Exposure of workers to nickel, copper and lead in a base metal recovery plant and laboratory

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ABSTRACT

Objectives: The objectives of this study were to establish the extent of dermal and respiratory exposure at selected locations at a South African platinum mine. The study included exposure to lead oxide fumes in an assay laboratory, nickel sulfate powder at a nickel sulfate crystallizer circuit and packing site and metallic copper dust whilst executing copper stripping.

Methods: In an availability study, the dermal metal exposures were measured before, during and at the end of shifts. Dermal exposure samples were taken with Ghostwipes$^{\text{TM}}$ from the dominant hand, wrist and forehead. Wipes were analyzed using Inductively Coupled Plasma-Atomic Emission Spectroscopy (ICP-AES). Wipe samples were taken from surfaces in the workplace and analyzed according to NIOSH 9102, using ICP-AES. Personal and static inhalable dust samples were taken and the dust samples were analyzed according to NIOSH 7300, using ICP-AES. A validated questionnaire was used to evaluate self reported dermatological complaints of the workers at the fire assay laboratory and base metal recovery plant.

Results: 100% of the nickel respiratory exposures and 36.8% of the lead respiratory exposures were above the occupational exposure limits (OEL). Copper respiratory exposure was present but less significant with a geometric mean of 0.071 mg m^{-3}. All of the dermal lead measurements and the majority of the nickel and copper dermal measurements were below the limit of detection. Nickel surface contamination was the most significant and ranged between 8.430 εg cm^{-2} and 387.488 εg cm^{-2}. Only 30% of the copper surface sample results were below the detection limit with a maximum surface sample of 14.41 εg cm^{-2}. Lead surface contamination was low with 90% of the samples below the limit of detection. All of the workers at the nickel crystallizer circuit and packing site had a Dalgard score above 1.3 and therefore are at a higher risk of developing a skin disease. None of the workers at the copper stripping site had a significant Dalgard score and only one worker at the fire assay laboratory had a score above 1.3 and therefore is at a higher risk of developing a skin disease.

Conclusions: Recommendations were made to lower the exposure to inhalable lead and nickel. The low lead dermal measurements may be due to adequate personal protective equipment usage and hygiene practices. Although the ethnicity of the workers may be the reason for the low incidence of dermatological complaints, the Dalgard score indicated that five workers are at risk of developing skin diseases.

Keywords: dermal exposure; respiratory exposure; nickel; copper; lead; fire assay laboratory; base metal recovery plant

OPSOMMING

Doelstellings: Die doel van die studie was om die omvang van dermale en respiratoriese blootstelling in geselekteerde areas by NJSuid Afrikaanse platinum myn te bepaal. Die studie het die volgende ingesluit: blootstelling aan lood-oksieddampe in NJsmelttoetslaboratorium, nikkelsulfaat poeier by NJ nikkelsulfaat kristalisasie proses- en verpakkingsarea en koper metaalstof terwyl koperstroping uitgevoer word.

Metode: In NJbeskikbaarheidstudie is die dermale metaalblootstelling voor, gedurende en aan die einde van skofte bepaal. Dermale blootstelling monsters is met Ghostwipes™ vanaf die dominante hand, gewrig en die voorkop versamel. Ghostwipes™ is daarna met behulp van Induktiewe-Gekoppelde Plasma Atoom Emissie Spektroskopie (ICP-AES) geanaliseer. Veeg monsters is ook vanaf oppervlaktes in die werksplek geneem en geanaliseer volgens die NIOSH 9102 metode met behulp van ICP-AES. Persoonlike en statiese stof monsters is geneem en is geanaliseer volgens die NIOSH 7300 metode met behulp van ICP-AES. NJGevalideerde vraelys is gebruik om self gerapporteerde dermatologiese klagtes van die werkers by die smelttoetslaboratorium, nikkelsulfaat kristalisasie proses en verpakkingsarea en koperstroping te evalueer.

Resultate: 100% van die nikkel respiratoriese blootstelling en 36.8% van die lood respiratoriese blootstelling was bo die beroepsblootstellingsdrempels (BBD). Koper respiratoriese blootstelling was teenwoordig maar minder betekenisvol met NJrekenkundige gemiddeld van 0.071mg m^{-3}. Al die dermale loodmonsters en die meerderheid van die nikkel en koper dermale monsters was onder die deteksielimiet. Die nikkel oppervlakkontaminasie was die betekenisvolste en was tussen 8.430 ε g cm^{-2} en 387.488 ε g cm^{-2}. Slegs 30% van die koper veegmonsters was onder die deteksielimiet met ón maksimum veegmonster van 14.41 ε g cm^{-2}. Lood oppervlakkontaminasie was laag met 90% van die monsters onder die deteksielimiet. Al die werkers by die nikkelsulfaat kristalisasie proses en verpakkingsarea het NJDalgard telling hoër as 1.3 gehad wat dui op NJhoë risiko om velsiektes te ontwikkel. Geen werkers by die koperstroping het NJbetekenisvolle Dalgard telling gehad nie en slegs een werker by die smelttoetslaboratorium het NJtelling hoër as 1.3 gehad wat dui op NJhoë risiko om velsiektes te ontwikkel.

Gevolgtrekking: Aanbevelings om die respiratoriese blootstelling aan lood en nikkel te verlaag is gemaak. Die lae dermale loodblootstelling mag wees as gevolg van die effektiewe gebruik van persoonlike beskermingstoerusting en doeltreffende persoonlike higïene. Die lae voorkoms van dermatologiese klagtes kan toegeskryf word aan die etnisiteit van die werkers, maar dit is belangrik om te let dat vyf werkers wel volgens die Dalgard telling NJrisiko dra om velsiektes te ontwikkel.

Kernwoorde: dermale blootstelling; respiratoriese blootstelling; nikkel; koper; lood; vuur essaiëringslaboratorium; basis metaal herwinningsaanleg

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CHAPTER 1

INTRODUCTION

1.1. Introduction

Workers are exposed to lead fumes in an assay laboratory, nickel sulfate powder at a packing site and copper dust whilst executing copper stripping at a South African platinum mine. The levels of their exposure are unknown and need to be assessed to ensure the health and safety of the workers. The HERAG report 2007 identified three routes of exposure that play a fundamental role in the workersô exposure to metals viz. inhalation, oral and dermal (ICMM, 2007). The three exposure routes are discussed below.

Inhalation is a key route of occupational exposure. Material that is deposited in the extra-thoracic and the trachea-bronchial region is subjected to clearance. This may be a considerable portion of material entering through the nose or mouth and is trans-located to the gastro-intestinal tract. This material contributes to systemic effects at target organs. Material that penetrates the alveoli is subjected to diffusion and it may be assumed that 100% of this material is absorbed (ICMM, 2007).

The importance of dermal exposure has been elevated over the past few years (Schneider *et al.*, 1999). Information regarding the levels of frequent skin sensitizers such as nickel is severely lacking from occupational data (Liden *et al.*, 2006). Potential dermal exposure may occur in three different ways: direct contact with the chemical, contact with contaminated surfaces in the work area and contact with an aerosol after deposition onto the body (Oppl *et al.*, 2003). When chemical substances are present on the skin percutaneous absorption could occur or substances will be ingested if transferred to the mouth (Boeniger, 2006).

Ingestion through hand-to-mouth and face-to-mouth is possible (ICMM, 2007). Contamination of the face and fingers may be a possible source of ingestion (Karita *et al.*, 1997). To ensure a more thorough measurement of the workersô exposure to lead nickel and copper it was decided to do dermal sampling in conjunction with inhalation sampling. The means of exposure and the health effects of lead, nickel and copper are discussed below.

Nickel

Nickel sulfate crystals are the final product of the base metal refinery. A crystallizer circuit leads to the formation of easily handled nickel sulfate hexahydrate crystals from a nickel sulfide solution. The nickel sulfate is dried in a rotary drier and packed in 1 ton heavy duty bags for transportation.

Nickel sulfate is a soluble compound and is readily absorbed through the respiratory tract. Respiratory effects of nickel inhalation are epithelial dysplasia, pathological changes of the nasopharynx, pneumoconiosis and allergic asthma (CRIOS, 2008). Nickel causing pulmonary fibrosis is caused by the inhibition of the fibrinolytic cascade resulting from nickel-induced overexpression of Plasminogen Activator Inhibitor-1 (PAI-1). This may increase fibrin deposition and interstitial hyperplasia (Andrew and Barchowsky, 2000).

The highest dermal exposures during nickel powder packing occur on the hands, arms, face and neck of exposed workers (Hughson, 2004). When dermal exposure occurs, nickel may cause allergic contact dermatitis (Beers *et al*., 2006).

Copper

The copper electro winning circuit produces copper metal as a final product. The metal is formed on the cathode side of the electro winning process and is stripped from the cathodes manually. Copper exposure would thus be measured during the stripping of the copper cathodes to determine the risk associated with this task.

Chronic copper toxicity mainly affects the liver as it is the first site where copper deposits after it enters the blood. High concentrations of copper in the human body may cause oxidative damage to lipids, proteins and DNA. It may also contribute to neurodegenerative disorders (Gaetke and Chow, 2003). Symptoms of exposure to copper dusts and mists are irritation of the eyes, cough, dispnea and wheezing (NIOSH, 2005). Inhalation of copper may cause headaches, shortness of breath and a sore throat and ingestion may cause abdominal pain, nausea and vomiting (NIOSH, 1993).

Industrial exposure to copper may lead to the development of metal fume fever with atrophic changes in nasal mucous membranes (Lenntech, 2008). However, Borak *et al.* (2000) found that a lack of evidence prevents that a correlation between copper and metal fume fever can be drawn. It has been suggested that it is the presence of other metals in the workplace that cause metal fume fever, rather than the copper to which workers are exposed (ATSDR, 2007).

Lead

Workers in the assay laboratory use a lead fire assay method to analyze slurry samples for three platinum group metals (platinum, palladium and rhodium) and gold (3PGM&Au) content. Cupellation is a procedure used during the lead fire assay.

OSHA has recognized lead overexposure found in the industry and has established the reduction of lead exposure to be a high strategic priority (OSHA, 2009). The most important source of occupational lead exposure is the inhalation of airborne lead. Another route of exposure is ingestion. If lead gets into the mouth by means of contaminated objects or hands and is swallowed it will be absorbed through the gastro-intestinal tract (OSHA, 2009).

Lead poisoning (plumbism) is most often a chronic disorder and may not cause acute symptoms. Workers with occupational exposure develop symptoms such as personality changes, headaches, abdominal pain and neuropathy over several weeks or longer (Beers *et al*., 2006). Low-level lead exposure that causes blood lead levels below 10 µg per deciliter leads to cognitive dysfunction, neurobehavioral disorders, neurological damage, hypertension and renal impairment (Patrick, 2006).

