Respirable crystalline silica dust exposure amongst foundry workers in Gauteng (South Africa):

A Task-based Risk Assessment

By

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Mini-dissertation submitted in partial fulfilment of the requirements for the degree of

Master of Public Health

(Occupational and Environmental Health)

In the

Faculty of Health Sciences

(School of Health Sciences)

University of Limpopo

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September 2012

DECLARATION

I, **Norman Nkuzi Khoza**, declare that this mini-dissertation hereby submitted to the University of Limpopo for the degree of Masters of Public Health (Occupational Hygiene) has not been previously submitted by me for a degree at this or any other university. I further declare that this is my work in design and in execution, and that all material contained herein has been duly acknowledged.

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Signature:	Date:

DEDICATION

This mini-dissertation is dedicated to my late father, Josiah Bonda Khoza (1918-2008), and Senior Pastor Elijah Msindiswa Mnisi (1961-2010).

ACKNOWLEDGEMENTS

The writing of this mini-dissertation is the culmination of interactions and consultations with special individuals and a wide variety of documents. I am grateful to God for the strength and divine inspirations throughout my life. I sincerely appreciate the support, patience and guidance of the following people because without you this project would not have been possible; to you I owe my deepest gratitude:

- My academic mother, Dr Anita Edwards, who undertook to act as my supervisor despite her work and other professional commitments. Your encouragement, motivation, support, professionalism and guidance in the writing of the dissertation and your knowledge and skills which you imparted for my success are greatly appreciated;

- Mr Percy Kekana, for his motivation, support and guidance in the writing of the dissertation and for sharing his knowledge as well. I have been inspired and motivated by your high standard of professionalism, commitment and wisdom;

- Mr Schu Schutte, Dr Declan Vogt and Dr Mpolokeng, to whom my sincere gratitude goes for their support and inspiration. Your professional work ethic gives me the edge;

- My wife, Luceth, and my son, Dzunisani; guys you light my world and your presence just gives me that extra strength;

- My parents, family, friends, teachers and spiritual family, for believing in and supporting me during years of study; and

- The CSIR Centre for Mining Innovation and the National Department of Labour, for their support.

ABBREVIATIONS, ACRONYMS AND SYMBOLS

ACGIH	-	American Conference of Governmental Industrial Hygienists
AIA	-	Approved Inspection Authority
AIDS	-	Acquired Immune Deficiency Syndrome
AIOH	-	Australian Institute of Occupational Hygienists
ANSI	-	American National Standards Institute
COIDA	-	Compensation for Occupational Injuries and Diseases Act
COPD	-	Chronic Obstructive Pulmonary Diseases
CSIR	-	Council for Scientific and Industrial Research
DMR	-	Department of Mineral Resources
DOL	-	Department of Labour
GPES	-	Global Programme for the Elimination of Silicosis
HCS	-	Hazardous Chemical Substance regulation
HEGS	-	Homogeneous Exposure Groups
HEPA	-	High Efficiency Particulate Air filters
HIV	-	Human Immunodeficiency Virus
HSE	-	Health and Safety Executive
IARC	-	International Agency for Research on Cancer
ILO	-	International Labour Organization
ISO	-	International Organization for Standardisation
MCE	-	Mixed Cellulose Ester
MDHS	-	Method for the Determination of Hazardous Substances
MHSC	-	Mine Health and Safety Council
MREC	-	Medunsa Research Ethics Committee
MSDS	-	Material Safety Data Sheet
mg/m^3	-	milligram per cubic metre
NIOSH	-	National Institute for Occupational Safety and Health
NPES	-	National Programme for the Elimination of Silicosis

OEL	-	Occupational Exposure Limit
OESSM	-	Occupational Exposure Sampling Strategy Manual
OSHA	-	Occupational Safety and Health Administration
PEL	-	Permissible Exposure Limit
RCS	-	Respirable Crystalline Silica
REL	-	Recommended Exposure Limit
RPD	-	Respiratory Protective Device
RPE	-	Respirable Protective Equipment
RSA	-	Republic of South Africa
SADC	-	Southern African Development Community
SANAS	-	South African National Accreditation System
SHE	-	Safety, Health and Environment
SiO_2	-	Silicon Dioxide
TB	-	Tuberculosis
TLV	-	Threshold Limit Value
TWA	-	Time-weighted Average
USA	-	United States of America
WAHSA	-	Work and Health in Southern Africa
WHO	-	World Health Organization
XRD	-	X-ray Diffraction

ABSTRACT

Background: The objective of this study was to quantify personal time-weighted average respirable dust and silica exposure of workers at foundries in Gauteng and to rank the occupations in foundries according to the risk of exposure to silica quartz.

Methods: A task-based risk assessment of 56 personal samples from two foundries was conducted. Personal exposure data was collected from workers' breathing zones for the full working shift. All analyses of samples for silica dust were carried out in the CSIR Centre for Mining Innovation's Laboratory, which has SANAS accreditation (ISO 17025) for both x-ray powder diffraction and particle size analysis methods.

Results: The personal time-weighted average mean and median respirable silica dust concentration was 0.184 mg/m³ and 0.167 mg/m³ respectively. The maximum exposure concentration was 0.835 mg/m³ and minimum exposure was 0.010 mg/m³.

The occupations within the foundries with the highest exposures were moulders, sand mixers, furnace operators and the lowest exposed occupations were grinders, closers, and casting operators. The majority of foundry workers (62%) in both foundries are exposed to respirable silica dust at above the South African occupational exposure level (OEL).

Conclusion and recommendations: Foundry workers are over-exposed to respirable silica dust and are potentially at high risk of contracting silicosis and other occupational diseases associated with respirable silica dust. It is recommended that a dust control programme be implemented and a baseline study be conducted.

Key concepts:

Respirable silica dust, foundry workers, task-based risk assessment

DEFINITION OF TERMS

Abrasive blasting

Abrasive blasting is an industrial process used to polish or clean various types of objects by using high-powered equipment to spray abrasively

Glass beads

Glass bead is the material used during the process of removing surface deposits by applying fine glass beads at a high pressure without damaging the surface

Inhalable dust

The particulate mass fraction of dust in the work environment that can be inhaled and deposited anywhere in the respiratory tract (particles smaller than 50 micrometers (µm) in aerodynamic diameter)

Non-mining industry

The non-mining industry is a broad sector that encompasses many industries, apart from industries that include mining and quarrying

Pneumoconiosis

An occupational and restrictive lung disease caused by the inhalation of dust and characterised by the formation of nodular fibrotic changes in the lungs

Respirable dust concentration

Respirable dust concentrations as measured by gravimetric dust monitoring instrumentation

Silica/silicon dioxide

One of the most abundant minerals in the earth's crust. It is present in almost all types of rock, sands, clays, shales and gravel.

Respirable crystalline silica (RCS)/quartz/respirable silica dust

A toxic portion of airborne silica that is capable of entering the gas-exchange region of the lungs when inhaled (smaller than 10 microns) and capable of causing silicosis

Silicosis

Silicosis is a form of pneumoconiosis and an occupational disabling, non-reversible and sometimes fatal respirable disease caused by the inhalation of dust that contains free crystalline silica (RCS)

Silica sand

Silica sand is sand that is commonly used in industrial processing, to make glass and to create moulds and castings

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CHAPTER 1

INTRODUCTION AND BACKGROUND

1.1 General introduction

Silica or silicon dioxide (SiO_2), which is formed from silicon (SI) and Oxygen (O) atoms, is the most common element in the earth's crust. Silica dust is formed during the processing of minerals or rock materials, i.e. through crushing, cutting, drilling, chipping or mixing (Park, *et al.,* 2002; Stanton, *et al.,* 2006). Exposure to respirable crystalline silica (RCS) dust has recently re-emerged as is known to be a serious public health problem and silicosis is common in industrial workers in South Africa because of inadequate dust controls (Motshelanoka, 2006). The burden of silicosis in industrial workers is exacerbated by the high prevalence of HIV/AIDS and tuberculosis in South Africa (Motshelanoka, 2006; Rees & Kielkowski, 1991; Rees, 2006).

Silicosis is a severe occupational and public health concern in both developed and developing countries (Bang, *et al.,* 2008; Nogueira, *et al.,* 2009). Developed countries have shown improvement in terms of reducing the incidence of silicosis; however, silicosis is still very prevalent in low- and middle-income countries (Bang, *et al.,* 2008; Gerhardsson, 2002). South African industries, both mining and non-mining, have indicated their commitment to the global effort to eliminate silicosis by 2030 (Nelson, *et al.,* 2010). Evidence of this commitment can be seen mainly in the mining industries. On the other hand, silicosis in the non-mining industries has received very little attention in the past decade.

To determine whether workers are exposed to silica dust above the occupational exposure limit (OEL) that can result in silicosis or other diseases associated with exposure to crystalline silica, a risk assessment is usually carried out. A risk assessment is the process of determining the likelihood that hazard exposure will result in illness or harm (Guild, *et al.,* 2001). The objective of risk assessment is to identify the relevant health hazard and the degree to which workers are exposed to that hazard (Guild *et al.,* 2001). There are three forms of risk assessments: baseline, issue-based and continuous risk assessments (Guild *et al.,* 2001; MHSC, 2007). The current study undertook a baseline risk assessment aimed at evaluating the level of risks from occupations and tasks performed.

The Department of Labour (DOL) has recently completed a two-year study (from 2009 to 2010) on worker exposure to silica dust across all non-mining industries that have the potential of exposing workers to silica dust. The study is a sign of commitment by the department to its National Programme for the Elimination of Silicosis; it serves as a baseline study to find the extent of the exposures in different non-mining industries.

The first phase of the study revealed that there are no silicosis elimination programmes or policies in these industries and that the prevention of dust exposure is poor in foundries. The first phase of the study also concluded that there was a need for dust measurements in non-mining industries and final phase showed that workers are exposed to silica dust, which includes foundries (Khoza & Grove, 2010).

1.2 Problem statement

Silicosis is a problem in South African foundries; the problem has been exacerbated by inadequate dust control and neglect of occupational health in foundry industries (Rees & Weiner, 1994). Because of the extent of the problem, the DOL revised its OEL of silica dust from 0.4 mg/m³ to 0.1 mg/m³ in 2008 (Department of Labour, 2010); however, cases of diseases associated with crystalline silica dust are still reported to the compensation commissioner every year (Department of Labour, 2008a).

Occupation and tasked-based worker exposure data appears to be absent for Gauteng Province. For this reason the study proposed to investigate the exposure levels of foundry workers to RCS dust and again present recommendations.

1.3 Aim and objectives

The aim of the study was to assess exposure levels to RCS dust amongst foundry workers in Gauteng Province in South Africa.

The objectives of the study were to:

- Determine the personal exposure levels to respirable crystalline silica dust of foundry workers in the Gauteng Province; and
- Identify and rank tasks and activities that are high risk for exposure to respirable crystalline silica dust in the foundry environment.

1.4 Research question

Exposure to respirable silica dust in the workplace puts foundry workers at risk for silicosis. The rationale for this study was therefore to quantify the risk in South African foundries. Therefore the research question for this study was:

What are the levels of exposure to respirable crystalline silica dust amongst foundry workers in Gauteng?

CHAPTER 2

LITERATURE REVIEW

The literature review was conducted to find literature regarding the extent of silicosis in national and international foundries. The investigation or literature review was looking at how a foundry works, the process undertaken, the raw material used and the by-products. How silica dust is generated, what was the extent of exposure and the relevant legislation regarding silica dust exposure in foundry industries?

2.1 Foundry process and silica dust exposure tasks

A foundry is a factory where metal castings are produced by means of the metal-forming process in which molten metal is poured into a prepared mould to produce a metal object. There are two types of foundries: ferrous and non-ferrous foundries (Crawford, 2007). Ferrous foundries produce gray ductile iron, malleable iron, and steel. Non-ferrous foundries produce aluminium, brass, bronze, copper-based alloys, zinc and magnesium. Sand casting is the method used in both ferrous and non-ferrous foundries owing to the high melting temperature of sand (NIOSH, 1985). The sand-casting process poses a health risk when foundry workers inhale dust that contains silica dust from the sands used to make moulds (NIOSH, 1985).

The process used in the production of metal castings is that sand is used as a moulding material into and around the area where molten metal is poured. The cooled metal casting is then cleaned and removed from the moulding material and extraneous metal (IARC, 1997). The worker activities that agitate dust in the above-mentioned metal-casting process are shake-out and mixing and other activities that fracture sand into respirable dust. The cleaning of both metal casting and machinery by means of air nozzles is a significant source of dust in a foundry as it releases dust into the air. The finishing process for metal casting includes grinding, blast cleaning and coating, which are also all high-risk worker activities for exposure to silica dust (see Figure 2.1).

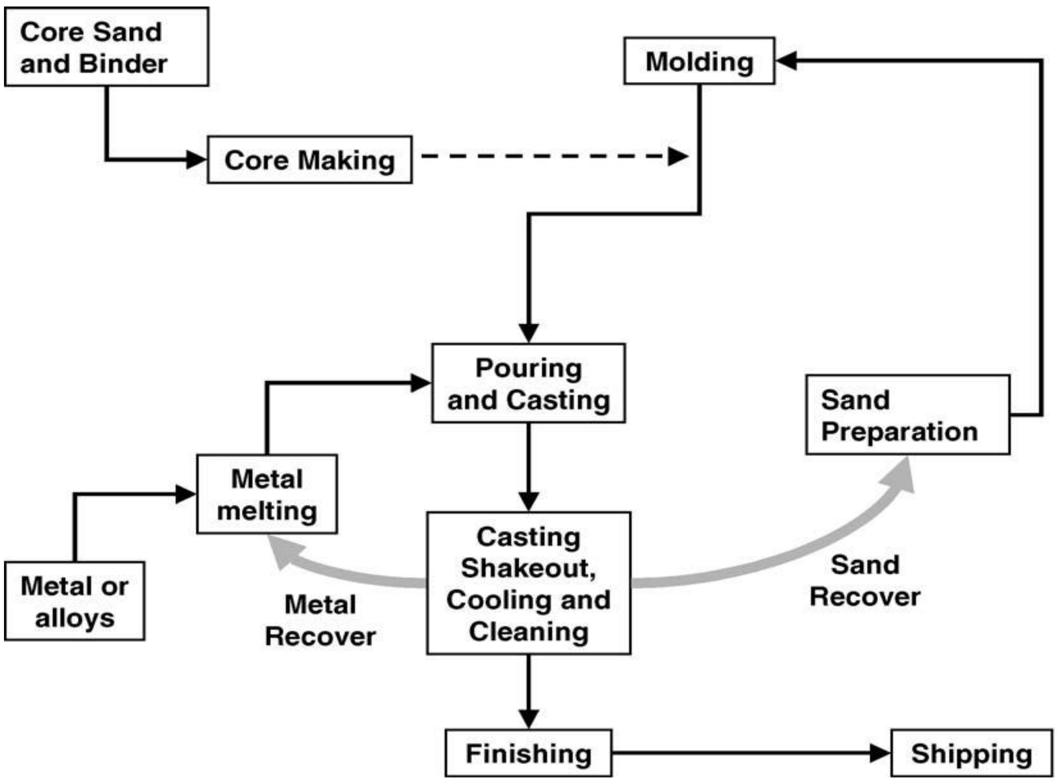


Figure 2.1 Metal-casting process **(Ribeiro & Filho, 2006)**

The highest-exposure jobs in foundries are reportedly grinders, chippers, and cut-off saw operators; shakeout and continuous mixer operators; shot blast operators; and muller operators (Boyd & Klempner, 2000; Bastian & Alleman, 1998; NIOSH, 1985). In a study conducted in Canadian foundries the jobs with the highest exposure to RCS dust were found to be shaking-out with control at the range 0.63 – 2.60 mg/m^3 and without control at 0.40 – 21.3 mg/m^3; moulding with control measures from 0.35 – 3.40 mg/m^3 and with no control measures at 0.95 – 6.13 mg/m^3; and in sand preparation with control from 0.75 – 16.80 mg/m^3 and sand preparation without control from 2.44 – 16.70 mg/m^3 (IARC, 1997). Excessive silica dust was found in cleaning work, sand mixing, and shake-out operations (Siltanen *et al.,* 1976). Grinding and chipping jobs have been historically associated with highest-exposure hazard for silica dust; other operations reported to have the highest exposures are melting, pouring, sand system, coremaking, moulding, cleaning (shake-out, chipping and grinding, abrasive blasting, and knock-out) and other miscellaneous occupational titles (Oudiz *et al.,* 1983).

