Tips	0.23	0.65	0.49	
		Transfer boxes	0.59	0.81	0.7	
		Return airway	0.49	1.77	0.88	
		Development	0.34	8.19	1.76	
		Stope tips	0.58	0.87	0.73	
		Stope face	0.57	1.40	0.89	
2	Gold [Vaal]	Intake	0.02	0.73	0.29	39.05
		Tips	0.06	5.65	1.41	
		Transfer boxes	0.74	3.99	2.19	
		Return airway	0.69	14.12	4.62	
		Stope tips	0.41	4.22	1.69	
3	Platinum [Western limb, BIC]	Intake	0.10	0.36	0.20	0.45
		Tips	0.02	0.59	0.30	
		Transfer boxes	0.22	1.49	0.53	
		Return airway	0.63	3.47	1.73	
		Development	0.76	1.88	1.23	
		Stope tips	0.59	2.63	1.31	
		Scraping	0.71	1.51	1.19	
4	Platinum	Intake	0.09	0.84	0.34	0.45

	[Western limb, BIC]	Tips	0.07	0.34	0.21	
		Conveyor belt	0.01	0.90	0.39	
		Return airway	0.44	1.69	1.06	
		Shaft	0.01	0.27	0.15	
		Development	0.48	2.09	1.23	
		Stope face	0.28	1.01	0.71	
		Scraping	0.25	0.92	0.54	
5	Diamond[Gauteng]	Intake	0.03	1.54	0.57	0.45

The Safety in Mines Research Advisory Council report (SIMRAC 060601) reported that an average of 9% of the employees at the project mines measured was exposed to respirable quartz dust concentrations above the DMR occupational exposure limit (OEL) of 0.1 mg/m³. The highest exposure was at the project underground gold mine, with an average of 0.14 mg/m³ (range 0.11 mg/m³-0.84 mg/m³) (SIMRAC , 2007).

The SIM 060601 study also showed that stope activity in the underground gold mine had average respirable quartz concentrations of 0.16 mg/m³ and ranged (0.31 mg/m³ - 0.84 mg/m³). The occupations with the highest respirable quartz concentration were stope team leaders with an average of 0.27 mg/m³ and a range (0.05 mg/m³ - 0.80 mg/m³) (SIMRAC,2007) .

The use of mechanized equipment leads to higher respirable dust exposure because of the movements of vehicles in relation to the dust load along the roadway (Biffi and Belle, 2003).

SIMRAC conducted another study on the mechanized section and conventional sections of the mine. The load haul dump (LHD) drivers had the highest respirable quartz concentration with an average 0.19 mg/m^3 (SIMRAC, 1996).

CHAPTER 2: METHODOLOGY

This chapter presents the research methodology used to address the study objectives under the following headings: the study design; study setting; quality assurance; limitations of the study, data analysis and ethics.

2.1. Study design

Secondary data analysis was conducted to determine the respirable quartz exposure amongst stope employees in the underground gold mine. The data analyzed in this study had been captured and stored in Microsoft Office Excel 2007. Personal gravimetric sampling was done between July 2008 and June 2010 at the three underground operations (shafts) of the mine. The samples were randomly selected based on the South African Mines Occupational Hygiene Programme (SAMOHP) codebook, see Tables 3 and 4 below for the SAMOHP sampling strategy that had been applied by the mine under study. The samples were collected by the mine occupational hygienists employed at the three shafts for legal compliance reporting, to comply with the Mine Health and Safety Act 29 (MHSA) of 1996, sections 11, 12 and 13.

Table 3 Classification band according to the SAMOHP codebook

Category (of occupation) **Classification band**	**Pollutants (excluding toxic gases and vapours)**
A	Exposure ≥ the OEL or mixture of exposures ≥ 1
B	Exposure ≥ 50 % of the OEL and < OEL or mixture of exposures ≥ 0.5 and < 1
C	Exposure ≥ 10% of the OEL and < 50% of the OEL or mixtures of exposures ≥ 0.1 and < 0.5

Table 4 Mandatory frequency of sampling according to the SAMOHP codebook

Category	**Sampling frequency**
A	Sample 5% of employees within a HEG on a 3 monthly basis with a minimum of 5 samples per HEG, whichever is the greater.
B	Sample 5% of employees within a HEG on a 6 monthly basis with a minimum of 5 samples per HEG, whichever is greater.
C	Sample 5% of employees within a HEG on annual basis with a minimum of 5 samples per HEG, whichever is greater.

Measurements were taken during each working shift (morning, afternoon, and night) and across all occupations in the conventional and TM^3 stopes. Personal gravimetric sampling was done to collect the samples. The sampling train was made of the sampler, Higgins-Dwell cyclone and 25 mm filter with 0.8 µm pore size and calibrated at 2.2 liters per minute (l/m).

Filters are placed in labeled petri slides with unique filter numbers. The unique filter number consists of 7 digits; the first two designate the year, the next two are alphanumerical numbers to designate the filter batch, followed by the last three digits which starts at 001 until the last filter from the batch has been used.

The samples were then sent to an analytical facility for gravimetric weighing and quartz content analyses. A 6-decimal Radwag or Citizen balance is routinely used for weighing procedures in the laboratory. The weighing is carried at an ambient temperature of 22°C ±5 °C and a relative humidity (RH) of 55% RH ± 15% RH.

Quartz content analyses in gravimetric sampling was determined by using two methods from the National Institute for Occupational Safety and Health (NIOSH) i.e. the NIOSH 7602 and the NIOSH 7500. The NIOSH 7602 method is used to determine quartz content by Infra Red (KBr pellet) and the NIOSH 7500 method is used to determine quartz content by direct on filter X-ray diffraction (XRD).

The mine under study used two methods from 2008 -2010. In 2008 they used the NIOSH 7602 method and from the middle of 2009 they used the NIOSH 7500 method.

2.2. Study setting

The mine under study is based on the West Rand of South Africa, 30 km from Johannesburg. The mine was conveniently chosen as the researcher is currently working there as an occupational hygienist. The mine is an independent resources company formed in November 2008 to capitalize on the global nuclear renaissance. Its underground operations (shafts) produce both gold and uranium about 45 000 tons of gold bearing rock per month per shaft.

The mine is about 1 400 m below surface and has typical dust generating sources encountered in an underground gold mine such as, blasting, scrapping, ore transportation, and drilling. The mine uses conventional and mechanized mining methods, trackless mining methods (TM^3), to extract gold bearing rocks from underground. The rocks are transported by conveyor belts and rock hoist for processing at the metallurgical plants on surface.

The mine has total work force of about 3000 employees including mining contractors and metallurgical plant employees. The stopes are the main production areas in a mine and majority of labour force is concentrated there. The flow of air in a stope is controlled by brattices, dip and strike ventilation curtains. The planned ventilation volume for each stope is $12m^3/s$ of air flow. The mine is ventilated by about $600m^3/s$ of air in each shaft by means of ascentional ventilation method. The return air from workings is transported through the return airways to the up-cast shaft .Each shaft has an independent up cast ventilation shaft. In this study the plant employees' exposure was excluded.

2.3. Quality assurance

The analytical laboratory that the mine is using for alpha quartz analyses is participating in a proficiency testing programme for South African National Accreditation System (SANAS) accreditation (see Appendix VI for a copy of the accreditation certificate). They are allowed to do silica analysis as per revised airborne pollutants guideline. All measurements with error code according to the code list (Appendix III) provided by the analytical laboratory had been excluded. All gravimetric dust sampling has been done under the supervision of qualified occupational hygienists appointed under section 12.1 of the Mine Health and Safety Act 29 of 1996 who was the holder the Chamber of Mines Environmental certificate (CMEC).

2.4. Limitations of the study

Out of the three underground shafts, only one shaft had sampled the trackless mechanized mining method (TM^3) stope sections separately from the conventional stope sections. The TM^3 sections were discontinued at Shafts A and B respectively. This resulted in failure to compare the TM^3 section exposure across the three shafts. Only the data from TM^3 section of Shaft C was analyzed in this study. The risk rating matrix did not compare the employee exposure to the following safe limit, ACGIH and NIOSH. There is no guarantee that the instrumentations were worn on the body for the whole shift or any tampering of the pumps did not happened. The quality control of samples during storage and transportation could not be verified. Also as far as training and supervision of pump wearers is concerned, no proof of such was provided by the mine under study.

2.5. Data analysis

The Microsoft Office Excel 2007 descriptive statistics function was used to analyze the raw data. The data shows a Log normal behavior. To address objective one, a risk rating matrix was used to determine which occupations within the conventional stope employees and TM^3 stope employees had the highest risk of exposure to respirable quartz. Risk rating was based on data already collected by the mine occupational hygienist between July 2008 and June 2010 for each occupation.

To determine the risk, the median value of the respirable quartz concentration per occupation was first statistically calculated and then, using the risk rating matrix (please refer to Appendix IV), the exposure was classified as High, Significant, Medium or Low risk. The probability of exceeding the OEL was based on the DMR-OEL of 0.1 mg/m^3.