Moderate exposure to lead can reduce the reproductive capacity in men (Telisman *et al*., 2000). The Merck Manual reports on the influence of lead on the reproductive system including the loss of sex drive, infertility and erectile dysfunction (The Merck Manual, 2009). Gender differences in health effects of lead exposure are related to normal physiological stages in a woman: pregnancy, lactation and menopause (Vahtera *et al*., 2007). Occupational lead exposure of female workers could result in the impairment of the reproductive system such as: polymenorrhea, hypermenorrhea and spontaneous abortions (Tang and Zhu, 2003). In late pregnancy, resorption of cortical bone with a high lead content leads to an increase in blood lead levels. During lactation the entire skeleton participates in resorption thus raising the blood lead levels even more (Riess and Halm, 2007). A study done by Jedrychowski *et al*. (2009) demonstrated the neurotoxic impact of very low-levels of pre-natal lead exposure in boys.

Workers can take lead home on their clothes, skin, hair, tools and vehicles potentially exposing their families (NIOSH, 2009). Data from a study done by Virji *et al*. (2009) suggested a high probability of take-home lead through contaminated skin and automobiles. Children of lead exposed workers have shown symptoms of lead poisoning, neurological effects and retardation (NIOSH, 2009). Intellectual impairment in preschool children with low lead exposure may be the result of oxidative damage (Jina *et al*., 2006).

When taking all of the above into account, one realizes the importance of determining the levels of lead exposure and using the results to manage the health and safety of both the workers and their families.

1.2. HYPOTHESES

The following hypotheses are postulated:

Hypothesis 1:

Workers at a South African platinum mine are exposed through the skin exposure route to lead in an assay laboratory, nickel sulfate powder at a crystallizer circuit and packaging site and copper dust whilst executing copper stripping.

Hypothesis 2:

While workers are executing tasks and maintaining their work locations they are exposed to airborne lead in an assay laboratory, airborne nickel sulfate powder at a crystallizer circuit and packaging site and airborne copper dust whilst executing copper stripping. The respiratory contaminants that the workers are exposed to are at levels higher than the occupational exposure limit given in the South African Mine Health and Safety Act (Act 29 of 1996, Regulation 22) for that specific contaminant.

1.3. AIMS AND OBJECTIVES

The aim of this study was to (i) establish the extent of the fire assay laboratory workersô dermal and respiratory exposure to lead oxide, (ii) establish the workers executing tasks at the crystallizer circuit and nickel packing siteôs dermal and respiratory exposure to nickel sulfate and (iii) establish the dermal and respiratory exposure of workers executing copper stripping to metallic copper.

The surface contamination at the fire assay laboratory, nickel crystallizer circuit and packing site and the copper stripping site was measured to determine the workers exposure through contaminated surfaces in the workplace.

Qualitative information was gathered through observations of the workersô working and hygiene habits as well through the use of a validated questionnaire.

Possible correlations between the dermal and respiratory exposure of workers at the fire assay laboratory, nickel crystallizer circuit and packing site and the copper stripping site were examined.

The potential correlation between the fire assay laboratory workersô lead exposure and their blood lead levels were examined.

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CHAPTER 2

LITERATURE REVIEW

This study covers three different facilities at a South African platinum mineȇs fire assay laboratory and base metal recovery plant. At each facility workers were exposed to a specific contaminant and, therefore, an availability study was designed to be repeated at each facility. The contaminants in the three facilities are discussed below:

2.1. Crystallizer circuit and packing site at the base metal recovery plant

Nickel sulfate crystals are the final product of the base metal recovery plant. Workers are potentially exposed to nickel directly through inhalation and through skin contact.

2.1.1. Properties of nickel

Table 1: Properties of nickel (Chemblink, 2010; Chemicalland21, 2010)

Chemical	Nickel sulfate ($NiSO_4.6H_2O$)
Atomic mass	262.85 g mole^{-1}
Melting point	53°C
Solubility	Water soluble 625 g L^{-1}
Stability	Non-flammable Stable under ordinary conditions
Toxicity	Oral rat LD 50: 264 mg kg^{-1}
Occupational exposure limit TWA-8h	0.1 mg m^{-3} South African Mine Health and Safety Act (Act 29 of 1996, Regulation 22)

Nickel sulfate is an emerald-green odourless powder that is harmful to humans and dangerous to the environment (Chemblink, 2010). The PAN pesticide database (2010) classifies Nickel sulphate as a fungicide, a PAN Bad actor chemical and a carcinogen. Nickel and its alloys are heat resistant and nickel is resistant to corrosion (Nickel institute, 2010).

2.1.2. Uses of nickel

Approximately 85% of nickel is used in combination with other metals to make alloys. Alloys that contain nickel include hundreds of different grades of stainless steels, different nickel alloys, alloy steels and a few copper-nickel alloys. About 65% of nickel is used to make stainless steel, the most common grades of which contain 8% to 12% nickel. Applications of nickel-containing materials include:

- building and infrastructure
- chemical production
- communications
- energy supply
- environmental protection, food preparation
- water treatment
- travel

Nickel electroplating is a well known application of nickel. This technique provides corrosion resistance and decorative finishes (Nickel institute, 2010).

2.1.3. Exposure to nickel

According to INCHEM (1991) atmospheric nickel levels range between 5 and 35 µg L^{-1} and the average nickel uptake through inhalation is between 0.1 and 0.7 µg per day. Drinking water may contain 10 µg L^{-1} but nickel containing plumbing fittings can cause water nickel levels of up to 500 µg L^{-1}. The nickel concentration in food is usually below 0.5 mg kg^{-1} fresh weight. Cocoa, soybeans, some nuts and oatmeal contains high nickel concentrations. The mean dietary intake of most countries is between 100 and 300 µg per day. The release of nickel from kitchen utensils contributes to the oral intake of nickel.

A person smoking 40 cigarettes per day will inhale up to 223 µg per day. Nickel skin contact occurs through the handling of nickel plated jewelry, coins and clips. Iatrogenic exposure may occur through nickel containing implants and prosthesis (INCHEM, 1991).

2.1.4. Occupational exposure to nickel

Nickel occupational exposure occurs in the following industries:

- Welding
- Plating
- Grinding
- Mining
- Nickel refining
- Steel plants
- Foundries (INCHEM, 1991).

Dermal nickel exposure in the occupational setting may occur at refining plants, electroplating and while handling tools that contains nickel (INCHEM, 1991).

In a study conducted by *Hughson et al,* (2010) it was found that high dermal exposure to nickel occurred during nickel powder packing. The exposure of the workers executing nickel powder packaging occurred on the hands, arms, face and neck and might have been due to deposition of nickel from the air onto the workers or due to workers touching their faces and necks with contaminated hands or gloves.

2.1.5. Health effects of nickel exposure

2.1.5.1. Allergic contact dermatitis

Chemical allergy is an adverse reaction that results from previous sensitization to a particular chemical. These reactions are mediated by the immune system (Hardman and Limbird, 2001). Allergic contact dermatitis represents a delayed (type IV) hypersensitivity reaction. For it to occur a person must be sensitized to the potential allergen, have sufficient contact with the sensitizing chemical and then have repeated contact later (Klaassen and Watkins, 2003).

In the sensitization phase allergens are captured by Langerhansô cells which migrate to regional lymph nodes where they process and present the antigen to T cells. This process may be brief or prolonged. Sensitized T cells then migrate back to the epidermis and activate on re-exposure to the allergen, releasing cytokines, recruiting inflammatory cells, and leading to the characteristic symptoms and signs of allergic contact dermatitis (Beers *et al*., 2006).

If a person is sensitized to a chemical such as nickel and nickel is ingested, a generalized skin eruption with associated symptoms such as headaches, malaise and arthralgia may occur. Less dramatic eruptions include flaring of previous contact dermatitis to the same substance, vesicular hand eruptions and an eczematous eruption in flexural areas (Klaassen and Watkins, 2003). Short term exposure to nickel sulfate causes skin irritation (NIOSH, 2005). It is well known that prolonged or repeated nickel dermal exposure causes allergic contact dermatitis (Beers *et al*., 2006). Inflammation of the skin is characterized by itching, scaling, reddening and occasional blistering (NIOSH, 2005). In allergic contact dermatitis the primary symptom is intense pruritus. Pain is the result of excoriation and infection. Any surface may be involved but hands are most common because of handling and touching potential allergens. With airborne exposure areas not covered by clothing are predominantly involved. The dermatitis is typically limited to the site of contact but may later spread due to scratching and autoeczematization (Beers *et al*., 2006).

Determining the cause of a contact dermatitis is very important because without avoidance of the chemical the dermatitis will continue. Diagnostic patch testing can be done to determine the causing chemical. Avoidance and substitution of the chemical will lead to improvement in the majority of cases in a few weeks (Klaassen and Watkins, 2003).

2.1.5.2. Carcinogenic properties of nickel

Metallic nickel is possibly carcinogenic to humans (Group 2B) (DEPA, 2008). The IARC has noted that there is sufficient evidence for humans for the carcinogenicity of nickel sulfate but not for metallic nickel (IARC, 1997).

2.2. Copper stripping at the base metal recovery plant

The copper electro winning circuit produces copper metal as a final product. Potential copper exposure will occur while workers strip the copper powder from the cathodes.

2.2.1. Properties of copper

Table 2: Properties of copper (University of Nevada, 1997; International Copper Association, 2010; J.T.Baker, 2008)

Chemical	Copper (Cu)
Atomic mass	63.54 g mole^{-1}
Melting point	1083.4°C
Solubility	Insoluble in cold water
Stability	Stable
Occupational exposure limit TWA-8h	1.0 mg m^{-3} South African Mine Health and Safety Act (Act 29 of 1996, Regulation 22)

Copper is a red powder that turns green on exposure to moist air. Copper has a molecular mass of 63.54 g mole^{-1} and is insoluble in cold water (NIOSH, 1993; Sciencelab.com, 2005). Copper is malleable, ductile and an excellent conductor of electricity and heat with thermal conductivity of 394 W m^{-1} K^{-1}. Copper is non-magnetic, durable and resistant to corrosion (University of Nevada, 1997; International Copper Association, 2010).

2.2.2. Uses of copper

Copper has a great number of uses but the major uses of copper include the following:

- Preparation of Bordeaux and Burgundy mixtures for use as fungicides
- Manufacturing of other copper fungicides such as copper-lime dust, tribasic copper sulfate, copper carbonate and cuprous oxide
- Manufacturing of insecticides such as copper arsenite and paris green
- The control of fungus diseases
- The correction of copper deficiency in soils

- The correction of copper deficiency in animals
- Growth stimulant for fattening pigs and broiler chickens
- Construction industries
- Electrical industries (Power generation)
- Telecommunication

Molluscicide for the destruction of slugs and snails, particular the snail host of the liver fluke (Copper Development Association, 2010). Copper is used in wire and cable to transmit power and information as well in plumbing systems for potable water (International Copper Association, 2010).