In a study done in the United State of America (USA) that showed the geometric mean exposure to silica dust per occupation were spruer (0.154 mg/m^3), hunter operator (0.093 mg/m^3), charger (0.091 mg/m^3) and core maker (0.078 mg/m^3) (Yassin, Yebesi & Tingle, 2005).

Oudiz *et al.* (1983) in their study on USA foundries found that ferrous and steel foundries had higher exposure to silica dust than non-ferrous foundries; this was due to increased metal penetration of the moulding sand as a result of hot metals which resulted in increased dust generation in the cleaning operations. Other factors they found to affect exposure levels were the size of the foundry, size of casting and production rate.

Dust concentrations in Vietnam foundries were reported to be highest (22 – 32 mg/m³) during handling used sand, moderate (7.4 – 14.8 mg/m³) during the moulding and core-removing stages and lowest (1 – 7.9 mg/m³) during melting and pouring the mould (Luong & Van Hai, 1999). The highest prevalence of pneumoconiosis in Taiwan foundries was found among furnace workers (15.9%), moulding workers (8.40%) and post-treatment workers, with 8.30% (Kuo *et al.,* 1998). Siltanen *et al.* (1976), investigating Finland foundries, found that occupations with the highest dust exposures were furnace, cupola, and pouring ladle repair. Operations with the lowest dust concentrations were melting and pouring.

In the USA, 40.6% of a foundry worker sample exceeded the time-weighted average (TWA) of the Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL), and the highest TWA was recorded on the melting process, with 0.079 mg/m³ for the period 1976 to 1981 (Koo, 2000).

2.2 Dust particulate

Dust is defined as the generation of solid particles that are dispersed into the air by handling, crushing or grinding of organic or inorganic materials, which include rock, ore, metal, coal, wood or grain (Belle and Stanton, 2007). The USA Mine Safety and Health Administration (MSHA) (2008) defines dust as finely divided solids that may become airborne from their original state without any chemical or physical change, other than fracture. Dusts are generated during the handling, pulverisation, grinding, crushing, rapid impact and decrepitation of organic and inorganic substance such as rock, ore, metal, coal and wood (Guild *et al.,* 2001). The type of dust that is dangerous to the human body is known as "fibrogenic dust", and includes coal, silica, asbestos, wood and cotton wool dust (OSHA, 2008a).

2.3 Dust classification

Dusts are primarily classified into three categories: respirable, inhalable and total dust.

2.3.1 Respirable dust

Respirable dust is the dust of a particle size small enough to enter the gas exchange region of the human lung (up to 10 micrometers (μm) aerodynamic diameter) (Belle & Stanton, 2007; OSHA, 2008a). If the dust is less than 10 microns in diameter, then it is capable of reaching the air sacs in the lung without being trapped by the mucus lining of the airways (Boyd & Klempner, 2000). Excessive or long-term exposure to harmful respirable dusts may result in a respiratory disease called "pneumoconiosis". This disease is caused by the build up of mineral or metallic dust particles in the lungs and the tissue reaction to their presence. "Pneumoconiosis" is a general name for a number of dust-related lung diseases, like silicosis, asbestosis and black lung disease (OSHA, 2008b).

2.3.2 Inhalable dust

Inhalable dust is a particulate of a particle size capable of entering the nose and mouth during breathing, generally regarded as dust that is up to 100 μm in aerodynamic diameter (Belle & Stanton, 2007). According to Belle and Stanton (2007), this type of dust can be deposited in the respiratory tract; it may also accumulate in the sputum or mucus and be coughed out or swallowed and then be absorbed in the digestive system.

2.3.3 Total dust

Total dust is classified as dust that consists of all airborne particles, regardless of size and/or composition; thus, total dust is a combination of all the different types of dust (OSHA, 1987; OSHA, 2008a). Total dust particles are not selectively collected in terms of their particle size and they may cause toxic effects when they are inhaled in large quantities (MSHA, 2006).

2.4 Respirable crystalline silica dust

In the types of dust mentioned above, RCS dust can be found in the form of SiO_2, one of the most abundant minerals in the earth's crust, and present in almost all types of rock, sands, clays, shales and gravel. The main forms of crystalline silica are quartz, cristobalite and tridymite, of which quartz is the most prevalent (AIOH, 2009). RCS dust is an aggressive and lung-damaging dust when penetrated into the lung in sufficient quantity (AIOH, 2009). The crystalline silica dust with a small particle size (less than 10 μm in diameter) is the dust capable of causing silicosis. Inhalation of RCS may result in the development of silicosis, chronic obstructive pulmonary diseases (COPD), lung cancer and accelerated incidences of pulmonary tuberculosis (TB) (Johnston & Ferrie, 2010; Tse *et al.,* 2011). There is also a strong association between silica exposure and TB, particularly in South Africa where TB and HIV rates are high (Nogueira *et al.,* 2009). Silica dust control is inadequate in mining and non-mining sectors (Rees & Kielkowski, 1991), which makes workers in these industries susceptible to occupational respiratory diseases.

The route of exposure for silica dust is through inhalation, and wind speed, wind direction, relative humidity and ambient temperature are regarded as confounding factors. Increased wind velocity reduces the silica dust concentration significantly. In addition, a study by Akbar-Khanzadeh and Brillhart (2002) found that working up-wind reduces exposure to silica dust more than working downwind and concluded that total respirable dust and silica dust had no significant correlation with ambient temperature and relative humidity.

The “flint”, as Crystalline Quartz is known, reaches the air sacs of the lungs and destroys white blood cells. The fresh surface of silica grain kills some of the lung cells where it has been deposited, while the remaining cells begin a chain of reactions, forming layer upon layer like an onion, ultimately forming growing nodules that create scar tissue and eventually thickening the lung surface. This process makes the lung surface stiffer and leather-like and reduces the elasticity of the lung and surface area, making it difficult for the person to breathe. The phenomenon continues even after the worker has been removed from the silica dust environment (Boyd & Klempner, 2000).

2.5 Silicosis and exposure trends

Silicosis is a severe, incurable and irreversible disease caused by the inhalation of dust that contains free crystalline silica (Fedotov, 1997; Rees & Murray, 2007; Hnizdo *et al.,* 1999). The inhaled silica dust particles have a fibrogenic capacity that leads to the development of pneumoconiosis (Hnizdo *et al.,* 1999). The disease is known as “fibrotic pneumoconiosis” and the lung disease is known as “silicosis” (DOL, 2007a). Silicosis is preventable (DOL, 2007a; WAHSA, 2007; NIOSH, 2002; Swanepoel *et al.,* 2009). This is why the global approach to the elimination of silicosis is focused on the control of exposure to silica-containing dusts (Fedotov, 1997). The extent of the disease also depends on various factors: the nature and concentration of the dust, the duration of exposure, and the individual’s susceptibility to the disease among them (Fedotov, 1997; DOL, 2007a).

In terms of exposure trends, 12% of foundry workers in the USA with 30 years or more of work service, had chest radiographs consistent with silicosis (Rosenman *et al.,* 1996). In the USA, from 1985 to 1990, about 11% of the workplace deaths were caused by silicosis, where silicosis was identified on the death certificates (Roznowski, 2008; Alazab, 2004). In 2003 about 3 030 foundry workers were reported to be exposed to silica dust and at risk of developing silicosis in Vietnam (Lan *et al.,* 2003).

In South Africa, as early as 1988, foundries were in the leading chart with regard to cases of silicosis. In that year, of 217 reported cases of silicosis in the non-mining industries, the foundry industry accounted for 49% of cases. The 108 foundry cases of silicosis were distributed as 51% fettling and grinding, 9% sandblasting, 9% moulding, 8% furnace maintenance, 4% sand plant and 19% others (Ehrlich *et al.,* 1988). Rees and Weiner (1994) found that the prevalence of silicosis ranged from 0% to 10.3% and increased with duration of service. Cases of silicosis are common in South African industrial workers. They concluded that the study provided convincing evidence of neglect of occupational health by the foundry industry. Only 20% of foundry industries in South Africa conduct regular dust level measurements, out of 82 foundries with approximately 10 826 workers (excluding administrative staff) (Rees & Weiner, 1994).

Studies conducted in 1994 revealed that 10.3% of 107 workers in South African foundries had pneumoconiosis and that its prevalence increased with years of service, at 38% for workers with more than 15 years of service (Myers *et al.,* 1987; Rees & Weiner, 1994). These studies pointed to the magnitude of the problem of silicosis in South African foundries at the time. The question today is: what are the levels of personal exposure to crystalline silica in these industries and are there enough control measures in place?

Foundry workers are well known to be at high risk of developing silicosis, especially those with more years of service has a high risk of developing the disease than those with less years of service. It was found that about six percent of workers with 20-29 years of works and 12 percent of workers with 30 of more years of work in the foundry had chest radiograph consistent with silicosis (Rosenman *et al,* 1996).

2.6 Health effects of silica dust exposure

Exposure to silica dust and the development of silicosis have serious health effects on the human body. Toxicity of silica or the ability of crystalline silica to cause silicosis is determined by the following factors (OSHA, 2008b; AIOH, 2009; HSE, 2000; Meldrum & Howden, 2002):

- *Polymorphic type of crystalline silica* – as cristobalite, tridymite and quartz are more reactive and cytotoxic than coesite and shishovite;

- *Dust concentration* – on the basis of weight in mg/m³; the more the dust concentration the faster and greater the likelihood of contracting silicosis;
- *Particle size, shape and surface area* – smaller dust particles produce more lung damage than larger dust particles; "shape" refers to whether a particle is fibrous or spherical;
- *Freshly fractured and "aged" surface area* – a newly or freshly fractured crystalline silica particle leads to an increase in cytotoxicity; and
- *The duration of exposure* – the prevalence of silicosis is increased with the years of service of the worker during which exposure has taken place.

There are no symptoms in the early stages of silicosis and the three types of silicosis are: chronic silicosis, accelerated silicosis and acute silicosis. **Chronic silicosis** usually has a latency period of 10 to 20 years of overexposure to crystalline silica. **Accelerated silicosis** results from exposures to crystalline silica and develops over five to 10 years of exposure. **Acute silicosis** occurs where exposures to RCS are the highest and this type of silicosis can cause symptoms to develop within a few weeks or up to five years (Hnizdo *et al.,* 1999; DOL, 2007a; Ding *et al.,* 2002; Rees, 2006; Gottesfeld *et al.,* 2008). Silicosis manifests itself through the following symptoms: shortness of breath following physical exertion, severe cough, fatigue, loss of appetite, chest pains, fever, and cyanosis. These symptoms of silicosis develop after lung tissue becomes irreversibly damaged by fibrosis and is replaced with solid nodules of scar tissue (Gottesfeld *et al.,* 2008).

People who are smokers are by far the most at risk for lung cancer, let alone those workers who smoke and are exposed to silica dust which is reported to be carcinogenic. In studies of workers who smoke and are exposed to silica dust have been found to develop clinical symptoms of silicosis much faster than non-smokers exposed to the same dose (Brown, 2009; Rosenman *et al,* 1996).

2.7 Occupational exposure limits

A certain minimum amount of silica dust (0.1 mg/m³) is needed in order for it to cause silicosis, and OELs are set as control limits. The current occupational exposure control limit for silica in South Africa is 0.1 mg/m³ as a TWA of eight hours/day during a 40-hour week (DOL, 2008a; DOL, 2010). The American Conference of Governmental Industrial Hygienists' (ACGIH) Threshold Limit Value for respirable silica is 0.025 mg/m³ (ACGIH, 2008a; ACGIH, 2008b). The NIOSH recommended exposure limit (REL) for respirable crystalline silica is 0.05 mg/m³ as a TWA for up to 10 hours/day during a 40-hour workweek (NIOSH, 1992b; Wickman & Middendorf, 2002). Motshelanoka (2006) argues that the South African OEL has not been adequate for reducing silicosis; reducing the South African OEL from 0.1 mg/m³ will bring the limit in line with international trends.

2.8 Programmes aimed at eliminating silicosis

Owing to the scourge of silicosis world-wide international health and labour organisations have developed specific programmes aimed at eliminating silicosis in the world and some of these programmes are described below.

2.8.1 Global Programme for the Elimination of Silicosis (GPES)

The International Labour Organization (ILO) and World Health Organization (WHO) Committee on Occupational Health proposed the joint “Global Programme for the Elimination of Silicosis” (GPES) in 1995. The programme has two objectives:

- *Immediate Objective*: To promote the development of a “National Programme on Elimination of Silicosis” in countries to reduce the incidence rates of silicosis significantly and globally by 2015; and

- *Developmental Objective*: To establish wide international cooperation on global elimination of silicosis in order to eliminate the disease as an occupational health problem by 2030 (Fedotov, 1997).

2.8.2 National Programme for the Elimination of Silicosis (NPES)

This programme, initiated by the DOL in 2004 (DOL, 2007c), outlines the South African government’s commitment to reducing the prevalence of silicosis significantly by 2015 and to eliminating silicosis in all workplaces by 2030, in line with the ILO/WHO “Global Programme for the Elimination of Silicosis” initiated in 1995.

2.8.3 Regional Work and Health in Southern Africa (WAHSA) initiatives

Silicosis elimination activity in the Southern African Development Community (SADC) takes the form of regional collaboration initiatives through the organisation Work and Health in Southern Africa (WAHSA), which has as its major objectives increased interventions regarding silica, silicosis and TB, and a reduction in dust exposure in key industries and improved prevention of TB in silica-exposed workers (Rees, 2006).

2.9 Conclusion

The literature review has clearly indicated that silicosis is a problem in foundries around the world and in South African foundries as well. The extent of the problem was unknown in terms of workers exposure to silica dust which causes silicosis.

CHAPTER 3

RESEARCH METHODOLOGY

A personal exposure to respirable crystalline silica dust survey was conducted at two foundries in Gauteng, using the method outlined below.

3.1 Study design

A quantitative, descriptive cross-sectional research design was used in this study. A descriptive cross-sectional research design involves measuring the variables once at a single point in time, to provide a perspective on the magnitude of risk of exposure and risk of health consequences (Technikon Free State, 2003).

3.2 Sampling

A convenience sample was used in two foundries in Gauteng. The foundries were chosen after contacting foundries on the DOL list of non-mining industries and requesting assistance from companies for the current research. Owing to limited time available, the restricted scope of the research project, budget constraints, and the reluctance of foundry owners to volunteer, data was collected at the two foundries willing to participate in the study. These foundries were located in the Ekurhuleni and Tshwane Metropolitans in Gauteng.

The sampling was based on the assessment of workers' personal exposures to respirable dust and silica dust, during normal working conditions in a pre-determined working section. The homogeneous exposure groups (HEGS) in foundries were identified on the basis of the available occupations in the section and the number of samples was determined by using the Occupational Exposure Sampling Strategy Manual (OESSM).