Various risk factors were first determined i.e. the consequence of exposure, the probability of exposure and the duration of exposure. A numerical value was then generated where the three risk factor values as described above are multiplied together (Appendix X):

- Risk = Probability x Exposure x Consequence

This risk is then classified by referring to Appendix IV, and ranked in order of numerical importance. This ranking then forms the basis for recommendations in terms of the risk identification process.

In order to address objective 2, the Microsoft Office Excel 2007 descriptive statistics function was also used to analyze the respirable quartz concentrations. The minimum, the mean, the median, the maximum, the geometric mean (GM), geometric standard deviation (GSD), interquartile range and the 90th percentile of respirable quartz concentration per occupation were calculated. The results are presented in tables and box and whisker plots. The range indicated in this study was regarded as minimum to maximum respirable quartz concentrations (RQC).

In order to address Objective 3, the measured respirable quartz concentrations were compared to the following wisely used safe limits: the DMR-OEL of 0.1 mg/m^3, the ACGIH-TLV of 0.025 mg/m^3 and the NIOSH-REL of 0.05 mg/m^3. The percentage exceeding the DMR-OEL, ACGIH-TLV and the NIOSH-REL was determined from both the conventional stope and the TM^3 section of the mine.

2.6. Ethics

The permission to use the mine data was obtained from the mine management and the permission letter is attached as Appendix I. The permission to conduct this study was also obtained from the University of Witwatersrand Human Research Ethics committee. The ethics clearance certificate numbered M10102 was issued and is attached as Appendix II.

CHAPTER 3: RESULTS

3.1. Introduction

The results presented in this chapter are the personal gravimetric sampling measurements taken between July 2008 and June 2010 in an underground gold mine. No samples were reported to be below the limit of detection (LOD) of 22µg during the quartz analysis.

This chapter presents the results of personal respirable quartz concentration under each objective. The results are presented in tables and graphically where appropriate. The box and whisker plots are used to show the difference between occupations. The median respirable quartz concentration used in the risk rating matrix is indicated in brackets. See appendix X for risk rating raw data of the results presented under objective 1.

3.2. Exclusions

All measurements with unacceptable status as per analytical laboratory error code (Appendix III) were excluded in this study.

3.3. The Respirable quartz exposure risk rating

The respirable quartz exposure risk rating matrix results are presented in Tables 5-8 below. See appendix IV for the risk rating matrix used in the study and appendix V for risk rating results.

Table 5 Shaft A conventional stope respirable quartz exposure risk rating matrix

Occupation	**High risk**	**Significant risk**	**Medium risk**	**Low risk**
Stope team workers			×(0.02 mg/m³)	
Stope team leader			×(0.04 mg/m³)	
Stoper			×(0.03 mg/m³)	
RDO			×(0.03 mg/m³)	
MINERS ASSISTANT				×(0 mg/m³)

All occupations at Shaft A conventional stope were rated as medium risks with the exception of the miner`s assistant which was rated as a low risk as indicated in Table 5 above. No occupations were rated as a high risk at Shaft A conventional stope. See Appendix V for the results of the risk rating matrix.

Table 6 Shaft B conventional stope respirable quartz exposure risk rating matrix

Occupation	**High risk**	**Significant risk**	**Medium risk**	**Low risk**
Stope team workers			×(0.04 mg/m³)	
Stope team leader			×(0.03 mg/m³)	
Scraper winch operator			×(0.03 mg/m³)	
Stoper			×(0.04 mg/m³)	
Night shift cleaner			×(0.04 mg/m³)	
RDO			×(0.01 mg/m³)	

All occupations at Shaft B conventional stope were rated as medium risks as indicated in Table 6 above. No occupations were rated as a high risk at Shaft B conventional stope. See Appendix V for the results of the risk rating matrix.

Table 7 Shaft C conventional stope respirable quartz exposure risk rating matrix

Occupation	**High risk**	**Significant risk**	**Medium risk**	**Low risk**
General Miner			×(0.04 mg/m³)	
Stope team workers			×(0.06 mg/m³)	
Stope team leader		×(0.14 mg/m³)		
Scraper winch operator			×(0.05 mg/m³)	
RDO			×(0.06 mg/m³)	

The stope team leaders were rated significant risk at Shaft C conventional stope and all other occupations were rated medium risk as indicated in Table 7 above. No occupations were rated high risk at Shaft C conventional stope. See Appendix V for the results of the risk rating matrix.

Table 8 Shaft C TM^3 section respirable quartz exposure risk rating matrix

Occupation	High risk	Significant risk	Medium risk	Low risk
DUMP TRUCK DRIVER		×(0.10 mg/m^3)		
L.H.D Driver			×(0.02 mg/m^3)	
Dev RDO			×(0.04 mg/m^3)	
Development Team Leader			×(0.02 mg/m^3)	
Development TEAM		×(0.14 mg/m^3)		
Vehicle op	×(0.23 mg/m^3)			

The vehicle operator was rated high risk at the Shaft C TM^3 section. The LHD driver, the development RDO and the development team leader were rated medium risks. The dump truck driver and development team were rated significant risk as indicated in Table 8 above. See Appendix V for the results of the risk rating matrix.

3.4. Quartz exposure in the conventional stope and TM³ sections

3.4.1. Quartz exposure in the conventional stope

Descriptive statistics were used to analyze respirable quartz concentration data of Shaft A conventional stope and is summarized in Table 9 and graphically displayed in figure 2 below.

Table 9 Shaft A conventional stope respirable quartz exposure descriptive statistics

Occupation	Number of samples (n)	Minimum	Mean	Median	Maximum	GM ± GSD	Interquatile range	90th percentile
Stope team workers	52	0	0.03	0.02	0.13	0.03±0.045	0.0-0.38	0.08
Stope team leader	14	0	0.05	0.04	0.17	0.05±0.05	0.02-0.06	0.12
Scraper winch operator	23	0	0.05	0.03	0.24	0.05±0.06	0.01-0.05	0.10
Stoper	6	0	0.04	0.03	0.17	0.04±0.06	0.00-0.04	0.11
RDO	38	0	0.07	0.03	0.65	0.07±0.12	0.02-0.06	0.18

GM = Geometric Mean

GSD = Geometric Standard Deviation

The rock drill operator had the maximum respirable quartz concentration (0.65 mg/m^3) and a median value of 0.03 mg/m^3 and (range 0.0 mg/m^3 to 0.65 mg/m^3) as indicated in Table 9 above. The stope team workers had the lowest with the maximum RQC of 0.13mg/m^3 and a median value of 0.02 mg/m^3 (range 0.0 mg/m^3 to 0.13 mg/m^3).

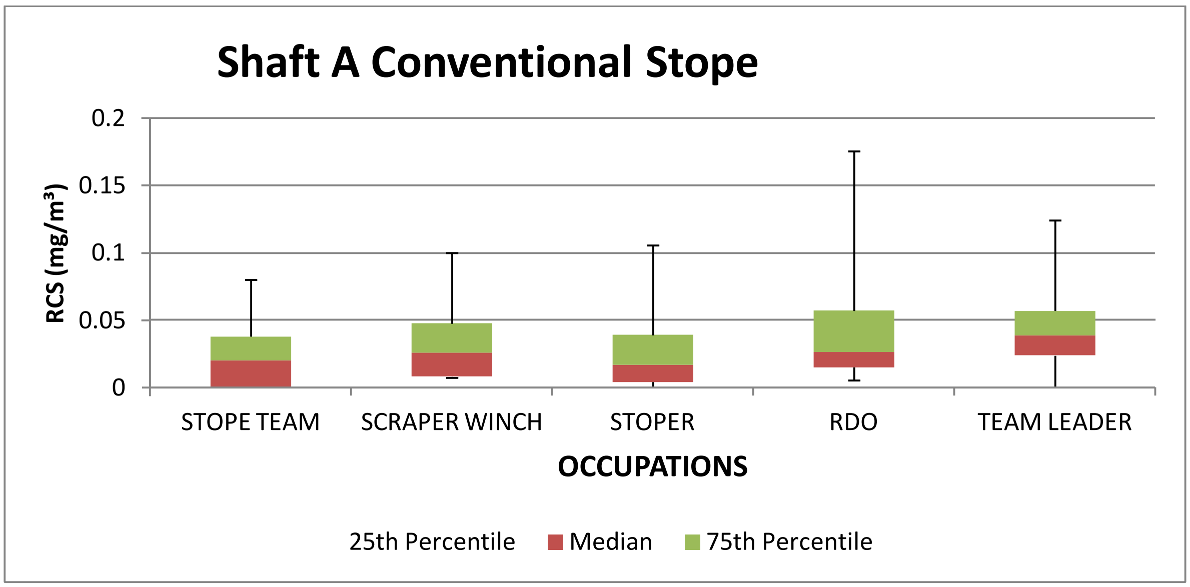

Figure 2 Box and whisker plot indicating personal quartz exposures per occupation of conventional stope employees at Shaft A between July 2008 and June 2010

Figure 2 above also shows that the rock drill operator (RDO) had the highest RQC exposure. The descriptive statistics was used to analyze raw data of Shaft B conventional stope and is summarized in Table 10 and graphically displayed in figure 3 below.