2.2.3. Exposure to copper

Copper occurs naturally in plants and animals. Copper is an essential element for life in low concentrations, but if these concentrations get higher it become toxic to life. Copper is widespread through the environment and this is caused by spreading from the following sources:

- Mining
- Waste dumps
- Domestic waste water
- The combustion of fossil fuels and wastes
- Wood production
- Phosphate fertilizer production
- Natural sources.

Exposure from drinking copper contaminated water, exposure through eating contaminated food, breathing contaminated air and exposure through skin contact to contaminated soil and water do occur (ATSDR, 2004).

2.2.4. Occupational exposure to copper

The major route of copper exposure would be through the generation and inhalation of copper oxide fume. Individuals with a rare disorder called ñWilsonôs Diseaseò (estimated prevalence 0.003% of the population) are predisposed to accumulate copper and should not be occupationally exposed (Teck, 2010).

Mining copper or processing the ore may lead to exposure to copper by breathing copper-containing dust or by skin contact. Grinding or welding copper metal may cause breathing high levels of copper dust and fumes. Occupational exposure to forms of copper that are soluble or not strongly attached to dust or dirt would most commonly occur in agriculture, water treatment, and industries such as electroplating, where soluble copper compounds are employed (Eco-usa, 1990).

2.2.5. Health effects of copper exposure

2.2.5.1. Copper as essential element

Essential nutrients cannot be synthesized by the body or are synthesized in amounts inadequate to keep pace with rates at which they are broken down or excreted. These nutrients need to be continually supplied by the diet. Thus essential nutrients are i) essential for health ii) not synthesized by the body in adequate amounts. Mineral elements cannot be synthesized or broken down by the body and are continually lost through urine, feces and other secretions. Large amounts of the major minerals must be supplied and only small quantities of the trace elements such as copper are required Copper is a trace mineral element within the body. Trace elements make up less than 0.01% of total atoms in the body (Widmaier *et al.,* 2008).

According to Beers *et al.* (2006) about half of ingested copper is absorbed. Copper in excess of metabolic requirements is excreted through bile. Many body proteins have copper as a component and most of the copper in the body is bound to proteins. Toxicity results from unbound copper ions in the body. The corporation of copper into apoproteins and the processes preventing accumulation of copper in the body are calculated by genetic mechanisms.

2.3. The fire assay laboratory

Workers in the assay laboratory use a lead fire assay method. Cupellation is a procedure used during the lead fire assay. During cupellation, volatilization of lead and the formation of lead oxide occur (McIntosh, 2004).

2.3.1. Properties of lead

Table 3: Properties of lead (Lenntech, 2009; Sciencelab, 2008)

Chemical	Lead (Pb)
Atomic mass	207.2 g $mole^{-1}$
Melting point	327°C
Solubility	Insoluble in cold water
Stability	Stable
Occupational exposure limit TWA-8h	0.1 mg m^{-3} South African Mine Health and Safety Act (Act 29 of 1996, Regulation 22)

Lead is a soft metal that is highly malleable, ductile, a poor conductor of electricity and resistant to corrosion (Lenntech, 2009). Lead oxide, PbO, (Litharge) has a molecular mass of 223.2 g $mole^{-1}$. Lead oxide is a reddish yellow odorless powder that is insoluble in water and alcohol (Lead oxide, 2009).

The South African Department of labor has recognized the immense effect of lead on human health by developing separate regulations for lead use in the Occupational Health and Safety Act (Act no. 85 of 1993). The Lead Regulations of 2001 emphasize the importance of regulating lead exposure by requiring medical surveillance for each employee potentially exposed to lead.

2.3.2. Uses of lead

All major radioactive elements such as uranium break down and create lead as an end product. Lead is used to safely store radioactive materials because it absorbs radiation from radioactive isotopes.

Due to leadʹs toxicity lead is no longer used as an additive in petrol and paint. The majority of lead consumed annually is in the production of:

- batteries for cars, trucks and other vehicles
- wheel weights
- solder
- bearings
- electronics
- communications
- ammunition
- Television glass.

Small amounts of lead is used in the production of protective aprons used to protect patients from radiation during x-ray procedures, crystal glass production, production of weights and ballots and specialized chemicals (Mineral prospector, 2010).

2.3.3. Exposure to lead

Lead exposure at home may occur in houses painted before 1978, where lead containing paint is damaged. This occurs during demolition, construction, flaking of paint, abrasion and water damage. Paint chips can be ingested and paint dust can be inhaled. Other sources of lead exposure at home are lead glazed ceramics and pottery, art and hobby supplies and folk medicine (NNCC, 1998). Exposure through contaminated soil and drinking water contaminated by lead solder may occur (Department of labor and industries, 1999).

Soil and air near buildings where people are working or have worked with lead will be contaminated. Soil where lead containing pesticides have been used will be contaminated with lead (Department of labor and industries, 1999).

In the Merck Manual signs and symptoms are categorized into seven groups: gastrointestinal, neuromuscular, central nervous system, hematological, renal, reproductive and other systems (Hardman and Limbird, 2001; The Merck Manual, 2009)

2.3.4. Occupational exposure to lead

Lead occupational exposure occurs in the following industries:

- Lead production and smelting

- Brass, copper and lead foundries
- Lead fishing weight production
- Thermal stripping or sanding of old paint
- Welding or cutting old painted metals
- Machining and grinding lead alloys
- Battery manufacturing and recycling
- Radiator manufacturing and recycling
- Scrap metal handling
- Lead soldering
- Indoor firing ranges
- Ceramic glaze mixing
- Steelbridge maintenance (Department of labor and industries, 1999).

In a study done by Hughson (2005), significant lead contamination occurred on the hands, arms, face, neck and chest of workers at lead refining and lead chemical producing industries. Larese *et al.* (2006) conducted a study in which they confirmed the role of the skin as a permeable membrane and the need to avoid contact with contaminants. They demonstrated the following: i) in vitro skin permeation of lead oxide, ii) increased permeation in damaged skin, iii) uncontrolled skin lead oxide exposure might contribute to the total body burden.

2.3.5. Health effects of lead exposure

2.3.5.1. Carcinogenic properties of lead

Lead is classified as a Group 2A or probable carcinogen by the International Agency for Research on Cancer (IARC, 2004) and induces tumors of the respiratory and digestive systems (Klaassen and Watkins, 2003).

2.3.5.2. The effects of lead on the central nervous system

Mansouri and Cauli (2009) recognize that chronic lead toxicity is still a great problem in all countries and both adults and children are susceptible for the central nervous system toxic effects of lead. Among central nervous system functions altered by chronic lead exposure, subtle motor alteration and psychomotor impairments have been observed in both adults and children. Lead exposure may lead to the development of a central nervous system syndrome termed lead encephalopathy. Lead encephalopathy is the most serious manifestation of lead poisoning and is more common in children than in adults (Hardman and Limbird, 2001). Leadõs ability to substitute for calcium is a factor common to most of its toxic effects (Lidsky and Schneider, 2003).

Early signs of lead encephalopathy include:

- Clumsiness
- Vertigo
- Ataxia
- Falling
- Headache
- Insomnia
- Restlessness
- Irritability

As lead encephalopathy developes, the patient may become excited and confused with delirium and repetitive tonic-clonic convulsions and lethargy. The patient may then fall into a coma. All symptoms are characteristic of an increase in the intracranial pressure. Exposure to lead occasionally produces clear-cut, progressive mental deterioration in children. Normal development is present during the first 18 months of life followed by a steady loss of motor skills and speech (Hardman and Limbird, 2001).

2.4. Exposure to metals

To assess the workersô exposure to metals, potential exposure routes need to be identified. In the Health Risk Assessment Guidance (HERAG) for Metals report for 2007, three routes of exposure associated with metals have been identified: dermal, inhalation and oral (ICMM, 2007).

2.4.1. DERMAL EXPOSURE

2.4.1.1. Skin histology and percutaneous absorption

There are three types of chemical-skin interactions: 1. the chemical passes through the skin and contribute to systemic load, 2. The chemical causes local effects such as irritation, 3. The chemical evoke an allergic reaction through immune system responses (Semple, 2004).

The skin consists of two major components: the outer epidermis and the underlying dermis. Epidermal appendages span the epidermis and are embedded in the dermis. Capillaries are located in the rete ridges at the dermal-epidermal junction. The epidermisô stratum corneum is the primary barrier to percutaneous absorption (Klaassen and Watkins, 2003).

The movement of all substances from the skinsô surface through both the epidermis and dermis are regulated by Fickôs law. Therefore the rate of diffusion of the substance across the epidermis and dermis will be directly proportional to the concentration gradient caused by the substance. This gradient produces a mass transfer that is dependent on the physical properties of the skin at that site and the chemical properties of the substance. The mass of the substance that is absorbed through the skin is determined by the concentration of the substance on the skin, the area exposed and the duration of exposure (Semple, 2004). Polar substances diffuse through the outer surface of protein filaments of the hydrated stratum corneum and nonpolar molecules dissolve in and diffuse through the lipid matrix between the protein filaments (Klaassen and Watkins, 2003).

Factors that will affect the absorption of a substance include anatomical site of exposure, occlusion, temperature and humidity, hairiness, pore density, sweatiness and skin metabolism (Semple, 2004). High environment temperatures cause vasodilatation of skin capillaries that leads to improved percutaneous absorption. Trapping of the substance occurs because of increased sweating caused by high temperatures and humidity in the environment. Skin metabolism of substances contributes to the skinôs barrier function. Metabolism occurs in the epidermis and pilosebaceous units and influences the potential biological activity of substances (Klaassen and Watkins, 2003).

Dermal exposure potentially occurs in three different ways: (i) direct contact with the contaminant, (ii) contact with contaminated surfaces in the work area and (iii) contact with an aerosol after deposition onto the body (Oppl *et al*., 2003). Schneider *et al.*(1999) recognized the importance of contaminated surfaces by including a surface contaminant layer in his multicompartment model used for the assessment of dermal exposure. The important relationship between surface contaminants to dermal exposure was clear and, therefore, the decision to include surface sampling into the study was made.

When the workersô skin are in contact with metals three types of contaminant-skin interactions may occur: (i) the contaminant passes through the skin and contributes to the systemic load, (ii) the contaminant causes local effects such as irritation, (iii) the contaminant evokes an allergic reaction through immune system responses (Semple, 2004). A validated questionnaire created by Dalgard *et al*. (2003) was used in this study to evaluate self reported dermatological complaints experienced by the workers. A conclusion can thus be made on the possibility of workers developing skin diseases caused by the metals they are being exposed to.

