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Occupational Exposure to Insoluble Nickel in a Primary Platinum Group Metal Smelter

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Mini-dissertation submitted in partial fulfilment of the requirements for the degree Masters in Public Health, in the School of Health Systems and Public Health, Faculty of Health Sciences, University of Pretoria

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December 2012

Declaration

I declare that this mini-dissertation, which I hereby submit for the degree Masters of Public Health at the University of Pretoria, is my own work and has not formerly been submitted by me for a degree at any other University.

Ethics Approval Number: S167/2011
Approval Date: 23 November 2011

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Signed: _________________

Acknowledgements

Thank You for being my source of strength and for Your guidance. Philippians 4:13 – “I can do all things through Christ who strengthens me.”

I would like to thank the following people for their invaluable contribution:

Dr Janine Wichmann, my Supervisor, for her support, time, effort and guidance. Thank you for believing in me. The completion of this research would not have been possible without you.

Professor Margaret Westaway, my Co-Supervisor, for sharing with me her wealth of knowledge and for her time and advice.

Professor Samuel Manda for the statistical analysis of the data.

Dr Ruan Kruger for his time with regard to statistical interpretations.

Professor Johan du Plessis for showing interest in this study as well as his time and support.

Dr Cas Badenhorst for initiating this project and Bayanda Mncwango for presenting me with the opportunity to do the research.

My family for their motivation and support. A special thank you to my parents, Irene and Francois, as well as my parents in-law, Lizette and Neels.

My friends for their continuous support and encouragement.

My husband, Corné, for his love, understanding, support, patience and motivation throughout this journey.

Our newborn son Eduan who is my inspiration.

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B: Permission to access records/files/database

C: Letter of permission from company

List of Abbreviations

ACGIH	American Conference of Governmental and Industrial Hygienists
AIDS	Acquired Immunodeficiency Syndrome
BSI	British Standard Institute
CEN	Comité Européen Normalisation
COSHH	Control of Substances Hazardous to Health Regulations
DoL	Department of Labour
DME	Department of Minerals and Energy
DMR	Department of Mineral Resources
IARC	International Agency for Research on Cancer
ISO	International Standards Organization
HIV	Human Immunodeficiency Virus
HSE	Health and Safety Executive
MEL	Maximum Exposure Limits
NA	Not available
NCD	Non-Communicable Disease
NCR	National Cancer Registry
NIOSH	National Institute for Occupational Safety and Health
NS	No standard
OEL	Occupational Exposure Limit
OES	Occupational Exposure Standard
OESSM	Occupational Exposure Sampling Strategy Manual
PEL	Permissible Exposure Limit
PGM	Platinum Group Metal
PPE	Personal protective equipment
SCOEL	Scientific Committee for Occupational Exposure Limits
STEL	Short Term Exposure Limit
TB	Tuberculosis
TLV	Threshold Limit Value
TRK	Technische Richtkonzentrationen
TWA	Time Weighted Average
UK	United Kingdom
USA	United States of America

VME	Valeur Moyenne d’Expositión
WHO	World Health Organization

Abstract

Introduction: Ruthenium, rhodium, palladium, osmium, iridium and platinum are known as platinum group metals (PGMs) and are, together with gold and silver, regarded as precious metals due to their scarcity. The world's biggest concentration of PGMs can be found in the Bushveld Complex, South Africa. PGMs are isolated from the ore and the metals concentrated into their pure form through a series of complex steps.

Insoluble nickel is considered to be a carcinogenic substance and therefore a hazard to human health. It is a by-product of the processes during mining, smelting and refining of PGMs and therefore released in the workplace where workers are exposed to it. Nickel has been classified as carcinogenic by the International Agency for Research on Cancer (IARC), the American Conference of Governmental and Industrial Hygienists (ACGIH), and South African legislation.

The general aim of this study was to determine the occupational exposure level to insoluble nickel at a Primary PGM smelter in the North West Province. Historical exposure monitoring data were used in order to identify associations between gender, age, years of employment and occupation, and the level of exposure. Results were also compared to the current Occupational Exposure Limit (OEL) of 0.5 mg/m^3 provided by South African legislation and to a stricter OEL of 0.01 mg/m^3 proposed by the Scientific Committee for Occupational Exposure Limits (SCOEL).

Methodology: One-hundred-and-fifty-two samples collected from 90 study participants over the period of 2010 and 2011 were available for the study. Due to the failure of five sampling pumps during the measurement period, the five samples were discarded as the flow rate and duration could not be determined. Therefore, only 147 samples were available. Descriptive statistics for categorical and continuous data were conducted. Demographic data of the sample population were analysed in order to determine relationships between categorical variables (gender, occupation) and the level of exposure. Correlations between continuous variables (age, years of employment) and exposure level were also determined. Results were also compared to the current South African OEL and to the SCOEL OEL in order to assess current compliance as well as future compliance should the new OEL be adopted.

Results: There was no statistically significant difference among the level of exposure of males and females ($z = -1.18$; $p = 0.24$), nor among the four age groups (Chi-square = 6.05; $p = 0.11$) nor among the four years of employment groups and the level of exposure (Chi-square = 1.25; $p = 0.74$). The difference between the occupation type and level of exposure was small (Chi-square = 20.99; $p = 0.051$). Single regression analyses indicated a positive significant correlation between the level of exposure and years of employment for instrumentation technicians only ($r = 0.77$; $p = 0.045$).

Conclusion: The level of exposure was not dependent on the age, duration of employment of an employee or their gender. It was, however, dependent on their occupation. Currently, the smelter complies with South African legislation, but should the SCOEL OEL be adopted in future, control measures should be improved in order to lower exposure levels.

Chapter 1

General Introduction

1.1 Context of the research report

The World Health Organization (WHO) principles within their constitution states that health is fundamental to all humans and that it is the right of every human being to enjoy the highest achievable health level without discrimination with regard to race, religion, political belief, economic or social condition.[1]

The WHO (1948) defined *health* as “a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity.”[1,2]

The South African Bill of Rights states that “everyone has the right to an environment that is not harmful to their health or well-being; and to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures” (p.1251).[3]

Mann highlights that medicine and public health complement each other by interacting with one another to uphold and protect health.[4] Even though they complement each other, they are different in a variety of ways. Public health has a population focus whereas medicine focuses more on individual health care. Public health responds to health threats to the population and develops policies to respond to these. In contrast, medical care focuses on diagnosis and treatment of the individual. Their problem solving methods will thus also differ in a variety of ways.[4,5]

Measuring population health status, epidemiological and other statistical methods and surveys are used by public health. Medicine makes use of other techniques, or a combination thereof such as physical examinations and laboratory studies of individuals. Therefore, public health is concerned with primary prevention by preventing adverse health events from happening by means of large scale public programmes etc. Medicine deals with an already existing health condition within a smaller setting such as medical offices or clinics and focuses more on secondary or tertiary prevention. These two different concepts complement each other as the one cannot exist without the other. Public health needs medical expertise and many medical practitioners’ services are implemented in settings such as maternal and child health clinics or HIV prevention programmes or immunisation programmes.[4]

Bonita *et al*. refer to public health as collective actions to improve population health and one of the tools used for improving public health is epidemiology. Epidemiology can be defined, as referred to by Bonita *et.al,* as "the study of the distribution and determinants of health-related states or events in specified populations, and the application of this study to the prevention and control of health problems (p.2)." Epidemiology is used in many ways such as being applied to investigate the causation of disease, (i.e. identify risk factors, classify exposures as human carcinogens), natural history of disease (i.e. aetiology), health status of populations (i.e. prevalence and incidence of health outcomes) and evaluating interventions (e.g. indoor tobacco smoking ban, setting of health guidelines such as the Occupational Exposure Limits (OELs) of the Scientific Committee for Occupational Exposure Limits (SCOEL) and the South African OEL).[6]

Toxicological studies are important for clarifying and explaining causal relationships, therefore complementing epidemiology; however, there are a few advantages of epidemiology over toxicology when it comes to hazard identification. Epidemiology directly assesses *human* health risk whereas with toxicology where absorption, metabolism, detoxification and so forth are of importance, varies between humans and animals. Therefore, extrapolation does not need to be taken into account with an epidemiological study. Epidemiological studies are important when assessing effects directly in humans and estimating the risks for a population.[7,8]

Epidemiological studies play a major role in any risk assessment in every phase – hazard identification, dose-response and the exposure assessment. Roseman further states that epidemiological studies have often been the first to indicate that environmental exposure is a hazard to health.[8]

Often, epidemiological studies are retrospective of nature and provide a background for the risk assessment of an environmental factor. Proper assessment of exposure forms an essential part thereof and has proven to be a difficulty in environmental epidemiology as a result of insufficient information on the exposure history of subjects. Exposure assessments in the majority of epidemiological studies rely on measurements of the environmental concentrations of a given chemical in combination with the knowledge of the presence of the study subjects in these environments, as is the case with occupational hygiene (e.g. occupational history).[9]

This report slots in specifically in the occupational health field, with the focus on all aspects of health and safety in the workplace and has a strong focus on primary prevention of hazards. This report focuses on the occupational exposure of insoluble nickel at a Primary Platinum Group Metal (PGM) smelter.

A comprehensive introduction to the science of environmental and occupational health and epidemiology is beyond the scope of this report and Bonita *et al*.[6], Yassi *et al*.[10] and Baker *et al*.[11] may be consulted by the reader in this regard.

1.2 Rationale for the study

Insoluble nickel is considered to be a carcinogenic substance and therefore a hazard to human health. It is a by-product of the processes during the mining, smelting and refining of Platinum Group Metals (PGMs) and is therefore released in the environment where workers are exposed to it. As South Africa, with special reference to the Bushveld Complex (where this study was conducted), is the main primary PGM producer globally, new information with regard to exposure to nickel in an occupational setting, specifically in a smelting set-up where matte is crushed after being smelted, may make a valuable contribution.

Cancer is a main cause of death globally. In 2008, 12.7 million incident cases and 7.6 million deaths were reported. Sixty-three per cent of all cancer deaths at the moment are from low- and middle- income countries and it is predicted by the WHO to increase. Nineteen per cent of all cancers worldwide are due to environmental exposure in an occupational setting and results in 1.3 million deaths each year. Most of the exposure risks for occupational cancer are preventable. Lung cancer, mesothelioma and bladder cancer are the most common occupational cancers diagnosed.[12,13]

Of all the cancers, lung cancer was the most common and also the main cause of cancer death in males globally in 2008. It is the fourth most common cancer diagnosed in females and the second leading cause of cancer deaths. Thirteen per cent (1.6 million) of the total cases and 18% (1.4 million) of the deaths in 2008 was due to lung cancer. For males, the countries with the highest incidence rates are Eastern and Southern Europe, North America, Micronesia, Polynesia, Eastern Asia, but, interestingly, rates are low in sub-Saharan Africa. Among the risk factors for lung cancer is occupational and environmental carcinogens. Smoking and occupational exposures are more prevalent risk factors in Western countries and chronic infections are more common in Africa and the Middle East.[12,13]

Half of the world's population is represented by workers. The workforce is therefore a major contributor to economic and social development. The health of workers is thus a crucial requirement for productivity and economic development. Workers' health is determined by workplace hazards as well as social and individual factors and access to health services.[14]

South African cancer statistics are reported in the National Cancer Registry (NCR), a pathology-based registry. The NCR indicates that cancer is a major problem in the South African population. The latest NCR statistics, as indicated in the 2000-2001 NCR report, shows that males have a lifetime risk (LR) of 1 in 6 of getting cancer. The top 5 cancers for males in South Africa include the following: prostate (1 in 23), lung (1 in 69), oesophagus (1 in 82), colon/rectum (1 in 97) and bladder (1 in 108). For females: breast (1 in 29), cervix (1 in 35), uterus (1 in 144), colorectal (1 in 162) and oesophageal (1 in 196). For both males and females, lung cancer is of concern.[15]

WHO launched its Non-Communicable Diseases Action Plan in 2008 which includes cancer-specific interventions.[16] During a South African Summit on the Prevention and Control of Non-Communicable Diseases (NCDs) held in Gauteng during September 2011, our country recognised the importance of non-communicable disease interventions.[17]

1.3 General aim and objectives

The general aim of this study was to determine the occupational exposure level to insoluble nickel at the smelter using historical personal exposure monitoring data.

The specific objectives of the study were to:

1) Analyse variables of demographic data of employees exposed to insoluble nickel, such as gender, age, years of employment and occupation in order to identify relationships between the above variables and the level of exposure.

2) Compare the exposure to insoluble nickel at the smelter to the current Occupational Exposure Limit (OEL) of 0.5 mg/m^3 provided by South African legislation.

3) Compare the exposure to insoluble nickel at the smelter to the proposed Scientific Committee for Occupational Exposure Limits (SCOEL) Occupational Exposure Limit (OEL) of 0.01 mg/m^3.

4) Describe the impact a stricter OEL such as the proposed SCOEL OEL, should it be adopted in future, will have on the smelter with reference to:
    a. financial viability of the smelter operation;
    b. work environment;
    c. employee health; and
    d. personal protective equipment.

5) Discuss possible control measures that could assist in reducing insoluble nickel exposure through inhalation.

1.4 Hypothesis

Insoluble nickel exposure exceeds the Occupational Exposure Limit provided by South African legislation.

1.5 Structure of the research report

PGMs, recovering PGMs, occupational exposure to nickel with regard to nickel speciation, particle-size and toxicology, carcinogenic properties, exposure patterns and occupational exposure limits and the measurement of personal occupational exposure will be elaborated on in Chapter 2.

Chapter 3 will deal in detail with the study design, study setting, study population and sampling procedure as well as the data management and analysis. The results of the study will be presented in Chapter 4 and discussed in Chapter 5. Study objectives 1 to 3 in Section 1.3 will be addressed in Chapters 4 and 5 and study objectives 4 and 5 in Chapter 6 (Recommendations).

Chapter 2

Literature Review

2.1 Platinum group metals

Platinum was initially discovered in the Chocó District of Columbia during the 16th century. Palladium, rhodium, osmium and iridium were discovered approximately 300 years after platinum. Ruthenium was the last PGM to be discovered.[18]

PGMs consist of a family of six metals namely ruthenium, rhodium, palladium, osmium, iridium and platinum.[18] They are classified as precious metals, together with gold and silver, due to their scarcity.[18,19] To place the scarcity thereof into context – approximately five million times as much iron as platinum is produced annually on the global scale. Initially, platinum was called “little silver” as it was thought to be a poor quality by-product of silver mining operations.[19]

Due to their physical and chemical properties, PGMs are highly valuable to the modern industry. They are resistant to oxidation and corrosion, have outstanding catalytic properties and are used in the chemical industry as well as in the automobile industry as catalytic converters.[18,19]

According to Jones, not only does South Africa contain more than three quarters of the global platinum reserves, it is also the world’s largest producer of PGMs.[19] The majority of global PGM reserves are found in the Bushveld Complex, South Africa, with Russia and Canada in second and third place respectively. PGM bearing ore is primarily mined to recover these PGMs.[18] Seventy-five per cent of the world’s resources of platinum, 52% of palladium and 82% of rhodium are located in the Bushveld Complex.[20]

2.2 Beneficiation (recovery) of platinum group metals

Detail regarding the PGM beneficiation process is beyond the scope of this MPH report and will be addressed briefly. Once PGM bearing ore have been mined, PGMs are separated from the ore during a succession of complex steps. The purpose of each step is to increase the concentration of the PGMs.[19] The beneficiation process can be summarised into three steps namely ore extraction, concentrating and refining.[21]

Ore extraction takes place underground at a nearby mine of the same company. During this labour intensive process, holes are bored and charged with explosives. The ore is removed and transported to the surface. Once the ore reaches the surface, it is transported from the mine to a nearby concentrator of the same company. At the concentrator, these rock particles are further reduced in size by crushing and milling ore for the purpose of exposing the minerals that contain PGMs.[21] The mine, concentrator and the smelter are located in close vicinity to each other. The smelter smelts concentrate received from the concentrators within the company, joint-venture partners as well as third parties.