Table 10 Shaft B conventional stope quartz exposure descriptive statistics

Occupation	Number of samples (n)	Minimum	MEAN	Median	Maximum	GM ± GSD	Inter Quartile Range	90th percentile
Stope team workers	29	0	0.07	0.04	0.43	0.07±0.09	0.00-0.1	0.16
Scraper winch operator	17	0	0.06	0.03	0.24	0.06±0.07	0.01-0.06	0.15
Stoper	5	0	0.05	0.04	0.17	0.05±0.07	0.02-0.04	0.12
RDO	17	0	0.08	0.01	0.65	0.08±0.16	0.00-0.08	0.15
GM = Geometric Mean GSD = Geometric Standard Deviation								

The rock drill operator had the maximum respirable quartz concentration (0.65 mg/m³) of and a median value of 0.01 mg/m³ (range 0.0 mg/m^{3}to 0.65 mg/m^3) as indicated in Table 10 above. The stoper had the lowest maximum respirable quartz concentration (0.17 mg/m³) with median value of 0.04 mg/m^3 (range 0.0 mg/m^{3}to 0.17 mg/m^3).

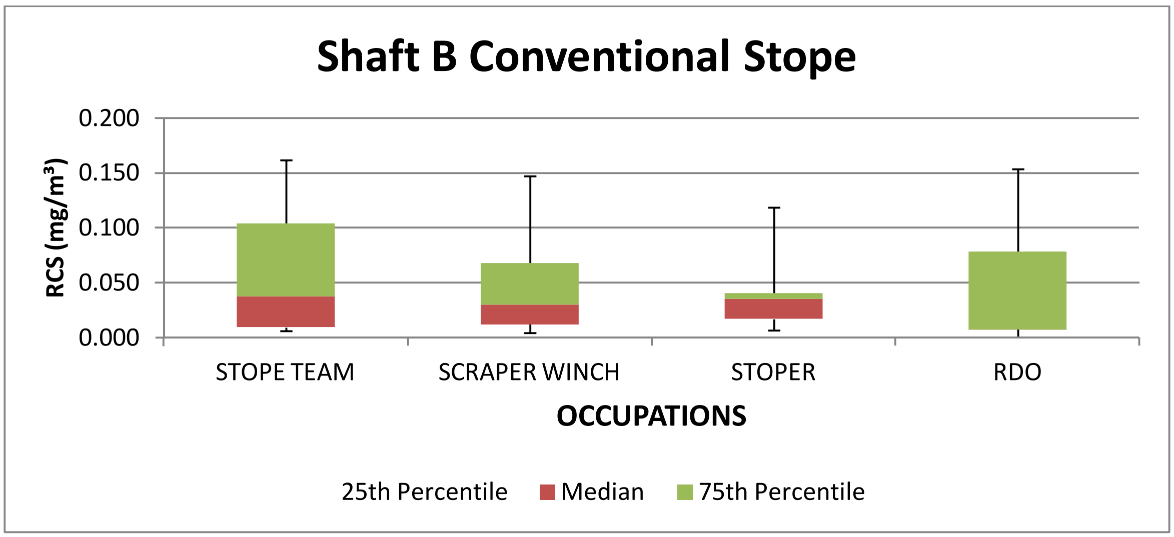

Figure 3 Box and whisker plot indicating personal quartz exposures per occupation of conventional stope employees at Shaft B between July 2008 and June 2010

Figure 3 above also shows that the rock drill operator had the highest RQC exposure. The descriptive statistics was used to analyze raw data of Shaft C conventional stope and is summarized in Table 11 and graphically displayed in figure 4 below.

Table 11 Shaft C conventional stope respirable quartz exposure descriptive statistics

Occupation	Number of samples (n)	Minimum	Mean	Median	Maximum	GM ± GSD	Inter Quartile Range	90th percentile
Stope team workers	38	0.00	0.09	0.06	0.48	0.09±0.09	0.03-0.11	0.17
Stope team leader	18	0.00	0.25	0.14	1.22	0.25±0.37	0.03-0.21	0.70
Scraper winch operator	26	0.00	0.13	0.05	0.64	0.13±0.17	0.03-0.14	0.31
Stoper	11	0.00	0.07	0.04	0.22	0.07±0.08	0.02-0.08	0.22
RDO	26	0.02	0.12	0.06	0.44	0.12±0.13	0.04-0.20	0.27

GM = Geometric Mean

GSD = Geometric Standard Deviation

The stope team leader had the highest maximum respirable quartz concentration (1.22 mg/m³) with a median value of 0.14 mg/m³ (range 0.0 mg/m³to 1.22 mg/m³) as indicated in Table 11 above. The stoper had the lowest maximum RQC (0.22 mg/m³) with median value of 0.04 mg/m³ (range 0.0 mg/m³to 0.22 mg/m³).

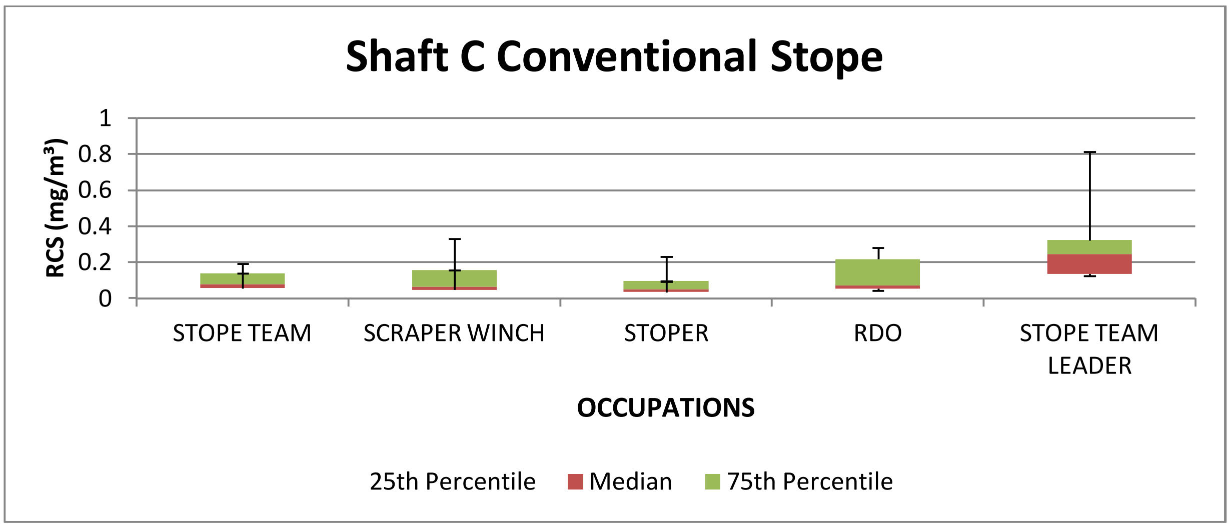

Figure 4 Box and whisker plot indicating personal quartz exposures per occupation of conventional stope employees at Shaft C between July 2008 and June 2010

Figure 4 above also shows that the stope team leader had the highest RQC exposure.

3.4.1. Quartz exposure in the TM³ section

The descriptive statistics was used to analyze raw data of Shaft C TM³section and is summarized in Table 12 and graphically displayed in figure 6 below.

Table 12 The TM^3 section respirable quartz exposure descriptive statistics.

Occupation	Number of samples (n)	Minimum	Mean	Median	Maximum	GM ± GSD	Inter Quartile Range	90th percentile
LHD DRIVER	10	0.00	0.10	0.02	0.60	0.10±0.18	0.01-0.10	0.15
Development Team Leader	3	0.01	0.03	0.02	0.06	0.03±0.03	0.01-0.04	0.05
DUMP TRUCK DRIVER	9	0.00	0.25	0.10	0.68	0.25±0.30	0.05-0.60	0.65
Development Team worker	2	0.06	0.14	0.14	0.12	0.14±0.02	0.13-0.15	0.16
RDO	4	0.00	0.09	0.04	0.28	0.09±0.13	0.02-0.10	0.21
Vehicle operator	4	0.01	0.24	0.24	0.48	0.23±0.12	0.05-0.42	0.45
GM = Geometric Mean GSD = Geometric Standard Deviation								

The dump truck drivers had the highest maximum RQC (0.68 mg/m³) with a median value of 0.10 mg/m³ (range 0.00 to 0.68 mg/m^3). The development team leader had the lowest maximum RQC (0.12 mg/m³) with the median of 0.02mg/m^3 (range 0.01 to 0.06 mg/m^3).