In this study dermal exposure was recognized as a measurable exposure route that can contribute to filling dermal data gaps as recognized by Dotson (2010). These gaps exist because dermal exposure has been seen as a secondary exposure route when compared to inhalation exposure. As a result of this the development of dermal sampling methods and occupational dermal exposure limits have been neglected (Dotson, 2010).

2.4.2. RESPIRATORY EXPOSURE

When workers are exposed to metals, one cannot ignore the possibility of workers inhaling contaminants as inhalation has been identified as a key route of occupational exposure. Metal particles that are deposited in the extra-thoracic and the trachea-bronchial region are subjected to clearance. This may be a considerable portion of material entering through the nose or mouth and is trans-located to the gastro-intestinal tract if absorbed and contributes to systemic effects at target organs (ICMM, 2007).

2.4.2.1. The respiratory system

The respiratory system is made up of the nasal passages, the conducting airways and the gas-exchange region. The nasal passages, reaching from the nostrils to the pharynx act as a filter for particles. Water-soluble gases are absorbed in the nasal passages and nasal epithelia metabolize foreign compounds (Klaassen and Watkins, 2003).

The conducting airways consist of the trachea and bronchi which are covered in mucous. The mucous traps pollutants and debris. The respiratory tract cilia continuously drive the mucous towards the pharynx where it is removed through swallowing or expectoration. The mucous layer is thought to have antioxidant, acid-neutralizing and free radical-scavenging functions (Klaassen and Watkins, 2003).

The gas-exchange region is the anatomic region that includes the alveolar ducts and alveoli distal to each bronchiolar-alveolar duct junction. Gas exchange occurs in the alveoli and capillaries are separated from the air space by a thin layer of tissue formed by epithelial, interstitial and endothelial components (Klaassen and Watkins, 2003).

2.4.2.2. Particle deposits

The behavior, deposition and fate of particles after entering the respiratory system depend on the nature and size of the particles. The mass concentration of airborne particles for occupational hygiene purposes are measured in terms of size fractions given in Table 4 (Belle and Stanton, 2007).

Table 4: Size fractions of airborne particles

		Aerodynamic diameter (AD)
Inhalable particles	Approximates the fraction of airborne material entering through the nose and mouth. Material deposits in the respiratory tract and may accumulate in the sputum and mucus.	Up to 100 µm
Thoracic particles	Material that deposits within the lung airways and the gas exchange region.	Less than 30 µm
Respirable particles	Materials that can deposit in the lung sacs, alveoli and bronchioles	Up to 10 µm

Deposition of particles occurs by interception, impaction, sedimentation and diffusion (Brownian movement).

- Interception: When the trajectory of a particle brings it close enough to a surface that the particle contacts the airway surface.
- Impaction: Particles tend to move along their original path and when inside a bending airstream a particle may be impacted on the respiratory tract surface.
- Sedimentation: Sedimentation causes deposition in the smaller bronchi, the bronchioles and the alveolar spaces. As a particle moves downward through air gravitational force equilibrates with the sum of the buoyancy and the air resistance and the particle then settles with a constant velocity known as the terminal settling velocity.
- Diffusion: Plays a role in the deposition of submicrometer particles.

Two factors that play an important role in particle deposition are the pattern of breathing and the diameter of the conducting airways (Klaassen and Watkins, 2003).

2.4.2.3. Clearance of particles

Particle clearance is very important for lung defense as it limits the time that a particle can cause damage. Particles are cleared to i) the stomach and gastrointestinal tract, ii) the lymphatics and lymph nodes and iii) the pulmonary vasculature.

- Nasal clearance: Particles in the anterior nose are removed by blowing and wiping while particles in other regions are cleared by the mucociliary epithelium. Mucous are propelled toward the glottis and is then swallowed.
- Tracheobronchial clearance: The tracheobronchial tree is covered with a mucous layer. The mucus layer moves upward by the movement of the underlying cilia. Particals are thus transported upwards towards the oropharynx where they are swallowed (mucociliary escalator).
- Pulmonary clearance: This may occur in one of the following ways:
    - Particles can be cleared upward in the tracheobronchial tree via the mucociliary escalator
        - Particles are phagocytized by macrophages and cleared by the mucociliary escalator.
        - Particles are phagocytized by alveolar macrophages and removed by lymphatic drainage.
        - Particles are dissolved and removed by the bloodstream or lymphatics.
        - Small particles may directly penetrate epithelial membranes (Klaassen and Watkins, 2003).

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CHAPTER 3

ARTICLE

Exposure of workers to nickel, copper and lead in a base metal recovery plant and laboratory

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3.2. INTRODUCTION

Workers at a South African platinum mine are potentially exposed to lead oxide fumes in an assay laboratory, nickel sulfate powder at a nickel sulfate crystallizer circuit and packaging site and metallic copper dust whilst executing copper stripping. These workers may be exposed to these metals through three different routes that have been identified in the Health Risk Assessment Guidance (HERAG) for Metals report for 2007: dermal, inhalation and oral (ICMM, 2007).

When workers are exposed to metals, inhalation is identified as a key route of occupational exposure. Metal particles that are deposited in the extra-thoracic and the trachea-bronchial region are subjected to clearance. This may be a considerable portion of material entering through the nose or mouth and is trans-located to the gastro-intestinal tract and contributes to systemic effects at target organs (ICMM, 2007).

Lead poisoning is most often a chronic disorder (plumbism) and may not cause acute symptoms (Beers *et al.*, 2006). Signs and symptoms can be categorized into seven groups: gastrointestinal, neuromuscular, central nervous system, haematological, renal, reproductive and other systems (Hardman and Limbird, 2001; The Merck Manual, 2009). Lead is classified as a Group 2A or probable carcinogen by the International Agency for Research on Cancer (IARC, 2004) and induces tumours of the respiratory and digestive systems (Klaassen and Watkins, 2003).

When nickel sulfate particles are inhaled they are readily absorbed through the respiratory tract and may cause epithelial dysplasia, pathological changes of the nasopharynx, pneumoconiosis and allergic asthma (CRIOS, 2008). The IARC has noted that there is sufficient evidence for humans for the carcinogenicity of nickel sulfate but not for metallic nickel (IARC, 1997). Metallic nickel is possibly carcinogenic to humans (Group 2B) (DEPA, 2008).

Symptoms of exposure to copper dusts and mists are: irritation of the eyes, cough, dyspnoea and wheezing (NIOSH, 2005). Inhalation of copper may cause headaches, shortness of breath and a sore throat and ingestion may cause abdominal pain, nausea and vomiting (NIOSH, 1993).

Table 5. Occupational exposure limits for inhalable metal particles according to the Mine Health and Safety Regulations

Metal	OEL TWA-8h mg m^{-3}
Ni	0.10
Cu	1.00
Pb	0.10

Notes: Limits as listed in the South African Mine Health and Safety Act (Act 29 of 1996, Regulation 22)

The HERAG report identified dermal exposure as a fundamental route of metal exposure (ICMM, 2007). Dermal exposure potentially occurs in three different ways: (i) direct contact with the contaminant, (ii) contact with contaminated surfaces in the work area and (iii) contact with an aerosol after deposition onto the body (Oppl *et al.*, 2003). Schneider *et al.*(1999) recognized the importance of contaminated surfaces by including a surface contaminant layer in his multicompartment model for the assessment of dermal exposure. There are three types of contaminant-skin interactions: (i) the contaminant passes through the skin and contributes to the systemic load, (ii) the contaminant causes local effects such as irritation, (iii) the contaminant evokes an allergic reaction through immune system responses (Semple, 2004).

Dotson (2010) recognizes that dermal exposure has traditionally been seen as a secondary route of entry when compared to inhalation exposure. As a result the development of dermal sampling methods and occupational dermal exposure limits has been neglected. There are data gaps that need to be filled and Dotson (2010) approach this by highlighting the comprehensive exposure and risk assessments that evaluate chemical exposure beyond what a worker may potentially inhale.

In a study done by Hughson (2005) it was found that significant lead contamination occurred on the hands, arms, face, neck and chest of workers at lead refining and leads producing industries. A study done by Virji *et al.* (2009) suggested a high probability of take-home lead through contaminated skin and automobiles of bridge surface preparation and painting contractors.

Hughson et al, (2010) found that high dermal exposure occurred during nickel powder packing. Exposure occurred on the hands, arms, face and neck and may be due to deposition of nickel from the air or touching the face and neck with contaminated hands or gloves. Dermal exposure to nickel may cause allergic contact dermatitis (Beers *et al.*, 2006).

This study included both inhalation and dermal exposure measurements and when realizing the importance of surface contaminants and its relation to dermal exposure into account, it was decided to include surface exposure measurements in this study. The aim of this study was to establish the extent of the refinery and laboratory workersô dermal and airborne exposure to lead, nickel sulfate and copper.

3.3. METHODS

3.3.1. Study design and workplace description

In an availability study, the exposure of workers to metals at three different facilities at a South African platinum mine was measured. Because of a high level of automation at the base metal recovery plant only a small number of workers supervised or operated the processes. Therefore only a small number of workers were available for sampling.

Workers in the assay laboratory used a lead fire assay method to analyze slurry samples for three platinum group metals and gold (3PGM&Au) content. The laboratory workers worked in one of two shifts ï morning or afternoon shift. The activities during both shifts were the same. Ten laboratory workers, five from each shift, were identified as high risk exposure employees and were sampled. Nine of these workers were African males and one worker was a Caucasian male. At the base metal recovery plant a crystallizer circuit produces nickel sulfate hexahydrate crystals (22% Ni) from a nickel sulfate solution. The nickel sulfate hexahydrate crystals are dried in a rotary drier and packed in one ton heavy duty bags for transportation. Operations at the crystallizer circuit and packaging site are divided into three shifts ï morning, afternoon and night shift. One worker was responsible for operations during each shift. A total of four workers rotate weekly to work the three shifts. The operations during the three shifts were the same and therefore all four workers were sampled. Three of these workers were African males and one worker was a Caucasian male.

The copper electro-winning circuit produces copper metal, free of platinum group metals, as a final product. In the electro-winning circuit, copper metal is formed on the cathode side of the electro-winning process. The copper deposits (99.96% Cu) were stripped from the cathodes manually on a daily basis. The four workers who were involved in this process were sampled. Three of these workers were African males and one worker was a Caucasian male.