The selection of occupations to be sampled was critical for the determination of personal exposures. The sampling strategy included the following:

- A representative sample of the workforce in the section was chosen;
- The occupations selected were operative in the section for the entire duration of the sampling period;
- The same workers were sampled for all the sampling days; if any worker was unable to attend a sampling day a substitute worker was sampled in his/her place, provided he/she performed the same activities and worked in the same work station as the absent worker; and
- The number of samples collected from the workers was spread equally over the

different occupations to ensure that occupations at high risk to silica dust exposure could be identified.

For quality control purposes wind speed, humidity and temperature were also collected during sampling because these environmental factors can affect the sampling results. Data regarding the gender, years of service and smoking was collected using a data collection sheet submitted to the management (see appendix 15).

3.2.1 Sample description

The two foundries had a total number of 148 (N=148) workers who were exposed to dust and samples were collected for dayshifts only. There were 78 workers in the first site and 71 workers in the second site. A representative sample of 56 (n=56) were collected, which was the representative sample of the most exposed workers. The most exposed employee or maximum risk employees' strategy was used to determine the samples (NIOSH, 1977). This sampling represented all occupations and tasks performed in each foundry. Occupations sampled were shot blaster, sand mixer, casting operator, shake-out operator, furnace operator, moulder, grinder, closer, loco sand filler and loco sand remover (see Table 3.1).

Personal sampling data was collected at the breathing zone for three consecutive days for approximately eight hours per day (average 476 minutes, minimum 405 minutes and maximum 519 minutes). The total numbers of samples collected per site or foundry were 26 (n=26) samples for foundry one and 30 (n=30) samples foundry two.

Three samples were excluded or discarded from the reported data owing to gravimetric sampling pumps malfunctioning, and filter damage.

Table 3. 1: Descriptions of occupations

Occupation	Description
Sand mixing operator	Operates the machines that mix sand in the plant
Shake-out operator	Operates the crane and machine that remove the cast from the mould
Shot-blast operator	Operates the compressed air pipe to remove rust or paint from objects
Furnace operator	Manages the furnace and operates the crane that is used to put the metals into the furnace
Casting operator	Operates the crane used to transport molten metals into the mould and also repair melting pots
Loco sand filler and	Removes sand from the trains while the locomotives are being

remover (technician)	serviced and refills the trains afterwards
Moulder	Makes the moulds or casts
Grinder	Operates the grinder in the fettling section to remove scale and access materials from the products
Closer	Closes the moulds

3.3 Data collection

Data was collected using the CSIR Centre for Mining Innovation (CMI) facilities and equipment.

3.3.1 Material and equipment

Gravimetric dust sampling (of respirable dust and respirable silica dust) was carried out, using personal gravimetric sampling pumps and sampling filters (see Appendix 10, Images 1 and 2). A sampling cassette containing a mixed cellulose ester (MCE) filter of 25 mm in diameter was attached to the sampling pump (see Appendix 10, Image 1). Each sampling pump was calibrated at a pre-calibration flow rate of 2.2 litres per minute and a post-calibration was conducted and externally calibrated by an independent laboratory (see calibration certificates attached as Appendix 9). Personal sampling pumps were attached to workers and their occupations and tasks were recorded with the serial numbers of the sampling pumps and their cyclone and filter cassette numbers (see Appendix 1).

Personal gravimetric sampling pumps were attached to the workers' waists, with a sampling filter extended to the workers' lapels or breathing zone (attached to the workers' collars) with a U-tube (see Appendix 10, Image 2). The sampling pumps were worn continuously during work and rest periods (NIOSH, 1977). A "Full Period Consecutive Sampling Strategy" was employed, where samples were collected for three consecutive days during the full working period. The total time covered during sampling was eight hours for an eight-hour TWA standard or in one day (NIOSH, 1977).

Wind speed, humidity, and temperature were measured using the Kestrel® 4000 Pocket Weather Meter during the sampling periods (see Appendix 10, Image 3). The instrument was held against the wind at about 1.5m above the working floor and the measurements of temperature, wind speed and humidity were taken three times a day.

3.4 Data analysis

3.4.1 Gravimetric weighing analysis

Filters (25 mm) were weighed in the laboratory using a Mettler Toledo Balance, in accordance with the accepted guidelines from the Department of Mineral Resources (DMR) (Stanton, 2007). Pre- and post-sampling filter mass was subtracted in order to calculate the total dust accumulated in the filter (HSE, 2000).

3.4.2 X-ray Diffraction (XRD) analysis

The crystalline silica content for all samples was determined by means of X-ray Diffraction (XRD) analysis. The alpha quartz content was determined by using a Bruker D8 Advance X-ray Powder Diffractometer. The procedure was carried out in accordance with the analytical method on alpha quartz analysis, MDHS 101 (HSE, 2005).

3.4.3 Particle size analysis (PSA)

All activity samples were analysed for particle size distributions by using a Horiba LA-950 V2 laser scattering particle size distribution analyser. PSA was performed on all the respirable dust samples measured for all the companies and their activities sampled.

All analysis was carried out in the CSIR CMI Laboratory, which has SANAS accreditation (ISO 17025) for both XRD and PSA methods and is currently the only laboratory in South Africa accredited for the XRD method (see Appendix 11).

3.4.4 Statistical analysis software used

The data was analysed using Statistical Package for the Social Science (SPSS) version 18. ANOVA was used to make statistical comparisons. The data was verified using the IHSTAT data analysis spreadsheet, an American Industrial Hygiene Association (1998) analysis tool (Industrial Hygiene Statistics), and Microsoft Excel® 2007 spreadsheet.

3.5 Ethical clearance

Written permission from the DOL was obtained for the use of a foundry fraction of the data collected from the non-mining industries (Reference number L007/07/2010, attached as Appendix 12) and the study was approved by the Medunsa Research and Ethics Committee (MREC), with the clearance certificate (project number MREC/HS/62/2011: PG) attached as Appendix 13.

3.7 Study limitations

The small sampling size of the study due to the lack of funds for the analysis of RCS dust makes it difficult to extrapolate the findings of this study to represent the whole of the Gauteng foundry industry.

The data was collected during a day shift and workers had concerns that much dust is generated during the night shift where intensive shake-out operations take place. Had the night shift been sampled as well this could have painted a different picture of the exposure image of both foundries.

3.8 Conclusion

The study was carried out according to the requirements and specification of the approved proposal, no deviation from the proposal experienced.

CHAPTER 4

RESULTS

The following chapter reports on the results of the investigation of personal exposure levels for respirable crystalline silica dust in foundry workers. This chapter includes a description of the sample and the environmental conditions during sampling.

4.1 Smokers

Forty three percent (43%) of all participants from both foundries sampled were smokers, 53% were non-smokers and for 4% of the participants' smoking status could not be established (see Figure 4.1 & appendix 2).

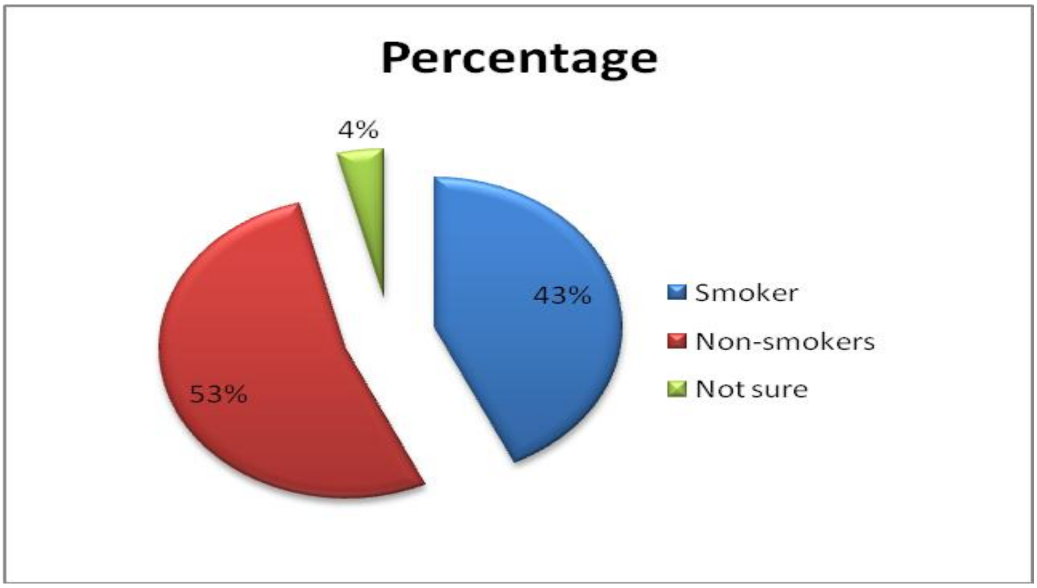


Figure 4.1: Smoking vs non-smoking

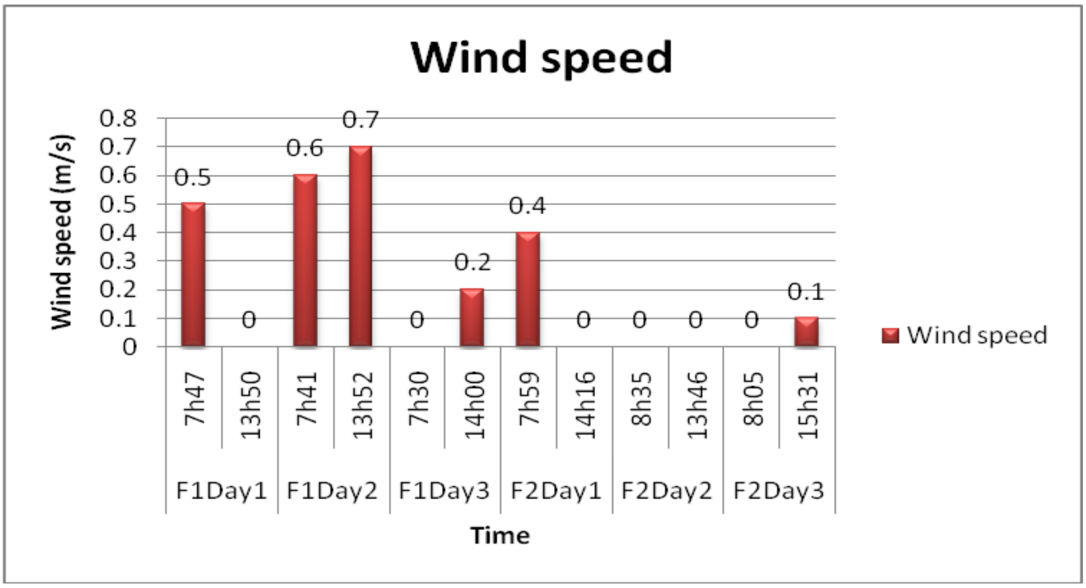
4.2 Years of service

Thirty three (33%) of the participants from all foundries sampled had 10 and more years of service. The participant with the most years of service had worked in the foundry for 40 years, while the participant with the least years of service had four months, and the mean years of service was 10.2, with a standard deviation of 12.5.

4.3 Environmental conditions

Working stations were located inside a factory and the weather outside exhibited clear skies and dry conditions without any rain on sampling days at both foundries.

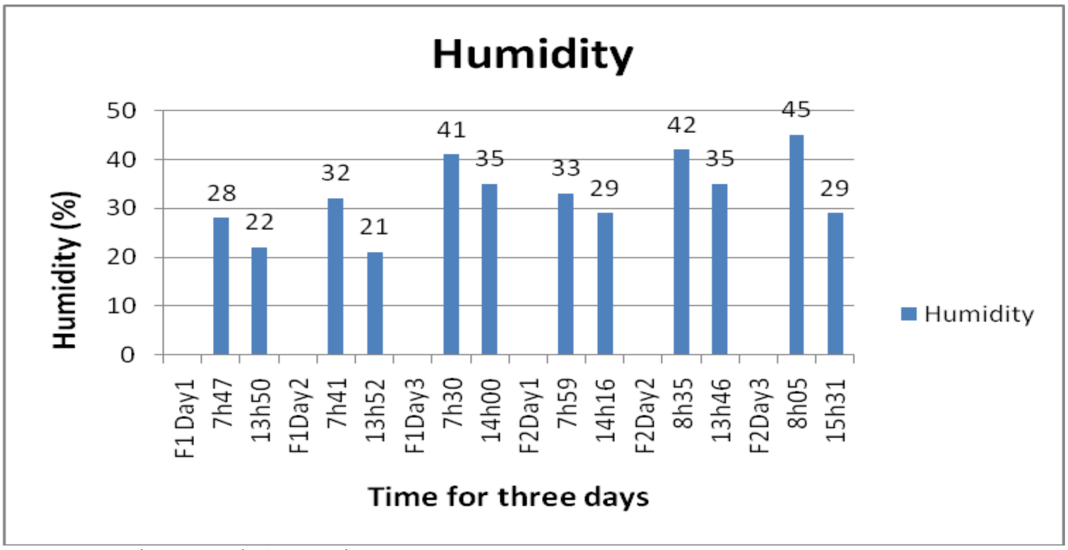
More than 33% of the averaged wind speed from site one (foundry one-F1) recorded a zero wind speed in metres per second inside the foundry. About 67% of the averaged wind speed measured in the second foundry (F2) recorded a zero in metres per second (m/s) inside the foundry. The overall maximum, average and minimum wind speed was 0.7, 0.2 and 0.0 m/s, respectively. Approximately 50% of the overall measurements for wind speed recorded a 0.0 m/s (see Figure 4.2 and Appendix 2).



NB! F1=Foundry one and F2=Foundry two

Figure 4.2: Wind speed recorded in both foundries for three days in each foundry

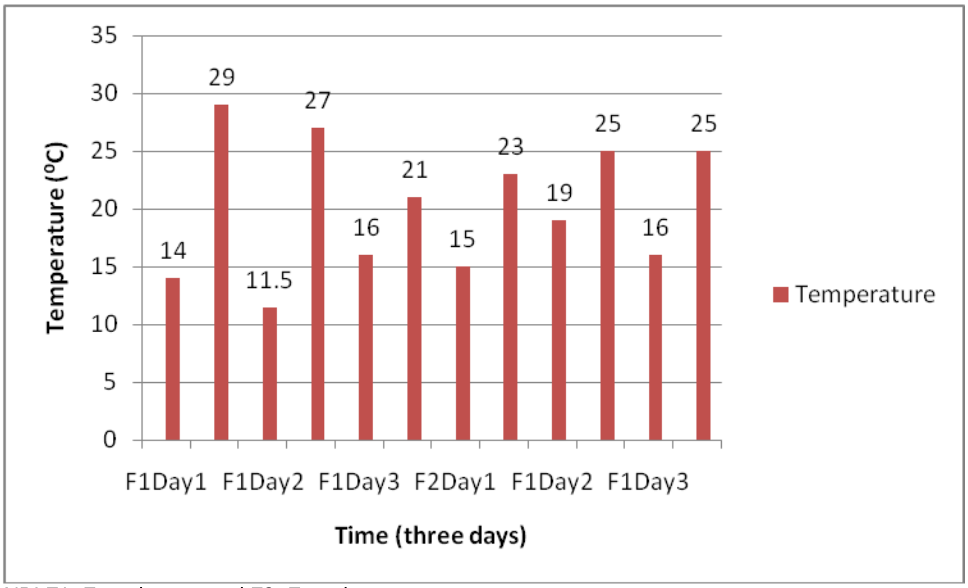
Humidity was 45%, 33% and 21% for maximum; average and minimum, respectively (see Figure 4.3 and Appendix 2).