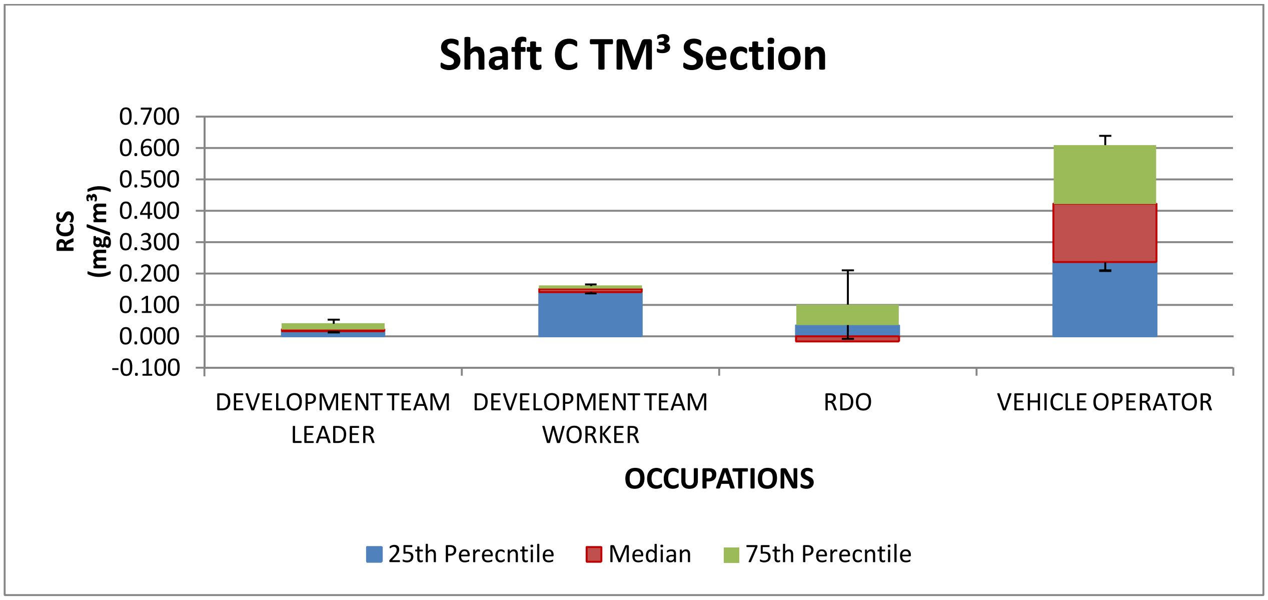

Figure 5 Box and whisker plot indicating personal quartz exposures per occupation of conventional stope employees at Shaft C TM^3 between July 2008 and June 2010

Contrary to the interpretation of the descriptive statistic of table 12 above, figure 5 above shows that the vehicle operators had the highest maximum RQC exposure. This is influenced by the minimum value between the vehicle operator and the dump truck driver.

3.5. Comparison of TWA- RQC to DMR-OEL, ACGIH –TLV and NIOSH -REL

Table 13 and Table 14 below show the percentage of measurements exceeding the DMR-OEL, ACGIH-TLV and NIOSH-REL from the conventional stope and TM³ stope respectively.

Table 13 Comparison of the conventional stope median RQC (mg/m³) to the national and international exposure limits

YEAR	Shaft	SAMPLING AREA	n	(A) %≥0.025 mg/m³	(B) %≥0.05 mg/m³	(C)%≥0.1 mg/m³
2008	Shaft A	**Conventional**	15	100	73	60
	Shaft B		4	100	0	0
	Shaft C		8	88	75	50
2009	Shaft A	**Conventional**	4	75	75	75
	Shaft B		14	86	71	50
	Shaft C		49	86	84	88
2010	Shaft A	**Conventional**	87	45	16	8
	Shaft B		63	41	22	11
	Shaft C		305	57	49	13

A : 0.025 mg/m³ is the ACGIH Thresh Hold Limit Value (TLV)

B : 0.05 mg/m^3 is NIOSH Recommended Exposure Limit (REL)

C : 0.1 mg/m^3 is the DMR Occupational Exposure Limit (OEL)

N : number of samples taken

The highest percentage of measurements that exceeded the DMR-OEL was 88 percent (%) at Shaft C in 2009 as indicated in Table 13 above.

Table 14 Comparison of the TM3 section median RQC (mg/m³) to the national and international exposure limits

YEAR	Shaft	SAMPLING AREA	n	(A) %≥0.025 mg/m³	(B) %≥0.05 mg/m³	(C) %≥0.1 mg/m³
2008	Shaft A	**TM³**		-	-	-
	Shaft B	**TM³**		-	-	-
	Shaft C	**TM³**	25	52	32	20
2009	Shaft A	**TM³**		-	-	-
	Shaft B	**TM³**		-	-	-
	Shaft C	**TM³**	4	100	100	50
2010	Shaft A	**TM³**		-	-	-
	Shaft B	**TM³**		-	-	-
	Shaft C	**TM³**	12	16.7	8.3	8.3

A : 0.025 mg/m³ is the ACGIH Thresh Hold Limit Value (TLV)

B : 0.05 mg/m³ is NIOSH Recommended Exposure Limit (REL)

C : 0.1 mg/m³ is the DMR Occupational Exposure Limit (OEL)

N : number of samples taken

- : no measurements taken

The highest percentage of measurements that exceeded the DMR-OEL was 50 percent (%) at Shaft C in 2009 as indicated in Table 14 above.

CHAPTER 4: DISCUSSION

4.1. Introduction

In this chapter the major findings are summarized and possible limitations are discussed. The personal exposure data are a significant indicator of the effectiveness of all control measures in place to ensure that the workers are not overexposed i.e. adequate dilution ventilation combined with the appropriate control technology.

Some of the results presented in this report indicated exposure levels higher than the international safe levels. This is indicative of the fact that greater emphasis needs to be placed on control measures. The outcome of the study is discussed per objective.

The aim of this study was to determine if the mine under study achieved the 2008 elimination of silicosis occupational hygiene milestones as set out by the South African mining industry in 2003. The findings from this study indicated that the mine failed to achieve the South African mining industry occupational hygiene milestone of having 95% of exposure measurements of respirable crystalline silica below the OEL of $0.1 mg/m^3$ by December 2008.

4.2. Limitations

In considering the findings of this study it is important to bear in mind the following limitations.

- The study did not look at health effects as specified in the mining industry 2013 occupational hygiene milestone;

- This study did not look at the quartz content (%) compared to the study done by Gibbs and co-workers where they found that quartz exposure among South African gold miners ranged from 2%-83%;
- No studies were found that used the risk rating matrix for quartz exposure similar to the one used in this project, so the findings of risk rating (objective 1) of this project could not be compared with other similar studies;
- The study did not consider the dust control / suppression methods implemented at various shafts;
- The sampling results of the mine were not as per DMR sampling strategy and this influenced the statistical interpretation of the results.
- Possible reasons for an increase in exposure were not considered as no record of such overexposure investigation existed;
- The study did not look at the quartz exposure during different shifts i.e. morning, afternoon and night shifts;
- The results of the study cannot be generalized within the commodity studied or within the industry as a whole; and

- Only data from Shaft C TM^3 section was analyzed in this report since Shaft A and B discontinued their TM^3 section operation.
- The risk rating matrix applied in this study was solely for the comparison to the DMR-OEL and not other safe limits indicated in the report, ACGIH-TLV and NIOSH-REL. The relevance of the risk rating matrix for these other limits was not tested.

4.3. The respirable quartz exposure risk rating

The miner`s assistant was rated to be a low risk, stope team leader at Shaft C was rated significant risk and all other occupations were rated medium risk (Tables 6 - 8). The vehicle operators at Shaft C TM^3 section were rated to be a high risk. The dump truck driver and the development team leader were rated significant risk. The LHD driver, development rock driller operator (RDO) and development team leader were rated medium risk.

These findings correlate with the findings of a study conducted by Biffi and Belle (2003) which indicated that work categories mostly at risk are: mining crew in stope, team leaders, rock drill operators, scraper winch operators and loco drivers and their crews (Biffi and Belle, 2003). A possible explanation of the correlation between the results could be that the use of mechanized equipment leads to higher respirable dust exposure because.

4.4. The respirable quartz exposure among employees in the conventional stope and TM3 section.

In comparing the findings of this study with the literature reviewed, the possible reasons for the difference in the outcome of the study and those of the literature was not possible as the reasons for any deviations from the limit was not provided by the mine understudy as indicated under the limitations of the study.

This study indicated that the respirable quartz concentration (RQC) across all measurements ranged from 0.0 mg/m³ to 1.2 mg/m³. These findings are higher than the Biffi and Belle findings (0.05 mg/m³ to 0.66 mg/m³) and the SIMRAC (SIM060601) findings (0.31 mg/m³ to 0.84 mg/m³). The possible reason for the difference could be the efficiency of controls that the mine implemented.

The stope team leaders had the highest respirable quartz concentration (range 0.0 mg/m³ to 1.22 mg/m³) compared to the SIM060601 study (range 0.05 mg/m³ to 0.80 mg/m³).

The occupations with the highest mean RQC from the TM^3 section were the dump truck driver (0.24 mg/m³) and vehicle operators (0.25 mg/m³); these concentrations were higher than the average reported by the SIMRAC study (GAP046). The LHD drivers had lower mean RQC (0.1

mg/m^3) compared to the SIMRAC study (GAP046) which reported mean RQC of 0.19 mg/m^3. Again the efficiency of controls in place and the ventilation flow could be associated with the difference in the outcome. The traffic flow of trackless equipments in the mine will have an impact on the efficiency of any road surface treatment. The wetness of the rock being transported may also have influenced the outcome of this study and that of the SIMRAC, as both studies did not look at the effect of wetness or road surface treatment. This also highlights the need to do a research on the efficiency of various available road surface treatments. The position of the drivers in relation to the direction of air flow is very important in the exposure and controls around his position (open or closed cubby).