During a “flotation process”, the crushed ore is mixed with water and special reagents. Air is then pumped through the liquid to create bubbles to which PGM containing particles adhere. These bubbles float to the surface and are removed. The flotation concentrate produced is then dried and smelted in an electric furnace at high temperatures in order to successfully separate the matte that contains the valuable metals from the slag containing unwanted materials and that is discarded as the matte settles at the bottom and the gangue at the top.[19,21]

Furnace matte produced by the smelter is sent away to convertors (not located on the premises), where air is blown through the matte to remove iron and sulphur. The converter matte tapped from the convertor is slow cooled, crushed and dispatched to the base metals refiners where PGMs are separated from base metals during base metal refining. The final stage, i.e. the extraction of PGMs, takes place at the precious metals refining section (not located on the premises).[21]

As only the smelting step is done at the smelter where this study was conducted, only the matte-smelting process is of interest and will be discussed.

There are various companies in South Africa that perform primary smelting of ore concentrates to recover PGMs. PGM smelting takes place in electric furnaces. During smelting, concentrate that contains the PGMs is smelted to separate oxide and silicate minerals (gangue) from the sulphide minerals associated with the PGMs. During smelting, a PGM containing nickel-copper matte is produced.[19]

Concentrate, containing PGMs, received from the concentrators, is dried in flash driers to remove moisture. The removal of moisture reduces the energy required for smelting as well as the possibility of explosions (blow-backs) inside the furnace. Dried concentrate from the flash drier product bin is fed into weighing vessels. Limestone is added as a flux and the mixture is pneumatically conveyed to the furnace feed bins directly above the furnace.[19,22]

During smelting in the furnace, two liquid phases form – molten matte which is denser as it is rich in nickel and copper sulphides and other base and precious metals, and a lighter silicate and iron rich slag. Due to gravity, the heavier molten matte settles under the slag. The matte and slag are tapped on opposite sides of the furnace. The slag is discarded whereas the matte, which contains the nickel, copper, cobalt, sulphur and PGMs is transferred to vessels which is moved by crane.[19, 22]

After the matte has cooled down sufficiently, it is crushed, loaded into a truck and transported to a converting smelter where it will be converted by blowing air into the molten matte to remove any remaining iron and sulphur by oxidation. Converter matte is subsequently milled before it is sent to a base metal refinery where copper and nickel are extracted. Final separation of pure precious metals takes place at the precious metals section.[19,22]

2.3 Occupational exposure to nickel

Millions of workers are globally exposed to airborne fumes, dusts and mists that contain nickel and its compounds.[23] Occupational exposure to nickel and its compounds may be anticipated in any of the beneficiation operations namely ore extraction, concentrating and refining.[23,24,25] The exposure to insoluble nickel species such as metallic nickel, nickel sulphide and nickel oxides liberated from dusts and fumes are the most common nickel species encountered in the workplace.[23] It is mainly during smelting and crushing operations that the insoluble form of nickel is liberated.[25] As previously mentioned (Zhao *et al*.), airborne exposure to insoluble nickel species liberated from dusts and fumes are the most common to be found in the workplace and may be anticipated in mining, concentrating and smelting.[23] During the smelting process, a molten matte rich in nickel and copper sulphides, as well as other base and precious metals forms together with a lighter silicate and iron rich slag.[19,22] When the furnace matte produced by the smelter is cooled down, it is crushed, liberating dust in the work environment that is rich in insoluble nickel.

Occupational exposure to nickel species may occur through ingestion, skin contact or through inhalation, with the latter being the main route of exposure, and thus the main focus of standard setting bodies.[25,26] The toxic effect that nickel may have on the human body is dependant on the specific nickel species in question and the particle size in the case of airborne particles.[25]

2.3.1 Nickel speciation

It is important to distinguish between the different species of nickel, as each of their toxic effects on the human body differs.[24,25] Nickel species may be classified in four groups as has been done by the International Committee on Nickel Carcinogenesis in Man (ICNCM). They have distinguished between *sulphidic, oxidic, metallic and water-soluble* nickel species.[24,25,26,27]

It is important to mention that it is the inorganic nickel compounds that are of toxicological relevance. These inorganic nickel compounds are classified based on the analytical methods applied to extract the nickel from an airborne nickel sample filter. Total nickel extracted is determined by means of atomic spectrometry or element mass spectrometry. Stepwise extraction of the nickel, as explained by Schaumlöffel, is followed and the result of these procedures is the four fractions, i.e. the four classes of nickel species – *soluble, sulfidic, metallic and oxidic* nickel.[25] Other classifications also exist based on analytical extraction procedures for distinguishing between water-soluble and water-insoluble nickel compounds.[25] Therefore, there are different classifications, and this may result in confusion.

Occupational exposure to metallic nickel occurs mainly during metallurgical operations such as the production or use of stainless steel, nickel alloy production and powder metallurgy operations. People may also be occupationally exposed to metallic nickel at nickel-cadmium battery manufacturing, plating and other applications such as coin production. Studies have shown that exposure to metallic nickel usually occurs in conjunction with exposure to other nickel compounds as well such as oxidic nickel etc.[28,29]

Insoluble nickel compounds occur in combination with other substances such as sulphur and oxygen, making this nickel combination, i.e. nickel sulphide and nickel oxide, insoluble in water. Insoluble nickel occurs in mining, refining and welding.[29] Soluble nickel forms also occur in combination with other compounds and will dissolve in water. The soluble form of nickel occurs in electroplating and refining. Nickel carbonyl (gaseous) is also present during refining.[29]

2.3.2 Particle-size

Particles that contain nickel may be classified into three health related size fractions of biological importance: *inhalable, thoracic* or *respirable*. Penetration of inhaled particles into the respiratory system depends on their aerodynamic diameter. Several organisations achieved international agreement during the 1990s on a set of particle aerodynamic diameter selective criteria. These organisations include

International Standards Organization (ISO), Comité Européen Normalisation (CEN) and the American Conference of Governmental Industrial Hygienists (ACGIH).[24,26,30,31]

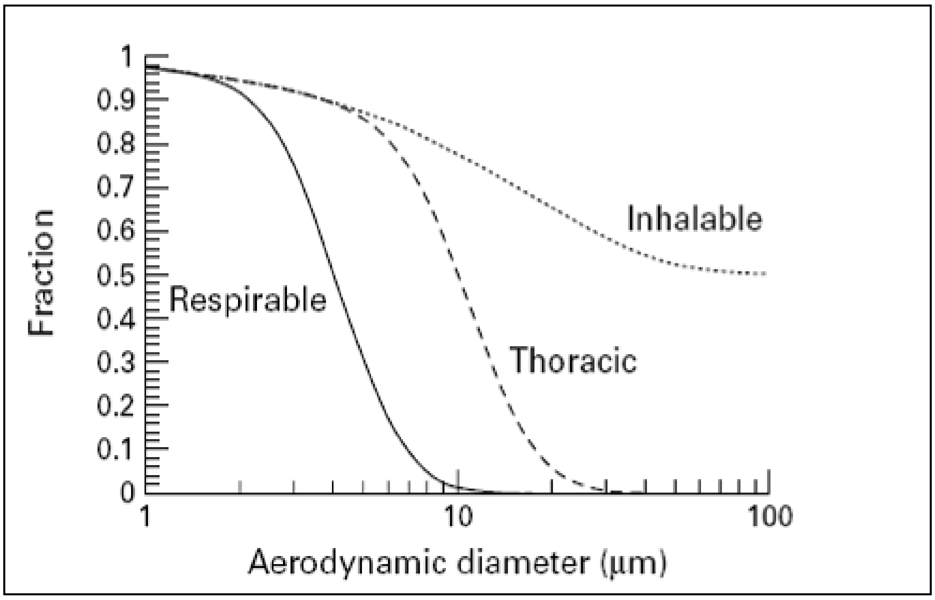


Figure 1: Inhalable, thoracic, and respirable sampling criteria[31]

The fraction of particles in the inspired air that penetrate the respiratory tract through the nose and mouth during breathing and reaches the nasal passages, the mouth and lungs, thus deposited anywhere in the respiratory system, are defined as *inhalable* particles.[26] Inhalable particles are hazardous wherever they are deposited in the respiratory tract.[32]

The fraction of inhaled particles that can penetrate into the lung below the larynx and reach the airways of the tracheobronchial region and further, is called the *thoracic fraction*.[26] These materials are hazardous when deposited anywhere within the lung's airways and the gas exchange region.[32]

The *respirable* particles are the smallest and penetrate into the gas exchange regions of the respiratory system.[26] Respirable particles are hazardous when deposited in the gas exchange area.[32] A good example of respirable particles are crystalline silica.

Respirable particles which form part of the inhalable and thoracic particles range in size from 0-10 µm. Thoracic particles ranging in size from 0-25 µm also form part of the inhalable fraction. Inhalable particles range in size from 0-100 µm. A particle of 1 µm is thus an inhalable, thoracic and respirable particle. A particle of 99 µm is only inhalable.[32]

The three fractions are defined in terms of penetration and not actual deposition. However, they still provide a good scientific foundation for exposure assessment in relation to a broad variety of health effects. Standard-setting organisations are still interested though in defining one or more of these fractions in terms of actual deposition, i.e. actual dose. Sivulka *et.al* (2007) state that a good way of doing so would be to measure exposure to all three fractions.[26]

However, in practice, simplifications are required. Therefore, for the majority of the aerosols, OELs are based on just *one* of the size fractions, currently the *inhalable* fraction. Sivulka *et al*. (2007) highlighted in a review that there remains ongoing interest by OEL setting groups in defining one or more of these size fractions in terms of actual deposition fractions, and hence actual dose.[26]

The particle fraction that is currently the biggest health concern regarding nickel exposure is the inhalable fraction. This is due to the fact that exposure to certain nickel species have been associated with both the upper and lower respiratory tract (nasal and lung cancers).[26]

Schaumlöffel demonstrated by means of a particle-size distribution curve with the aerosol size fractions of health relevance (respirable, thoracic and inhalable size fractions) that the predominant fraction in the workroom air of a nickel refinery was the inhalable fraction.[25]

In summary, when air that contains nickel is inhaled, the amount of nickel that reaches the lungs and ultimately enters the bloodstream depends on the size of the nickel particles, i.e. their physical properties, and the chemical properties of the nickel species. The more soluble the nickel species is, the more readily it will be eliminated from the lungs through absorption into the bloodstream and ultimate filtration in the kidneys with the associated excretion thereof in the urine.

2.3.3 Toxicology

Primarily inorganic nickel compounds are regarded as toxicologically relevant. As mentioned previously, there are four nickel species. The nickel speciation classification, i.e. sulfidic, oxidic, metallic and soluble, is extensively used in toxicological studies that deal with nickel particulate matter in workplace air.[25]

The deposition of nickel particles depends on their physical form. The absorption thereof depends on their chemical form. Physically, the particle’s aerodynamic size influences the region of the respiratory tract where the particle will ultimately settle. After the particle has been deposited in that particular area, absorption can take place and this depends also on the physical size and surface area of the particle, as well as on their chemical composition.[25]

One of the most important variables that may play a role in the determination of the toxicity of nickel is the solubility thereof, as absorption depends on the solubility of the nickel species.[23,25] Inorganic nickel compounds are classified by the Health and Safety Executive (HSE) into two groups based on their solubility in water. Indeed many OELs for nickel and its inorganic compounds are based upon their solubility in water.[33]

A nickel compound that is water soluble may be defined as a compound that has solubility in excess of 10% by weight in water at 20°C. Table 1 lists a few commercially important nickel species based on their solubility.[33]

Table 1: Commercially important nickel species based on their solubility.[33]

Water-soluble nickel compounds	Water-insoluble nickel compounds
Nickel chloride	Nickel carbonate
Nickel nitrate	Nickel hydroxide
Nickel sulphate	Nickel monoxide
Nickel sulphamate	Nickel sulphide
Nickel cyanide complex	Nickel sub-sulphide

Nickel salts such as sulphate and chloride (water soluble) are easily absorbed into the blood stream and eliminated via urine, whereas the less water soluble nickel is slowly absorbed into the bloodstream from the lungs and accumulates in the lungs over years of exposure.[34,35] Sivulka (2005) suggests that less water soluble nickel substances such as metallic nickel may be absorbed from the respiratory tract to a lesser extent and that the particles either remain in the airways or are removed by mucociliary action. It can also be swallowed depending on the size of the particle.[36]

In summary, absorbed nickel is distributed by the blood as it binds to albumin, L-histidine and α-2-macroglobulin and is mainly excreted via the urine, independent of the route of exposure. Inhaled less soluble sulfidic and oxidic nickel species are more carcinogenic than soluble nickel species as soluble nickel particles are dissolved in the mucus and nickel ions are rapidly removed by means of cilliary transport. In contrast, less soluble nickel enters the epithelial cells of the lung by means of phagocytosis and dissolves slowly, continuously releasing nickel ions.[25]

Nickel can also be absorbed from the skin as metallic nickel and nickel salts come into contact with sweat during long term exposure. Nickel penetrates the skin through the horny layer of the epidermis and leads to contact dermatitis.[25]

2.4 Nickel as a carcinogen

Schaumlöffel highlights that people exposed to nickel during the inhalation thereof in an occupational setting such as nickel producing or using industries, have a higher risk of respiratory cancer than the general population. The main exposure route for workers is through inhalation and not dermal contact. An increased cancer risk was associated with the less soluble forms of nickel such as the oxidic and sulfidic nickel species, as was the case with refinery dust in another study Schaumlöffel examined.[25]

The strongest evidence for a high cancer risk exists for sulfidic nickel. Historical exposures of nickel refinery workers in Norway indicated that in the crushing and smelting department, the nickel species present were oxidic and sulfidic, the insoluble form of nickel.[25]

The possibility that airborne nickel species may result in cancer is a big concern within the occupational setting. Various inhalation studies done on experimental animals showed a high number of lung tumours. There are not any studies currently that indicates the general population to be at risk to develop cancer through environmental exposure.[25]

The most complete analysis of historical epidemiological data (before 1990) was done by the International Committee on Nickel Carcinogenesis in Man (ICNCM). They used data from 80 000 occupational exposed workers at different locations and occupations and the key conclusion of their report was that nickel refinery workers have a higher risk of developing lung and nasal cancer which could be associated with the presence of less soluble nickel compounds in excess of 10 mg/m^3. The ICNCM also looked at nickel miners and found that there was no evidence linking lung cancer to nickel exposure, such as in the case of the nickel refinery workers. Sulfidic nickel species were found to be present during refining, as was not the case with mining. The main mineral found to be present in the ore during mining operations was pentlandite, which has not been found to be carcinogenic to experimental animals.[25]

The nickel species therefore definitely determines the carcinogenic property thereof and toxicology can explain why inhaled less soluble sulfidic and oxidic, in particular sulfidic nickel species are more carcinogenic than soluble species. Refer to the toxicology section for elaboration.