NB! F1=Foundry one and F2=Foundry two

Figure 4.3: Humidity recorded during sampling in both foundries for three days in each foundry

The maximum, average and minimum temperatures were 29°C; 20.1°C and 11.5°C, respectively during sampling time (see Figure 4.4 and Appendix 2).



NB! F1=Foundry one and F2=Foundry two

Figure 4.4: Temperature recorded in both foundries for three days in each foundry

4.4 Respirable exposure results from foundries in Gauteng

The main objectives of the study were to report on and discuss the findings in relation to respirable silica dust, but the findings related to respirable dust are also discussed simply because silica dust is found in respirable dust. Only respirable dust is collected when collecting and analysing samples for respirable silica dust. The control of silica dust is aimed at controlling the respirable dust in the work place. So respirable dust findings are reported and discussed in this report to act as a baseline for the two foundries sampled.

The analysed personal sampling results are outlined and discussed as minimum, average, median and maximum per occupations sampled in the two foundry industries. These results are expressed and discussed in terms of personal respirable dust and personal respirable silica dust for occupations believed to put employees at maximum risk. The results are presented per foundry sampled and also as the minimum, average, median and maximum of the combined foundries to highlight the occupations with the highest exposure to and risk of silicosis.

4.4.1 Respirable dust and crystalline silica dust exposure levels in Foundry one

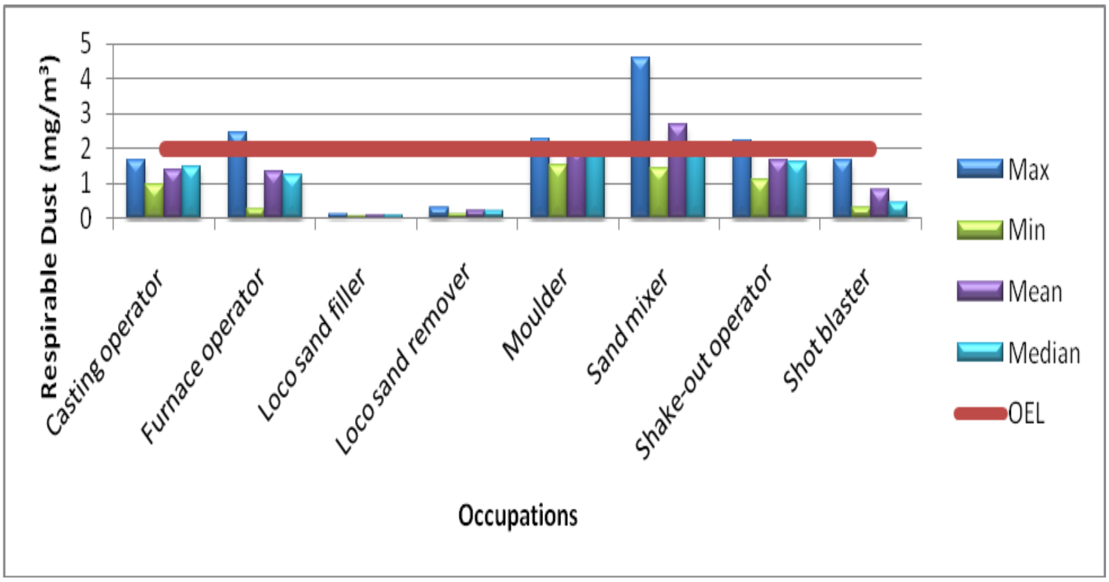


Figure 4.5: Respirable dust exposure per occupation for workers at Foundry one

The overall mean TWA concentration of respirable dust for foundry one was 1.189 mg/m³ with a standard deviation of ±1.062. The average maximum and minimum respirable dust concentrations were 4.571 mg/m³ and 0.058 mg/m³, respectively. Overall TWA median concentration for respirable dust for foundry one was 1.163 mg/m³. Twenty-three per cent of the respirable dust concentration measured in foundry one (n=26) exceeded the South African OEL of 2 mg/m³ (see Appendix 3).

Occupations found to have the highest respirable dust concentration exposure were sand mixer with maximum of 4.571 mg/m³, mean of 2.702 mg/m³ and minimum of 1.444 mg/m³; furnace operator with maximum concentration of 2.448 mg/m³, mean of 1.320 mg/m³ and minimum of 0.282 mg/m³, and moulder with maximum 2.278 mg/m³, mean of 1.976 mg/m³ and minimum 1.517 mg/m³. The least high exposed occupation was shake-out operator with maximum exposure of 2.220 mg/m³, mean of 1.644 mg/m³ and minimum 1.097 mg/m³. The lowest exposed occupation was loco sand filler with maximum, mean and minimum exposure of 0.127 mg/m³, 0.093 mg/m³ and 0.058 mg/m³, respectively (see Appendix 3).

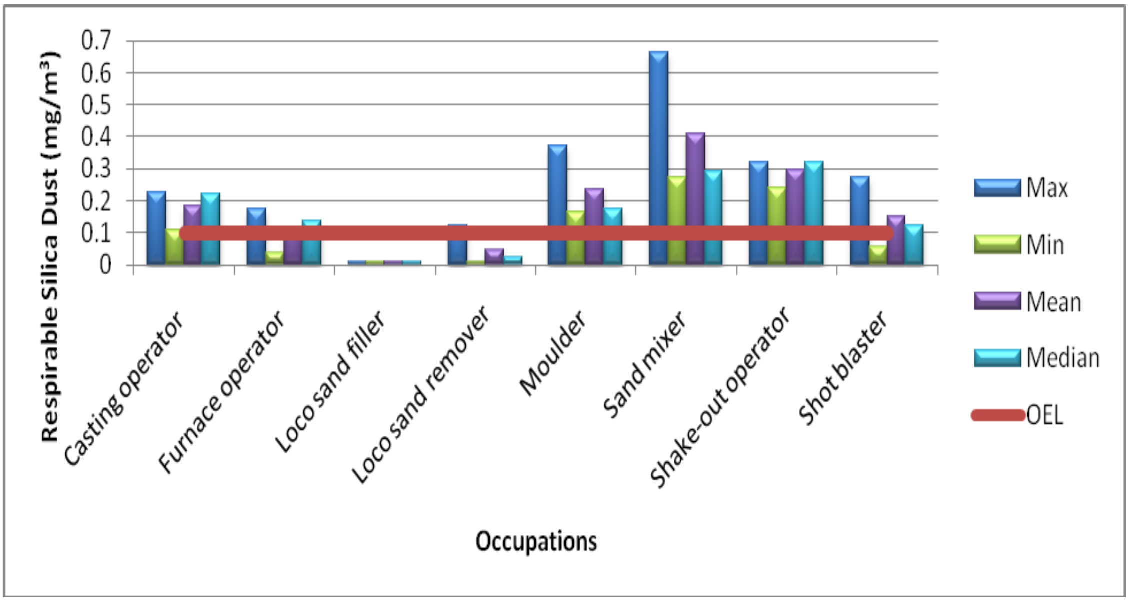


Figure 4.6: Respirable silica dust exposure per occupation for workers at Foundry one

The overall mean TWA of respirable silica dust (quartz) concentration was 0.172 mg/m³, with the standard deviation at ±0.2. The overall maximum and minimum respirable silica dust exposure for foundry one was 0.662 mg/m³ and 0.010 mg/m³, respectively. The overall TWA median for respirable silica dust concentration for foundry one was 0.153 mg/m³ (see Appendix 4). Sixty-five per cent of the overall respirable silica dust concentration measured exceeded the South African OEL of 0.1 mg/m³ (see also Figure 4.6).

Occupations with the combined highest exposure to personal respirable silica dust in site one foundry were sand mixer with maximum exposure at 0.662 mg/m³, mean at 0.409 mg/m³ and minimum at 0.273 mg/m³; moulder with maximum, mean and minimum personal respirable silica dust exposure of 0.372 mg/m³, 0.237 mg/m³ and 0.166 mg/m³, respectively; shake-out operator with maximum at 0.322 mg/m³, mean at 0.295 mg/m³ and minimum at 0.242 mg/m³; shot-blast operator with maximum exposure of 0.271 mg/m³, mean exposure of 0.150 mg/m³ and minimum exposure 0.056 mg/m³; casting operator with maximum 0.228 mg/m³, mean 0.186 mg/m³ and minimum of 0.107 mg/m³; and furnace operator with maximum of 0.174 mg/m³, mean of 0.117 mg/m³, and minimum at 0.037 mg/m³ (see Figure 4.6 and Appendix 4).

4.4.2 Respirable dust and crystalline silica dust exposure levels in Foundry two

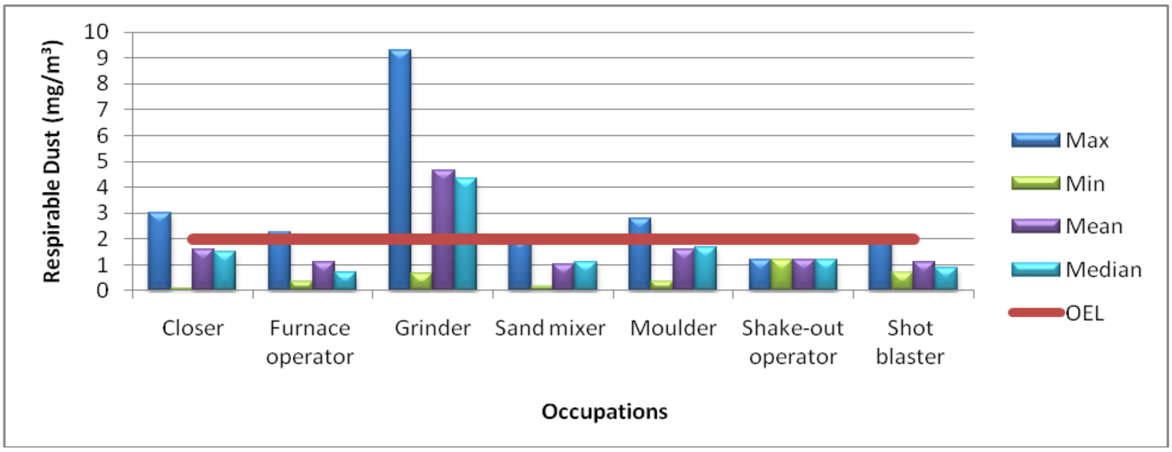


Figure 4.7: Respirable dust exposure per occupation for workers at Foundry two

The overall mean TWA concentration for personal respirable dust in the second foundry was 1.695 mg/m³, with the standard deviation at ±1.9. The overall maximum and minimum exposure to personal respirable dust were 9.294 mg/m³ and 0.104 mg/m³, respectively. The overall median TWA respirable dust concentration for the second foundry was 1.139 mg/m³. Approximately 27% of personal respirable dust measured in the second foundry exceeded the South African OEL of 2 mg/m³.

Occupations that recorded overall personal respirable dust concentrations of above the OEL of 2 mg/m³ were grinder with maximum at 9.294 mg/m³, mean at 4.664 mg/m³ and minimum at 0.668 mg/m³; and closer with maximum of 3.014 mg/m³, mean of 1.597 mg/m³ and minimum at 0.104 mg/m³ (see Figure 4.7). The least exposed occupation was shake-out operator with overall maximum, mean and minimum exposure of 1.207 mg/m³, 1.207 mg/m³, and 1.207 mg/m³, respectively (see Appendix 5).

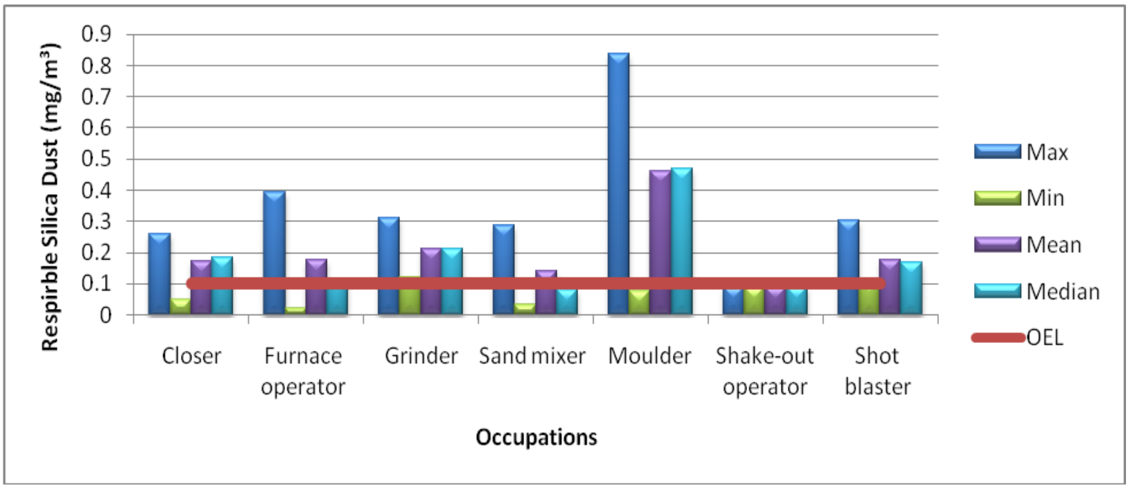


Figure 4.8: Respirable silica dust exposure per occupation for workers at Foundry two

The overall mean TWA concentration of personal respirable silica dust in the second foundry was 0.194 mg/m³, with mean standard deviation at ±0.16. The overall maximum and minimum of personal respirable silica dust exposures from the second foundry were 0.836 mg/m³ and 0.023 mg/m³, respectively. The overall TWA median of respirable silica dust concentration in the second foundry was 0.176 mg/m³. A total of 70% of personal respirable silica dust measured in the second foundry exceeded the South African OEL of 0.1 mg/m³.

Occupations or tasks and activities with the highest personal respirable silica dust exposure of above OEL were moulder with maximum at 0.836 mg/m³, mean at 0.460 mg/m³ and minimum at 0.077 mg/m³; furnace operator with a maximum of 0.392 mg/m³, mean of 0.177 mg/m³ and minimum of 0.023 mg/m³; grinder with maximum of 0.309 mg/m³, mean of 0.212 mg/m³ and minimum of 0.12 mg/m³; shot-blast operator with maximum of 0.301 mg/m³, mean of 0.176 mg/m³ and minimum of 0.110 mg/m³; sand mixer with maximum of 0.286 mg/m³, mean of 0.139 mg/m³ and minimum of 0.032 mg/m³; and closer with maximum of 0.261 mg/m³, mean of 0.171 mg/m³ and minimum of 0.050 mg/m³ (see Figure 4.8 and Appendix 6).

4.4.3 Respirable dust and crystalline silica dust exposure levels in all foundries

Figure 4.9: Respirable dust exposure per occupation for workers at both foundries (site one and two foundries)

The overall mean TWA concentration of personal respirable dust in both foundries was 1.460 mg/m³, with an overall mean standard deviation of ±1.6. The overall maximum and minimum exposures to personal respirable dust were 9.294 mg/m³ and 0.058 mg/m³, respectively. The overall TWA median concentration of respirable dust in both foundries was 0.138 mg/m³. A total of 25% of personal respirable dust samples measured from both foundries exceeded the South African OEL of 2 mg/m³ (see Figure 4.9 and Appendix 7).