3.3.2. Dermal exposure samples

Dermal samples were taken using a removal method with commercial wipes (Ghostwipes™ ï moistened with distilled water, each wipe individually sealed by the manufacturers). Samples were taken before workers washed their hands to ensure that the samples were representative of dermal exposure during shifts. Samples were taken at the start of each shift, before each break (i.e. tea break and lunch) and at the end of a shift.

Wipe samples were taken by swabbing the inside of the dominant hand, the dominant wrist and the forehead of each worker. One wipe was used per predetermined area for every sample interval. Templates (4 x 2.5 cm) were used to demarcate sample areas. The wipe was folded three times. Swabbing over the whole area before the first fold and again after each of the three folds resulted in swabbing each area four times. Each wipe was placed in a separate labeled container. To assure consistent sampling, one researcher was assigned to sampling. Therefore the same wipe pressure and method was used throughout the sampling period. Wipes were analyzed for lead, nickel and copper by an accredited analytical laboratory using Inductively Coupled Plasma-Atomic Emission Spectroscopy (ICP-AES) in accordance to the NIOSH 9102 method.

3.3.3. Surface exposure samples

Through observation a number of surfaces in each work area were identified as possible contaminated surfaces through which the workers could be exposed to the metals. A surface sample was taken by swabbing one wipe in a overlapping s-pattern over the possibly contaminated surface area using a 10 x 10 cm cardboard template. The wipe was folded three times resulting in a total of four complete swabs over the entire template area. Samples were collected, stored and analyzed as with the dermal samples.

3.3.4. Airborne exposure samples

Airborne exposure samples consisted of both personal samples within the workersô breathing zones and static/area air samples. Samples were taken using Gilian® Personal air sampler pumps (flow rates of 2 L/min) and 0.8 µm mixed cellulose ester membranes. Airborne exposure measurements for each metal were done over two working days. Two static samples were taken per day. The duration of the lead and nickel airborne samples were 8 hours. The copper airborne samples were taken over 4 hours because of shift duration of 4 hours. Membranes were analyzed for lead, nickel and copper by an accredited analytical laboratory in accordance with the NIOSH 7300 method, using ICP-AES.

3.3.5. Questionnaire

A validated questionnaire created by Dalgard *et al.* (2003) was used to evaluate self reported dermatological complaints experienced by the workers. The questionnaire was translated into Setswana which is the native language of the African workers. The questionnaire consists of 10 simple questions asking about the most common skin complaints experienced during the previous week. The answers to the questions were scored on a four point scale (1: no; 2: yes, a little; 3: yes, quite a lot; 4: yes, very much). All individuals with a self-reported score above 1.3 are more likely to have or develop skin disease. Information regarding basic hygiene habits at work and the workers use of personal protective equipment was also recorded.

3.3.6. Blood lead levels

The blood lead levels of the fire assay laboratory workers are taken every 12 months or as required by Lead Regulations (OHS Act), determined by the workersô previous blood lead levels. The blood levels were studied to evaluate a possible correlation between the blood levels and the results of this study.

3.3.7. Ethical aspects

All participating workers gave informed consent to participate in the study and all data and results were handled confidentially. The methods used during this project were approved by the Ethics Committee of the North-West University (number NWU-0026-07-S6).

3.3.8. Statistical analysis

All results were statistically analyzed using Statistica Version 8.0 (Statsoft Inc., 2009). The dermal exposure data for each metal was summarized in terms of median, geometric mean (GM), geometric standard deviation (GSD), maximum and minimum. The inhalation exposure measurements (total inhalable dust and total inhalable metal), static air measurements and surface contamination measurements for each metal were also summarized in this manner.

All data were tested for normality and log transformed where appropriate. Pearson correlations between hand, arm and forehead exposure measurements for nickel and copper were established. The

Pearson correlations between the total inhalable dust and total inhalable metal were established for each metal category for both personal air measurements and static air measurements. Pearson correlations between dermal exposure samples and personal inhalation samples were calculated. p values < 0.05 were considered as statistically significant. Statistical analysis results that were below the limit of detection were set to D/ã2 (D: detection limit).

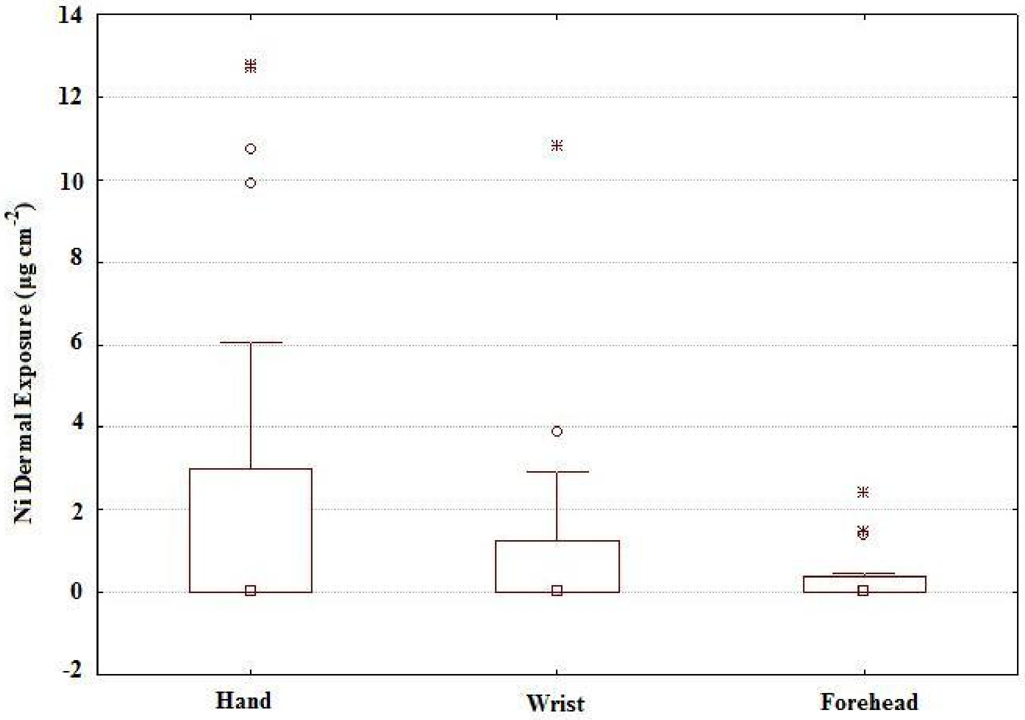
3.4. RESULTS

3.4.1. Crystallizer circuit and packaging

3.4.1.1. Dermal exposure measurements

A total of 72 dermal exposure samples were collected for nickel analysis of which 61% were below the limit of detection (0.01 εg cm^{-2}). Figure 1 shows the nickel dermal exposure measurements. When comparing the results obtained for hand, wrist and forehead nickel analysis the only statistical significant correlation were the hand versus forehead data (Table 2).

A total of four workers reported one or more of the skin conditions given in Table 3. Of those workers who reported to have a skin condition one indicated that the skin condition had started within the previous six months and one worker indicated that it had started more than six months ago. All of the workers had a Dalgard score >1.3.



Notes: * : Extremes; o : outliers; Ĭ : median; The box limits represent the 25th and 75th percentiles respectively while the whiskers represents the 90th percentiles.

Figure 1. Nickel dermal exposure measurements by anatomical area sampled at the crystallizer circuit and nickel packing

Table 6. Dermal exposure relationship of nickel exposure at the crystallizer circuit and nickel packing

		Wrist	**Forehead**
Hand	Pearson correlation (r)	0.58	0.64
	Significance (p)	0.16	0.01
Wrist	Pearson correlation (r)	-	0.9
	Significance (p)	-	0.11

Notes: Significant p values when p< 0.05.

Table 7. Percentage of workers reporting skin conditions

	Ni	**Cu**	**Pb**
Skin condition	Percentage reported (%)		
Itchy skin	50	0	40
Dry/sore rash	75	25	30
Scaly skin	25	25	0
Itchy rash on hands	75	25	0
Pimples	25	0	20
Other rashes on face	50	0	0
Warts	25	25	10
Troublesome sweating	100	50	40

3.4.1.2. Surface contamination measurements

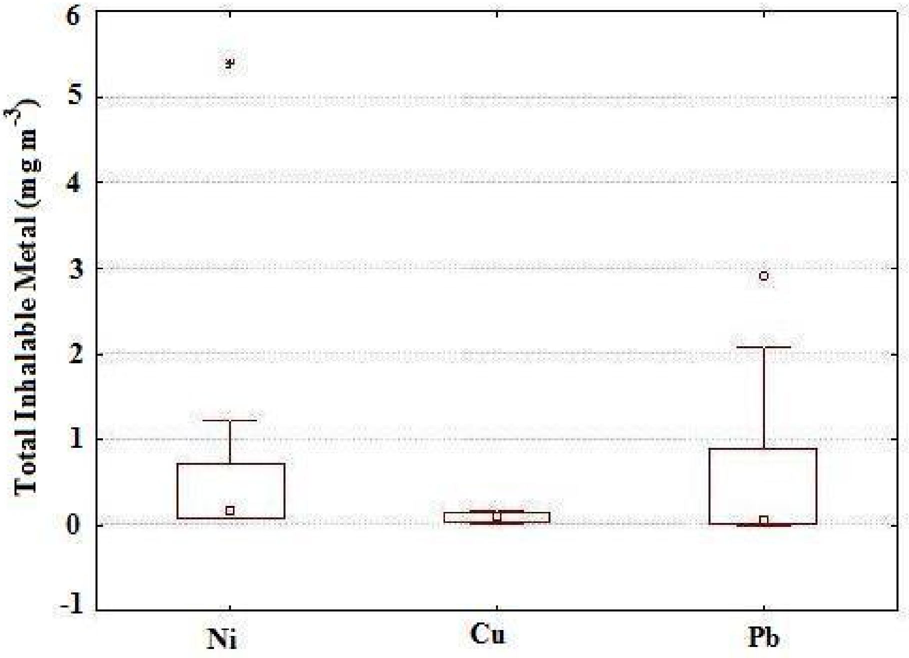
All of the nickel surface samples (*n*=10) were above the limit of detection with a geometric mean of 46.180 µg cm^{-2} (Table 4) and ranged between 8.430 εg cm^{-2} and 387.488 εg cm^{-2}. Samples were taken from surfaces on the crystallizer circuitôs apparatus from where the workers were most likely to come into contact with the contaminated surfaces whilst operating and maintaining the circuit.