Nickel species are not only known for their carcinogenic properties, but are amongst others responsible for various other health effects as well. As the inhalation of nickel mainly affects the respiratory tract, it induces various lung diseases and damages the nasal cavity and mucosa, independent of the nickel species. Schaumlöffel states that cases of lung irritation, lung inflammation (pneumonia), emphysema, hyperplasia of pulmonary cells, fibrosis, pneumoconiosis and allergic asthma have been reported. These are related to short-term high-dose inhalation exposure. The only data available for chronic nickel inhalation exposure that exist are from occupational exposure studies. High mortality rates from non-cancerous lung diseases have been observed for nickel refinery workers after five years of exposure and pneumoconiosis could result after 12 to 20 years of exposure. Absorption through the skin can lead to contact dermatitis, a sensitised skin reaction that can ultimately result in reddened skin as the skin becomes inflamed and the skin may also erupt or in extreme cases, cause pustules and ulcers.[25]

The carcinogenicity of nickel compounds in humans is supported by various animal studies. In contrast, there is only limited information available on human studies with regards to metallic nickel. Despite this limitation, metallic nickel may be considered to be a human carcinogen as there is sufficient evidence available of the carcinogenicity thereof in experimental animal studies.[23] However, SCOEL excluded metallic nickel in their carcinogenic classification as they state that neither sufficient animal data nor epidemiological data points towards a carcinogenic action of nickel metal for the inhalable fraction.[37] The latest International Agency for Research on Cancer (IARC) document available on nickel and nickel compounds states that there is sufficient evidence that supports the human carcinogenicity of soluble nickel compounds as well as oxidic and sulphidic nickel compounds.[38] The IARC therefore considers all nickel compounds, except metallic nickel, to be *carcinogenic to humans* (Group 1). Metallic nickel is currently a Group 2B agent (*possibly carcinogenic to humans*).[38]

In contrast to IARC, the American Conference of Governmental and Industrial Hygienists (ACGIH) have only classified insoluble nickel species and nickel sub-sulphide in the A1 category, namely *confirmed human carcinogens*. Soluble nickel species are classified in the A4 category (*not classifiable as a human carcinogen*) and metallic nickel is in category A5 (*not suspected as a human carcinogen*).[39]

The group classification of nickel as done by the IARC[38] and the ACGIH[39] is depicted in Table 2.

Table 2: Group classification of nickel by IARC[38] and ACGIH[39]

ACGIH		IARC	
Insoluble inorganic compounds	A1	Nickel compounds	Group 1
Nickel sub-sulphide	A1	Nickel, metallic and alloys	Group 2B
Soluble inorganic compounds	A4		
Elemental	A5		

Legend to Table 2:

ACGIH classification[39]		**IARC classification**[38]	
A1	*Confirmed human carcinogen*	1	*Carcinogenic to humans*
A2	*Suspected human carcinogen*	2A	*Probably carcinogenic to humans*
A3	*Confirmed animal carcinogen with unknown relevance to humans*	2B	*Possibly carcinogenic to humans*
A4	*Not classifiable as a human carcinogen*	3	*Not classifiable as to its carcinogenicity to humans*
A5	*Not suspected as a human carcinogen*	4	*Probably not carcinogenic to humans*

2.5 Nickel exposure patterns and occupational exposure limits

Sivulka *et al*. (2007) reported that the presence of different nickel species is not consistent across different sectors. In the study, six different operational processes were investigated in the nickel mining industry. Milling operations, including crusher plants, were characterised by the presence of mainly sulphidic nickel compounds, ranging from 56% to 84%. The inhalable nickel dust percentages at feed preparation operations (matte crushing, matte processing and grinding) consisted mainly of sulphidic nickel compounds with a range of 68% to 81%. High temperature operations such as smelting operations indicated inhalable nickel dust percentages which consisted mainly of oxidic (82% at smelting operations) and sulphidic nickel compounds, whereas aqueous operations were characterised by the presence of mainly soluble nickel compounds (90% at electrolysis sections).[26]

Sivulka *et al*. (2007) also highlighted the need for research on particle-size selective sampling for the different nickel species, as there is not enough particle-size data currently available. The study concluded that when regulatory bodies establish OELs, they should take into account the particle-size distribution of nickel particles in various nickel industry sectors. More research is encouraged with regards to particle-size distribution and nickel species.[26] Another study by Vincent *et al*. reported that the distribution of the four groups of nickel species did not vary significantly over the various particle-size fractions.[40]

In South Africa, both the Department of Labour (DoL) and the Department of Minerals and Energy (DME), currently known as the Department of Mineral Resources (DMR), issue Occupational Exposure Limits for airborne pollutants. OELs from the DoL are based on the OELs of the United Kingdom (UK) and can be found in the Hazardous Chemical Substances Regulations (1995), Annexure 1.[41] The South African Minister of Labour sets these limit values after consultation with the Advisory Council for Occupational Health and Safety.[42] All nickel compounds are considered to be confirmed human carcinogens by South African legislation.[41,43] The criteria on which the UK based their limits may be found in the 1993 edition of the Health and Safety Executive Note EH 64.[33] The UK OELs can be found under the Control of Substances Hazardous to Health Regulations (COSHH). The list of limits can be found in the EH40.[44]

It should be mentioned that some governments have based their OELs on the TLVs of ACGIH. Others have not, such as Germany, the UK and the USA. The ACGIH is not a “true” governmental body and their TLVs are therefore not enforceable. Employers therefore do not have to legally comply to the TLVs unless otherwise stated.[45]

The current South African OEL according to the Occupational Health and Safety Act, Act 85 of 1993 and the Mine Health and Safety Act, Act 29 of 1996, for the inhalable fraction of water-soluble nickel is 0.1 mg/m^3 and 0.5 mg/m^3 for insoluble nickel and nickel metal.[41,43] Thus, exposure limits for nickel species are set for the inhalable fraction of the nickel dust, and the inhalable fraction is therefore of importance.[46]

In May 2009, the European Union’s Scientific Committee for Occupational Exposure Limits (SCOEL) proposed an eight-hour Time Weighted Average (TWA) OEL of 0.01 mg/m^3. This OEL was set for only one fraction, the inhalable particle fraction, i.e. did not differentiate between the different particle-size fractions. It was set for all nickel species (excluding metallic nickel). This was based on an inhalation study in rats with water-soluble nickel sulphate. The document further states that this proposed OEL should also be able to protect against the inflammatory effects (i.e. non-cancer effects) of insoluble nickel and metallic nickel. Sufficient evidence suggested protection against nickel-induced carcinogenicity as well.[47] SCOEL based their proposals on various documents, one of which was the IARC monographs.[48]

However, the document was revised in 2011, stating that differences between rats and humans with regard to particle deposition in the alveolar region need to be taken into account. Therefore, an eight-hour TWA OEL of 0.005 mg Ni/m^3 was proposed for the respirable fraction for poorly water-soluble nickel compounds and metallic nickel. It is acknowledged that respirable particles may further aggravate lung tumour development but epidemiological studies have not only shown lung tumour development, but nasal tumours as well. Therefore, the inhalable particle-size fractions also need to be taken into account. Particles in the workplace are also not limited to the respirable fraction. Consequently, a TWA OEL of 0.01 mg/m^3 was proposed for the inhalable fraction of water-soluble and poorly water-soluble nickel compounds, excluding metallic nickel since neither animal data nor epidemiological data indicated carcinogenic action thereof.[37]

Both recommendation documents state that epidemiological studies on metallic nickel do not indicate a carcinogenic potential. However, the current data alone is not enough in order to leave out any nickel species such as metallic nickel from these considerations as no studies have been done where people were exposed to only one nickel species exclusively.[37,47]

Table 3: SCOEL's revised proposals[37,47]

Nickel species	SCOEL 2009 proposal		SCOEL 2011 proposal	
	TWA OEL	Fraction	TWA OEL	Fraction
Soluble	0.01 mg/m^3	Inhalable	0.01 mg/m^3	Inhalable
Sulfidic	0.01 mg/m^3	Inhalable	0.005 mg/m^3	Respirable
			0.01 mg/m^3	Inhalable
Oxidic	0.01 mg/m^3	Inhalable	0.005 mg/m^3	Respirable
			0.01 mg/m^3	Inhalable
Metallic	0.01 mg/m^3	Inhalable	0.005 mg/m^3	Respirable

The Time Weighted Average (TWA) OEL is an exposure limit indicative of an eight-hour workday, 40-hour work week. It is the concentration to which an employee may be exposed repeatedly, daily, for his working lifetime without adverse effects.[49]

The SCOEL's OEL is much stricter than those of most countries, as listed in Table 3. The implications thereof may be significant with regard to cost in terms of compliance for safety and health of workers.

About two per cent of the nickel-related industries' workforce in the United States are exposed to airborne particles that contain nickel with concentrations ranging from 0.1 to 1 mg/m^3, according to Kasprzak *et al.*[50] The National Occupational Hazard Survey done during the periods 1972 to 1974 and 1981 to 1983 estimated that 23 272 and 507 681 workers were potentially exposed to nickel and nickel compounds respectively. The 507 681 workers from 1981 to 1983 included 19 673 women.[51]

Table 4, as adapted from the Nickel Institute, summarises the TWA OELs of a few countries.[45] "Current" is as of April 2008. Their website was last accessed 06 June 2012. All concentrations, in mg/m^3, are eight-hour Time Weighted Averages for total inhalable nickel. The TLV value for Austria applies to nickel metal and alloys, nickel sulfide, sulfidic ores, oxidic nickel, nickel carbonate in inhalable dust, as well as any nickel compound in the form of inhalable droplets.

Table 4: Occupational exposure limits for different nickel species according to country.[45]

Country/Body	Status of Standard	Metallic (mg/m^3)	Insoluble (mg/m^3)	Soluble (mg/m^3)	Nickel carbonyl (mg/m^3)
Argentina	Current	1.5	0.2 0.1 (sulfidic)	0.1	0.35
Austria	Current	0.05	0.05[2]	0.05	0.05 (ml/m^3)
Australia, Belgium, Italy, New Zealand	Current	1.0	1.0	0.1	0.12
Brazil	Current	NA	NA	NA	0.28
Canada – Ontario	Current	1.0	0.2 0.1 (subsulphide)	0.1	0.35
Canada – Alberta	Current	1.0 [2]	1.0 (sulphide roasting fume) [3]	0.1 [0.3]	0.12 [0.36]
Canada – British Columbia	Current	0.05	0.05 0.1 (subsulfide)	0.05	0.002
Canada Québec	Current	1.0	1.0	0.1	0.007

Table 4: continues

Country/Body	Status of Standard	Metallic (mg/m^3)	Insoluble (mg/m^3)	Soluble (mg/m^3)	Nickel carbonyl (mg/m^3)
Chile	Current	0.8	0.8	0.08	NA
Denmark	Current	0.05	0.05	0.01	0.007
Finland	Current	1.0	0.1	0.1	0.007 [0.021 - STEL]
France	Current	1.0 (VME)	1.0	0.1	0.12
Germany	Under revision	0.5 – TRK [2.0 - STEL]	0.5 – TRK [2.0 - STEL]	0.05 – TRK △ [0.2 - STEL]	[0.24 - STEL]
Greece	NA	NA	NA	NA	NA
Japan	Under revision	1.0	NS	NS	0.007
Netherlands	Current	0.1	NS	0.1	0.35
Norway	Current	0.05	0.05	0.05	0.007
Portugal	Current	1.0	NS	0.1	0.12

Table 4: continues

Country/Body	Status of Standard	Metallic (mg/m^3)	Insoluble (mg/m^3)	Soluble (mg/m^3)	Nickel carbonyl (mg/m^3)
South Africa	Current	0.5	0.5 0.1 (subsulphide)	0.1	[0.24 - STEL]
Spain	Current	1.0	0.2	0.1	0.12
Sweden	Current	0.5	0.1 0.01 (subsulfide)	0.1	0.007
United Kingdom	Current	0.5 (MEL)*	0.5	0.1 (MEL)*	0.24 (OES)
USA	Current■	1.0 - PEL	1.0	1.0	0.007
(USA) ACGIH TLV Non-enforceable standard	Current (1997)	1.5 △	0.2 △ 0.1 (subsulpfide)△	0.1 △	0.35

Legend to Table 4 will follow on the next page.

Legend to Table 4:

VME	Valeur Moyenne d'Expositiòn (1 mg/m^3 applies to the following: nickel carbonate, dihydroxide, subsulfide, monoxide, sulfide, trioxide and for other chemical forms non-otherwise specified such as 'insoluble nickel compounds' and nickel sulfide roasting fume and dust).
TRK	Technische Richtkonzentrationen
STEL	Short Term Exposure Limit of 15 minutes
NA	Not available
MEL	Maximum Exposure Limit
*	Based on "total inhalable" aerosol as measured with the 7-hole sampler.
OES	Occupational Exposure Standard
NS	No standard
■	OSHA reduced the soluble nickel PEL to 0.1 mg Ni/m^3 in 1989. It was changed back to 1.0 mg/m^3, the same as for nickel metal and insoluble nickel compounds after the Eleventh Circuit Court of Appeals sent the air contaminants standard back for review in 1992 [OSHA's approach was too generic (for over 400 chemicals that includes nickel)]. The PEL for soluble nickel compounds may be less than 1.0 mg Ni/m^3 in individual states that have obtained OSHA's approval.
PEL	Permissible Exposure Limit
ACGIH	American Conference of Governmental Industrial Hygienists
△	Based on the inhalable particulate fraction. In response to comments regarding the differential sampling efficiency of inhalable and 'total' aerosol samplers, the ACGIH proposed increases to the 1996 proposed TLV values during January, 1997. ACGIH also proposed carcinogen classifications.

In summary, different nickel species classifications exist in literature. This is due to the fact that different countries and organisations develop OELs for nickel and nickel compounds with different outcomes in mind. ACGIH base their TLVs solely on health factors and do not take economic/technical feasibility into account. NIOSH on the other hand makes recommendations and conducts research with the outcome in mind to prevent injury and illness in the workplace. Germany has the Technische Richtkonzentrationen or TRK which are technical exposure limits. The UK has OEL-TWA, MEL (Maximum Exposure Limits) and OES (Occupational Exposure Standard). France also has OEL-TWA values as well as the Valeur Moyenne d'Expositión (VME) values. [23,34]

Not only does the nickel species' classification vary, but the carcinogenic classification of each nickel species also vary among different organisations. ACGIH considers metallic nickel not to be carcinogenic whereas IARC considers metallic nickel as possibly carcinogenic to humans. South Africa considers all nickel species to be confirmed human carcinogens, and this includes metallic nickel and also has OELs for all of them. It is therefore clear that there are some mixed emotions when it comes to the carcinogenic properties of especially metallic nickel. A great deal of literature indicates that exposure to metallic nickel did not result in mortality but other studies have shown the opposite. More research is suggested by the Nickel Institute.[28]

The Nickel Institute indicates this to be the case for soluble nickel as well as data are inconsistent as studies done on nickel refinery workers in Wales, Norway and Finland indicated human evidence for carcinogenicity whereas electrolysis workers in Canada (with the same exposure level as the electrolysis workers in Norway) and plating workers in the UK) have shown no increased risk of lung cancer. In the scientific community, soluble nickel's carcinogenic potential is still open for debate.[52]

Evidence for carcinogenic potential of nickel oxides are more convincing as refineries in Kristiansand, Norway, Clydach, Wales to name a few indicated an increase in respiratory cancer risk for workers. It must be mentioned though that in all cases, they were exposed to combinations of oxidic, sulfidic and soluble nickel compounds. The risk for cancer was increased by additional exposure to soluble nickel.[53]

However, workers in the roasting, smelting and calcining department of the Kristiansand refinery were exposed to oxidic nickel only and there was also evidence indicating potential for developing lung cancer. Studies done on workers mining and smelting lateritic ores were again different from the refinery workers, indicating no evidence for nickel related respiratory cancer risks. According to the Nickel Institute, sulfidic nickel poses the highest respiratory carcinogenic risk, compared to the other species.[53]

It is recommended in future research that individual OELs are established for the different nickel species, and that various particle-sizes should be taken into account. The carcinogenic properties of each nickel species should also be investigated further. Each worksite should characterise their individual nickel species present as well as the particle-size distribution, as recommended by Zhao *et al*.[23]

These different definitions and classifications with regard to nickel make it quite complex to implement OELs for nickel and its compounds.