Occupations or activities and tasks with personal respirable dust concentrations of above the OEL for respirable dust were grinder with maximum of 9.294 mg/m³, mean of 4.664 mg/m³ and minimum of 0.668 mg/m³; sand mixer with maximum of 4.571 mg/m³, mean of 1.454 mg/m³ and minimum of 0.157 mg/m³; closer with maximum at 3.014 mg/m³, mean at 1.597 mg/m³ and minimum at 0.104 mg/m³; moulder with maximum at 2.803 mg/m³, mean at 1.793 mg/m³ and minimum at 0.358 mg/m³; furnace operator with maximum at 2.448 mg/m³, mean at 1.214 mg/m³ and minimum at 0.282 mg/m³; and shake-out operator with maximum at 2.220 mg/m³, mean at 1.535 mg/m³ and minimum at 1.097 mg/m³ (see Figure 4.9 and Appendix 7).

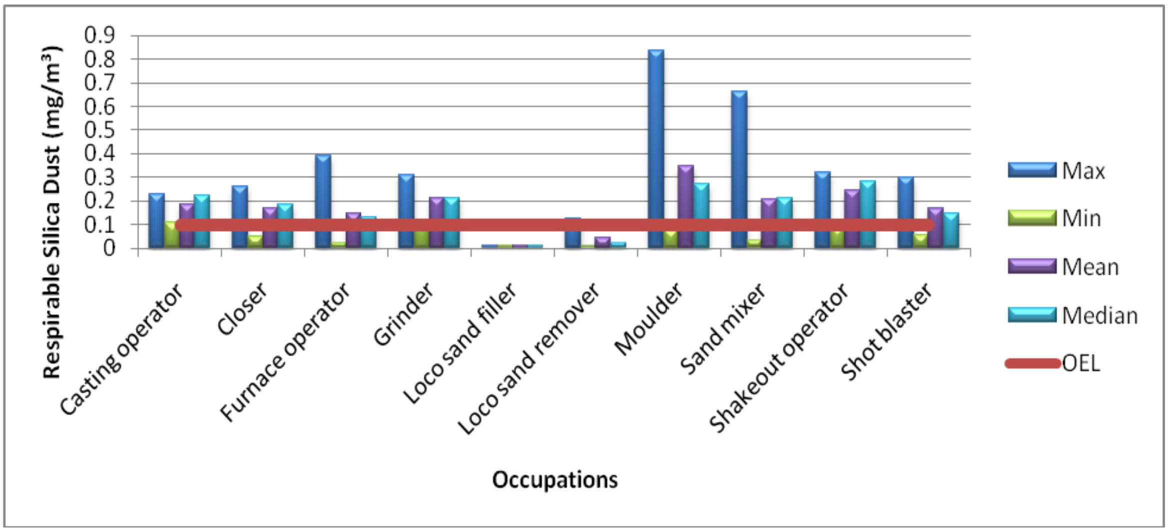


Figure 4.10: Respirable silica dust exposure per occupation for workers at both foundries (foundry one and two combined)

The mean TWA concentration for personal respirable silica dust for both sites measured was 0.184 mg/m³, with an overall mean standard deviation of ±0.16. The overall maximum and minimum exposures for both foundries were 0.836 mg/m³ and 0.010 mg/m³, respectively. The overall TWA median of respirable silica dust concentration for both foundries was 0.167 mg/m³. Sixty-eight per cent of the overall personal respirable silica dust samples measured in both foundries exceeded the South African OEL of 0.1 mg/m³ (see Figure 4.10 and Appendix 8).

The occupations with the personal respirable silica dust exposure concentrations of above the South African OEL of 0.1 mg/m³ were moulder with maximum at 0.836 mg/m³, mean at 0.349 mg/m³ and minimum at 0.077 mg/m³; sand mixer with maximum at 0.662 mg/m³, mean at 0.206 mg/m³ and minimum at 0.032 mg/m³; furnace operator with maximum exposure at 0.392 mg/m³, mean at 0.147 mg/m³ and minimum at 0.023 mg/m³; shake-out operator with maximum concentration of 0.322 mg/m³, mean of 0.243 mg/m³ and minimum of 0.089 mg/m³; grinder with maximum of 0.309 mg/m³, mean of 0.212 mg/m³ and minimum of 0.120 mg/m³; shot-blast operator with maximum of 0.301 mg/m³, mean of 0.166 mg/m³ and minimum of 0.056 mg/m³; closer with maximum of 0.261 mg/m³, mean of 0.171 mg/m and minimum of 0.050 mg/m³; and casting operator with maximum of 0.228 mg/m³, mean of 0.186 mg/m³ and minimum of 0.107 mg/m³ (see Figure 4.10 and Appendix 8).

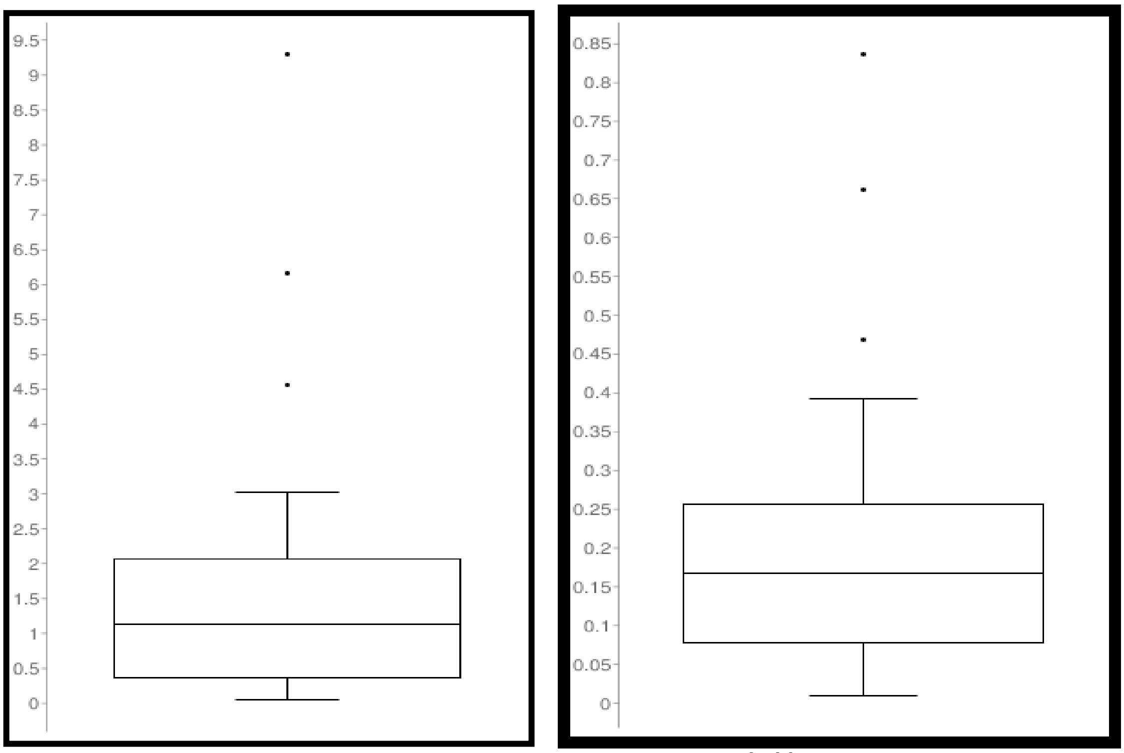


Figure 4.11: Box plot data summary of respirable dust and respirable silica dust for the two study foundries in Gauteng (foundry one and two combined)

The overall 25th percentile (first quartile) measurement result for personal respirable silica dust is reported to be 0.078 mg/m³ and the 75th percentile (third quartile) is 0.256 mg/m³. The symmetric data is positively skewed as indicated by the location of the box to the bottom of the whiskers in Figure 4.11 above and that the mean is larger than the median; the box also indicates a wider peak. There are three outliers (0.836, 0.662 and 0.468 mg/m³), which are also indicated by the significant variability in the median and mean of the respirable silica dust at 0.167 mg/m³ and 0.184 mg/m³, respectively. Outliers are defined as observations that lie in an abnormal distance from other values of samples (Doyle & Swanepoel, 2009).

The overall 25th percentile (first quartile) measurement result for respirable dust is 0.367 mg/m³ and the 75th percentile (third quartile) is 2.067 mg/m³. The data is positively skewed or significantly skewed to the right as indicated by the box at the bottom of the whiskers and also by the mean, which is greater than the median. There is also the presence of outliers in the data as indicated by the presence of three dots (see Figure 4.11).

4.5 Conclusion

The results have shown that workers in South African foundries are exposed to high level of silica dust. Most of the workers were exposed to silica dust above the South African occupational exposure limit of 0.1mg/m³.

CHAPTER 5

DISCUSSION

The study was undertaken in order to quantify foundry workers' exposure to respirable silica dust (quartz). The study further sought to rank occupations, activities or tasks that are most at risk for exposure to personal respirable silica dust in foundries in Gauteng. The following chapter discusses the results and the implications for the foundry industry.

5.1 Population characteristics

Approximately 43% of the participants from both foundries are smokers and 33% had 10 or more years of service. Smoking and workers with increased years of service are at increased risk of developing silicosis if exposed to silica dust exceeding the OEL. This fact is supported by scientific studies carried out in South Africa and other countries worldwide (Erhlich, Rees & Zwi, 1988; Brown, 2009; Kurihara and Wada, 2004; OSHA, 2008b; It and La, 2007; IARC, 2002).The results of these studies suggested that workers who are smokers and have increased years of service, and who are also exposed to personal respirable silica dust are at higher risk of developing silicosis and other respirable occupational diseases. Therefore the foundry workers who smoke are at higher risk of developing silicosis. This factor should be taken note of when planning awareness training and when conducting medical surveillance examinations as part of the prevention interventions for foundry workers.

5.2 Environmental factors

To ensure quality control and to improve reliability and validity of the results, sampling was done when there were favourable environmental conditions and when the skies were clear without rain that could settle the dust. However, the results of the environmental measurements raised a concern about poor ventilation in the foundries where workers are working, as the wind speed was low in both foundries (50% of measurements recorded were 0 m/s). Good ventilation or extraction systems remove the dust from the work station and thus protect the workers from being exposed to silica dust. Improvements in the environmental conditions in foundries, particularly in ventilation should be included in the planning for control measures for silicosis prevention.

Humidity can affect the optimal running of the sampling pump and mixed cellulose ester (MCE) filters, which were used for this study (Cornelissen, 2007; Akbar-Khanzadeh and Brillhart, 2002). The humidity ranged from 21 to 45 % in all foundries sampled in this study.

5.3 Personal respirable dust and silica dust levels per individual foundries.

This sub-section will discuss both the respirable dust and respirable silica dust results emanating from foundry one and two separately to outline exposure levels from each foundry sampled. The occupations from each foundry will be ranked to facilitate prioritisation of risk for the different occupations. The results are compared with both the local and international studies. For the purpose of this study the respirable dust occupational exposure limit will be discussed as 2 mg/m³, it should however be noted that this is not the Department of labour's current limit but the ACGIH TLV. The DoL respirable dust OEL is 5 mg/m³, but because the studies referred in this report has used 2 mg/m³ as a best practice. Throughout the discussion this will be referred as the RSA-OEL, as previously referred in other studies (Swanepoel *et al.*, 2009)

5.3.1 Personal respirable dust levels in Foundry one (site one)

The highest exposed occupation had a maximum silica dust concentration of 4.571 mg/m³, which is four times higher than the RSA OEL of 2 mg/m³, and the lowest exposed occupation, was 0.058 mg/m³, which is above the 50% action level by 8% of the RSA OEL (see Appendix 3). The median exposure results were lower than the results of two foundry surveys carried out in 1992, where the first foundry with 25 samples was found to have a median exposure to respirable dust of 3.0 mg/m³ and the second foundry with 29 samples had a median exposure of 1.6 mg/m³ (NCOH, 1992a; NCOH, 1992b).

In foundry one study only two occupations recorded maximum and median personal respirable dust concentrations of above the RSA OEL. Those were sand mixer and moulder. Furnace operator and shake-out operators had only a maximum concentration that exceeded the OEL (see Appendix 3).

About 23% of the samples measured exceeded the RSA OEL of respirable dust and 54% of the measured samples were above the action level of the RSA OEL which implies that control measures need to be in place to prevent silicosis. Occupations where the mean exceeded the RSA OEL action level were casting operator at 1.364 mg/m³, and furnace operator at 1.320 mg/m³. The results were lower than for the two South African foundry surveys conducted in 1992, which had a total of 68% and 44% of samples, respectively, that exceeded the legislated exposure limit (NCOH, 1992a; NCOH, 1992b).

Occupations with the highest maximum were sand mixer, moulder, furnace operator and shake-out operator. The results were similar to results reported nationally and internationally (NCOH, 1992a; NCOH, 1992b; Siltanen *et al.,* 1976; Oudiz *et al.,* 1983).

The personal respirable dust exposure in foundry one was found to be high for certain occupations and/or tasks. The mode of dust control was the use of personal respirable devices. Had other means of dust control been used, such as engineering controls, dust might have been eliminated more easily. Alternative prevention and control methods should be introduced with specific prevention methods for the high risk occupations.

5.3.2 Personal respirable silica dust levels in Foundry one (site one)

Exposure levels to crystalline silica dust in foundry one were high because both the median and the mean were above the RSA OEL of 0.1 mg/m^3, which is a reason for concern as this indicates that workers are at risk for silicosis. A total of four occupations recorded 100% of samples that exceeded the RSA OEL (see Appendix 4). The results were consistent with the results of the two occupational hygiene surveys of 1992 mentioned above, with the median at 0.2 and 0.05, respectively (NCOH, 1992a; NCOH, 1992b).

Approximately 65% of measurements exceeded the South African respirable silica dust OEL of 0.1 mg/m^3. The results were higher than for a survey conducted in 1992 which reported that only 44% of the samples exceeded the then OSHA threshold limit value (TLV) of 0.1 mg/m^3 (NCOH, 1992a). However, the results were lower than for the survey conducted in the same year at a different foundry, which reported 73% of samples exceeding the OSHA TLV (NCOH, 1992b), and in 1986 a foundry surveyed found that 100% of samples measured exceeded the OSHA TLV (NCOH, 1986). The results differed from the 1743 air sampling results obtained in the USA, where it was reported that only 40.6% of samples taken from foundries exceeded the OSHA PEL (Oudiz *et al.,* 1983). It is obvious that South African foundries are still lagging behind international standards in terms of controlling silica dust in foundry one. However, in South Africa the situation appears to be improved since 1988, which could be attributed to improved technology and awareness of airborne particulates.

This study revealed that workers are exposed to unacceptable levels of respirable dust and silica dust, which is attributed to the lack of dust control measures. The study concurred with studies conducted in South Africa in 1994 which concluded that inadequate dust control and neglect of occupational health in foundries were prevalent (Rees & Weiner, 1994).

Occupations that recorded the highest maximum and mean exposure concentration to respirable silica dust in the first site were sand mixer, moulder, shake-out operator, shot-blast operator, casting operator, and furnace operator (see Appendix 4). The findings on occupations are similar to those from research undertaken in South Africa (Rees & Weiner, 1994; Erhlich *et al.,* 1988), Finland (Siltanen *et al.,* 1976), the USA (Oudiz *et al.,* 1983) and Vietnam (Luong and Von Hai, 1999).

5.3.3 Personal respirable dust exposure levels in Foundry two (site two)

The mean and the median exposure concentrations for personal respirable dust at foundry two were below the RSA OEL. The results were lower than those from earlier studies conducted in South African and Finish foundries (Siltanen **et al.,** 1976; NCOH, 1992a; NCOH, 1992b). The improvement in dust exposure for both local and international exposure may be attributed to the improved awareness of the dangers of silica dust worldwide.