Table 8. Summary of surface measurements at the assay laboratory, copper stripping and crystallizer circuit and nickel packing

	GM	**GSD**	**Minimum**	**Maximum**
µg Ni cm^{-2}	46.180	2.740	8.430	387.488
µg Cu cm^{-2}	0.157	24.113	0.057	14.405
µg Pb cm^{-2}	0.001	4.447	0.010	0.079

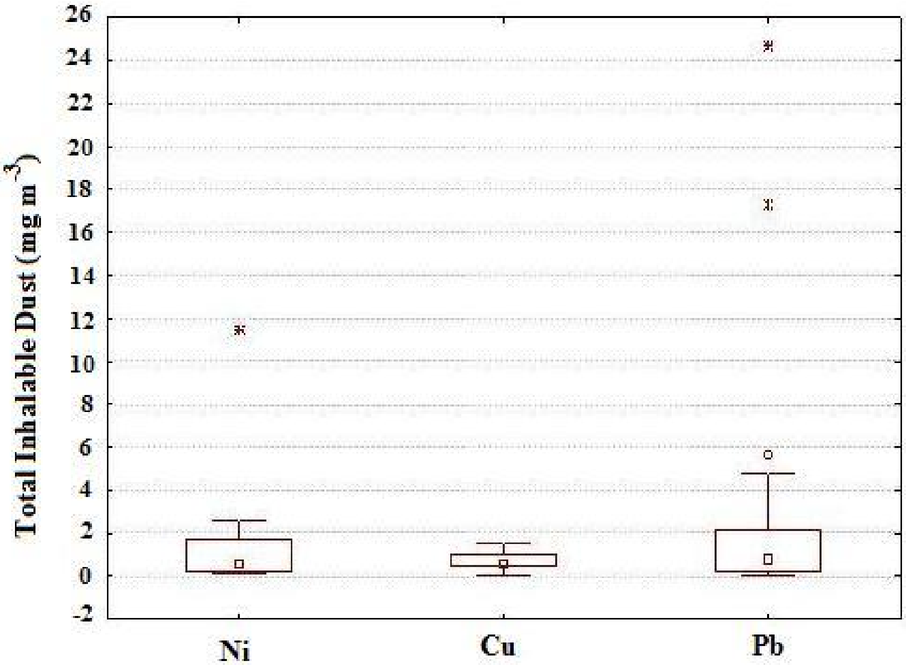
3.4.1.3. *Inhalable dust monitoring*

To measure inhalation exposure eight personal air samples and four static air samples were taken. The summary of the personal inhalable exposure measurements are given in Figure 2 and Figure 3 for each metal group. The results of the Pearson correlation test for personal measurements showed a positive correlation between total inhalable dust and total inhalable nickel (r = 0.998). The Pearson test results for static measurements indicated a positive linear correlation between total inhalable dust and total inhalable nickel (r = 0.998). For personal air measurements 100% of the inhalable nickel measurements (*n* = 8) were above the OEL of 0.1 mg m^{-3}. 50% of the static air measurements were below the OEL and only one measurement below the action level.



Notes: * : Extremes; o : outliers; Ĭ : median; The box limits represent the 25th and 75th percentiles respectively while the whiskers represents the 10th and 90th percentiles. Nickel represents the nickel crystallizer circuit, copper represents the copper stripping at the base metal recovery plant and lead represents the fire assay laboratory.

Figure 2. Personal inhalable metal exposure measurements at the assay laboratory, copper stripping and the crystallizer circuit and nickel packing



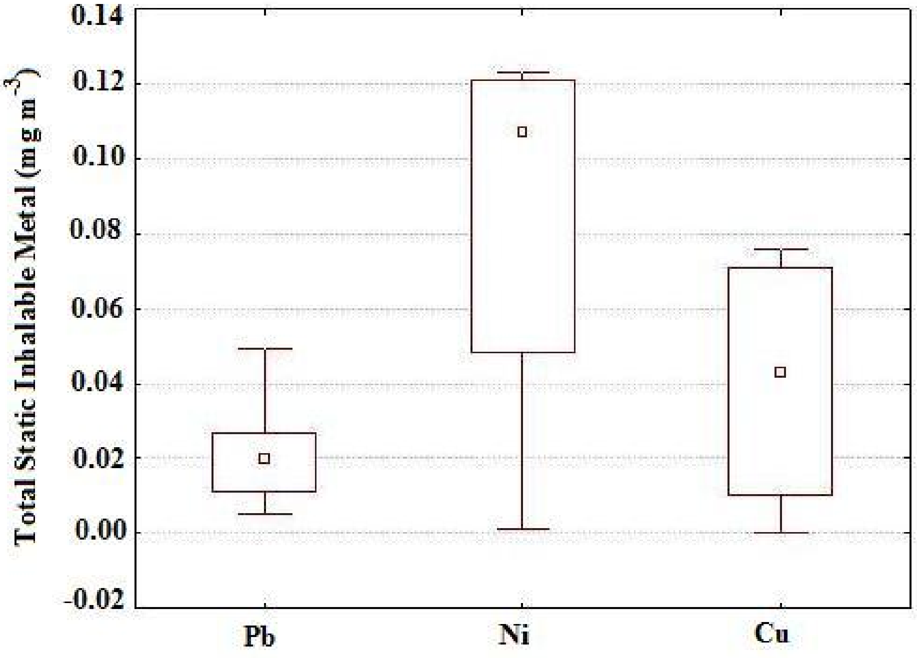
Notes: * : Extremes; o : outliers; Ĭ : median; The box limits represent the 25th and 75th percentiles respectively while the whiskers represents the 10th and 90th percentiles. Nickel represents the nickel crystallizer circuit, copper represents the copper stripping at the base metal recovery plant and lead represents the fire assay laboratory.

Figure 3. Personal inhalable dust exposure measurements at the assay laboratory, copper stripping and the crystallizer circuit and nickel packing

Table 9. Inhalation exposure relationships of personal lead exposure at the assay laboratory, personal copper exposure at the copper stripping and personal nickel exposure at the crystallizer circuit and nickel packing

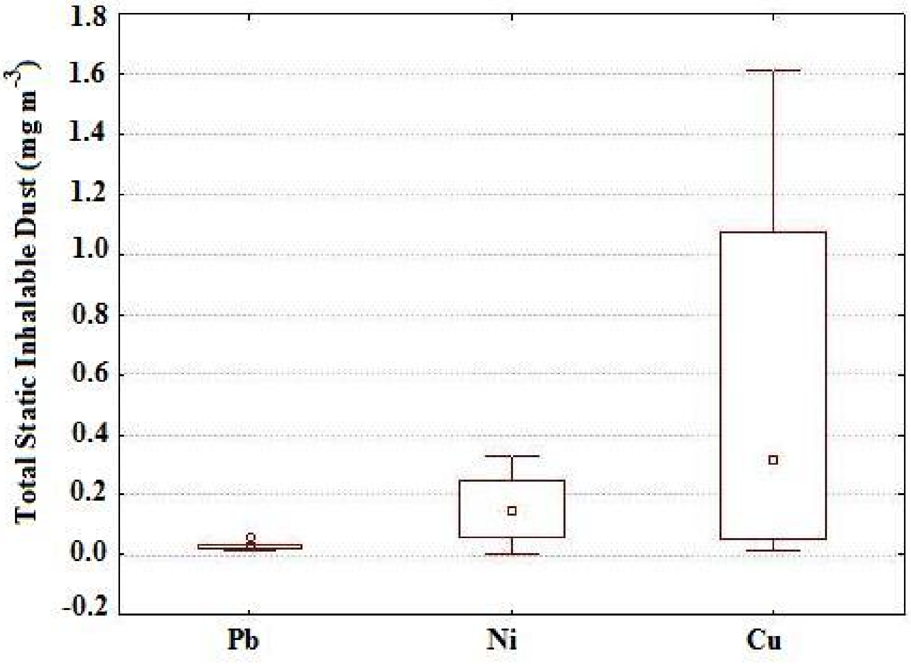
		Total Inhalable Ni	**Total Inhalable Cu**	**Total Inhalable Pb**
Total Inhalable Dust	Pearson correlation (r)	0.998	0.850	-0.064
	Significance (p)	0.005	< 0.001	0.003

Notes: Significant p values when $p < 0.05$.



Notes: * : Extremes; o : outliers; Ĭ : median; The box limits represent the 25th and 75th percentiles respectively while the whiskers represents the 10th and 90th percentiles. Nickel represents the nickel crystallizer circuit, copper represents the copper stripping at the base metal recovery plant and lead represents the fire assay laboratory.

Figure 4. Static inhalable metal exposure measurements at the assay laboratory, copper stripping and the crystallizer circuit and nickel packing



Notes: * : Extremes; o : outliers; Ĭ : median; The box limits represent the 25th and 75th percentiles respectively while the whiskers represents the 10th and 90th percentiles. Nickel represents the nickel crystallizer circuit, copper represents the copper stripping at the base metal recovery plant and lead represents the fire assay laboratory.

Figure 5. Static inhalable dust exposure measurements at the assay laboratory, copper stripping and the crystallizer circuit and nickel packing

3.4.1.4. Comparison between dermal exposure measurements and inhalable dust monitoring

The relationships between nickel dermal samples and nickel personal air samples are given in Table 10. Positive linear correlations existed between average total inhalable nickel and the average nickel dermal hand exposure (r=0.94).

Table 10. Relationships between nickel dermal samples and nickel personal air samples

		Hand average	Wrist average	Forehead average
Average total inhalable nickel	Pearson correlation (r)	0.94	0.06	0.21
	Significance (p)	0.23	0.24	0.23

Notes: Significant p values when $p < 0.05$.

3.4.2. Copper stripping

3.4.2.1. Dermal exposure measurements

A total of 48 dermal exposure samples were collected for copper analysis ï 90% of the samples were below the limit of detection (0.057 εg cm^{-2}). A positive linear correlation existed between the wrist and forehead exposure measurements with $r = 1$.

A total of four workers reported one or more of the skin conditions given in Table 3. Of those workers who reported to have a skin condition two indicated that the skin condition had started within the previous six months.

Table 11. Copper dermal exposure measurements by anatomical area sampled at the copper stripping site

	GM	GSD	Minimum	Maximum
	µg Cu cm^{-2}			
Hand	0.062	1.408	0.057	0.224
Wrist	0.057	1.004	0.056	0.057
Forehead	0.057	1.014	0.054	0.057

Table 12. Dermal exposure relationships of copper exposure at the copper stripping site

		Wrist	**Forehead**
Hand	Pearson correlation (r)	-0.19	-0.19
	Significance (p)	0.55	0.54
Wrist	Pearson correlation (r)	-	1
	Significance (p)	-	0.92

Notes: Significant p values when $p < 0.05$.

3.4.2.2. Surface contamination measurements

Thirty percent of the copper surface samplesô (*n*=10) analysis results were below the limit of detection. The maximum surface sample, 14.41 εg cm^{-2}, was taken from the outside surface of the inside palm of a glove worn during copper stripping (Table 4).