There is a between worker variability across the three shafts. The rock drill operator had the highest RQC at Shaft A and Shaft B, with median of 0.03 mg/m^3 and 0.01 mg/m^3 and range (0.0 to 0.65 mg/m^3) respectively. The rock drill operator`s at Shaft C had a median of 0.06 mg/m^3 and range of (0.02 to 0.44 mg/m^3) but was not the highest at that Shaft. These findings are lower than those reported by Kemsley who measured median RQC of 0.69 mg/m^3 for rock drill operators (Kemsley, 2008).

The difference could be the respirable quartz silica content between the two regions as illustrated in both the studies of Kemsley and Biffi and Belle, where they illustrated respirable quartz concentration of equal or greater than 100 percent at the Free State province and 4.5 percent to 57 percent at the West Wits where the mine under study is situated.

The conventional stope and the TM^3 section / stope are classified as category A (Tables 2 and 3) at this mine. That means their 90^{th} percentile value of RQC exceed the DMR-OEL (0.1 mg/m^3). In considering this, the mine should have at least sampled a minimum of 20 samples per year (Table 3) for conventional stope and for the TM^3 section / stope employees. Tables 12 and 13 above indicated that the mine has not complied with the SAMOHP code book between 2008 and 2009 for the conventional stope and the TM^3 section / stope sections. When one considers the maximum RQC, they are all higher than the DMR-OEL of 0.1 mg/m^3. With the maximum RQC measured during this study, it is possible that the 90^{th} percentile of the RQC measurements from both the conventional and the TM^3 section still falls within category A classification of the SAMOHP sampling strategy. This is an indication of overexposure and a possible result of poor controls. It has been demonstrated in the Churchyard and colleagues study that the prevalence of silicosis was 18 percent despite the fact that employees exposure was below the DMR-OEL (0.1 mg/m^3). Thus with continuous exposure of employees at this mine under these conditions, the employees are at the risk of developing both silicosis and pulmonary tuberculosis. As it has been indicated literature review that for every quartz increase of mg.year/m^3, the prevalence of silicosis increases 3.2 times.

It also indicated that the mine has not evaluated the effectiveness and appropriateness of their implemented controls and that the mine had failed to reach the South African mining industry elimination of silicosis milestone of 2008 resulting in overexposure to their employees.

4.5. Comparison of TWA RQC to DMR-OEL, ACGIH –TLV and NIOSH -REL

In the study published by the Safety in Mines Research Advisory Council (SIMRAC) it was reported that an average of 9% of the employees measured were exposed to quartz dust concentrations above the DMR-OEL of 0.1mg/m³. From this study 8-88% of the measurements from the mine exceeded the DMR-OEL. This is higher than what the SIM060601 study reported. Kemsley reported rock drill operators' measurements exceeded the DMR-OEL, NIOSH-REL and ACGIH-TLV by 32%, 72% and 97% respectively (Kemsley, 2008). The findings from these three studies indicate that the overall population of South African gold miners are at the risk of developing silicosis due to over exposure to the respirable crystalline silica.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

From the results obtained during this study, the following conclusions can be made:

5.1 Conclusions

- The conventional stope employees` RQC exposure was rated medium risk across all three shafts with the exception of miner assistant which was rated low risk and stope team leaders at shaft C which was rated significant risk. This indicated that the mine needs to pay attention to their current controls and consider other controls to reduce the employee exposure.
- The TM^3 employee RQC exposure ranged from medium to significant risk rating. No occupation was rated low risk.
- This indicated that the conventional stope employees were at lesser risk than the TM^3 section employees.
- The respirable quartz concentration (RQC) of conventional stope across all three shafts ranged from 0.0 mg/m^3 to 1.22 mg/m^3. The highest RQC range was at shaft C (0.0 mg/m^3 to 1.22 mg/m^3). The 90^{th} percentile value is more than the DMR-OEL (0.1 mg/m^3), this classifies conventional stopes as category A. The range for the 90^{th} percentile value for shaft A, B and C was (0.08 mg/m^3 to 0.18 mg/m^3), (0.12 to 0.16 mg/m^3) and (0.17 to 0.7 mg/m^3) respectively.

- The percentage of samples exceeding the safe limits is tabulated in table 13. This indicates that the mine under study failed to reach the occupational hygiene milestone from 2008 to 2010. There is a significant improvement for 2010. When the exposure was compared to the ACGIH-TLV (0.025 mg/m^3) and NIOSH-REL (0.05 mg/m^3) the exposure is worsened.

- The sampling strategy implemented by the mine understudy from 2008-2009 did not comply with the SAMOHP codebook, as the minimumm samples needed per homogenous exposure group (HEG) was 5 depending of HEG classification as explained in Table IV and Table V above, even though there was an improvement from mid 2009 to current. Worryingly, this indicates that the mine could have been underreporting the quartz exposure.

5.2 Recommendations

As a result of these findings, the following recommendations can be made:

- The mine needs to evaluate the effectiveness of their engineering controls and enforce compliance
- The study had highlighted the need for the DMR to establish the quartz exposure data base that will make it simple for the mining houses to benchmark themselves with the industry. The database can also highlight the occupations at risk.

- The study also highlighted the need for further research so as to determine the respirable quartz exposure across different shifts (morning, afternoon and night shift) as the mining practice differs during different shifts.
- The mine must ensure compliance to the SAMOHP sampling strategy.
- Since Shaft A and B discontinued the TM^3 section operations, the mine can use the Shaft C TM^3 section results as a baseline when they resume the operation at Shaft A and B TM^3 sections.

CHAPTER 6: REFERENCE

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Appendix I The gold mine permission to conduct the study

RAND URANIUM

To: Whom it may concern

University of Witwatersrand

School of Public Health

From: Rand Uranium

Mine Technical Services

Occupational Hygiene Department

Permission to use personal gravimetric sampling data

The permission is granted for Senki Kesilwe, who is currently employed at our Cooke 3 shaft as occupational hygienist, to use the personal gravimetric sampling data collected from July 2008 to June 2010 for his MPH (Occupational Hygiene) research.

Yours Faithfully

Mervin van Rooyen

Rand Uranium
2010 -10- 07
Manager Occupational Hygiene

Appendix II The University of Witwatersrand Human Research Ethics clearance certificate

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG
Division of the Deputy Registrar (Research)

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)
R14/49 Mr Senki Kesilwe

CLEARANCE CERTIFICATE	**M10102**
PROJECT	Exposure to Respirable Crystalline Silica amongst Stope Employees in an Underground Gold Mine between July 2008 and June 2010
INVESTIGATORS	Mr Senki Kesilwe.
DEPARTMENT	School of Public Health
DATE CONSIDERED	29/10/20101
DECISION OF THE COMMITTEE*	Approved unconditionally

\

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

DATE 29/10/2010 **CHAIRPERSON** ....
(Professor PE Cleaton-Jones)

*Guidelines for written 'informed consent' attached where applicable
cc: Supervisor : Andrew Swanepoel

DECLARATION OF INVESTIGATOR(S)

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

Appendix III Analytical laboratory error code list

Number	Description	Action
Error 1	Missing sampling time	Resample
Error 2	Sampling time too short	Resample
Error 3	Flow rate(s) missing	Resample
Error 4	Before flow rate calibration out of spec	Resample
Error 5	After flow rate calibration out of spec	Resample
Error 6	Average flow rate out of spec	Resample
Error 7	Before and after flow rate differ too much	Resample
Error 8	Weigh control filter mass missing	Reweigh
Error 9	Weigh control filter mass exceed the tolerance level	Reweigh
Error 10	Sample filter mass missing	Reweigh
Error 11	Sample filter mass too large negative	Reweigh
Error 12	Difference between 3 weighs exceeds 0.00005g	Reweigh
Error 13	Mass piece weighs too low	Reweigh
Error 14	Mass piece to high	Reweigh
Error 15	Sample filter past use by date	Resample
Error 16D	Sample filter deposit uneven	Resample
Error 16L	Sample filter overloaded	Resample
Error 16M	Sample filter multitudes of problems	Resample
Error 16T	Sample filter torn	Resample
Error16 W	Sample filter wet	Resample
Error 17	Dust mass below quantification limit (Ql)	Resample
Error 20	XRD DoF control filter out of spec	Resample
Error 21	FTIR DoF control filter out of spec	Resample
Error 22	FTIR KBr control filter out of spec	Resample