2.6 Measuring personal occupational exposure

According to Vincent, personal sampling is the preferred method used by occupational hygienists. Various studies indicated that personal sampling is the most effective way to determine the actual exposure of employees to aerosol and gaseous contaminants in the workplace.[40]

It has been suggested by occupational hygienists in the earlier days that results generated by means of personal sampling might differ from static sampling results. Vincent states that Sherwood and Greenhalgh (1960) were the first to produce evidence confirming the existence of the difference in results. Their results indicated that personal sampling almost always provided higher concentrations than the corresponding static or area measurements. Although static sampling underestimates exposure, it is still a good indicator of the contaminant concentration in the work area. However, static exposure monitoring does not represent the personal exposure of an employee, and is not of importance for the purposes of this study.[40]

The dust fraction that should be collected by the sampler is dependent on the potential health effects the particles might have. This depends on the work situation. Mark and Vincent provide an example. The fraction of importance to health for diseases such as pneumoconiosis, caused specifically by the deposition of fine respirable particles (i.e. particles smaller than 2.5 µm, Figure 1) in the gas exchange regions of the lung, would be the respirable fraction. Silicosis, a type of pneumoconiosis, is caused by the inhalation of small crystalline silica dust particles that penetrates the gas exchange regions in the lungs. Therefore, sampling of the respirable fraction (i.e. particles smaller than 10 µm, Figure 1) is appropriate as the target area is the gas exchange regions of the lung, and this is the particle-size of health importance.[54]

Therefore, in order to establish as precisely as possible a person’s occupational exposure to an aerosol in the workplace environment, a personal dust sampler is worn by the worker. Mark and Vincent designed the *Institute of Occupational Medicine* (IOM) sampler. It is stated that the ideal sampler should be able to collect the same aerosol size fraction at the same concentration as what the person wearing the sampler would inspire, independently of the particle-size distribution, uniformity and movement of the dust and the position of the person.[54]

It is highlighted by Mark and Vincent that, except in cases such as pneumoconiosis, it is common practice to recognise that all particles are capable of being taken into the body and lead to specific or non-specific health risks.[54] Various studies have shown that nickel poses a risk to the respiratory system as a whole. Nasal cancer, as well as lung cancer has been reported in nickel refinery workers.[55] It would thus make sense to determine the total inhalable dust fraction (i.e. particles smaller than 100 µm, Figure 1).

Mark and Vincent's study evaluated the performance of various personal samplers with regard to their ability to sample the biologically relevant inspirable fraction of airborne dust and the results for all the various samplers were unsatisfactory (under sampling due to internal wall losses and the distribution of dust on the filter). The IOM sampler was developed and the importance of relating the dust mass collected by the sampler directly with the mass of the dust the wearer of the sampler would inhale was emphasised. The IOM sampler samples particles smaller than 100 µm, i.e. the inhalable fraction.[46,54]

Figure 2 summarises the different particle-size fractions for airborne particulate matter, the different nickel species classification, carcinogenic classification by the ACGIH and IARC as well as South Africa and finally the Occupational Exposure Limits provided by each, including the recommended SCOEL OELs.

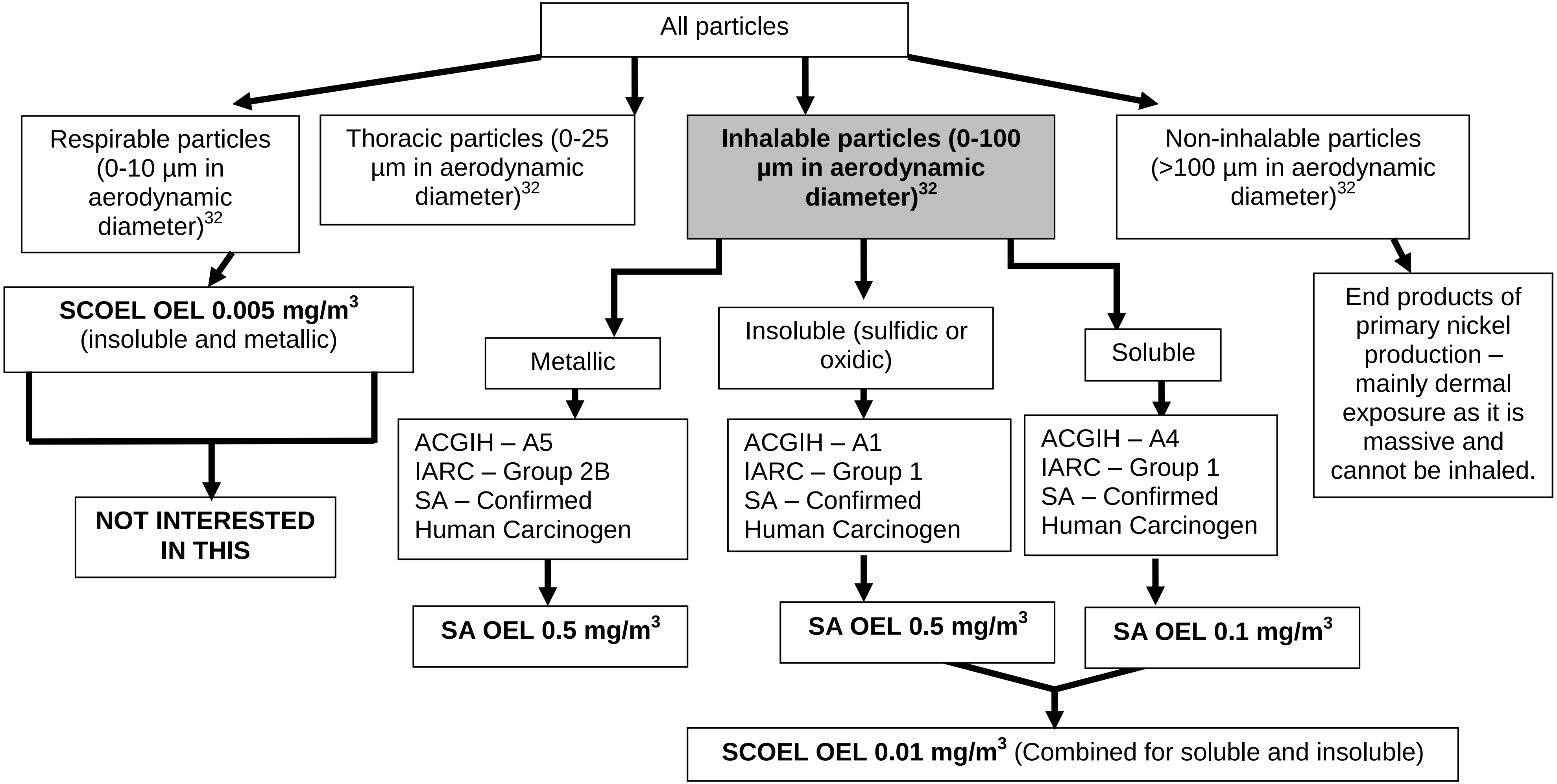


Figure 2: Particle-size differentiation, nickel speciation, carcinogenic classification and the current South African Occupational Exposure Limit, as well as the limit proposed by SCOEL.

Chapter 3

Methodology

3.1 Study design

This study was of a quantitative retrospective nature. Available historical personal exposure monitoring data of smelter employees were analysed.

In addition to the personal exposure monitoring data, demographic data were also considered in order to identify possible relationships between certain demographic variables and the level of exposure. Compliance with current South African legislation was determined, as well as possible compliance to the stricter OEL as proposed by SCOEL, should it be adopted in the future.

3.2 Study setting

This study was conducted by making use of historical personal exposure monitoring data of the smelter employees at a Primary Platinum Group Metal smelter in the North West Province of South Africa. The historical data that were available for the study were generated by the monitoring programme currently implemented at the smelter.

The monitoring programme is in line with the Mine Health and Safety Act, Act 29 of 1996 – *Guideline for the compilation of a mandatory code of practice for an occupational health programme on personal exposure to airborne pollutants.*

3.3 Study population and sampling procedure

The monitoring programme currently implemented at the smelter provides for personal exposure monitoring of occupations exposed to nickel. Personal exposure monitoring data that were available for each occupation were used for the purposes of the study.

Personal exposure monitoring data were generated by taking one or more personal air samples for each occupation.

Cellulose ester membrane filter papers with a 25 mm diameter and a 0.8 µm pore size were stabilised for a minimum of 12 hours in a temperature and humidity controlled room at an independent laboratory. After stabilisation, the filter papers were weighed on an analytical balance (Precisa) and inserted into a cassette holder. The cassette with the pre-weighed filter paper was then placed inside a sampler designed by the *Institute of Occupational Medicine (IOM)*. These samplers have a 15 mm inlet and measure the inhalable dust fraction.

At the smelter, Gilian Gilair personal sampling pumps were pre-calibrated to a flow rate of two litres per minute using a Gilian Gilibrator air flow calibrator as per the requirements of Method MDHS 14/3, *Methods for the Determination of Hazardous Substances*.[56]

After pre-calibration of the personal sampling pumps, the IOM sampler with the cassette containing the pre-weighed filter paper was connected to the personal sampling pump by means of flexible Tygon tubing.

The personal sampling pump was attached to each employee’s belt while the IOM sampler was clipped onto each employee’s collar in their breathing zone which is within a radius of 300 mm of the nose and mouth.[56]

The personal sampling pumps were switched on for a duration of at least 80% of the eight-hour shift after which they were switched off and post-calibrated. After sampling, the IOM cassette containing the filter papers was placed in a transport clip and transported back to the laboratory for stabilisation and post-weighing of the filter.

At the laboratory, the filter papers were analysed by flame atomic absorption spectrometry according to MDHS 42/2, *Methods for the Determination of Hazardous Substances – Nickel and inorganic compounds of Nickel in air (except nickel carbonyl).* This method complies with the “*General requirements for the performance of procedures for the measurement of chemical agents in workplace* *atmospheres"* described by the CEN, and is the preferred method. This method can measure all types of nickel that may be present, i.e. the water-soluble and the water insoluble (which includes nickel metal).[33]

The laboratory selects the appropriate procedure for sample dissolution based on the nature of exposure, i.e. the type of nickel present in the atmosphere. If it is known that there is no insoluble nickel compounds present in the test atmosphere (workplace), the "water-soluble nickel compounds" route is followed. A citrate leach procedure (outlined in Appendix A1 of MDHS 42/2) or 1+1 nitric acid dissolution procedure (outlined in Appendix A2 of MDHS42/2) is used. Results are then compared with the soluble nickel limit (0.1 mg/m^3).

When it is known that there are no soluble nickel compounds present in the test atmosphere, one of the procedures outlined in Appendices A2-A5 of MDHS 42/2 are followed. Results are compared with the insoluble limit (0.5 mg/m^3). This route is used for "nickel metal and water-insoluble nickel compounds".

Finally, when water-soluble and water-insoluble nickel compounds may be present in the test atmosphere, i.e. mixed exposure took place, a citrate leach procedure (outlined in Appendix A1 of MDHS 42/2) is used to determine the water-soluble nickel content and results are compared with the soluble nickel limit (0.1 mg/m^3). Thereafter, one of the procedures in Appendices A2-A5 of MDHS 42/2 is used to analyse the residue for water-insoluble nickel compounds and results are compared with the limit for insoluble nickel.

Therefore, the laboratory will use the appropriate method based on the nature of the nickel and also the availability of laboratory apparatus. This is outlined in Figure 3, adopted from the MDHS 42/2 method.[33]

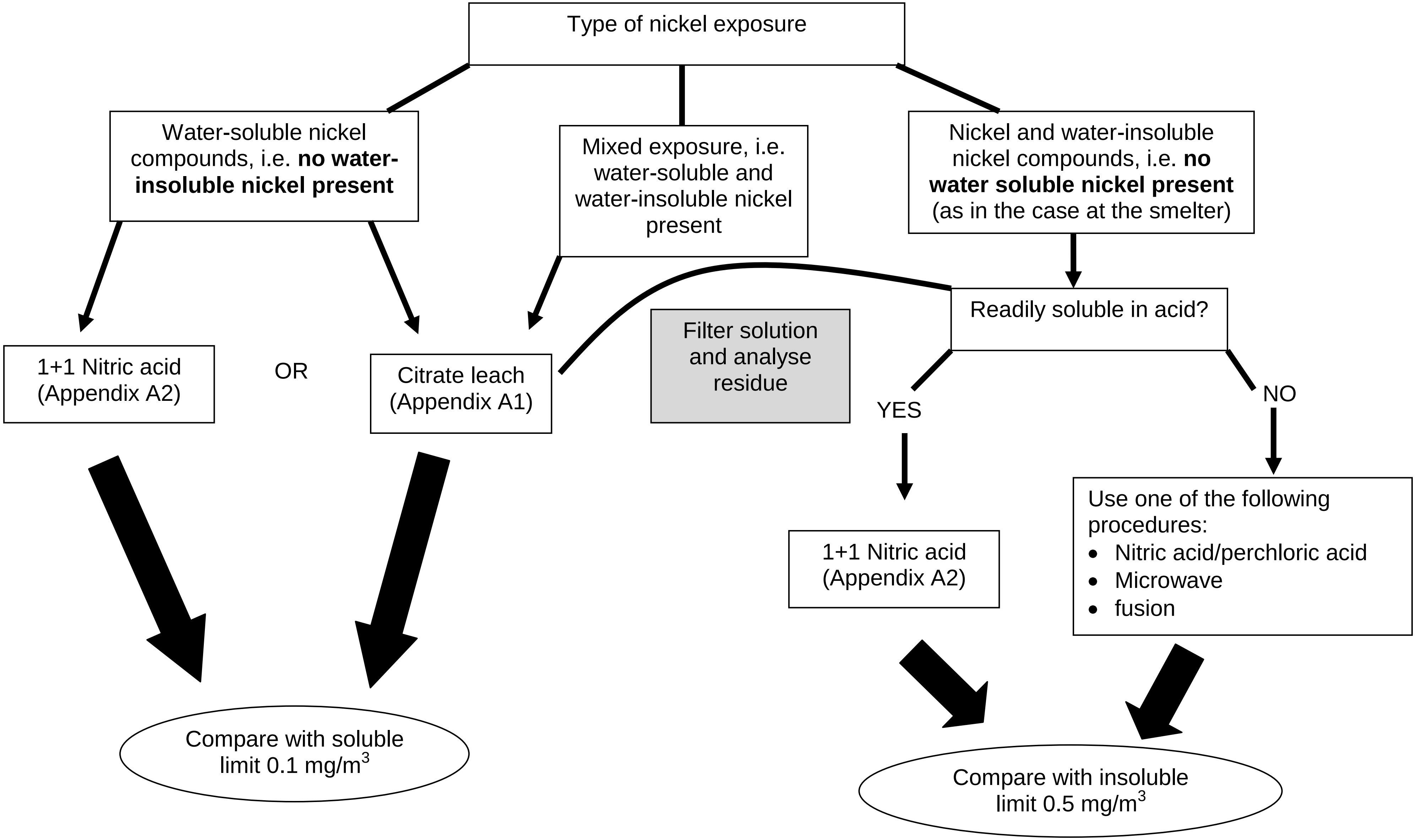


Figure 3: Dissolution selection procedure according to nickel containing material present in the workplace.[33]

Initially, during a baseline assessment where the nature of the nickel present at the smelter had to be determined, the laboratory was requested to analyse the mixed exposure because the nickel species present had to be determined. Samples revealed insignificant amounts of soluble nickel. Based on this information, samples collected thereafter were analysed only for the insoluble form of nickel, as it was known that insignificant amounts of soluble nickel was present. A report of this finding however was not available at the time of the study. More recent results that were available included both the soluble and insoluble nickel content, as was initially done. And again, results revealed insignificant amounts of soluble nickel present (data not shown; available on request). After confirmation of the existence of insignificant soluble nickel amounts, only the insoluble nickel content was determined onwards. Comparison with the soluble OEL of 0.1 mg/m^3 will play a role when soluble nickel is present. However, if it is known that it is not present, and that there is only nickel metal and insoluble nickel present, the content of insoluble nickel will be determined and compared to 0.5 mg/m^3 (South African OELs). Soluble nickel is more commonly found at the base metals refinery section where nickel is extracted.