3.4.2.3. Inhalable dust monitoring

To measure inhalation exposure eight personal air samples and four static air samples were taken (Figure 2 and Figure 3). A significant positive correlation between personal total inhalable dust and total inhalable copper existed (r = 0.85) (Table 5).

The geometric mean (GM = 0.071 mg m^{-3}) exposure of the group was below the OEL of 1 mg m^{-3} as well as all of the inhalable copper measurements (Figure 2 and Figure 3). All static air measurements were below the action level (Figure 4 and Figure 5).

3.4.2.4. Comparison between dermal exposure measurements and inhalable dust monitoring

The relationships between copper dermal samples and copper personal air samples are given in Table 13. Significant positive linear correlations existed between average total inhalable copper and the average copper dermal wrist exposure (r = 0.94) and between average total inhalable copper and the average copper dermal forehead exposure (r = 0.94).

Table 13. Relationships between copper dermal samples and copper personal air samples

		Hand average	Wrist average	Forehead average
Average total inhalable copper	Pearson correlation (r)	-0.08	0.94	0.94
	Significance (p)	0.01	0.01	0.01

Notes: Significant p values when $p < 0.05$.

3.4.3. Fire assay laboratory

3.4.3.1. Dermal exposure measurements

A total of 120 samples were collected for lead analysis and all of the samplesô analysis results were below the detection limit (0.01 εg cm^{-2}). A total of ten workers reported one or more of the skin conditions given in Table 3. Of those workers who reported to have a skin condition three indicated that the skin condition had started within the previous six months and four workers indicated that it had started more than six months ago. One worker had a Dalgard score >1.3.

3.4.3.2. Surface contamination measurements

Ninety percent of the lead surface samplesô (*n*=10) were below the limit of detection (Table 4).

3.4.3.3. Inhalable dust monitoring

To measure inhalation exposure 20 personal air samples and six static air samples were taken. The summary of the personal inhalable exposure measurements are given in Figure 2 and Figure 3. A positive linear correlation existed between total inhalable dust and total inhalable lead (r = 0.847; p = 0.054) for the static inhalable results. The geometric mean of the lead (GM = 0.08 mg m^{-3}) exposure group was below the OEL of 0.1 mg m^{-3} but 36.8% of the inhalable lead measurements were above the OEL. Of the inhalable lead measurements 57.9% were above the action level of 0.05 mg m^{-3}. The geometric mean (GM = 0.018 mg m^{-3}) of the static air measurements for lead was below the OEL.

3.4.3.4. Blood lead level comparison

The blood lead levels of the fire assay laboratory workers measured in 2010 were compared to the personal total inhalable lead measurements. Blood lead levels ranged between 7 µg dL^{-1} and 24 µg dL^{-1}. Three of the workers had blood lead levels above 20 µg dL^{-1} (22 µg dL^{-1}, 24 µg dL^{-1} and 23 µg dL^{-1}) which indicate the need for shorter intervals between blood level monitoring as indicated by Lead Regulations (OHSA no. 85 of 1993) used by the fire assay laboratory. Comparisons between both days and the blood lead levels resulted in highly significant Pearson correlations 0.457 and 0.584 for day 1 and day 2 respectively.

Table 14. Blood lead levels and Total inhalable lead

		Total inhalable lead mg m^{-3}	
Worker	**Blood lead level µg/dL**	Day 1	Day 2
1	15	0.027	0.015
2	16	0.017	0.014
3	22	0.337	2.910
5	24	0.088	0.0001
7	12	0.071	0.180
8	10	0.062	0.024
9	23	1.173	2.074
10	16	0.051	0.097
11	19	1.658	0.884
12	7	0.030	0.028

Table 15. Summary of blood lead level relationships

		Personal inhalable lead	
		Day 1	Day 2
Blood lead level	Pearson correlation (r)	0.457	0.584
	Significance (p)	<0.001	< 0.001

3.5. DISCUSSION

Data was grouped into the three specific work sites where the workers were potentially exposed to metals.

3.5.1. Crystallizer circuit and packaging

The results showed that 30% of the dermal samples were above the detection limit. This confirmed that there were dermal exposure present at the crystallizer circuit and nickel packaging site. The dermal exposure levels were lower than the surface concentration levels. This may be the result of the correct use of gloves and protective clothing, the use of gloves that are in a good condition and good personal hygiene habits exhibited by the workers. Although the majority of the dermal samples were below the detection limit, all four of the workers had a Dalgard score above 1.3 and therefore are at a higher risk of developing a skin disease.

The forehead nickel concentrationsô geometric mean was much lower than the hand and wristsô geometric means. Hughson *et al*. (2010) reported a geometric mean of 8.73 µg cm^{-2} for hand and wrist nickel exposure and 15.16 µg cm^{-2} for face nickel exposure. The geometric means obtained during this study were much lower. Airborne nickel was generated around the crystallizer circuit as powder spillages were clearly noticeable around the circuit. Dust was generated during the packing process or from spillages from the crystallizer circuit causing levels of airborne nickel in the workersô working environment and it was possible that airborne particles landed on the skin causing contamination (Schneider *et al*., 1999).

A linear correlation between the hand and forehead dermal exposure indicated that higher hand-wrist nickel exposure accompanied higher forehead nickel exposure. During this study it was observed that workers do not regard washing their faces as a hygienic practice at work. When workers touched their faces with contaminated gloves or contaminated hands or wrists when removing sweat from their faces, metal particles were deposited on their skin.

Not only did the results confirm that airborne nickel was present at the crystallizer circuit and nickel packaging site but it indicated that the levels were above the occupational exposure limit for nickel. The maximum personal inhalable nickel exposure is 114 times the OEL, and 100% of the total inhalable nickel results are above the OEL which indicates non compliance with legislation. The

South African Mine Health and Safety act (Act 29 of 1996, Regulation 22) states that nickel exposures must be kept as far below the OEL as reasonably possible.

The crystallizer circuit's highly automated nature resulted in workers supervising the process and maintaining efficient processing on a daily basis. The different tasks performed by the operators have resulted in differences in the personal inhalable nickel exposure. This was demonstrated when one worker's total inhalable metal sample was significantly higher than the other three workers at the crystallizer circuit and nickel packaging due to a maintenance job on the day of sampling. In contrast the static inhalable nickel and dust showed less variation than the personal inhalation measurements.

Hughson *et al*. (2010) reported a geometric mean of 1.7 mg m^{-3} for total inhalable dust exposure and a geometric mean of 0.77 mg m^{-3} for total inhalable nickel exposure. The geometric means reported by Hughson *et al*. (2010) are two and a half and three times higher than the geometric means found in this study for total inhalable dust and total inhalable nickel respectively. The correlation between the total inhalable dust and total inhalable nickel determined by Hughson *et al*. (2010) of 0.364 is much lower than the correlation of 0.998 found in this study. This may be due to Hughson *et al*. (2010) pooling the data from five different workplaces, including three nickel refineries producing a range of nickel metal products and nickel compounds. Differences between the data from Hughson *et al*. (2010) and data from this study may also be the result of differences in sampling methods used.

The positive correlation between total inhalable dust and total inhalable nickel was indicative of the amount of exposure. If the amount of dust increased the level of nickel exposure increased as well.

A positive linear correlation existed between the average total inhalable nickel and the average hand nickel exposure. This relationship was biased as one worker exhibited 3.8 times the average total inhalable nickel and 3.5 times the average hand nickel exposure of the other workers' average total inhalable and average hand nickel exposures. The worker's high personal inhalable sample was the result of a maintenance job on the day the worker was sampled.

3.5.2. Copper stripping

Results indicate that the workers executing copper stripping were likely to be exposed to copper through the skin. The great variation in the data was the result of the large number of the samples being below the limit of detection. The data comparison of the dermal hand, wrist and forehead samples have a high p value and this is an indication that dermal exposure is uniform on the three anatomical sites sampled.

The forehead copper concentration geometric mean was much higher than the hand and wrist geometric means. This may be due to the forehead not being covered by PPE during performance of tasks and workers touching their faces with contaminated gloves or contaminated hands when removing sweat from their faces.

Low levels of copper contamination were found on surfaces. The copper stripping was done in a well ventilated open area which explains the low total inhalable dust and copper exposures. The positive correlation between total inhalable dust and total inhalable copper signify that the level of copper exposure was dependent on the amount of dust exposure.

A statistical significant linear correlation existed between the average total inhalable copper and the average wrist copper exposure. A positive linear correlation existed between the average total inhalable copper and the average forehead copper exposure. The positive linear correlations existed due to the same worker exhibiting a higher forehead copper exposure, wrist copper exposure and total inhalable copper exposure than the other three workers. The above mentioned workerồs forehead and wrist samples were the only copper forehead and wrist dermal samples that were reported above the detection limit. The maximum personal inhalable copper exposure was 17.4% of the OEL, which indicate low levels of exposure.

3.5.3. Fire assay laboratory

All of the dermal and surface lead results were below the detection limit. This indicated no significant dermal lead exposure on the hands, wrists and forehead of the assay laboratory workers.

In contrast with the low dermal lead exposures, personal and static air samples confirmed that laboratory workers were exposed to airborne lead levels above the occupational exposure limit. The maximum personal inhalable lead exposure was 7.4 times the OEL, and 36.8% of the personal inhalable lead results were above the OEL which indicate non compliance with legislation. The South African Mine Health and Safety act (Act 29 of 1996, Regulation 22) states that lead exposures must be kept as far below the OEL as reasonably possible.

A negative linear correlation existed between the personal total inhalable dust and the personal total inhalable lead. A positive linear correlation existed between the static total inhalable dust and the static total inhalable lead which indicated that higher static dust may indicate higher lead exposure.

The maximum measured personal inhalable dust and personal inhalable lead were both outliers of the sample group. In a study done by NIOSH (1990) in a lead fire assay laboratory full shift air lead exposures of 0.120 mg m^{-3} and 0.200 mg m^{-3} were found. No local exhaust ventilation was being used in the laboratory surveyed by NIOSH. Six of the personal inhalable lead exposures in this study were higher than those found by NIOSH (1990). The variation in data may be due to the variety of tasks performed in the assay laboratory or inadequate ventilation. It may be assumed that each worker was exposed to an immediate breathing zone containing lead concentrations representative of his specific task performed within the laboratory.

3.5.4. Blood lead levels

The Pearson correlations suggested that the inhalable lead and blood lead levels ($p < 0.05$) have a positive linear correlation. The blood lead levels were however the product of exposure over an extended period while only two days of exposure data was collected.