About 27% of the measured samples exceeded the RSA OEL and approximately 70% of the measured samples exceeded the 50% (action level) of the RSA OEL (see Appendix 5). There was a significant decrease in the percentage of samples exceeding the RSA OEL observed in comparison to occupational hygiene surveys conducted from 1983 to 1992, where the lowest percentage recorded was 44% (NCOH, 1992b).

A total of four occupations had maximum exposures that exceeded the RSA OEL, with the highest maximum exposure being 9.294 mg/m^3, which is more than twice the RSA OEL (see Appendix 5). The only occupation of the highest exposed occupations in terms of maximum, median and mean to exceed the limit was a grinder. But the closer, moulder and furnace operator were exposed to maximum personal respirable dust concentrations that exceeded the occupational exposure limit.

5.3.4 Personal respirable silica dust exposure levels in Foundry two (site two)

The overall median exposure concentration of personal respirable silica dust in site two (foundry two) was 0.176 mg/m^3, and the mean TWA concentration was 0.194 mg/m^3 (see Appendix 6). The results differed from the results of earlier studies undertaken in South Africa which found the median value to be higher (NCOH, 1992a), although another South African study obtained a median value of 0.05 mg/m^3 (NCOH, 1992b), which was lower than the mean TWA concentration. However, the results of all these studies showed that employees are exposed to silica dust exceeding the OEL in South Africa.

Approximately 70% of measured samples exceeded the RSA OEL of personal respirable silica dust exposure concentration (see Appendix 6). The percentage of samples that exceeded the OEL was higher than that of a similar study conducted in 1992, where the percentage was 44%. Lack of silica dust awareness and control measures in this foundry could be contributing factors to the increase. About 82% of the measured samples exceeded the 50% action level concentration (see Appendix 6). Measures should be put in place to reduce exposure that exceeds the action levels in the foundry.

A total of five occupations recorded mean, median and maximum exposures that exceeded the OEL. The occupations with the highest exposures were moulder, grinder, sand mixer, closer, furnace operator and shot blaster. The occupation of shake-out operator had the lowest exposure. The reason that the shot blaster had the lowest of the high exposures could be because steel grit was sometimes used instead of silica sand on site (see Appendix 6).

5.4 Respirable dust and silica dust levels from both foundries sampled

Respirable dust and respirable silica dust results from the combined foundry one and two to outlined exposure levels from both foundries sampled. Occupations will be integrated and ranked to facilitate the overall exposure levels according to each occupation.

5.4.1 Respirable dust levels in both foundries

The overall median exposure concentration to personal respirable dust from the two foundries was 1.138 mg/m³ (see Appendix 7). The results of this study were similar to the lowest results of the surveys conducted in the Pretoria Witwatersrand Vereeniging (PWV) foundries from 1983 to 1992, where the highest and the lowest median were 1.2 mg/m³ and 3.1 mg/m³, respectively (Rees & Weiner, 1994). The results were also far lower than the Finish iron and steel foundries' measurement concentrations taken in 1976, where the high median and lower median concentrations were 3.5 mg/m³ and 1.7 mg/m³, respectively (Siltanen *et al.,* 1976). However, the results were higher than the median concentration of respirable dust in the USA foundries of 0.90 mg/m³ (Oudiz *et al.,* 1983). The decline of respirable dust from the previous PWV study observed could be attributed to the improved inspection and enforcement of occupational health and awareness of airborne particulates by foundries and the DOL Inspectorate. The difference observed between South African foundries and the USA foundries could mean that the South African foundries have not yet met the international levels of dust elimination.

About 25% of the occupations measured were exposed to personal respirable dust of above the South African OEL of 0.1 mg/m³ and 60% of the measurements exceeded the 50% (action level) of the South African OEL of 2 mg/m³. The percentage of numbers that exceeded the OEL was lower than for the surveys conducted in different foundries in 1983, 1984, 1986, 1987 and 1992 using the ACGIH TLV at the time of the surveys, where the percentage was 79%, 81%, 89%, 89% and 44%, respectively. There was a significant improvement in a foundry sampled in 1986, with 89%, and in 1992, when a survey recorded that 44% of samples exceeded ACGIG TLV (Rees & Weiner, 1994). The 23% observed in this study might be a true reflection of the current situation, taking cognisance of the improved technology and awareness of occupational health issues.

The occupations found to have the highest maximum exposures to personal respirable dust from both foundries were the grinder with maximum exposure of 9.294 mg/m³, mean at 4.664 mg/m³, and median at 4.348 mg/m³ (about 75% of all samples measured exceeded the RSA OEL of 2 mg/m³); sand mixer with maximum exposure of 4.571 mg/m³, mean of 1.454 mg/m³, and median of 1.245 mg/m³ (with 17% of measured samples exceeding the RSA OEL); and closer at maximum exposure of 3.014 mg/m³, mean of 1.597 mg/m³, and median of 1.504 mg/m³ (with about 40% of measured samples exceeding the RSA OEL). The occupation that recorded the lowest exposure results to personal respirable dust was the loco sand filler with a maximum exposure of 0.127 mg/m³, mean of 0.093 mg/m³, and median at 0.093 mg/m³, and with none of the samples exceeding the RSA OEL (see Figure 4.9 and Appendix 7). The loco sand filler and remover were not occupations that usually fell under a foundry but the researcher was requested to include them since they were working with silica sand used in the foundry and were operating in the same company.

5.4.2 Respirable silica dust levels in both foundries

The overall TWA median exposure concentration for personal respirable silica dust (quartz) from both foundries was 0.167 mg/m³ and the TWA mean was 0.184 mg/m³. The highest exposed worker was exposed at 0.836 mg/m³, which is an exposure of eight times higher than the RSA OEL of 0.1 mg/m³. The results were consistent with the median results of occupational hygiene surveys carried out in the PWV area in 1983 at 0.15 mg/m³, but lower than the results of the same studies conducted in 1984, 1986, and two in 1992, which recorded 0.21 mg/m³, 15.5 mg/m³ and 0.2 and 1.05 mg/m³, respectively. The findings were higher than the results from the Finland and USA foundries (Siltanen *et al.,* 1976; Yassin *et al.,* 2005). Again the difference of median could be the contribution of many factors, such as improving technology and the fact that the developed countries have already eliminated silicosis.

Approximately 68% of measured samples exceeded the RSA OEL of 0.1 mg/m³. There has been an improvement in terms of reducing the number of samples exceeding the OEL recorded in 1983, 1984, and 1986, which had the percentage of 96%, 85%, and 100%, respectively. In 1992 there were two occupational hygiene surveys conducted in two foundries and these exceeded the limits by 73% and 44%, respectively (Rees & Weiner, 1994). Again the results in terms of the number of samples that exceeded the OEL were much higher than the reported results in the USA of 43.7% in ferrous and 26.5% in nonferrous foundries (Oudiz *et al.,* 1983). About 87% of the measured samples exceeded the 50% action level for the South African OEL.

5.5 Risk ranking for occupations in foundries

The overall occupations that had both maximum and average concentrations exceeding the RSA OEL and therefore putting workers at risk of exposure to personal respirable silica dust were moulders; sand mixers; furnace operators; shake-out operators; shot blasters; grinders; closers; and casting operators (see Appendix 8). The results are consistent with the results of several local and international studies, which reported nearly the same occupations as these high exposure occupations, but with different exposure levels (Koo *et al.,* 2000; Rees & Weiner, 1994; Siltanen *et al.,* 1976; Oudiz *et al.,* 1983).

Eight out of ten occupations had crystalline silica exposure concentrations above the South African OEL of 0.1 m/g³ (see Table 5.1 and Figure 5.1), but only one occupation had exposure levels for respirable dust above 2 m/g³ (see Table 5.2). The important finding is that it is possible for a worker to be exposed to less respirable dust, yet exposed high levels of crystalline silica dust.

Table 5. 1: Occupations ranked according to mean exposure levels of respirable silica dust

No.	Occupations	±SD	*Mean*	Min	Max	Median
1	Moulder	0.279	***0.349***	0.077	0.836	0.273
2	Shake-out operator	0.109	***0.243***	0.089	0.322	0.281
3	Grinder	0.079	***0.212***	0.12	0.309	0.210
4	Sand mixer	0.174	***0.206***	0.032	0.662	0.213
5	Casting operator	0.068	***0.186***	0.107	0.228	0.223
6	Closer	0.084	***0.171***	0.050	0.261	0.184
7	Shot blaster	0.084	***0.166***	0.056	0.301	0.146
8	Furnace operator	0.134	***0.147***	0.023	0.392	0.128
9	Loco sand remover	0.046	***0.046***	0.01	0.123	0.023
10	Loco sand filler	0.000	***0.012***	0.012	0.012	0.012

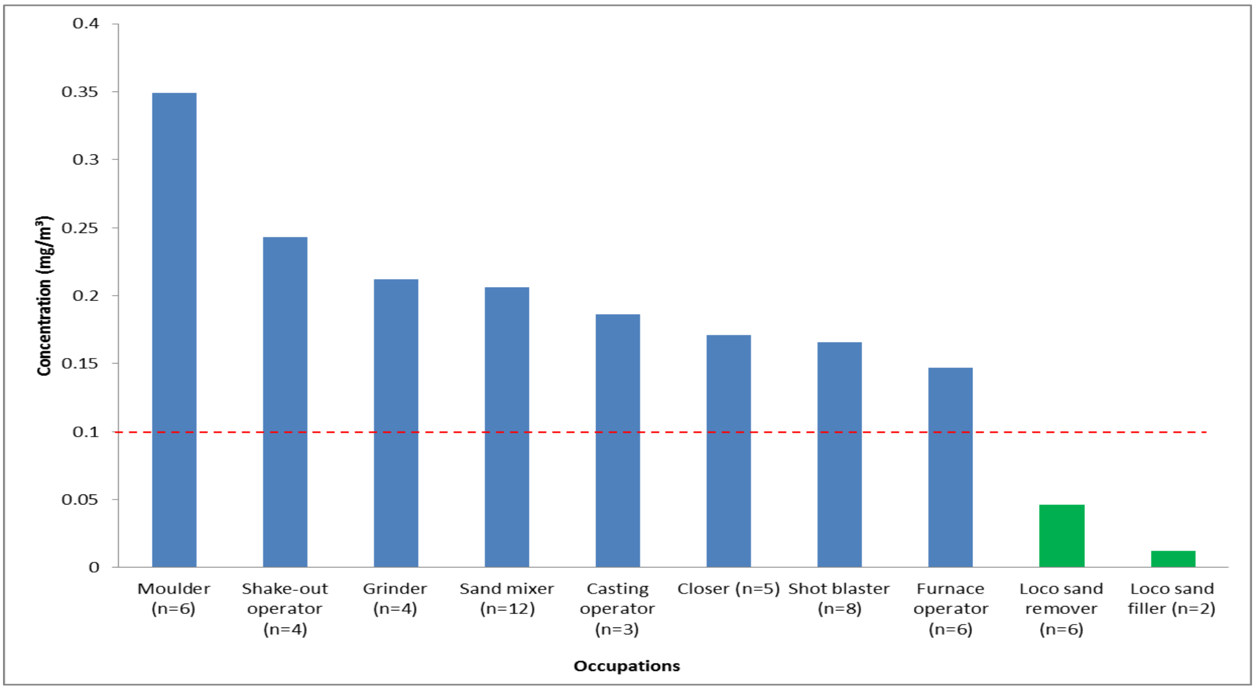


Figure 5.1: High exposed occupations

Table 5. 2: Occupations ranked according to mean exposure levels of respirable dust

No.	Occupations	±SD	*Mean*	Min	Max	Median
1	Grinder	3.838	***4.664***	0.668	9.294	4.348
2	Moulder	0.839	***1.793***	0.358	2.803	1.902
3	Closer	1.209	***1.597***	0.104	3.014	1.504
4	Shake-out operator	0.508	***1.535***	1.097	2.220	1.411
5	Sand mixer	1.142	***1.454***	0.157	4.571	1.245
6	Casting operator	0.350	***1.364***	0.976	1.656	1.461
7	Furnace operator	0.951	***1.214***	0.282	2.448	0.971
8	Short blaster	0.614	***0.992***	0.291	2.099	0.808
9	Loco sand remover	0.068	***0.214***	0.127	0.297	0.202
10	Loco sand filler	0.049	***0.093***	0.058	0.127	0.093

Occupational exposure to respirable silica dust ranked according to mean exposure revealed that the highest exposed occupations are moulder, shake-out, grinder, sand mixer, casting, closer, shot blaster and furnace in descending order and the lowest was loco sand filler and remover (see Table 5.1). This ranking indicates that moulders are at high risk of developing acute and accelerated silicosis that develop as results of exposure to high concentration of silica dust (Hnizdo *et al.,* 1999; DOL, 2007a; Ding *et al.,* 2002; Rees, 2006; Gottesfeld *et al.,* 2008).

It was observed and discovered during data collection that foundries employed poor dust control mechanisms in the workplace: apart from supplying workers with disposable dust masks, which are capable of reducing pneumoconiosis, fibrosis-producing dust and mists, no other prevention measures were evident to control dust. In foundry one only one extraction fan was working out of four and foundry two did not have any extraction fans. The foundries did not have any programme aimed at eliminating silicosis or any plan towards meeting the goals of the NPES.

The combined personal respirable silica dust figures clearly indicated that workers are exposed to high concentrations of respirable silica dust. The same problems have been reported in the same industries but no control measures have been implemented to reduce overexposures (NCOH, 1992a). The personal respirable dust and silica dust concentrations measured for all occupations and operations varied slightly. The concentrations of the measured samples revealed that the occupations and activities emit different concentrations and this suggests that workers are exposed to different exposure levels and that the same occupations emit different exposure levels at given times. There was no significant difference on the exposure levels from both foundries.

5.6 Conclusion

The results of the current study revealed that there had been no improvement in silica dust control since 1988, the year in which a survey undertaken in a similar environment revealed similar results. The results of this study support the neglect of occupational hygiene practices noted by Rees and Weiner (1994).

The significance of these results is that they highlight the respirable silica dust exposure levels and the risk associated with such exposures to South African foundry workers' health. Furthermore, they highlighted the urgency to implement effective silica dust prevention and control strategies. This will eventually lead to the elimination of silicosis in South African foundry workers.

CHAPTER 6:

CONCLUSION AND RECOMMENDATIONS

The aim of this chapter is to draw conclusions from the results, to make recommendations emanating from the two objectives of the study, i.e. determining the workers' exposure to respirable silica dust and ranking occupations or activities with the highest exposure to respirable silica dust and finally, to discuss the limitations of the study.

6.1 Conclusion

The study has clearly indicated that the majority of workers in the two foundries sampled are over-exposed to silica dust at above the OEL, as 68% of measured samples exceeded the RSA OEL from both foundries and about 87% of measured samples exceeded the 50% action level for respirable silica dust. This means that workers are potentially at risk of developing silicosis, silico-tuberculosis, lung cancer and other occupational diseases associated with exposure to respirable silica dust (see Appendix 8/Figure 4.10). The results concurred with the study undertaken by Rees and Weiner (1994) as reported in Chapter 5 of this study. The study also found that some foundry workers are exposed to personal respirable dust below the OEL, yet the respirable silica dust content of the dust exceeded the OEL for silica quartz.

The study also showed that eight of the twelve occupations in a foundry of the all occupations from both foundries were exposed crystalline silica dust concentrations that were above the RSA OEL. Occupations ranked from the highest to the lowest, were moulder, sand mixer, furnace operator, shake-out operator, shot-blast operator, grinder, and closer and casting operator (see Appendix 8/Figure 4.10). These occupations had exposures above the OEL and that pose a risk to workers doing these types of jobs. South African foundry workers appear to have similar exposures to those reported internationally (NCOH, 1992a; NCOH, 1992b; Koo *et al.,* 2000).