In summary – South African legislation considers all nickel species to be carcinogenic, therefore the insoluble nickel compounds (including nickel metal) as well as the soluble nickel is of importance. However, only the insoluble portion was of interest in this study, as this is the form of nickel liberated in the processes carried out at the smelter.

The average of the pre-calibration flow rate and post-calibration flow rate was expressed in litres per minute and multiplied by the period over which the sample was taken (minutes) in order to determine the volume (litres). Volume in litres was converted to cubic metre. The concentration of a sample was calculated by using the filter mass received from the laboratory (milligram) and the volume (cubic metre).

Concentration was expressed in milligram per cubic metre. Concentration results were converted to Time Weighted Averages (TWA). This is done by dividing the actual running time by 480 minutes (8hrs x 60min) and multiplying it with the concentration (mg/m^3). This is usually done as not all samples are collected for similar periods. In order to compare results with statutory requirements (which are set for an eight-hour TWA period) and with each other, they needed to be standardised to an eight-hour TWA period. Each shift consists of eight hours, but samples are usually collected in practice over shorter periods than eight hours. The same strategy is adopted in the Occupational Exposure Sampling Strategy Manual (OESSM) of the National Institute for Occupational Safety and Health (NIOSH), an acceptable international methodology.[57]

The OESSM indicates that at least 70% to 80% of the full shift should be sampled in order to make provision for the time an employee does not spend performing his/her tasks. This includes time spent in the change house prior to the shift to shower and get dressed (approximately 30 minutes), lunch (one hour) and time spent in the change house after the shift to shower and get dressed (30 minutes).

Control (blank) filters for each batch of samples taken were supplied to the laboratory for quality control purposes. Control (blank) samples were not exposed to sampling in order to serve as a quality control check. No contamination was detected on the control (blank) filters.

Concentration results were compared to the South African OEL and to the proposed SCOEL OEL to determine current compliance.

3.4 Study population and data analysis

One-hundred-and-fifty-two samples collected from 90 study participants over the period of 2010 and 2011 were available for the study. Due to the failure of five sampling pumps during the measurement period, these five samples were discarded as the flow rate and duration could not be determined. Therefore, only 147 samples were available for the study. Descriptive statistics for categorical and continuous data were conducted. Demographic data of the sample population were analysed in order to determine relationships between categorical variables (gender, occupation) and the level of exposure. Correlations between continuous variables (age, years of employment) and exposure level were also determined.

The exposure level did not have a normal Gaussian distribution and was not transformed in order to keep the interpretation of the results simple. Hence, mostly non-parametric tests were performed.

Kruskal-Wallis tests for non-parametric data were done to determine whether there was an association between a person’s exposure, and age (four groups), years of employment (four groups) and occupation (13 groups). Age was categorised into four equal parts. Group 1: 24 to 41 years; Group 2: 42 to 48 years; Group 3: 49 to 52 and Group 4: more than 52 years of age. The age of two of the sample subjects was unknown, hence only the remaining 145 data points were used. Years of employment was categorised into four equal parts. Group 1: 0 to 15 years; Group 2: 16 to 21 years; Group 3: 22 to 26 years and Group 4: more than 26 years. The years of employment of two of the sample subjects were unknown, hence only the remaining 145 data points were used. Occupation included: boilermaker, concentrate crane driver, electrician, fitter, furnace charger, furnace tapper, hot metal crane driver, instrumentation, mason, plant operator, process supervisor, rigger and slag tapper.

A two-sample Wilcoxon rank-sum (Mann-Whitney) test was performed to determine the association between gender and the level of exposure.

One-sample t-tests were used to compare exposure levels to the South African OEL of 0.5 mg/m^3 and to the proposed SCOEL OEL of 0.01 mg/m^3.

A statistician was consulted for the statistical analysis of the data and all analyses were carried out in STATA 11.

Chapter 4

Results

4.1 Socio-demographic characteristics

The following section summarises the descriptive statistics for occupation, gender, age and years of employment (Table 5).

Just over 50% of the 90 study participants had one measurement, whilst a quarter had at least two measurements and the rest had three to five measurements during the study period.

The majority (16%) of the samples that were available was for the furnace tappers (24 of the 147 samples). The majority of the study participants were male (94%).

The youngest and oldest study participant was 24 and 60 years old, respectively. The average and median age of the study participants was 46.3 years (sd = 8.72) and 48 years, respectively. The majority (31%) of the study participants were between 42 and 48 years old. A quarter of the study participants were 24-41 years old or 53-60 years old.

The average and median number of years that the study participants were employed at the smelter was 19.9 years (sd = 9.31) and 21 years, respectively. Seventy-four per cent of the study participants had been employed for more than 15 years. The majority (30%) of the study participants were employed for 16-21 years.

Five samples were discarded due to the failure of pumps. These samples consisted of four males and one female (each sample was taken on a different individual) between the ages of 34 and 55. The female was an instrumentation technician, employed for two years. The remaining male participants consisted of two furnace chargers, a furnace tapper and a plant operator, employed for a period range of 16 to 23 years.

Table 5: Frequency distribution for occupation, gender, age group and years of employment groups

		Frequency	**Percentage (%)**
Occupation	Boilermaker	8	5.44
	Concentrate crane driver	10	6.80
	Electrician	7	4.76
	Fitter	9	6.12
	Furnace charger	12	8.16
	Furnace tapper	24	16.33
	Hot metal crane driver	10	6.80
	Instrumentation	7	4.76
	Mason	8	5.44
	Plant operator	22	14.97
	Process supervisor	11	7.48
	Rigger	9	6.12
	Slag tapper	10	6.80
Gender	Female	9	6.12
	Male	138	93.88
Age	1 (24-41)	37	25.17
	2 (42-48)	45	30.61
	3 (49-52)	27	18.37
	4 (53-60)	36	24.49
	Missing	2	1.36
Years of employment	1 (0-15)	38	25.85
	2 (16-21)	43	29.25
	3 (22-26)	29	19.73
	4 (27-36)	35	23.81
	Missing	2	1.36
	Total	**147**	**100.00**

The exposure level is indicated as a Time Weighted Average (TWA) exposure concentration value (Table 6). The overall average and median TWA concentration for all 147 samples collected from 90 study participants was 0.24 mg/m^3 (sd = 0.96) and 0.01 mg/m^3, respectively. These findings did not provide support for the hypothesis as the smelter complied with current South African regulations. The lowest TWA concentration measured was for a boilermaker (0.0005 mg/m^3) and the highest TWA concentration measured was for a process supervisor (8.84 mg/m^3). The boilermakers also had the lowest average (0.0071 mg/m^3, sd = 0.01) and median (0.0031 mg/m^3) concentration. Exposure levels were relatively uniform among this occupation. The process supervisors had the highest average exposure of 0.93 mg/m^3 (sd = 2.65). However, the median (0.01 mg/m^3) was very different from the average and this was due to outliers that increased the mean concentration value. Therefore, the median for this specific occupation was a better representation of the exposure level within this group. However, when results are compared to standards and with each other, the mean still has to be used in favour of the median.

The minimum TWA concentration for the male participants (0.0005 mg/m^3) was less than the minimum TWA concentration for the female participants (0.0016 mg/m^3). However, the average exposure for the male participants (0.2553 mg/m^3) was higher than that of the female participants (0.0175 mg/m^3). This may be due to the outliers as a maximum of 8.8370 mg/m^3 was recorded for the male participants. Therefore, when looking at the medians of both genders, exposure was more or less the same (female = 0.0068 mg/m^3, male = 0.0121 mg/m^3).

Within the age groups 24-41 and 42-48 the average exposure was 0.3492 mg/m^3 and 0.3229 mg/m^3 respectively. For the older groups, 49-52 and 53-60, exposure was lower, 0.0432 mg/m^3 and 0.1740 mg/m^3 respectively. The median exposure was uniform among the different years of employment groups, whereas their means differed due to the presence of outliers.

Table 6: Descriptive statistics for insoluble nickel exposure level by occupation, gender, age and years of employment

		Minimum	Maximum	Median	Mean	Standard Deviation
All		0.0005	8.84	0.01	0.24	0.96
Occupation	Boilermaker	0.0005	0.0239	0.0031	0.0071	0.0080
	Concentrate Crane Driver	0.0018	0.0736	0.0079	0.0137	0.0214
	Electrician	0.0015	0.3747	0.0296	0.0816	0.1324
	Fitter	0.0023	0.1622	0.0060	0.0301	0.0537
	Furnace Charger	0.0020	0.3529	0.0109	0.0475	0.0982
	Furnace Tapper	0.0036	5.2200	0.0351	0.7135	1.4390
	Hot Metal Crane Driver	0.0026	0.3230	0.0416	0.0950	0.1094
	Instrumentation	0.0016	0.1232	0.0138	0.0331	0.0440
	Mason	0.0029	0.1334	0.0122	0.0272	0.0438
	Plant Operator	0.0005	1.3420	0.0102	0.1844	0.3436
	Process Supervisor	0.0010	8.8370	0.0114	0.9296	2.6500
	Rigger	0.0019	0.1143	0.0059	0.0195	0.0360
	Slag tapper	0.0026	0.1215	0.0132	0.0316	0.0436

Table 6: continues

		Minimum	**Maximum**	**Median**	**Mean**	**Standard Deviation**
Gender	Female	0.0016	0.0736	0.0068	0.0175	0.0232
	Male	0.0005	8.8370	0.0121	0.2553	0.9983
Age	1 (24-41)	0.0005	5.2200	0.0107	0.3492	1.1620
	2 (42-48)	0.0022	8.8370	0.0119	0.3229	1.3340
	3 (49-52)	0.0011	0.3529	0.0067	0.0432	0.0826
	4 (53-60)	0.0005	2.1730	0.0186	0.1740	0.4153
	Missing	0.0044	0.0139	0.0092	0.0092	0.0067
Years of employment	1 (0-15)	0.0016	5.2200	0.0096	0.1997	0.8578
	2 (16-21)	0.0005	8.8370	0.0113	0.4606	1.5240
	3 (22-26)	0.0021	1.0250	0.0127	0.0888	0.2001
	4 (27-36)	0.0005	2.1730	0.0137	0.1405	0.4197
	Missing	0.0044	0.0139	0.0092	0.0092	0.0067

4.2 Comparison between insoluble nickel exposure level among occupation, gender, age and years of employment

There was no statistically significant difference among the level of exposure of males and females ($z = -1.18$; $p = 0.24$), nor among the four age groups (Chi-square = 6.05; $p = 0.11$) nor among the four years of employment groups and the level of exposure (Chi-square = 1.25; $p = 0.74$). Therefore, the level of exposure was not influenced by gender, age group or number of years of employment.

In addition, the difference between the occupation type and level of exposure was quite small (Chi-square = 20.99; $p = 0.051$). The level of exposure was influenced by the occupation type (borderline significance).

In order to investigate which occupation was more exposed to the insoluble nickel levels, single regression analyses were performed for each occupation type. No significant correlation was evident in any other occupation type (data not shown). A positive significant correlation existed between the level of exposure and years of employment for instrumentation technicians only ($r = 0.77$; $p = 0.045$).

4.3 Comparison between insoluble nickel exposure level and OELs

The average TWA concentration for all 147 samples collected from 90 study participants (0.24 mg/m^3, sd = 0.96, 95% confidence level 0.08 – 0.39 mg/m^3) was significantly lower than the South African OEL of 0.5 mg/m^3 ($p = 0.0006$). Therefore, the smelter currently conforms to the South African OEL and does not provide support for the hypothesis. This was not the case for furnace tappers and the process supervisors with an average of 0.71 mg/m^3 and 0.93 mg/m^3 respectively. The furnace tappers and process supervisors had an average exposure level in excess of the South African OEL. Unfortunately, due to the fact that there were too few study participants in these two occupations, a statistical test could not be performed.

However, the average TWA concentration for all 147 samples was statistically significantly higher than the proposed SCOEL OEL of 0.01 mg/m^3 ($p = 0.0024$). The smelter is currently not in a position to meet the proposed SCOEL OEL should they be adopted in the future.

Ninety-three per cent of the workers (92.5%) within the sample population were exposed to levels below the South African OEL of 0.5 mg/m^3. Eight per cent of the sample population (7.5%) were exposed to levels that were equal to or in excess of the South African OEL (furnace tappers, plant operators and process supervisors). Refer to Table 7.

Forty-five per cent of the study participants were exposed to concentrations below the proposed SCOEL OEL, which means more than half of the sample population were in excess of the proposed OEL. The occupations that had the greatest proportion of samples exceeding the SA OEL were the furnace tappers, plant operators and process supervisors (highlighted in red of Table 7). When comparing concentrations with the proposed SCOEL OEL, every occupation had some values that did not comply with 0.01 mg/m^3.

This is supported by the 95% confidence interval of 0.08-0.39 mg/m^3. We can say with 95% confidence that the true population mean will indeed fall within this range (0.08-0.39 mg/m^3), in other words, will comply with the South African OEL of 0.5 mg/m^3, but in excess of the proposed SCOEL OEL of 0.01 mg/m^3.

Table 7 was adapted from a feasibility study done on crystalline silica to determine whether the proposed SCOEL OEL for crystalline silica was feasible or not. Most companies responded that the only means of compliance would be to use personal protective equipment (dust masks) which is considered the last resort of control.[58]

Table 7: Current compliance with SA OEL and SCOEL OEL

		Compliance with SA OEL	Non-compliance with SA OEL	Compliance with SCOEL OEL	Non-compliance with SCOEL OEL
		<0.5 mg/m^3	≥0.5 mg/m^3	<0.01 mg/m^3	≥0.01 mg/m^3
Occupation	**Number of workers in sample population**				
Boilermaker	8	8	0	6	2
Concentrate Crane Driver	10	10	0	6	4
Electrician	7	7	0	2	5
Fitter	9	9	0	6	3
Furnace Charger	12	12	0	6	6
Furnace Tapper	24	17	7	6	18
Hot Metal Crane Driver	10	10	0	3	7
Instrumentation	7	7	0	1	6
Mason	8	8	0	4	4

Table 7: continues

		Compliance with SA OEL	**Non-compliance with SA OEL**	**Compliance with SCOEL OEL**	**Non-compliance with SCOEL OEL**
		<0.5 mg/m^3	**≥ 0.5 mg/m^3**	**<0.01 mg/m^3**	**≥ 0.01 mg/m^3**
Occupation	**Number of workers in sample population**				
Plant Operator	22	20	2	11	11
Process Supervisor	11	9	2	5	6
Rigger	9	9	0	5	4
Slag Tapper	10	10	0	5	5
All study participants	147	136	11	66	81
% of study participants	**100**	**92.5**	**7.5**	**44.9**	**55.1**

Chapter 5

Discussion

One of the study objectives was to determine whether there was any relationship between the demographic variables (i.e. gender, age group, years of employment group and occupation type) of an employee and their level of exposure. Results suggested that there were no statistically significant difference among the level of exposure between males and females, the four different age groups, nor between the years of employment group. However, exposure level was somewhat influenced by the occupation type.