Appendix IV The risk identification matrix

RISK FACTOR	VALUE
Probability of exceeding OEL	
Exceeding OEL-C or OEL more than three fold	5
Exceeding OEL-TWA	4
Exceeding action limit (50% of TWA)	3
Exceeding 10% of TWA	2
Virtually no exposure	1
Exposure	
Continuous for longer than 12 hours	5
Continuous for between 8 and 12 hours	4
Continuous for less than 8 hours	3
Short periods of time, a few times per day	2
Very unusual, a few times per week	1
Consequence	
Exposure to health hazards/agents (significantly over the OEL) resulting in irreversible impact on health with loss of quality of life of a numerous group/ population or multiple fatalities	5
Exposure to health hazards/agents (significantly over the OEL) resulting in irreversible impact on health with loss of quality of life or single fatality	4
Exposure to health hazards/agents (over the OEL) resulting in reversible impact on health (with lost time)	3
Exposure to health hazard resulting in temporary alterations/ limitations (no lost time)	2
Exposure to health hazard resulting in temporary discomfort	1

Risk calculation	Risk classification	Action
70 - 125	High	Consider to discontinue
30-69	Significant	Correction needed
8 - 29	Medium	Attention necessary
Under7	Low	Little attention required

					Likelihood		Consequence		
Sampling area	Number of exposed	Hazard	Route of entry	Type	Probability	Exposure	Consequence	Risk	Risk ranking
					3	2	4	24	Tolerable risk
								0	Tolerable risk
								0	Tolerable risk
								0	Tolerable risk
								0	Tolerable risk
								0	Tolerable risk
								0	Tolerable risk

Appendix V Risk rating results

Shaft	Sampling area	Occupation	Median (RQC)	Probability	Exposure	Consequence	Risk	Risk ranking
Shaft A	Conventional Stope	Stope team worker	0.02	2	4	2	16	Possible risk
		Stope team leader	0.04	2	4	2	16	Possible risk
		Stoper	0.03	2	4	2	16	Possible risk
		Miner Assistant	0	1	4	1	4	Tolerable
Shaft B	Conventional Stope	Stope team workers	0.04	2	4	2	16	Possible risk
		Stope team leader	0.03	2	4	2	16	Possible risk
		Scraper winch operator	0.03	2	4	2	16	Possible risk
		Stoper	0.04	2	4	2	16	Possible risk
		Night shift cleaner	0.04	2	4	2	16	Possible risk
		RDO	0.01	2	4	2	16	Possible risk
Shaft C	Conventional Stope						0	Tolerable
		General Miner	×(0.04)	2	4	2	16	Possible risk
		Stope team workers	×(0.06)	3	4	2	24	Possible risk
		Stope team leader	×(0.14)	4	4	4	64	Risk
		Scraper winch operator	×(0.05)	3	4	2	24	Possible risk
		RDO	×(0.06)	3	4	2	24	Possible risk
Shaft C	TM³	DUMP TRUCK DRIVER	×(0.10)	4	4	3	48	Risk
		L.H.D Driver	×(0.02)	2	4	2	16	Possible risk
		Dev RDO	×(0.04)	2	4	2	16	Possible risk
		Dev team leader	×(0.02)	2	4	2	16	Possible risk
		Development TEAM	×(0.14)	4	4	4	64	Risk
		Vehicle op	×(0.23)	5	4	5	100	High risk

Appendix VI Analytical laboratory SANAS accreditation certificate

BBE Laboratory participates in two proficiency schemes.

In both 25 mm PVC filters are loaded with alpha-quartz and sent to laboratories for the determination of the mass of quartz present on the filters.

NIOH: Locally BBE Laboratory participates in the National Institute for Occupational Health's EQA Programme – Respirable Crystalline Silica. Only DoF XRD was used to determine the quartz content. The results for the round 4 and round 5 are displayed. The "target" value is the value obtained by NIOH by means of gravimetric analysis on a balance with a resolution of 0.001 mg (so-called 6-decimal balance). Results for round 6 have not been received to date.

NIOH uses the z-score as an indication of the performance of the laboratory.

WASP: The Workplace Analysis Scheme for Proficiency (WASP) is an independent analytical performance testing scheme, operated by the Health and Safety Laboratory (HSL in the UK. BBE Laboratory participates in the WASP- alpha-quartz on membrane filters. Both DoF XRD (lab 1571) and KBr FTIR (lab 1572) analytical techniques were used to determine the quartz content. The results for rounds 81 and 82 are displayed. Trimmed participant means have been used as the "true" results.

WASP is using a scoring system based on the Rolling Performance Indicator (RPI). The Performance Index (PI) statistic is calculated from the four sample results in each round

$$Performance\ Index = \frac{\sum_{s=1}^{4}\left(\frac{x_s}{\overline{x}}-1\right)^2 \times 10{,}000}{4}$$

- where x_s is the result obtained by the laboratory for sample number s (of four), and $\overline{x}$ is the assigned value for sample 's'. (The ratio $x_s/\overline{x}$ is the "standardised result", i.e. the result obtained by the participant, divided by the "assigned value".) (The multiplication factor of 10,000 is arbitrary, to avoid having to deal with very small numbers).

Criteria:

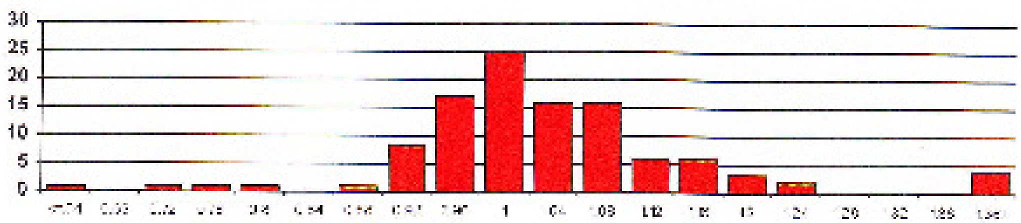
• **GOOD**: Results obtained by the participating laboratory are on average within 7.5% of the assigned value. This equates to an **RPI of 56.25 or less.**
• **ACCEPTABLE**: Results obtained by the participating laboratory are on average within 15% of the assigned value. This equates to an **RPI of 225 or less.**
• **UNACCEPTABLE**: Results obtained by the participating laboratory differ by more than 15% of the assigned value. This equates to an **RPI of greater than 225.**

WASP Results

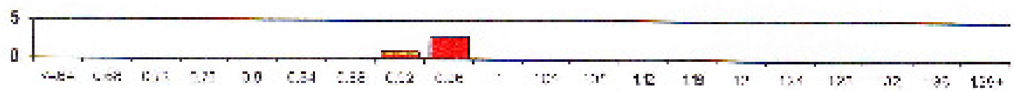
Round: 86 Laboratory: 1571

alpha-Quartz on Membrane Filters

Frequency Count of Results for this Analyte



Results for this Laboratory



Summary of your results and their ratio to the mean

sample number	your result	'true' result	Difference(%)	standardised results
1	91.30	[illegible]	-5.4	0.946
2	68.90	74.52	-7.54	0.925
3	86.90	94.95	-8.48	0.915
4	86.00	[illegible]	-6.43	0.936

RPI	performance category
< 52	1
52 to 216	2
> 216	3

RPI Reference Value: [illegible]

Reference Value Used: No mean: 0.93

Results for Your Laboratory:

Number of outliers: 0

Performance Index (PI): 50

RunningPerformanceIndex (RPI):

Performance Category:

Results for All Participants:

Mean PI: 92.44 Median PI: 38

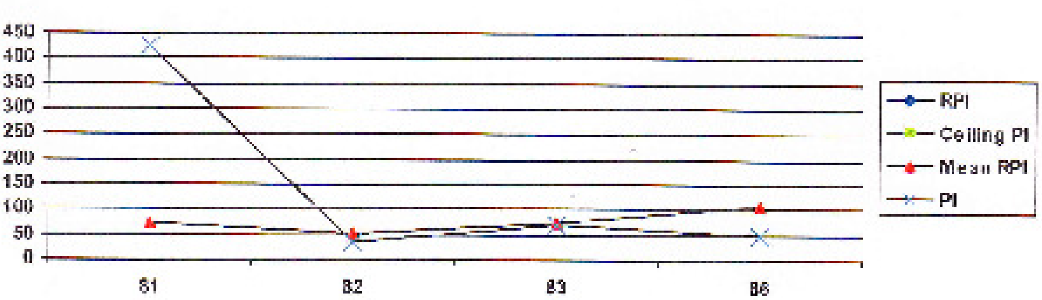
Mean RPI: 108.15 Median RPI: 61

Your laboratory is ranked out of 17 labs.

additional statistical data (see the statistical protocol paragraphs 12 to 18)

analysis of variance Delta: -0.068669 SSW: 0.000533 Coefficient of variation:

RPI Plot for your Laboratory

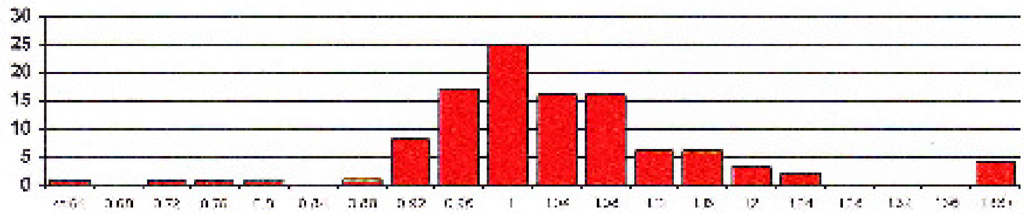


WASP Results

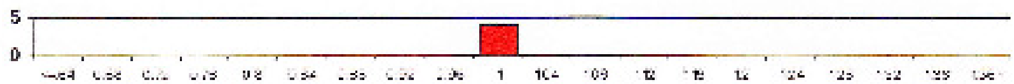
Round: 86 Laboratory: 1572

alpha-Quartz on Membrane Filters

Frequency Count of Results for this Analyte



Results for this Laboratory



Summary of your results and their ratio to the mean

sample number	your result	'true' result	Difference(%)	standardised results
1	96.50	96.53	-0.03	1.000
2	92.20	94.52	-3.12	0.969
3	93.00	94.95	-2.06	0.979
4	91.10	91.92	-0.89	0.991