6.2 Recommendations

It is recommended that an airborne particulate prevention and dust-control programme be implemented in both foundries. The silicosis prevention strategy that needs to be considered by foundries should involve inspections, monitoring, isolation of processes that produce silica dust, airborne dust suppression, installation and maintenance of ventilation and extraction systems, and provision of the approved respiratory protective devices. Workers must undergo medical surveillance, and both managers and workers must undergo training on dangers, work habits, personal hygiene, and the health effects of silica dust. There is also a great need for silicosis awareness nationally, as most workers are not acquainted with the dangers posed by silica dust to their health.

There is also a need for a comprehensive baseline study on silica dust for foundries in South Africa . Exposure comparisons for both day and night shifts; and ferrous and non-ferrous foundries are strongly needed in South Africa. There is also a need for a study to investigate the prevalence of silicosis in foundries.

The most important step for reduction and elimination of silicosis and other occupational diseases associated with exposure to silica dust is dust control. The dust-control measures available are elimination, substitution, isolation/enclosure, dust suppression/wet methods, engineering control, administration and respiratory protective equipment. These dust-control measures are not applicable across all activities performed in a foundry; for example, the wet method cannot be implemented in a shot blasting section because water will make the product rust quickly. The methods are described briefly below.

Elimination simply means changing technology or altering the process by completely removing hazardous substances or replacing them with non-hazardous substances, where workers will no longer be exposed to dust.

Substitution is applied when elimination is impossible; it involves substituting the hazardous substance with a less hazardous substance, for example using steel grit, glass beads, plastic blast material, aluminium oxide, zirconium oxide and olivine sands instead of silica sands. Care must be taken not to substitute one problem with another problem (Kahkonen & Beaudet, 1997; WHO, 1999).

Isolation involves enclosing the process into a cab or booth that is supplied with fresh, clean and filtered air. This will protect both workers and the general environment and workplace from the release of and exposure to harmful dust.

Mechanical Control: ***Local exhaust ventilation*** captures dust from the sources and removes it before it can spread throughout the workplace and reach the breathing zones of the workers. ***General ventilation*** refers to supply and exhaust of a large volume of air to a place with a number of scattered dust sources for diluting and displacing airborne particles.

Wet Method: ***Wet dust suppression system*** uses liquids (water) to wet materials for them to generate low dust. ***Water sprays*** produce fine water droplets that capture fine dust and prevent it from spreading by forming agglomerates (NIOSH, 2010; WHO, 1999; Riala, 2002). Carlo *et al.* (2010) state that water is an effective method for reducing occupational respirable silica dust exposure.

Administrative control involves good housekeeping and cleaning, using a wet method or vacuum cleaners with high efficiency particulate air filters (HEPA). Rotating workers to reduce exposure time; restricting unauthorised personnel entry to these areas and jobs; properly selecting workers; and providing information, instructions and training regarding the silica dust health effects, prevention and control are involved in administrative control.

Respiratory Protective Equipment (RPE) should be implemented as a last resort, according to the Occupational Health and Safety Act, 1993 (Act No. 85 of 1993) as amended. RPE does not protect the work environment and the worker completely. This type of equipment should be SABS approved and should be appropriate and recommended for controlling exposure to RCS dust (Mody & Jakhete, 1988; WHO, 1999; Riala, 2002). Refer to Appendix 14 for recommended respiratory protective devices for respirable dust in the working place.

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APPENDICES

Appendix 1: Sampling sheets

Occupation	Pump	Filter	Avg flow	% difference	Calculated minutes	Volume (m^3)	Dust (mg/m^3)	Dust TWA (mg/m^3)	Quartz (mg/m^3)	Quartz TWA (mg/m^3)	% Quartz (mg/m3)
Casting operator	LB6	108675	2.188	2.0%	422	0.923	1.884	1.656	0.253	0.223	13%
Casting operator	LB1	108679	2.192	1.0%	475	1.041	0.987	0.976	0.109	0.107	11%
Casting operator	LB9	108687	2.179	3.1%	464	1.011	1.512	1.461	0.235	0.228	16%
Closer	25	107582	2.252	3.3%	492	1.108	2.511	2.573	0.255	0.261	10%
Closer	3	107587	2.225	1.4%	479	1.066	3.021	3.014	0.231	0.230	8%
Closer	LB3	108627	2.245	3.2%	515	1.156	0.097	0.104	0.046	0.050	48%
Closer	LB10	108629	2.221	1.3%	511	1.135	1.413	1.504	0.123	0.131	9%
Closer	B4	108715	2.227	2.0%	504	1.122	0.752	0.789	0.176	0.184	23%
Furnace operator	LB5	108674	2.186	2.0%	427	0.933	2.751	2.448	0.156	0.139	6%
Furnace operator	LB5	108683	2.217	0.6%	476	1.055	1.240	1.229	0.175	0.174	14%
Furnace operator	LB5	108691	2.207	0.1%	479	1.057	0.282	0.282	0.037	0.037	13%
Furnace operator	LB8	108631	2.217	0.4%	486	1.077	0.338	0.342	0.023	0.023	7%
Furnace operator	Rad23	108705	2.195	0.5%	496	1.089	2.198	2.272	0.379	0.392	17%
Furnace operator	Rad23	108711	2.201	0.0%	504	1.109	0.678	0.712	0.110	0.116	16%
Grinder	B4	107583	2.183	2.1%	496	1.083	8.994	9.294	0.186	0.192	2%
Grinder	25	108626	2.170	3.4%	512	1.111	5.777	6.163	0.290	0.309	5%
Grinder	Rad1	108628	2.228	1.1%	516	1.149	2.355	2.532	0.211	0.227	9%
Grinder	LB10	108709	2.223	0.9%	490	2.201	0.324	0.668	0.058	0.120	18%
Loco sand filler	LB7	108676	2.202	0.2%	451	0.993	0.135	0.127	0.013	0.012	10%

Occupation	Pump	Filter	Avg flow	% difference	Calculated minutes	Volume (m^3)	Dust (mg/m^3)	Dust TWA (mg/m^3)	Quartz (mg/m^3)	Quartz TWA (mg/m^3)	% Quartz (mg/m3)
Loco sand filler	LB2	108680	2.188	1.5%	472	1.033	0.059	0.058	0.012	0.012	20%
Loco sand remover	LB1	108673	2.216	0.4%	477	1.057	0.128	0.127	0.023	0.123	18%
Loco sand remover	LB8	108677	2.204	0.3%	452	0.996	0.190	0.179	0.014	0.013	8%
Loco sand remover	LB9	108678	2.192	1.3%	463	1.015	0.308	0.297	0.085	0.082	28%
Loco sand remover	LB4	108682	2.174	3.7%	476	1.035	0.225	0.224	0.017	0.017	8%
Loco sand remover	LB2	108688	2.187	1.5%	492	1.076	0.280	0.287	0.027	0.028	10%
Loco sand remover	LB8	108693	2.202	0.9%	499	1.099	0.165	0.171	0.010	0.010	6%
Moulder	LB10	108669	2.191	1.0%	428	0.938	2.393	2.134	0.417	0.372	17%
Moulder	LB10	108685	1.675	4.8%	422	0.707	2.591	2.278	0.198	0.174	8%
Moulder	LB3	108689	2.218	1.0%	464	1.029	1.569	1.517	0.172	0.166	11%
Moulder	Rad1	107585	2.236	2.3%	503	1.125	0.341	0.358	0.074	0.077	22%
Moulder	D2	108702	2.093	3.9%	481	1.006	2.797	2.803	0.835	0.836	30%
Moulder	LB8	108712	2.230	2.3%	506	1.128	1.584	1.670	0.444	0.468	28%
Sand mixing operator	LB1	108670	2.200	0.6%	405	0.891	2.487	2.090	0.345	0.291	14%
Sand mixing operator	LB6	108684	2.185	2.0%	439	0.959	1.579	1.444	0.298	0.273	19%
Sand mixing operator	LB6	108692	2.169	3.4%	470	1.019	4.669	4.571	0.676	0.662	14%
Sand mixing operator	LB3	107586	2.257	3.8%	493	1.113	1.096	1.126	0.201	0.207	18%
Sand mixing operator	LB6	108625	2.226	1.6%	519	1.155	0.145	0.157	0.030	0.032	21%
Sand mixing operator	Rad20	108630	2.229	1.8%	512	1.141	1.440	1.536	0.214	0.228	15%
Sand mixing operator	LB6	108703	2.235	2.2%	476	1.064	0.396	0.393	0.040	0.039	10%
Sand mixing operator	Rad20	108704	2.234	1.9%	478	1.068	1.156	1.151	0.082	0.082	7%
Sand mixing operator	Rad23	108701	2.223	1.4%	485	1.078	0.592	0.598	0.078	0.079	13%
Sand mixing operator	3	108708	2.211	0.7%	486	1.074	1.973	1.998	0.282	0.286	14%
Sand mixing operator	LB6	108710	2.212	0.3%	483	1.068	1.331	1.339	0.077	0.077	6%
Sand mixing operator	LB3	108714	2.214	1.2%	510	1.129	0.987	1.048	0.206	0.219	21%

Occupation	Pump	Filter	Avg flow	% difference	Calculated minutes	Volume (m^3)	Dust (mg/m^3)	Dust TWA (mg/m^3)	Quartz (mg/m^3)	Quartz TWA (mg/m^3)	% Quartz (mg/m3)
Shake-out operator	LB2	108671	2.192	1.4%	409	0.896	1.287	1.097	0.284	0.242	22%
Shake-out operator	LB8	108686	2.198	1.0%	446	0.980	2.390	2.220	0.347	0.322	15%
Shake-out operator	LB4	108690	2.168	3.0%	467	1.012	1.660	1.615	0.329	0.320	20%
Shake-out operator	Rad20	108707	2.197	1.0%	486	1.068	1.192	1.207	0.088	0.089	7%
Short blast operator	LB3	108672	2.228	1.6%	420	2.049	0.243	0.466	0.064	0.123	26%
Short blast operator	LB3	108681	2.208	0.7%	438	0.967	1.830	1.670	0.297	0.271	16%
Short blast operator	LB10	108695	2.178	2.0%	471	1.026	0.297	0.291	0.057	0.056	19%
Short blast operator	LB8	107581	2.238	2.8%	483	1.081	0.885	0.891	0.110	0.111	12%
Short blast operator	LB10	108706	2.225	2.3%	479	1.066	1.103	1.101	0.190	0.190	17%
Short blast operator	25	108713	2.227	1.6%	501	1.115	0.664	0.693	0.106	0.110	16%
Short blast operator	Rad1	108716	2.233	2.7%	492	1.099	0.707	0.725	0.164	0.168	23%
Short blast operator	3	1088632	2.211	0.5%	505	1.116	1.994	2.099	0.286	0.301	14%

Appendix 2: Environmental conditions

Date	Time	Temp	Wind speed	Humidity	Weather conditions
Site One (Foundry)					
Day 1	7h47	14°C	0.5 m/s	28%	Dry, windy and clear skies; dusty inside and outside of the foundry. Poor ventilation system
	13h50	29°C	0.0 m/s	22%	
Day 2	7h41	11.5°C	0.6 m/s	32%	Clear skies and dry; dusty environment
	13h52	27°C	0.7 m/s	21%	
Day 3	7h30	16°C	0.0 m/s	41%	Dry, windy and clear skies; dusty inside and outside of the foundry. Poor ventilation system
	14h00	21°C	0.2 m/s	35%	
Site Two (Foundry)					
Day 1	7h59	15°C	0.4 m/s	33%	Skies clear and dry; dusty inside the factory and walk and driveways
	14h16	23°C	0.0 m/s	29%	
Day 2	8h35	19°C	0.0 m/s	42%	Dry and dusty environment without ventilation system
	13h46	25°C	0.0 m/s	35%	
Day 3	8h05	16°C	0.0 m/s	45%	Clear skies and dry; dry and dusty environment
	15h31	25°C	0.1 m/s	29%	

Temperature	Maximum	29°C
	Average	20.1°C
	Minimum	11.5°C
Humidity	Maximum	45%
	Average	33%
	Minimum	21%
Wind speed	Maximum	0.7 m/s
	Average	0.2 m/s
	Minimum	0.0 m/s

Appendix 3: Respirable dust exposure (mg/m^3) from site one foundry occupations in Gauteng

Occupations	n	±SD	Mean	Min	Max	%≥ 2[a]mg/m³	Median
Casting operator	3	0.350	1.364	0.976	1.656	00	1.461
Furnace operator	3	1.086	1.320	0.282	2.448	33	1.229
Loco sand filler	2	0.049	0.093	0.058	0.127	00	0.093
Loco sand remover	6	0.068	0.214	0.127	0.297	00	0.202
Moulder	3	0.404	1.976	1.517	2.278	67	2.134
Sand mixer	3	1.651	2.702	1.444	4.571	67	2.090
Shake-out operator	3	0.562	1.644	1.097	2.220	33	1.615
Shot blaster	3	0.751	0.809	0.291	1.670	00	0.466
Total	26						
Overall		**1.062**	**1.189**	**0.058**	**4.571**	**23**	**1.163**

[a] 2 mg/m³ Occupational Exposure Limit (OEL) for respirable dust was used (5 mg/m³ is RSA-OEL for respirable dust)
Max= Maximum; Min=Minimum; SD = Standard Deviation; n=number of samples

Appendix 4: Respirable silica dust (quartz) exposure (mg/m^3) from site one foundry occupations in Gauteng

Occupations	n	±SD	Mean	Min	Max	%≥0.1[a] mg/m³	Median
Casting operator	3	0.068	0.186	0.107	0.228	100	0.223
Furnace operator	3	0.071	0.117	0.037	0.174	67	0.139
Loco sand filler	2	0.000	0.012	0.012	0.012	00	0.012
Loco sand remover	6	0.046	0.046	0.01	0.123	17	0.023
Moulder	3	0.117	0.237	0.166	0.372	100	0.174
Sand mixer	3	0.220	0.409	0.273	0.662	100	0.291
Shake-out operator	3	0.046	0.295	0.242	0.322	100	0.320
Shot blaster	3	0.110	0.150	0.056	0.271	67	0.123
Total	26						
Overall		**0.151**	**0.172**	**0.01**	**0.662**	**65**	**0.153**

[a] 0.1 mg/m³ Occupational Exposure Limit (OEL) for quartz in South Africa
Max= Maximum; Min=Minimum; SD = Standard Deviation; n=number of samples

Appendix 5: Respirable dust exposure (mg/m³) from site two foundry occupations in Gauteng

Occupations	n	±SD	Mean	Min	Max	%≥2[a] mg/m³	Median
Closer	5	1.209	1.597	0.104	3.014	40	1.504
Furnace operator	3	1.024	1.109	0.342	2.272	33	0.712
Grinder	4	3.838	4.664	0.668	9.294	75	4.348
Sand mixer	9	0.577	1.038	0.157	1.998	00	1.126
Moulder	3	1.224	1.610	0.358	2.803	33	1.670
Shake-out operator	1		1.207	1.207	1.207	00	1.207
Shot blaster	5	0.581	1.102	0.693	2.099	20	0.891
Total	30						
Overall		**1.870**	**1.695**	**0.104**	**9.294**	**27**	**1.139**

[a] 2 mg/m³ Occupational Exposure Limit (OEL) for respirable dust was used (5 mg/m³ is RSA-OEL for respirable dust)
Max= Maximum; Min=Minimum; SD = Standard Deviation; n=number of samples

Appendix 6: Respirable silica dust (quartz) exposure (mg/m³) from site two foundry occupations in Gauteng