The six female study participants (contributing nine samples – some study participants were sampled more than once as there were not enough employees) consisted of concentrate crane drivers, electricians, riggers, furnace tappers and instrumentation technicians. A possible reason for no difference between the exposure level among males and females may be that there is no discrepancy between gender and occupation, i.e. male and female perform the same occupations, and will therefore also be exposed to the same levels as they perform the same occupations. The sample population for the female participants was also much smaller than the male sample population generated from the male study participants and may therefore not be comparable. The five discarded samples consisted of four male study participants and one female, thus, even if these samples were taken into account, the male sample population would have still not been comparable to the female sample population. If however the majority of these five discarded samples consisted of female study participants, the influence perhaps would have been more noticeable.

A study done by Camp *et al*. indicated that occupational settings are often dominated by men, and therefore studies frequently exclude women. It is assumed that men are more likely to be associated with “high risk” jobs such as mining and smelting where in actual fact, even though there are less women in mining and smelting, those that are doing the same job are exposed to the same occupational hazards at the same exposure level, as was indicated by this study (no difference in exposure level for males and females).[59]

Camp *et al*. further highlighted that research investigating occupational lung diseases in women must consider the physiological differences between gender as women are more prone to developing occupational lung disease than men. In the study done by Camp *et al.*, reference is made to a case control study conducted by Jahn *et al.* that investigated the occupational risk factors for lung cancer in women. Jahn *et al.'s* study indicated that there was an increased risk of lung cancer in occupations that were traditionally associated with men.[59]

Research studies are usually hampered by the lack of record keeping, as was indicated by Davies *et al*. who reported that the mining industry in South Africa rarely kept labour registries of female workers.[59] Previously, gender was a barrier for women in mining as it was a male-dominated workforce. Women were prohibited from working underground until the 1990s in South Africa. It is now however government policy to increase the percentage of woman in the mining industry.[60] Including both genders in future studies is of importance as there can no longer be distinguished between a man's job and a woman's job, as well as the fact that women indeed are more susceptible to risk factors in the workplace and are physiologically predisposed, which makes it even more important to include women in research studies.[59,60]

From the results it is evident that no statistically significant correlation existed between the exposure of an employee and his or her age. The same was found for exposure and their years of employment. It may be argued that due to the fact that the employees are not in control of their own exposure their exposure is relatively uniform, independent of their age and how long they have been working. As an example, a welder who is in control of the manner in which he welds may be more responsible for his own exposure to welding fumes. Another possible reason for no correlation between the years of employment and exposure levels may be that it does not matter what age the study participants are as they may be equally distributed across the 13 occupation types.

A possible reason why the lowest exposure level and also the lowest average were observed for boilermakers may be because this occupation is responsible for metal maintenance on plant equipment. These maintenance tasks such as welding and gas cutting are performed on a regular basis; however, they are mostly performed inside the workshop and not in the smelter. Their exposure may be lower than the other occupations due to this fact. Their limited exposure takes place when performing daily plant walkthrough inspections.

The highest average exposure levels were observed for the furnace tappers and the process supervisors. One of the main tasks of the furnace tappers is loading operations at the matte crushing section. It was visibly evident that high levels of dust were liberated at the crusher building during matte loading and crushing. Process supervisors also spend time at the crusher building during matte loading and crushing processes.

Of the five discarded samples, two were furnace chargers, one a furnace tapper and one a plant operator (four male study participants). The one remaining sample was a female instrumentation technician. Would these five excluded samples have been included, they might not have had a significant influence on the average exposure and compliance. If all five samples came from furnace tappers or process supervisors, found to be the highest average exposure occupations, the influence on average exposure levels and compliance might have had a different outcome.

The second objective of the study was to compare exposure results with the current South African OEL for inhalable fraction of insoluble nickel (0.5 mg/m^3). The mean TWA concentration was significantly lower than the South African OEL. Thus, for the 147 study participants the smelter currently conforms to South African legislation. This finding did not provide support for the hypothesis. However, for some occupation types, the smelter does not conform. Levels were recorded in excess of 0.5 mg/m^3 for the furnace tappers, plant operators and process supervisors, of which the process supervisors and furnace tappers had average exposures levels that exceeded 0.5 mg/m^3. All the other occupations had levels lower than 0.5 mg/m^3. When it comes to protection of employees, these three occupations (furnace tappers, plant operators and process supervisors) need to be on top of the priority list, as they were the highest exposed occupation types.

The third objective was to compare exposure results with the proposed SCOEL OEL for inhalable fraction of all nickel species (excluding metallic nickel) (0.01 mg/m^3). The average TWA concentration for the 147 samples collected from the 90 study participants was significantly higher than the proposed OEL. The smelter is currently not in a position to meet the proposed SCOEL OEL should it be adopted in future. All occupation types had levels that exceeded 0.01 mg/m^3.

It is important to compare the exposure levels observed in the smelter with those from studies that were published in the public domain. Sivulka *et al*. (2007) studied exposure levels at various nickel industry operations (i.e. not PGM smelters necessarily) for different countries. At two Canadian companies A and B, the average concentration was 0.022 mg/m^3 and 0.087 mg/m^3 respectively for their crushing sections (milling). However, the matte crushing section of company A (feed preparation) had a concentration of 0.47 mg/m^3, not far from levels measured at the smelter for employees that spent a vast amount of time in the crushing building. Company A’s matte processing section (feed preparation) had an average exposure level of 1.19 mg/m^3, more than twice the level permitted by South African legislation. Levels in excess of the SA OEL have also been measured at the primary PGM smelter where the study was conducted. The grinding sector of a Norwegian company had an average concentration of 0.478 mg/m^3. Overall, the Russian refinery levels were not very high, except for the anode casting section (2.3 mg/m^3) which had a high level of metallic nickel due to the fact that they use metallic nickel anodes. Thus, when comparing exposure levels to other countries, the smelter’s exposure level is not that much different from theirs.[26]

A study by Thomassen *et al*. studied the inhalable dust nickel concentrations at Monchegorsk nickel refinery (i.e. not a PGM smelter specifically), Russia. Their roasting/anode casting operations also had considerably higher dust levels and nickel levels. (2.3 – 21 mg/m^3).[24]

South Arica is still the largest producer of primary PGMs. PGMs are mined as the primary product and other metals such as nickel, copper and cobalt are the by-products. Russia is the second largest PGM producing country. However, the majority of PGMs produced in Russia is as a by-product of nickel and copper mining.[61]

Norilsk Nickel, Russia, is globally the largest nickel and palladium producer. Norilsk Nickel is also one of the world's leading producers of platinum and copper and produces by-products namely cobalt, rhodium, silver and gold to name a few. According to their annual review report in 2010, they have measurements in place to limit health and safety risks. Their *Industrial Health and Safety Policy* ensure occupational safety. Working conditions were improved with new equipment that liberated less dust. Technology was also improved, as well as management systems. Workplace production risks are assessed and the conditions are certified, employees are regularly trained with regard to health and safety by means of briefing sessions and workshops. Employees are provided with personal protective equipment that conforms to the necessary standards.[62] In 2011, 30 operational machines and mechanisms were replaced with more advanced machines at their Polar Division, costing approximately 800 million Russian Rouble, an estimated 211 million South African Rand.[63]

Bearing in mind the following limitations when considering the findings of this study: The employees at the smelter used to be confined to a particular area, performing particular tasks associated with a specific occupation. This simplified the way in which exposure was quantified as the occupation could be linked with the problem area. The problem area can then be assessed in order to determine the source of contamination and control measures can be implemented to mitigate the source. Therefore, exposure concentrations measured can be directly linked with the source of contamination. However, the company has started to implement a multi-skill approach and therefore employees now have to be trained in multiple tasks in various areas of the plant in order to become acquainted with the other occupations as well. The reason for this is to ensure that production can continue in the case of employee shortage due to absenteeism, leave etc. Therefore, employees rove the smelter and are not necessarily confined to one particular area for their entire shift, making it increasingly difficult for the hygienist to determine the contamination source as the hygienist has to rely on information given to them by the employee pertaining to where they were that day, and for how long in order to effectively interpret the results. In this communication process, illiteracy and language is a huge barrier and has an impact on the reliability of the information. It may be recommended that static samples are also taken in all areas of the smelter in addition to personal samples in order to determine major contamination sources. The smelter already has programmes in place to improve illiteracy and the continuation thereof is encouraged. It may be suggested for future studies that an interpreter is present when the researcher has interviews with the employees after their shift, to limit misinterpretation.

The 147 samples came from 90 study participants. Some employees were sampled more than once on different occasions. The smelter only has approximately 180 full-time employees of which about 30 to 40 employees do not work in the smelter area. All the employees that work in the smelter area were not present at the same time as they work in shifts. It may be that not all of the employees within an occupation type were present in the shift as some go on leave, are absent or on training. And if the occupation type already has a limited amount of people, for example the mason occupation that consists of four employees in total, sampling an employee more than once is inevitable. This may be considered as a study strength as more samples taken on the same person may aid as follow-up measurements for that same person. A study limitation may be that no duplicate measurements were taken on the same person simultaneously which could indicate whether sample contamination or tampering had taken place. More samples should be collected over a longer period for a true reflection.

Possible methodological limitations may include measurement errors during for e.g. the calibration of pump flow rates, the weighing of filters, poor quality control at the laboratory or at the smelter and the transport methods of the filters etc. For results to remain representative as far as is reasonably practicable, good quality control (e.g. the provision of blank/control samples in order to determine whether contamination took place), increasing the number of samples taken (in order to acquire a better estimate of true exposure) and to continuously link results with the control measures that are being implemented based on the results. One of the most important issues in occupational hygiene is the quality control as it is difficult to ascertain that the correct steps are being followed during each phase.

Another limitation may be the confusion regarding carcinogenic classification of the different species as this differs among various organisations. The IARC classifies metallic nickel as possibly carcinogenic to humans whereas ACGIH does not regard metallic nor soluble nickel as a carcinogen.

Sivulka *et al*. recommends further research with regard to the setting of species-specific OELs in future as setting one or two OELs, i.e. one for soluble and one for insoluble and metallic nickel may not be sufficient as the different species occur in various workplaces at different concentrations. It is also recommended that more data is collected across various sectors in different industries on the particle-size distributions of the different nickel species. Currently, the inhalable fraction is of health interest. However, more morbidity studies are being done on nickel workers and knowing not only the inhalable fraction, but also the thoracic and respirable fractions, may be of interest if nickel and its compounds can be linked with deep-lung diseases such as fibrosis.[26] Laboratories in South Africa can currently only distinguish between the water-soluble and water-insoluble portions. It is therefore important to obtain the necessary new instruments and techniques to enable the measurement of individual nickel species as this currently cannot be done.

Chapter 6 recommends some control measures that may be implemented at the smelter in order to reduce exposure and possibly ensure compliance with the proposed SCOEL OEL before it is enforced or implemented. After these control measures are implemented, the current “before” results may be compared to results taken afterwards. This will provide an indication of the effectiveness of these control measures. This is a strength and weakness of the study as we already know what the current exposure is, but still need to find out whether the control measures that will be implemented in future, will indeed be effective or not. Thus, there is not much confidence at the moment with regard to whether the controls are effective or not. Exposure levels after these changes have been implemented will have to be measured again in order to compare it with existing levels. It is recommended that a follow-up study must be done.

Chapter 6

Conclusions and Recommendations

6.1 Financial viability

Currently the crusher building at the smelter is the main area of concern and the results from this study confirmed this. The crusher building was initially intended to be used on a temporary basis. As time elapsed, however, the crusher building became used on a permanent basis as more and more matte was being crushed on the premises instead of being sent away to be crushed elsewhere as was initially planned. The ventilation system is not very effective and dust levels are visibly high during crushing operations. As mentioned previously, samples with the highest dust load were taken from employees that spent an amount of time during their shift at the crushing building during matte crushing and loading. The engineering department has already done a cost analysis of the upgrading of the ventilation system and it is estimated at a few million Rand but it is strongly recommended that the engineering department proceed with the upgrading as this is the only way to reduce high dust levels in the crusher building effectively. Upgrading the ventilation system may have a great financial impact on the smelter operation, but in the long run will have a positive impact on the environment as well as smelter employees due to lower exposure levels.

Elevated dust levels were also evident at the material feed conveyors on the paste floor which was confirmed by dust load readings from the paste loader. A control measure that is already in place is the enclosed charging chutes for charging material into the furnace which limits dust emissions. During cleaning operations of the charging floor, settled dust may become airborne and increase exposure further. Maintenance of the equipment is of upmost importance, but not always a priority.

Employees are exposed to high total dust concentration levels for the majority of their shifts at various plant areas such as the furnace charge floor, slipping floor and paste floor. Automation of some of these processes is recommended.

If it is not possible to lower exposure levels, better respiratory protection with a higher protection factor should be provided to the employees. This unfortunately costs more.

Not all the possible control measures cost money. For example, during crushing operations, employees can be prohibited to enter the building. Thus, access control can lower the exposure at the crusher building. Good employee hygiene can also lower exposure. Washing hands regularly can lower exposure via ingestion. It is recommended that no employees must remove dirty or contaminated protective clothing or equipment from the premises. It is recommended that employees should refrain from removing their dirty or contaminated personal protective equipment (PPE) from the workplace. Dirty or contaminated clothes should rather be washed at the laundry provided on the premises. As it has been reported that tumble driers and washing machines are sometimes out of order, it is recommended that a designated employee is appointed to ensure that the washing machines and tumble driers are maintained in a working condition at all times.

6.2 Work environment and employee health

When an occupational exposure limit is lowered, it is mandatory for an operation to comply with it. With a lower OEL, compliance becomes more difficult. The health of employees may however be positively affected. Productivity of the employees may increase as absenteeism is limited due to illness as a result of high dust exposure. Future compensation claims could also be avoided.

6.3 Control measures

A number of steps known as the “hierarchy of controls” are steps that need to be followed in order to attempt to eliminate or reduce a hazard. The hierarchy of controls consist of *elimination (substitution or isolation); engineering controls; administrative controls*; and as a last resort – *personal protective equipment*.

The Mine Health and Safety Act requires the employer to identify hazards employees may be exposed to while performing their tasks. These potential hazards should be, once identified, eliminated. Elimination is unfortunately not always possible as it may not be practical and/or expensive. Therefore, the second line of defence would be to control the hazard at the source. The last resort of protection, when elimination or control at the source is not possible, is personal protective equipment.

At an operation such as the smelter, a risk assessment is done as the first step of identifying hazards. During a risk assessment, nickel was identified as a possible risk to employees as it forms part of the dust composition liberated during crushing and smelting operations. Once nickel was identified, employees' personal exposure was monitored. Once the hazard is measured, it can be quantified and monitored. By doing personal exposure monitoring, the effectiveness of the implemented control measures are also tested.

As part of administrative controls, the smelter has an induction session that serves as a training session for any person that conducts work on site and must be attended before the person is permitted on site. During the induction, all the hazards that a person may encounter whilst at work are discussed thoroughly.

It is recommended that the smelter focus more on information sharing and training. It is already compulsory for all employees to regularly attend formal health and safety courses. But there is no specific training with regard to occupational exposure to dust levels and more specifically nickel exposure. The smelter has safety talk topics, but it is recommended that they implement a system where occupational exposure to high dust levels is discussed on a weekly basis during a meeting. Employees may be evaluated with regard to whether respiratory protection is being used, how to use it, whether the respiratory zones on site are known and whether respirators are being replaced regularly. Upon arrival at the clock-in gate when reporting for work, the hygienist can request to inspect the employees' respiratory protection. The same concept is currently taking place with hearing protective devices.