RPI	performance category
< 52	1
52 to 216	2
> 217	3

RPI Reference Value: 126

Reference Value Used: No mean: 0,98

Results for Your Laboratory:

Number of outliers: 0

Performance Index (PI): 4

RunningPerformanceIndex (RPI):

Performance Category:

Results for All Participants:

Mean PI: 92.44 Median PI: 38

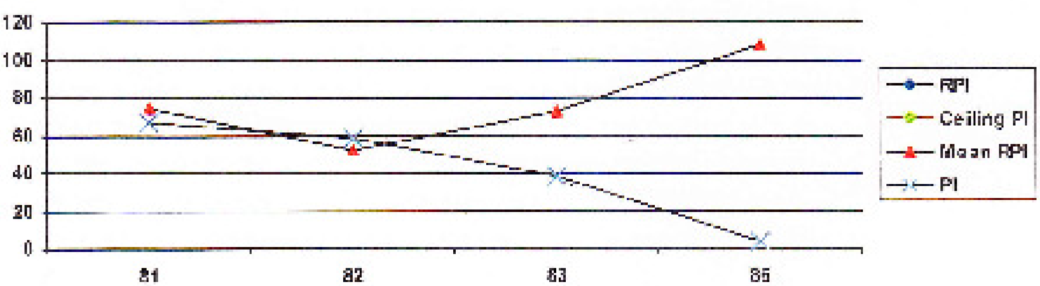
Mean RPI: 108.15 Median RPI: 61

Your laboratory is ranked out of 17 labs.

additional statistical data (see the statistical protocol paragraphs 12 to 18)

analysis of variance Delta: -0.015198 SSW: 0.000548 Coefficient of variation:

RPI Plot for your Laboratory



Appendix VII Shaft A Raw sampling data

SHAFT A RAW SAMPLING DATA (RQC-TWA)

YEAR	OCCUPATION SAMPLED	RQC (TWA)
2008	Stoper	0.006
2008	RDO	0.000
2008	RDO	0.108
2008	RDO	0.024
2008	RDO	0.000
2008	RDO	0.009
2008	RDO	0.000
2008	Stope team	0.022
2008	Stope team	0.000
2008	Team Leader	0.017
2008	Team Leader	0.022
2008	Team Leader	0.008
2008	Team leader	0.028
2008	Team Leader	0.009
2008	Stoper	0.028
2009	Stope team worker	0.294
2009	Stope team worker	0.014
2009	Stope team worker	0.002
2009	Stope team worker	0.016
2009	Stope team worker	0.035
2009	Stope team worker	0.008
2009	Stope team worker	0.049
2009	Stope team worker	0.006
2009	Stope team worker	0.277
2009	Stope team worker	0.014
2009	Miner	0.028
2009	RDO	0.028
2009	Team leader	0.000
2010	GENERAL MINER	0.017
2010	GENERAL MINER	0.035
2010	GENERAL MINER	0.04
2010	Learner Miner	0.00
2010	Loader Operator	0.00
2010	RDO	0.02
2010	RDO	0.00
2010	RDO	0.03

2010	RDO	0.04
2010	RDO	0.24
2010	RDO	0.18
2010	RDO	0.02
2010	RDO	0.13
2010	RDO	0.02
2010	RDO	0.03
2010	RDO	0.02
2010	RDO	0.06
2010	RDO	0.01
2010	RDO	0.00
2010	RDO	0.01
2010	RDO	0.01
2010	RDO	0.01
2010	RDO	0.18
2010	RDO	0.01
2010	RDO	0.03
2010	RDO	0.02
2010	RDO	0.12
2010	RDO	0.04
2010	RDO	0.18
2010	RDO	0.02
2010	Scraper Winch Driver	0.00
2010	Scraper Winch Driver	0.00
2010	Scraper Winch Driver	0.04
2010	Scraper Winch Driver	0.01
2010	Scraper Winch Driver	0.03
2010	Scraper Winch Driver	0.03
2010	Scraper Winch Driver	0.10
2010	Scraper Winch Driver	0.01
2010	Scraper Winch Driver	0.01
2010	Scraper Winch Driver	0.01
2010	Scraper Winch Driver	0.02
2010	Scraper Winch Driver	0.03
2010	Scraper Winch Driver	0.09
2010	Scraper Winch Driver	0.01
2010	Scraper Winch Driver	0.01
2010	Scraper Winch Driver	0.05
2010	Scraper Winch Driver	0.03
2010	Stope Team Leader	0.03
2010	Stope Team Leader	0.08

2010	Stope team worker	0.00
2010	Stope team worker	0.04
2010	Stope team worker	0.00
2010	Stope team worker	0.00
2010	Stope team worker	0.00
2010	Stope team worker	0.05
2010	Stope team worker	0.00
2010	Stope team worker	0.00
2010	Stope team worker	0.02
2010	Stope team worker	0.02
2010	Stope team worker	0.02
2010	Stope team worker	0.00
2010	Stope team worker	0.03
2010	Stope team worker	0.02
2010	Stope team worker	0.02
2010	Stope team worker	0.00
2010	Stope team worker	0.00
2010	Stope team worker	0.08
2010	Stope team worker	0.05
2010	Stope team worker	0.02
2010	Stope team worker	0.05
2010	Stope team worker	0.02
2010	Stope team worker	0.01
2010	Stope team worker	0.01
2010	Stope team worker	0.04
2010	Stope team worker	0.03
2010	Stope team worker	0.01
2010	Stope team worker	0.03
2010	Stope team worker	0.02
2010	Stope team worker	0.06
2010	Stope team worker	0.01
2010	Stope team worker	0.10
2010	STOPING TEAM LEADER	0.03
2010	STOPING TEAM LEADER	0.04
2010	STOPING TEAM LEADER	0.03
2010	STOPING TEAM LEADER	0.00
2010	STOPING TEAM LEADER	0.00
2010	Scraper Winch Driver	0.05

Appendix VIII Shaft B Raw sampling data

SHAFT B RAW SAMPLING DATA (RQC-TWA)

YEAR	OCCUPATION SAMPLED	RQC (TWA)
2008	Stoper	0.000
2008	RDO	0.014
2008	RDO	0.007
2008	RDO	0.084
2008	RDO	0.024
2008	RDO	0.036
2008	RDO	0.010
2008	RDO	0.062
2008	RDO	0.036
2008	Stope team	0.014
2008	Stope team	0.033
2008	Stope team	0.002
2008	Stope team	0.026
2008	Stope team	0.041
2008	Stope team	0.000
2008	Stope team	0.010
2008	Team leader	0.007
2008	Scaper winch operator	0.012
2008	Scaper winch operator	0.060
2008	Scaper winch operator	0.005
2008	Scaper winch operator	0.000
2008	Scaper winch operator	0.019
2008	Scaper winch operator	0.000
2008	Scaper winch operator	0.052
2009	Stope team worker	0.014
2009	Stope team worker	0.062
2009	General miner	0.084

2009	Shift boss	0.084
2009	Stope team worker	0.000
2009	Stope team worker	0.010
2009	RDO	0.000
2009	Stope team worker	0.086
2009	Stope team worker	0.029
2009	Stope team leader	0.000
2010	WINCH DRIVER (SCRAPER)	0.038
2010	Stope Team Worker	0.033
2010	STOPER	0.000
2010	Stope Team Worker	0.055
2010	WINCH DRIVER (SCRAPER)	0.000
2010	STOPER	0.259
2010	STOPER	0.029
2010	STOPE TEAM LEADER	0.032
2010	Stope Team Worker	0.027
2010	Stope Team Worker	0.044
2010	Stope Team Worker	0.428
2010	WINCH DRIVER (SCRAPER)	0.068
2010	Stope Team Worker	0.056
2010	Stope Team Worker	0.000
2010	Stope Team Worker	0.030
2010	Stope Team Worker	0.041
2010	Stope Team Worker	0.000
2010	Stope Team Worker	ERROR
2010	WINCH DRIVER (SCRAPER)	0.000
2010	WINCH DRIVER (SCRAPER)	0.050
2010	Stope Team Worker	0.000
2010	WINCH DRIVER (SCRAPER)	0.012
2010	Stope Team Worker	0.007