Occupations	n	±SD	Mean	Min	Max	%≥0.1[a] mg/m³	Median
Closer	5	0.084	0.171	0.050	0.261	80	0.184
Furnace operator	3	0.192	0.177	0.023	0.392	67	0.116
Grinder	4	0.079	0.212	0.12	0.309	100	0.210
Sand mixer	9	0.095	0.139	0.032	0.286	44	0.082
Moulder	3	0.380	0.460	0.077	0.836	67	0.468
Shake-out operator	1		0.089	0.089	0.089	0.000	0.089
Shot blaster	5	0.078	0.176	0.110	0.301	100	0.168
Total	30						
Overall		**0.162**	**0.194**	**0.023**	**0.836**	**70**	**0.176**

[a] 0.1 mg/m³ Occupational Exposure Limit (OEL) for quartz in South Africa
Max= Maximum; Min=Minimum; SD = Standard Deviation; n=number of samples

Appendix 7: Respirable dust exposure (mg/m³) from two study foundries in Gauteng

Occupations	n	±SD	Mean	Min	Max	%≥2[a] mg/m³	Median	Interquartile of range
Casting operator	3	0.350	1.364	0.976	1.656	00	1.461	None
Closer	5	1.209	1.597	0.104	3.014	40	1.504	None
Furnace operator	6	0.951	1.214	0.282	2.448	33	0.971	1.989
Grinder	4	3.838	4.664	0.668	9.294	75	4.348	7.377
Loco sand filler	2	0.049	0.093	0.058	0.127	00	0.093	None
Loco sand remover	6	0.068	0.214	0.127	0.297	00	0.202	0.1295
Moulder	6	0.839	1.793	0.358	2.803	50	1.902	1.182
Sand mixer	12	1.142	1.454	0.157	4.571	17	1.245	1.172
Shake-out operator	4	0.508	1.535	1.097	2.220	25	1.411	0.944
Short blaster	8	0.614	0.992	0.291	2.099	13	0.808	1.005
Total	56							
Overall		**1.556**	**1.460**	**0.058**	**9.294**	**25**	**0.138**	**1.700**

[a] 2 mg/m³ Occupational Exposure Limit (OEL) for respirable dust was used (5 mg/m³ is RSA-OEL for respirable dust)
Max= Maximum; Min=Minimum; SD = Standard Deviation; n=number of samples
None=statistical software could not compute the interquartile range as the number of samples was lower than four.

Appendix 8: Respirable silica dust (quartz) exposure (mg/m³) from occupations at the two study foundries in Gauteng

Occupations	n	±SD	Mean	Min	Max	%≥0.1[a]mg/m³	Median	Interquartile of range
Casting operator	3	0.068	0.186	0.107	0.228	100	0.223	None
Closer	5	0.084	0.171	0.050	0.261	80	0.184	0.155
Furnace operator	6	0.134	0.147	0.023	0.392	67	0.128	0.195
Grinder	4	0.079	0.212	0.12	0.309	100	0.210	0.1505
Loco sand filler	2	0.000	0.012	0.012	0.012	00	0.012	None
Loco sand remover	6	0.046	0.046	0.01	0.123	17	0.023	0.08
Moulder	6	0.279	0.349	0.077	0.836	83	0.273	0.41625
Sand mixer	12	0.174	0.206	0.032	0.662	58	0.213	0.20525
Shake-out operator	4	0.109	0.243	0.089	0.322	75	0.281	0.194
Shot blaster	8	0.084	0.166	0.056	0.301	88	0.146	141
Total	56							
Overall		**0.156**	**0.184**	**0.010**	**0.836**	**68**	**0.167**	**0.179**

[a] 0.1 mg/m³ Occupational Exposure Limit (OEL) for quartz in South Africa
Max= Maximum; Min=Minimum; SD = Standard Deviation; n=number of samples
None=statistical software could not compute the interquartile range as the number of samples was lower than four.

Appendix 9: Gilian Sampling Pump Calibration Certificates

envirocon instrumentation cc
environmental and occupational hygiene instruments

SERVICE & CALIBRATION CERTIFICATE

CUSTOMER	**CSIR**
DATE	**23 NOVEMBER 2009**
REFERENCE No.	**C0004-156/172**

PUMP No.

RC-11636(RAD4)	**RC-1214(D10)**
RC-11605(RAD6)	**RC-12155(D5)**
RC-11631(RAD8)	**RC-16950(B2)**
RC-12155(RAD2)	**RC-16955(B3)**
RC-9942(RAD20)	**RC-16949(B4)**
RC-11606(RAD40)	**RC-12295(B5)**
RC-16951(25)	**RC-13939(D16)**
RC-22797(17)	
RC-112995(D9)	

THE ABOVE PUMPS HAVE BEEN SERVICED AND VERIFIED AS PER THE MANUFACTURERS OPERATION MANUAL – SECTION 4

PLEASE NOTE THE SECTION ON BATTERY LIFE – BATTERY CAPACITY HAS BEEN CHECKED, HOWEVER NO WARRANTY IS GIVEN ON BATTERY PACKS

VERIFIED BY:

NEXT SERVICE / CALIBRATION DUE: NOVEMBER 2010

T. DU TOIT

envirocon instrumentation cc
environmental and occupational hygiene instruments

SERVICE & CALIBRATION CERTIFICATE

CUSTOMER **CSIR**

DATE **30 NOVEMBER 2009**

REFERENCE No. **C0004-159/183**

PUMP No.

RC-80901007(LB3)
RC-14361(8)
RC-80901008(LB1)
RC-80901001(LB6)
RC-80401024(LB7)
RC-80401025(LB8)
RC-17166(2)
RC-14363(7)
RC-80901010(LB2)
R-25144(RAD23)
RC-80901002(LB4)
RC-80901004(LB5)
RC-80901009(LB9)
RC-16956(RAD15)
RC-23218(13)
RC-11599(RAD1)
RC-80901003(LB10)

THE ABOVE PUMPS HAVE BEEN SERVICED AND VERIFIED AS PER THE MANUFACTURERS OPERATION MANUAL – SECTION 4

PLEASE NOTE THE SECTION ON BATTERY LIFE – BATTERY CAPACITY HAS BEEN CHECKED, HOWEVER NO WARRANTY IS GIVEN ON BATTERY PACKS

VERIFIED BY:

T. DU TOIT

NEXT SERVICE / CALIBRATION DUE: NOVEMBER 2010

Appendix 10: Instruments used for data collection

Image 1: Gilian Sampling Pump with filter and cyclone

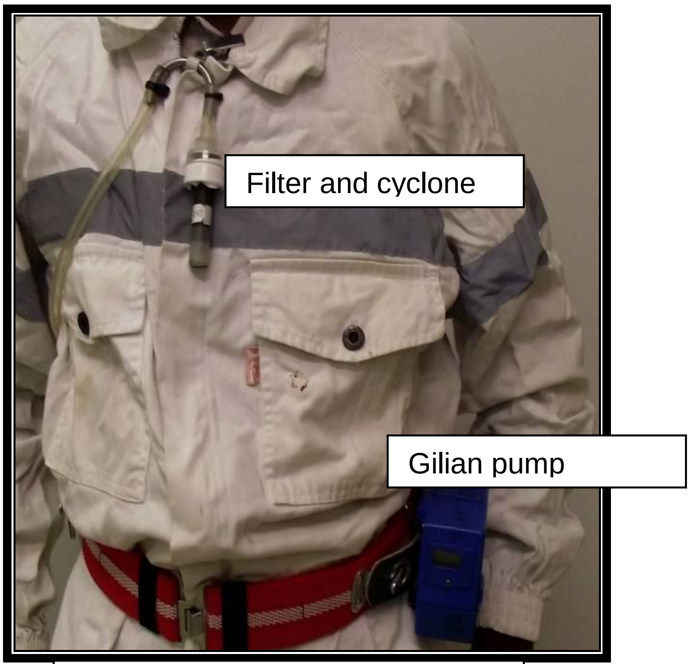

Image 2: Worker wearing Gilian Sampling Pump

Image 3: Kestrel® 4000 pocket weather tracker

Appendix 11: CSIR CMI Laboratory SANAS Certificate

sanas
South African National
Accreditation System

CERTIFICATE OF ACCREDITATION

In terms of section 22(2) (b) of the Accreditation for Conformity Assessment, Calibration and Good Laboratory Practice Act, 2006 (Act 19 of 2006), read with sections 23(1), (2) and (3) of the said Act, I hereby certify that:-

CSIR OCCUPATIONAL HEALTH & ERGONOMICS LABORATORY

Facility Accreditation Number: **T0420**

is a South African National Accreditation System accredited Testing Laboratory provided that all SANAS conditions and requirements are complied with

This certificate is valid as per the scope as stated in the accompanying schedule of accreditation, Annexure "A", bearing the above accreditation number for

ENVIRONMENTAL ANALYSIS

The facility is accredited in accordance with the recognised International Standard

ISO/IEC 17025:2005

The accreditation demonstrates technical competency for a defined scope and the operation of a laboratory quality management system

While this certificate remains valid, the Accredited Facility named above is authorised to use the relevant SANAS accreditation symbol to issue facility reports and/or certificates

Mr R Josias
Acting Chief Executive Officer

Effective Date: 29 January 2010
Certificate Expires: 29 January 2015

ANNEXURE A

SCHEDULE OF ACCREDITATION

Testing Laboratory Number: T0420

Permanent Address of Laboratory: CSIR Occupational Health & Ergonomics Laboratory Cnr Carlow and Rustenburg Road Emmerentia Johannesburg 2195	**Technical Signatories** : Ms CJ Pretorius : Ms ED Mukwevho
Postal Address: P O Box 91230 Auckland Park 2006	**Nominated Representative** : Ms CJ Pretorius
Tel : (011) 358-0000 Fax : (011) 482-3267 E-mail : cpretorius@csir.co.za	Issue No. : 01 Date of issue : 29 January 2010 Expiry date : 29 January 2015

Materials/Products Tested	Types of Tests/Properties Measured, Range of Measurement	Standard Specifications, Equipment/ Techniques Used
Respirable dust on filters	Alpha quartz analysis using XRD Gravimetric weighing Particle size analysis Diesel particulate matter analysis	MDHS 101 MDHS 14/3 ASTM C1070 NIOSH 5040

Original date of accreditation: 29 January 2010

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ISSUED BY SOUTH AFRICAN NATIONAL ACCREDITATION SYSTEMS

Field Manager

Appendix 12: Department of Labour's permission letter to conduct MPH Research

labour

Department:
Labour
REPUBLIC OF SOUTH AFRICA

Private Bag X117, PRETORIA, 0001. Laboria House, 215 Schoeman Street, PRETORIA
Tel: (012) 309 4000, Fax: (012) 320 5129, www.labour.gov.za

Enquires : V. Singh
Our Ref : L007/07/2010
Date : 2 August 2010

Mr Norman Nkusi Khosa
c/o CSIR
PO Box 91230
Auckland Park
2006

Dear Sir

REQUEST USE FOR DEPARTMENT OF LABOUR'S INFORMATION ON SILICA DUST IN FOUNDRIES FOR MASTERS IN PUBLIC HEALTH RESEARCH STUDY

Your letter dated 18 June 200 refers.

Please be advised that your request for access to the Department of Labour's (DoL) information on silica dust in Foundries for your Masters in Public Health Research Study has been granted. However, the access to the information requested is restricted to selected sections of the data for the study on "Respirable crystalline silica dust exposure of foundry workers in Gauteng: A task-based risk assessment."

Please be advised that you will treat the information furnished by DoL for the execution of your research as confidential. In addition to this you must at all times be obliged to safeguard the confidential information in pursuant of your research and must prevent the use, reproduction, disclosure or other dissemination of any such information to any person, firm or corporation including third parties, except with the express prior consent of DoL.

It is recorded that you may have access to the information as per your request specific for the purpose of your research. Furthermore you must not modify the data, merge it with any other data, use it for any commercial purpose or do any other thing that may in any manner whatsoever, affect the integrity, security or confidentiality of such data. You are further not to permit any third party to read, copy or use the data other than may be specifically required in terms of your request.

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Departement van Arbeid • Department of Labour • UmNyango wezemiSebenzi • ISebe lezeMisebenzi • uMnyango wezeMisebenzi • Kgoro ya Merero ya Mešomo • Lefapha la Mesebetsi • Lefapha la Mediro • LiTiko le Temisebenti • Muhasho wa zwa Mishumo • Ndzawulo ya ta Mintirho

You are further not allowed to publish articles in any journal or book based on your research without the final approval of DoL.

Please be advised that Mr Thobile Lamati (Senior Executive Manager: Inspection and Enforcement Services) will be the contact point of access for the applicable information.

We trust that the above is in order.

Yours faithfully

For: DIRECTOR GENERAL:LABOUR

Appendix 13: Medunsa Research and Ethics Committee (MREC) Clearance Certificate

UNIVERSITY OF LIMPOPO
Medunsa Campus

MEDUNSA RESEARCH & ETHICS COMMITTEE

CLEARANCE CERTIFICATE

P O Medunsa
Medunsa
0204
SOUTH AFRICA

Tel: 012 - 521 4000
Fax: 012 - 560 0086

MEETING: 04/2011

PROJECT NUMBER: MREC/HS/62/2011: PG

PROJECT :

Title: Respirable crystalline silica dust exposure amongst foundry workers in Gauteng: A task-based risk assessment.

Researcher: Mr NN Khoza
Supervisor: Dr A Edwards
Co-supervisor: MP Kekana
Department: Public Health
School: Health Sciences
Degree: MPH

DECISION OF THE COMMITTEE:

MREC approved the project.

DATE: 13 May 2011

pp. [signature]

PROF GA OGUNBANJO
CHAIRPERSON MREC

Note:	
i)	Should any departure be contemplated from the research procedure as approved, the researcher(s) must re-submit the protocol to the committee.
ii)	The budget for the research will be considered separately from the protocol. PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES.

African Excellence - Global Leadership

Appendix 14: Respirator selection when exposed to respirable crystalline silica dust

Exposure	Respirator Recommendation	Assigned Protection Factor and Description
0.5 mg/m^3	**95 XQ**	(APF = 10) Any air-purifying respirator with a high-efficiency particulate filter
1.25 mg/m^3	**PaprHie/Sa:Cf**	(APF = 25) Any powered, air-purifying respirator with a high efficiency
2.5 mg/m^3	**100F/Papr THie**	(APF = 50) Any air-purifying, full-facepiece respirator with a high-efficiency particulate filter/(APF = 50). Any powered, air-purifying respirator with a tight-fitting facepiece and a high-efficiency particulate filter
25 mg/m^3	**Sa:Pd,Pp**	(APF = 1000) Any supplied-air respirator operated in a pressure-demand or other positive-pressure mode
Emergency	ScbaF:Pd,Pp/SaF: Pd,Pp:AScba	(APF = 10,000) Any self-contained breathing apparatus that has a full facepiece and is operated in a pressure-demand or other positive-pressure mode/(APF = 10,000). Any supplied-air respirator that has a full facepiece and is operated in a pressure-demand or other positive-pressure mode in combination with an auxiliary self-contained positive-pressure breathing apparatus
Escape	**100F**/ScbaE	(APF = 50) Any air-purifying, full-facepiece respirator with a high-efficiency particulate filter or any appropriate escape-type, self-contained breathing apparatus

*Table taken from ***NIOSH Pocket Guide to Chemical Hazards*****, Table 3, p xx-xxiv**

Appendix 15: Work and personal information collection sheet

No	Name	Job description	Section	Smoker		Gender		No of years worked on the company
				Yes	No	M	F	
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								