Employees must become involved in their own health and the protection thereof. Pamphlets may be distributed on a regular basis where health hazards and issues are discussed. By providing training that specifically focuses on nickel as a health hazard and carcinogen might motivate employees even more to look after their health. Job specific training is enforced at the smelter. This is important and should be continued as it is important for employees to be trained on new systems that are implemented. It may happen that the upgrading of systems takes place, or a new system is installed and then employees are left behind with regard to the training of how to use these new systems.

Regulation 9 of the Mine Health and Safety Act requires the personal exposure monitoring of employees by means of a sampling strategy. This sampling strategy must be aligned with the Mandatory Code of Practice for Airborne Pollutants which outlines a basic occupational health programme. The purpose of this sampling strategy, enforced by the occupational hygienist, is to link personal occupational exposure with employee medical records. The smelter is already conforming to this requirement, as they have historical data records of personal employee exposure. This data can be used in making recommendations, and then after control measures have been implemented, results will indicate whether these were effective. The hygienist has to be consulted in engineering decision making.

New employees are subjected to an initial medical examination that is specific for the health hazards or exposures for the particular occupation. Thereafter, periodic examinations are performed at intervals that depend on the hazard the employee is exposed to. For individuals that will be required to perform work in a dusty environment, the employee will be screened by means of a lung function test in order to detect whether the respiratory system is free of any acute or chronic diseases that may impair their ability to perform the task. No specific tests are done for nickel exposure specifically currently. It is highly recommended that a few employees representative of each occupation are sent for urine screening. Biological monitoring can be useful in order to physically measure what the actual nickel exposure is.

When it is not possible to enforce engineering control measures that will lower employee exposure to below the limit for nickel and its components, employees must be provided with respiratory protection that will reduce the concentration of dust inhaled by the employee to a level below the limit for nickel and its components.

At the smelter, it is compulsory for employees to wear personal protective equipment and clothing when entering a respirator zone. A respirator zone is a workplace or part of a workplace where the concentration of an airborne pollutant (nickel in this case) in the air is or may be such that the exposure of employees in that workplace exceeds the OEL without wearing respiratory protective equipment. A respirator zone must also be clearly demarcated and identified by notice that indicates that the relevant area is a respirator zone and that respiratory protective equipment must be worn.

6.4 In conclusion

Cancer is one of the main causes of death globally and it is estimated that incident cases will rise by 50 per cent over the following 20 years. In the mining sector specifically, biological and social factors also come into play, aggravating the current situation. Acquired immunodeficiency syndrome (HIV/AIDS) and tuberculosis (TB) have been associated with lung cancer development. Other diseases associated with mining operations such as silicosis have been indicated to increase the risk of TB. Social risk factors such as migrancy lead to high-risk sexual behaviour, the main reason for an increase in HIV rates.[64]

Currently in our country, occupational exposures and disease surveillance is frail in spite of Department of Mineral and Resources' (DMR) effort to maintain registers (South African Mining Occupational Diseases database, introduced in 1998). There are exceptions such as the "Pathology Automation System" which provides a source of research and disease trends. This article also mentions that one of the main barriers is to translate research into action. Academics, the mining sectors etc. all have made various efforts with regard to recommending interventions, however, we fail to implement these policies in practice.[65]

References

1. Constitution of the World Health Organization. Basic Documents, 45th ed.;2006.
   Available online at http://www.who.int/governance/eb/who_constitution_en.pdf
   Date last accessed: 27 May 2012

2. Callahan D. The WHO definition of 'health'. The concept of Health. Hastings Cent Rep 1973;1(3):77-87.

3. Constitution of the Republic of South Africa, Act 108 of 1996.
   Available online at
   http://www.info.gov.za/documents/constitution/1996/a108-96.pdf
   Date last accessed: 27 May 2012

4. Mann JM. Medicine and Public Health, Ethics and Human Rights. Hastings Cent Rep 1997;27(3):6-13.

5. Joubert G, Ehrlich R. Epidemiology: A Research Manual for South Africa. 2nd ed. Cape Town: Oxford University Press Southern Africa; 2007.

6. Bonita R, Beaglehole R, Kjellström T. Basic Epidemiology. 2nd ed. World Health Organization; 2006.

7. Environmental Health Risk Assessment Guidelines for assessing human health risks from environmental hazards. Australian Government. Department of Health and Ageing.
   Available online at
   http://www.health.gov.au/internet/publications/publishing.nsf/Content/ohp-ehra-2004.htm~ohp-ehra-2004-epi.htm~ohp-ehra-2004-epi-5.htm
   Date last accessed: 27 May 2012

8. Roseman J. What can be done to ensure the usefulness of epidemiologic data for risk assessment purposes? Hum Ecol Risk Assess 1998;4(3):737-746.

9. Guiding principles for the use of biological markers in the assessment of human exposure to environmental factors: An integrative approach of epidemiology and toxicology. Toxicology 1995;101:1-10.

10. Yassi A, Kjellström T, de Kok T, Guidotti T. Basic Environmental Health. Oxford University Press; 2001.

11. Baker D, Nieuwenhuijsen. Environmental Epidemiology: Study methods and application. Oxford University Press; 2008.

12. Environmental and occupational cancers. World Health Organization; 2011 March.
Available online at
http://www.who.int/mediacentre/factsheets/fs350/en/index.html
Date last accessed: 27 May 2012

13. Jemal A, Bray F, Center M, Ferlay J, Ward E, Forman D. Global Cancer Statistics. CA Cancer J Clin 2011 Feb 4;61(2):69-90.
Available online at http://onlinelibrary.wiley.com/doi/10.3322/caac.20107/pdf
Date last accessed: 27 May 2012

14. Workers' health: global plan of action. 60th world health assembly. World Health Organization; 2007 May 23.
Available online at
http://www.who.int/occupational_health/WHO_health_assembly_en_web.pdf
Date last accessed: 27 May 2012

15. CANSA – The Cancer Association of South Africa. National Cancer Registry.
Available online at http://www.cansa.org.za
Date last accessed:27 May 2012

16. 2008-2013 Action Plan for the Global Strategy for the Prevention and Control of Non-communicable Diseases. World Health Organization; 2008.
Available online at http://www.who.int/nmh/Actionplan-PC-NCD-2008.pdf
Date last accessed: 27 May 2012

17. Department: Health. Republic of South Africa. South African Declaration on the Prevention and Control of Non-Communicable Diseases; South African Summit on the Prevention and Control of Non-Communicable diseases; 2011 September.
Available online at
http://www.doh.gov.za/docs/dcl/2011/draft_declaration_sa.pdf
Date last accessed: 27 May 2012

18. Xiao Z, Laplante AR. Characterizing and recovering the platinum group minerals – A review. Miner Eng 2004;17:961-979.

19. Jones RT. An overview of South African PGM Smelting. Mintek; 2005.
Available online at
<http://www.mintek.co.za/Pyromet/Files/2005JonesPGMsmelting.pdf>.
Date last accessed: 6 June 2012

20. Naldrett T, Kinnaird J, Wilson A, Chunnett G. Concentration of PGE in the Earth's Crust with Special Reference to the Bushveld Complex. Earth Science Frontiers 2008;15(5):265-297.

21. Johnson Matthey. Platinum Today – Production: South Africa. Platinum Today online; 2011b November 15.
Available online at http://www.platinum.matthey.com/production/south-africa/
Date last accessed: 22 Feb 2012

22. Sima C, Legoabe M. Mortimer Smelter: Operations Description. Southern African Pyrometallurgy 2006;29-34.

23. Zhao J, Shi X, Castranova V, Ding M. Occupational toxicology of nickel and nickel compounds. J Environ Pathol Toxicol Oncol 2009;28(3):177-208.

24. Thomassen Y, Nieboer E, Ellingsen D, Hetland S, Norseth T, Odland J, et.al. Characterisation of workers’ exposure in a Russian nickel refinery. J Environ Monitor 1999;1:15-22.

25. Schaumlöffel D. Nickel species: Analysis and toxic effects. J Trace Elem Med Bio 2012;26:1-6.

26. Sivulka D, Conard B, Hall G, Vincent J. Species-specific inhalable exposures in the nickel industry: A new approach for deriving inhalation occupational exposure limits. Regul Toxicol Pharmacol 2007;48:19-34.

27. Weinbruch S, Aken P, Ebert M, Thomassen Y, Skogstad A, Chashchin V, et. al. The heterogeneous composition of working place aerosols in a nickel refinery: A transmission and scanning electron microscope study. J Environ Monitor 2002;4:344-350.

28. Nickel Institute. Inhalation Exposure: Metallic Nickel.
Available online at
http://www.nickelinstitute.org/en/NiPERA/HealthScience/ToxicityOfNickelCompounds/MetallicNickel/InhalationExposureMetallicNickel.aspx
Date last accessed: 14 June 2012

29. Nickel. Occupational Health Clinics for Ontario Workers Inc.
Available online at
http://www.ohcow.memberlodge.com/resources/Documents/Nickel.pdf
Date last accessed: 14 June 2012

30. Tsai P, Vincent J, Wahl G, Maldonado G. Worker exposures to inhalable and total aerosol during nickel alloy production. Ann Occup Hyg 1996;40(6):651-659.

31. Cherrie J, Aitken J. Measurement of human exposure to biologically relevant fractions of inhaled aerosols. J Occup Environ Med 1999;56:747-752.

32. American Conference of Governmental Industrial Hygienists. Particle Size-Selective Sampling in the Workplace 2011. p. 74-76.

33. Nickel and inorganic compounds of nickel in air (except nickel carbonyl). Health and Safety Executive. Methods for the Determination of Hazardous Substances 1996;42/2.
Available online at http://www.hse.gov.uk/pubns/mdhs/pdfs/mdhs42-2.pdf
Date last accessed: 4 June 2012

34. Safe Use of Nickel in the Workplace. A guide for health maintenance of workers exposed to nickel, its compounds and alloys. 3rd ed. Nickel Institute; 2008. Available online at
http://www.nickelinstitute.org/MediaCentre/Publications/~/media/Files/MediaCentrePublications/HG%203rd%20Ed%202008.ashx#Page=1
Date last accessed: 4 June 2012.

35. Toxicological profile for Nickel. U.S. Department of Health and Human Services. Public Health Service. Agency for Toxic Substances and Disease Registry; 2005.
Available online at http://www.atsdr.cdc.gov/toxprofiles/tp.asp?id=245&tid=44
Date last accessed: 14 June 2012

36. Sivulka D. Assessment of respiratory carcinogenicity associated with exposure to metallic nickel: A review. Regul Toxicol Pharmacol 2005;43:117-133.

37. Recommendation from the Scientific Committee on Occupational Exposure Limits for nickel and inorganic nickel compounds. European Commission. SCOEL/SUM/85. 2011 June
Available online at httm://ec.europa.eu/
Date last accessed: 6 June 2012

38. International Agency for Research on Cancer. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. A Review of Human Carcinogens. Part C: Arsenic, Metals, Fibres, and Dusts. IARC Scientific Publications 2012;100:169-218.
Available online at
http://monographs.iarc.fr/ENG/Monographs/PDFs/index.php
Date last accessed: 14 June 2012

39. American Conference of Governmental Industrial Hygienists. Appendix A: Carcinogenicity 2011;73-74.

40. Vincent J. Aerosol Sampling: Science, Standards, Instrumentation and Applications. John Wiley & Sons; 2007.

41. Occupational Health and Safety Act, Act 85 of 1993. Hazardous Chemical Substances Regulations 1995 August 25.
Available online at www.labour.gov.za
Date last accessed: 6 June 2012

42. European Agency for safety and health at work. Occupational Exposure Limits.
Available online at
http://osha.europa.eu/en/topics/ds/oel/nomembers.stm/#RSA
Date last accessed: 06 June 2012

43. Mine Health and Safety Act, Act 29 of 1996. Occupational Exposure Limits for Airborne Pollutants 1997 January 15.

44. EH40/2005 Workplace exposure limits containing the list of workplace exposure limits for use with the Control of Substances Hazardous to Health Regulations (as amended). Health and Safety Executive 2005.
Available at http://www.hseni.gov.uk/eh40_2005.pdf
Date last accessed: 15 June 2011

45. Nickel Producers Environmental Research Association. Limit Values and Hazard Communication.
Available online at
http://www.nipera.org/HealthScience/LimitValuesAndHazardCommunication/ExposureLimits/UnitedStatesUS.aspx
Date last accessed: 15 September 2011.

46. Harmse JL, Engelbrecht JC. Air sampling of nickel in a refinery. Int J Environ Health Res 2007;17(4):319-325.

47. Recommendation from the Scientific Committee on Occupational Exposure Limits for Nickel and Nickel Compounds. SCOEL/SUM/85 2009 May 22.
Available online at http://www.epma.com/New_non_members/pdf/SCOEL-SUM-85_Ni_Recommendation.pdf
Date last accessed: 4 June 2012

48. International Agency for Research on Cancer. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. Chromium, Nickel and Welding. IARC Scientific Publications 1990;49:257-445.
Available online at http://www.iarc.fr/en/publications/list/monographs/
Date last accessed: 2 March 2012

49. American Conference of Governmental Industrial Hygienists. Introduction to the chemical substances 2011. p. 4.

50. Kasprzak K, Sunderman F, Salnikow K. Nickel Carcinogenesis. Mutat Res 2003;533:67-97.

51. Nickel Compounds and Metallic Nickel. Report on Carcinogens. 12th ed. National Toxicology Program. Department of Health and Human Services. 2011.
Available online at http://ntp.niehs.nih.gov/ntp/roc/twelfth/profiles/Nickel.pdf
Date last accessed: 8 June2012

52. Nickel Institute. Inhalation Exposure: Soluble Nickel.
Available online at
http://www.nickelinstitute.org/NiPERA/HealthScience/ToxicityOfNickelCompounds/SolubleNickel/InhalationExposureSolubleNickel.aspx
Date last accessed: 14 June 2012

53. Nickel Institute. Inhalation Exposure: Oxidic Nickel.
Available online at
http://www.nickelinstitute.org/NiPERA/HealthScience/ToxicityOfNickelCompounds/OxidicNickel/InhalationExposureOxidicNickel.aspx
Date last accessed: 14 June 2012

54. Mark D, Vincent JH. A new personal sampler for airborne total dust in workplaces. Ann Occup Hyg 1986;30:89-102.

55. Denkhaus E, Salnikow K. Nickel essentiality, toxicity, and carcinogenicity. Crit Rev Oncol Hematol 2002;42:35-56.

56. General methods for sampling and gravimetric analysis of respirable and inhalable dust. Health and Safety Executive. Methods for the Determination of Hazardous Substances 2000;14/3.
Available online at http://www.hse.gov.uk/pubns/mdhs/pdfs/mdhs14-3.pdf
Date last accessed: 4 June 2012

57. Occupational Exposure Sampling Strategy Manual. U.S. Department of Health, Education, and Welfare. Public Health Service. Center for Disease Control. National Institute for Occupational Safety and Health. DHEW (NIOSH) Publication 1977;77-173.
Available online at http://www.cdc.gov/niosh/docs/77-173/pdfs/77-173.pdf
Date last accessed: 4 June 2011

58. Potential socio-economic effects of setting an EU occupational exposure limit for respirable crystalline silica. Eurosil 2005 May 19.
Available online at
http://www.crystallinesilica.eu/fileadmin/eurosil/sociostudyfinal.pdf
Date last accessed: 4 June 2012.

59. Camp PG, Dimich-Ward H, Kennedy SM. Women and occupational lung disease: Sex differences and gender influences on research and disease outcomes. Clin Chest Med 2004;25:269-279.