2010	RDO	ERROR
2010	RDO	ERROR
2010	WINCH DRIVER (SCRAPER)	ERROR
2010	WINCH DRIVER (SCRAPER)	ERROR
2010	RDO	ERROR
2010	Stope Team Worker	ERROR
2010	WINCH DRIVER (SCRAPER)	ERROR
2010	RDO	ERROR
2010	WINCH DRIVER (SCRAPER)	0.107
2010	WINCH DRIVER (SCRAPER)	ERROR
2010	WINCH DRIVER (SCRAPER)	ERROR
2010	RDO	0.007
2010	Stope Team Worker	0.013
2010	WINCH DRIVER (SCRAPER)	0.012
2010	WINCH DRIVER (SCRAPER)	ERROR
2010	WINCH DRIVER (SCRAPER)	0.007
2010	WINCH DRIVER (SCRAPER)	0.021
2010	WINCH DRIVER (SCRAPER)	0.030
2010	Stope Team Worker	0.166
2010	Stope Team Worker	0.037
2010	WINCH DRIVER (SCRAPER)	0.007
2010	RDO	0.007
2010	Stope Team Worker	0.007
2010	RDO	0.008
2010	RDO	0.008
2010	RDO	0.008
2010	Stope Team Worker	0.008

Appendix IX Shaft C Raw sampling data

SHAFT C RAW SAMPLING DATA (RQC-TWA)

YEAR	OCCUPATION SAMPLED	RQC (TWA)
2008	Stope team worker	0.006
2008	Stope team worker	0.004
2008	Driver: haul truck (underground and opencast)	0.021
2008	Stope team worker	0.023
2008	Stope team worker	0.014
2009	Driver: haul truck (underground and opencast)	0.021
2009	Driver: haul truck (underground and opencast)	0.006
2009	Driver: bulldozer	0.025
2009	Stope team worker	0.004
2009	Stope team worker	0.035
2009	Stope team worker	0.000
2009	Stope team worker	0.020
2009	Driver: haul truck (underground and opencast)	0.299
2009	Stope team worker	0.021
2009	Driver: haul truck (underground and opencast)	0.133
2009	Stope team worker	0.084
2009	Stope team worker	0.041
2009	Driver: bulldozer	0.010
2009	Stope team worker	0.064
2009	Stope team worker	0.027
2009	Stope team worker	0.166
2009	General miner	0.045
2009	Haulage/underground rail transport worker (n.e.c.)	0.020
2009	Driver: haul truck (underground and opencast)	0.010
2009	Stope team worker	0.023
2009	Stope team worker	0.037
2009	Stope team worker	0.033
2009	Development team leader/supervisor	0.100
2009	Stope team worker	0.252
2009	Stope team worker	0.014
2010	LHD Driver	0.270
2010	LOCO DRIVER	0.023
2010	LOCO GANG SUPERVISOR	0.124
2010	MINERS ASSISTANT	0.064
2010	R.D.O	0.041
2010	R.D.O	0.051
2010	R.D.O	0.055

2010	R.D.O	0.054
2010	DEVELOPMENT MACHINE OPERATO	0.030
2010	WINCH DRIVER (SCRAPER)	0.060
2010	R.D.O	0.039
2010	R.D.O	0.056
2010	R.D.O	0.055
2010	R.D.O	0.202
2010	DUMP TRUCK DRIVER	0.045
2010	R.D.O	0.044
2010	R.D.O	0.025
2010	R.D.O	0.072
2010	R.D.O	0.072
2010	R.D.O	0.062
2010	R.D.O	ERROR
2010	R.D.O	0.027
2010	R.D.O	0.023
2010	R.D.O	0.035
2010	R.D.O	0.017
2010	R.D.O	0.030
2010	Scraper Winch Driver	0.048
2010	DEVELOPMENT MACHINE OPERATO	0.041
2010	STOPE TEAM	0.043
2010	WINCH DRIVER (SCRAPER)	0.042
2010	PLANT MAINT. OPER.	0.000
2010	Scraper Winch Driver	0.048
2010	Scraper Winch Driver	0.008
2010	Scraper Winch Driver	0.038
2010	Scraper Winch Driver	0.048
2010	Scraper Winch Driver	0.623
2010	Scraper Winch Driver	0.000
2010	Scraper Winch Driver	0.332
2010	Scraper Winch Driver	0.035
2010	Scraper Winch Driver	0.040
2010	Scraper Winch Driver	0.026
2010	Scraper Winch Driver	0.039
2010	Scraper Winch Driver	0.104
2010	Scraper Winch Driver	0.295
2010	Scraper Winch Driver	0.017
2010	Scraper Winch Driver	ERROR
2010	Scrapper Winch Driver	0.637
2010	Scrapper Winch Driver	0.071

2010	Scrapper Winch Driver	0.027
2010	Stope Team Leader	0.015
2010	Stope Team Leader	0.201
2010	Stope Team Leader	0.053
2010	Stope Team Leader	0.020
2010	Stope Team Leader	ERROR
2010	Stope Team Leader	0.015
2010	Stope team leader	0.280
2010	DUMP TRUCK DRIVER	0.647
2010	Stope team leader	0.105
2010	BULLDOZER OPERATOR	0.351
2010	Stope team leader	0.027
2010	Stope team leader	0.000
2010	DUMP TRUCK DRIVER	0.683
2010	Stope team leader	0.029
2010	STOPE TEAM WORKER	0.170
2010	STOPE TEAM WORKER	ERROR
2010	STOPE TEAM WORKER	0.177
2010	STOPE TEAM WORKER	0.176
2010	STOPE TEAM WORKER	0.042
2010	STOPE TEAM WORKER	0.086
2010	STOPE TEAM WORKER	0.039
2010	STOPE TEAM WORKER	0.053
2010	STOPE TEAM WORKER	0.051
2010	STOPE TEAM WORKER	0.048
2010	STOPE TEAM WORKER	0.159
2010	STOPE TEAM WORKER	0.136
2010	STOPE TEAM WORKER	0.019
2010	STOPE TEAM WORKER	0.012
2010	STOPE TEAM WORKER	0.058
2010	STOPE TEAM WORKER	0.012
2010	STOPE TEAM WORKER	0.117
2010	STOPE TEAM WORKER	0.034
2010	STOPE TEAM WORKER	ERROR
2010	LHD DRIVER	0.000
2010	STOPE TEAM WORKER	0.079
2010	Dump Truck Driver	0.000
2010	Stope Team Leader	0.017
2010	Dump Truck Driver	0.011
2010	LHD DRIVER	0.000
2010	STOPE TEAM WORKER	0.030

2010	STOPE TEAM WORKER	0.032
2010	STOPE TEAM WORKER	0.008
2010	STOPE TEAM WORKER	0.024
2010	LHD DRIVER	0.011
2010	LHD DRIVER	0.018
2010	STOPE TEAM WORKER	0.025
2010	STOPE TEAM WORKER	0.058
2010	STOPE TEAM WORKER	0.038
2010	STOPE TEAM WORKER	0.031
2010	STOPER	0.103
2010	STOPER	0.035
2010	STOPER	0.050
2010	STOPER	ERROR
2010	STOPER	0.000
2010	Vehcile op	0.008
2010	Stope team leader	0.008
2010	Vehcile op	0.475
2010	STOPER	0.057
2010	STOPER	0.023
2010	STOPER	0.018
2010	STOPER	0.029
2010	STOPER	ERROR
2010	LHD DRIVER	0.029
2010	LHD DRIVER	0.007
2010	STOPER	0.017
2010	W/ERECTOR & MAINTENANCE T/L	0.045
2010	W/ERECTOR & MAINTENANCE T/L	0.000

Appendix X Risk rating matrix raw data

				Likelihood		Consequence		
Shaft	**Sampling area**	**Occupation**	**Median (RQC)**	**Probability**	**Exposure**	**Consequence**	**Risk**	**Risk ranking**
Shaft A	**Conventional Stope**	Stope team worker	0.02	2	4	2	16	Possible risk
		Stope team leader	0.04	2	4	2	16	Possible risk
		Stoper	0.03	2	4	2	16	Possible risk
		Miner assistant	0	1	4	1	4	Tolerable
Shaft B	**Conventional Stope**	Stope team workers	0.04	2	4	2	16	Possible risk
		Stope team leader	0.03	2	4	2	16	Possible risk
		Scraper winch operator	0.03	2	4	2	16	Possible risk
		Stoper	0.04	2	4	2	16	Possible risk
		Night shift cleaner	0.04	2	4	2	16	Possible risk
		RDO	0.01	2	4	2	16	Possible risk
	Conventional Stope	General Miner	×(0.04)	2	4	2	16	Possible risk
		Stope team workers	×(0.06)	3	4	2	24	Possible risk
		Stope team leader	×(0.14)	4	4	4	64	Risk
		Scraper winch operator	×(0.05)	3	4	2	24	Possible risk
		RDO	×(0.06)	3	4	2	24	Possible risk
Shaft C	**TM³**	DUMP TRUCK DRIVER	×(0.10)	4	4	3	48	Risk
		L.H.D Driver	×(0.02)	2	4	2	16	Possible risk
		Dev RDO	×(0.04)	2	4	2	16	Possible risk
		Dev team leader	×(0.02)	2	4	2	16	Possible risk
		Development TEAM	×(0.14)	4	4	4	64	Risk
		Vehicle op	×(0.23)	5	4	5	100	High risk