60. Anglo American pays tribute to South African women in mining.
Available online at
http://uscdn.creamermedia.co.za/assets/articles/attachments/08309_anglo.pdf
Date last accessed: 4 June 2012

61. Kirk-Othmer Encyclopedia of Chemical Technology. Platinum Group Metals. John Wiley & Sons.
Available at http://www.scribd.com/doc/30131919/Platinum-Group-Metals
Date last accessed: 4 June 2012

62. Annual Review of MMC. Norilsk Nickel for 2010.
Available at http://www.nornik.ru/en/investor/report/annual/
Date last accessed: 15 May 2012

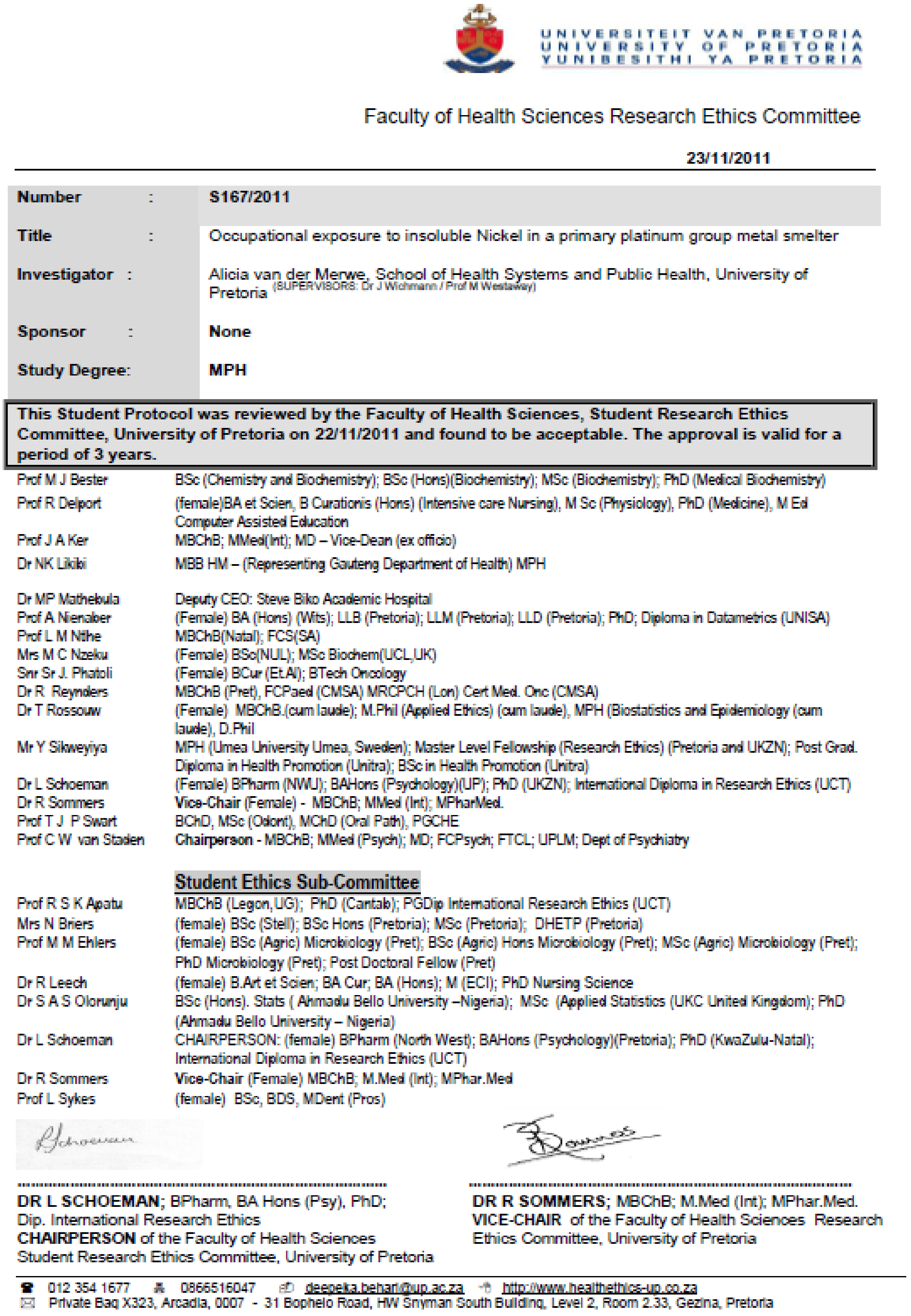
63. MMC Norlisk Nickel increases its spending on industrial safety systems and improvement of working conditions 2012 May 5.
Available online at http://www.nornik.ru/en/press/news/3533/
Date last accessed: 4 June 2012

64. Bello B, Fadahun O, Kielkowski D, Nelson G. Trends in lung cancer mortality in South Africa: 1995-2006. BMC Public Health 2011; 11:209.

65. Murray J, Davies T, Rees D. Occupational lung disease in the South African mining industry: Research and policy implementation. J Public Health 2011:32:65-79.

Appendices

A: Ethics Approval Letter



UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Health Sciences Research Ethics Committee

23/11/2011

Number :	**S167/2011**
Title :	Occupational exposure to insoluble Nickel in a primary platinum group metal smelter
Investigator :	Alicia van der Merwe, School of Health Systems and Public Health, University of Pretoria (SUPERVISORS: Dr J Wichmann / Prof M Westaway)
Sponsor :	**None**
Study Degree:	**MPH**

This Student Protocol was reviewed by the Faculty of Health Sciences, Student Research Ethics Committee, University of Pretoria on 22/11/2011 and found to be acceptable. The approval is valid for a period of 3 years.

Prof M J Bester	BSc (Chemistry and Biochemistry); BSc (Hons)(Biochemistry); MSc (Biochemistry); PhD (Medical Biochemistry)
Prof R Delport	(female)BA et Scien, B Curationis (Hons) (Intensive care Nursing), M Sc (Physiology), PhD (Medicine), M Ed Computer Assisted Education
Prof J A Ker	MBChB; MMed(Int); MD – Vice-Dean (ex officio)
Dr NK Likibi	MBB HM – (Representing Gauteng Department of Health) MPH
Dr MP Mathebula	Deputy CEO: Steve Biko Academic Hospital
Prof A Nienaber	(Female) BA (Hons) (Wits); LLB (Pretoria); LLM (Pretoria); LLD (Pretoria); PhD; Diploma in Datametrics (UNISA)
Prof L M Ntlhe	MBChB(Natal); FCS(SA)
Mrs M C Nzeku	(Female) BSc(NUL); MSc Biochem(UCL,UK)
Snr Sr J. Phatoli	(Female) BCur (Et.Al); BTech Oncology
Dr R Reynders	MBChB (Pret), FCPaed (CMSA) MRCPCH (Lon) Cert Med. Onc (CMSA)
Dr T Rossouw	(Female) MBChB.(cum laude); M.Phil (Applied Ethics) (cum laude), MPH (Biostatistics and Epidemiology (cum laude), D.Phil
Mr Y Sikweyiya	MPH (Umea University Umea, Sweden); Master Level Fellowship (Research Ethics) (Pretoria and UKZN); Post Grad. Diploma in Health Promotion (Unitra); BSc in Health Promotion (Unitra)
Dr L Schoeman	(Female) BPharm (NWU); BAHons (Psychology)(UP); PhD (UKZN); International Diploma in Research Ethics (UCT)
Dr R Sommers	Vice-Chair (Female) - MBChB; MMed (Int); MPharMed.
Prof T J P Swart	BChD, MSc (Odont), MChD (Oral Path), PGCHE
Prof C W van Staden	Chairperson - MBChB; MMed (Psych); MD; FCPsych; FTCL; UPLM; Dept of Psychiatry

Student Ethics Sub-Committee

Prof R S K Apatu	MBChB (Legon,UG); PhD (Cantab); PGDip International Research Ethics (UCT)
Mrs N Briers	(female) BSc (Stell); BSc Hons (Pretoria); MSc (Pretoria); DHETP (Pretoria)
Prof M M Ehlers	(female) BSc (Agric) Microbiology (Pret); BSc (Agric) Hons Microbiology (Pret); MSc (Agric) Microbiology (Pret); PhD Microbiology (Pret); Post Doctoral Fellow (Pret)
Dr R Leech	(female) B.Art et Scien; BA Cur; BA (Hons); M (ECI); PhD Nursing Science
Dr S A S Olorunju	BSc (Hons). Stats (Ahmadu Bello University –Nigeria); MSc (Applied Statistics (UKC United Kingdom); PhD (Ahmadu Bello University – Nigeria)
Dr L Schoeman	CHAIRPERSON: (female) BPharm (North West); BAHons (Psychology)(Pretoria); PhD (KwaZulu-Natal); International Diploma in Research Ethics (UCT)
Dr R Sommers	Vice-Chair (Female) MBChB; M.Med (Int); MPhar.Med
Prof L Sykes	(female) BSc, BDS, MDent (Pros)

....

DR L SCHOEMAN; BPharm, BA Hons (Psy), PhD;
Dip. International Research Ethics
CHAIRPERSON of the Faculty of Health Sciences
Student Research Ethics Committee, University of Pretoria

....

DR R SOMMERS; MBChB; M.Med (Int); MPhar.Med.
VICE-CHAIR of the Faculty of Health Sciences Research Ethics Committee, University of Pretoria

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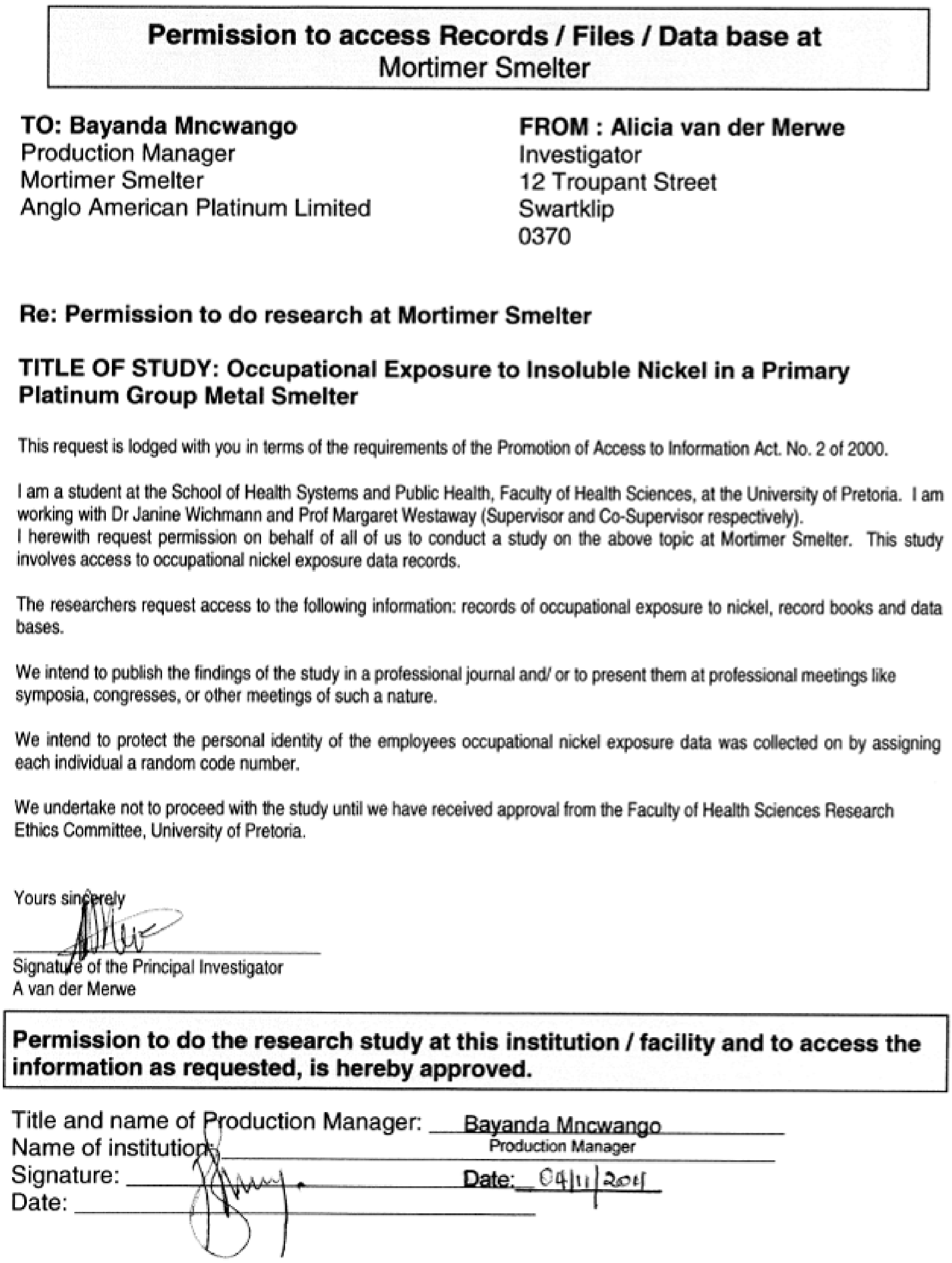
B: Permission to access records/files/database



Permission to access Records / Files / Data base at Mortimer Smelter

TO: Bayanda Mncwango
Production Manager
Mortimer Smelter
Anglo American Platinum Limited

FROM : Alicia van der Merwe
Investigator
12 Troupant Street
Swartklip
0370

Re: Permission to do research at Mortimer Smelter

TITLE OF STUDY: Occupational Exposure to Insoluble Nickel in a Primary Platinum Group Metal Smelter

This request is lodged with you in terms of the requirements of the Promotion of Access to Information Act. No. 2 of 2000.

I am a student at the School of Health Systems and Public Health, Faculty of Health Sciences, at the University of Pretoria. I am working with Dr Janine Wichmann and Prof Margaret Westaway (Supervisor and Co-Supervisor respectively).
I herewith request permission on behalf of all of us to conduct a study on the above topic at Mortimer Smelter. This study involves access to occupational nickel exposure data records.

The researchers request access to the following information: records of occupational exposure to nickel, record books and data bases.

We intend to publish the findings of the study in a professional journal and/ or to present them at professional meetings like symposia, congresses, or other meetings of such a nature.

We intend to protect the personal identity of the employees occupational nickel exposure data was collected on by assigning each individual a random code number.

We undertake not to proceed with the study until we have received approval from the Faculty of Health Sciences Research Ethics Committee, University of Pretoria.

Yours sincerely

Signature of the Principal Investigator
A van der Merwe

Permission to do the research study at this institution / facility and to access the information as requested, is hereby approved.

Title and name of Production Manager: Bayanda Mncwango
Name of institution: Production Manager
Signature: Date: 04/11/2011
Date:

C: Letter of Approval from Anglo American Platinum

AngloAmerican

Anglo Platinum Limited

To whom it may concern:

On behalf of Anglo American Platinum, I indicate our awareness of the research proposed by A van der Merwe, entitled *Occupational Exposure to Insoluble Nickel in a Primary Platinum Group Metal Smelter.*

A van der Merwe is in the process of completing a Masters Degree in Public Health at the University of Pretoria and as part of the degree she is conducting the study. Dr Cas Badenhorst, Occupational Hygiene Specialist for Anglo American identified the project.

We are aware that A van der Merwe will be using data on occupational exposure to nickel at our operation. I herewith give A van der Merwe permission to conduct her research at our company, to use the data and that the results may be published. We however insist that the identities of individual persons participating in the project or whose data is used, be kept strictly confidential.

If there is questions or concerns, I may be contacted at (+27)14 786 1091 or emailed at BayandaM@angloplat.com

Yours Sincerely,

Mortimer Smelter Production Manager
Bayanda Mncwango

Smelting Operations, RPM Union Section, Private Bag x351, Swartklip, 0370
Tel: +27 (0) 14 7860211 / 786 1020 Fax: +27 (0) 14 7860221 / 7860223
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Alternates PG Whitcutt *(British) **(Zambian) ***(American) ****(French)
Company Secretary JD Meyer

A member of the Anglo American plc group