The blood lead levels indicate that there are lead present in the blood and three of the laboratory workers have blood lead levels between 20 εg/dL and 39 εg/dL. This identify them as workers that need to be monitored every six months according to Lead Regulations in contrast with the other workers that need to be monitored every twelve months. Because the blood lead levels represent lead exposure over a period of twelve or six months it seems to be more effective to sample workersô lead exposure over a longer period of time if a correlation needs to be identified.
Workers were not wearing their respiratory equipment as they were trained to do. This could be contributing to high blood lead levels.

3.5.5. Dalgard Questionnaire

A validated questionnaire created by Dalgard *et al*. (2003) was used to evaluate self reported dermatological complaints experienced by the workers. Six workers (n = 18, representing the combination of all three metal groups) had no dermatological complaints. The low incidence of skin complaints may have been due to ethnic differences in skin structure. The report by Berardesca *et al* (2002) stated that the incidence of occupational allergic contact dermatitis in South Africa is less in black Africans.

Based on the Dalgard score five of the workers (n = 18) had a score >1.3 which indicates them being at risk of developing skin diseases. One of the five workers was an African male that works in the assay laboratory and the other four workers were based at the crystallizer circuit and nickel packaging site. Their risk of skin sensitization is high and needs to be lowered.

3.6. CONCLUSION

3.6.1. Crystallizer circuit

The average dermal concentration of nickel was 430 times lower than that measured average for the surface samples which indicate that the use of protective clothing and gloves and the hygiene habits of the workers were effective. The existing dermal exposure may be due to workers coming into contact with contaminated protective clothing and respiratory equipment after taking off their gloves at break times and at the end of the shift.

It was difficult to establish if there were a possible correlation between the total inhalable nickel and the dermal exposure of the workers as the number of samples below the detection limit were higher than the number of samples above the detection limit. It is recommended that a larger study needs to be done to increase the number of samples and therefore broadening the extent of known dermal exposure levels above the detection limit. The presence of high levels of airborne nickel as indicated by the personal total inhalable samples recommend further studies being done to fully evaluate the extent of the nickel airborne exposure and identify all workers being exposed.

When enforcing lower nickel exposure the cleanliness of the work area needs to be evaluated and monitored. When nickel sulfate powder is spilled corrective measures need to be taken immediately. The powder can be cleared with vacuum-cleaning equipment or surfaces can be dampened. The person undertaking the cleaning needs to wear protective clothing and respiratory protective equipment. Respiratory equipment needs to be worn when packing of nickel sulfate powder is undertaken as the dispersible nature of the powder cannot be eliminated.

The condition of the workersô skin needs to be monitored to ensure that they do not develop skin diseases. The workers have to be educated on skin diseases and their signs and symptoms to enable the workers to identify and report any possible skin diseases.

3.6.2. Copper stripping

Due to a great percentage of the dermal copper exposure samples being below the detection limit, a correlation between the copper dermal exposure measurements could not be established. It was found that exposure was uniform over the body and dermal exposure was low. The use of protective clothing and gloves need to be sustained as recognized during this study to ensure that dermal exposure levels are kept low.

The total inhalable copper results indicate that airborne copper is present at the copper stripping facility. As all of the exposure levels are below the action level the exposure were considered to be low. The well ventilated work area can be held responsible for the low airborne copper exposure.

A positive linear correlation between total inhalable copper and wrist and total inhalable copper and forehead dermal exposure was identified. Although this correlation existed because of one workerӧs high exposure levels it may be possible that it is an indication of a overall correlation between airborne copper levels and dermal copper exposure. Therefore it is recommended that a larger sampling population is used to gather a greater amount of data to examine the possibility of a correlation.

3.6.3. Fire assay laboratory

No measurable dermal exposures to lead were obtained. This indicates that the gloves and protective clothing used by the workers in the assay laboratory are effective. Low lead concentrations were found on surfaces inside the furnace room of the assay laboratory. To keep dermal lead exposure low the workers have to keep using their gloves and protective clothing in an effective way.

Although high amounts of dust were present in the assay laboratory, only a small percentage of the dust was lead metal. This may explain why the airborne lead did not have a significant influence on the dermal sample lead concentrations as, according to Oppl *et al.* (2003), it could have.

Workers were not wearing their respiratory equipment as they were trained to do. This is a concern because of the high levels of lead in the work area. It is recommended that workers receive updated courses on the importance of PPE usage, the effective use of respiratory equipment and the health effects of lead exposure. Supervision will also be effective to ensure that workers do wear their respiratory equipment in designated respirator zones.

The high number of samples above the OEL emphasizes the importance of introducing additional engineering controls to lower the inhalable lead exposure as much as reasonably possible. It was observed that the dust on the floor of the furnace room of the assay laboratory was cleaned using a broom. This action may result in additional airborne dust and lead exposure. It is recommended that other methods of cleaning needs to be implemented such as the use of vacuum-equipment with a filtration system. Where the use of vacuum-equipment may be impractical surfaces can be dampened. Any person executing cleaning needs to wear protective clothing and respiratory equipment.

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CHAPTER 4

CONCLUSION

4.1. CONCLUSION

To conclude on this study each specific facility will be discussed individually to put the focus on each metalôs exposure probability.

4.1.1. Crystallizer circuit and packing site at the base metal recovery plant

While workers were executing tasks and maintaining the nickel crystallizer circuit and packing site they were exposed to nickel airborne levels that were higher than the occupational exposure limit given in the South African Mine Health and Safety act (Act 29 of 1996, Regulation 22). This concludes that hypothesis 2 is accepted.

Workers at the crystallizer circuit and packing site were exposed to dermal nickel at levels higher than the detection limit for nickel and therefore the hypothesis made is accepted. Results showed that 30% of the dermal samples were above the detection limit and this confirmed that there was dermal exposure present at the crystallizer circuit and nickel packing site. The workersô use of protective clothing and gloves and the hygiene habits of the workers were effective in reducing exposure. The existing dermal exposure may be due to workers coming into contact with contaminated protective clothing and respiratory equipment after taking off their gloves at break times and at the end of the shift. Although the majority of the dermal samples were below the detection limit, all four of the workers had a Dalgard score above 1.3 and therefore are at a higher risk of developing a skin disease.

Surface samples that were taken from surfaces that the workers were most likely to come into contact with confirmed that surface contamination was present. All of the surface sample results were above the detection limit for nickel.

It was difficult to establish if there was a possible correlation between the total inhalable nickel and the dermal exposure of the workers as the number of samples below the detection limit were higher than the number of samples above the detection limit. Results showed that the nature of the workersô task at the crystallizer circuit has a great influence on the levels of nickel exposure. This needs to be kept in mind as the automated nature of the circuit will affect day to day tasks.

4.1.1.1. Recommendations

When enforcing lower nickel exposure the cleanliness of the work area needs to be evaluated and monitored. When nickel sulfate powder is spilled corrective measures need to be taken immediately. Nickel powder on surfaces needs to cleansed to limit exposure. The powder needs to be cleared using vacuum-cleaning equipment with a filtration system. The nickel powder is then discarded in a suitable container. The person undertaking the cleaning needs to wear protective clothing including overalls, goggles and approved gloves and respiratory protective equipment such as FFP2 facemasks.

Approved respiratory equipment needs to be worn when packing of nickel sulfate powder are undertaken as the dispersible nature of the powder cannot be eliminated. Workers executing nickel powder packing need to wear overalls, approved gloves and goggles.

The condition of the workersô skin must be monitored periodically to ensure that they do not develop skin diseases. This can be done by using a validated questionnaire to monitor the self reported dermatological complaints experienced by the workers. Workers skin needs to be examined by an occupational medical practitioner or dermatologist at their yearly medical examination. The workers have to be educated on skin diseases and their signs and symptoms to enable the workers to identify and report any possible skin diseases.

4.1.2. Copper stripping at the base metal recovery plant

While workers were executing copper stripping they were exposed to airborne copper levels lower than the occupational exposure limit for copper given in the South African Mine Health and Safety act (Act 29 of 1996, Regulation 22). Hypothesis 2 made is therefore not accepted. The results do confirm airborne copper to be present but the copper stripping was done in a well ventilated open area which explains the low total inhalable dust and copper exposures.

Workers who executed copper stripping were exposed to dermal copper levels above the copper detection limit. Although only 10% of the dermal sample results were above the detection limit hypothesis 1 is accepted. None of the workers executing copper stripping had a significant Dalgard score. Surface copper contamination was present at the copper stripping site with 70% of the sample results being above the detection limit for copper. Positive correlations existed between copper dermal and respiratory exposure.

4.1.2.1. Recommendations

The use of protective clothing such as approved gloves, overalls and goggles need to be sustained as recognized during this study to ensure that dermal exposure levels are kept low. The continuous use of approved respiratory equipment is very important to protect workers from airborne copper as measured in this study. The use of FFP1 facemasks are recommended to prevent the workers from inhaling copper powder.

4.1.3. The fire assay laboratory

While workers were executing their tasks in the fire assay laboratory they were exposed to airborne lead levels above the occupational exposure limit given in the South African Mine Health and Safety act (Act 29 of 1996, Regulation 22) and therefore hypothesis 2 regarding their lead respiratory exposure is accepted.

No measurable dermal exposure to lead was obtained on the skin of the workers in the fire assay laboratory which indicated very low dermal exposure to lead. All of the sample results were below the detection limit for lead and therefore hypothesis 1 regarding their dermal lead exposure is not accepted. All of the surface samples taken in the fire assay laboratory were below the detection limit.

A positive correlation was identified between the lead exposure of the fire assay laboratory workers and their blood lead levels as measured by the mineǿs health personnel. The blood lead levels were however the product of exposure over an extended period while only two days of exposure data was collected.

4.1.3.1. Recommendations

The South African Mine Health and Safety act (Act 29 of 1996, Regulation 22) states that lead exposures must be kept as far below the OEL as reasonably possible. The high number of samples above the OEL emphasizes the importance of introducing additional engineering controls to lower the inhalable lead exposure as much as reasonably possible. These controls can include the investigation of the ventilation in the laboratory. Carefully designed airflow within the laboratory, using exhaust airfiltration systems, would improve ventilation in specific areas of the laboratory where workers are more likely to do most of their work.

To keep dermal lead exposure low the workers have to keep using approved gloves and protective clothing in an effective way. It is recommended that FFP3 facemasks with an appropriate assigned protection factor (APF) are worn by the laboratory workers. It is recommended that workers receive updated courses on the importance of personal protective equipment usage, the effective use of respiratory equipment and the health effects of lead exposure. The fire assay laboratory workers were not wearing their respiratory equipment as they were trained to do. Respiratory exposure due to not wearing respiratory equipment will contribute to blood lead levels.

It was observed that the dust on the floor of the furnace room of the assay laboratory was cleaned using a broom. This action may result in additional airborne dust and lead exposure. It is recommended that other methods of cleaning needs to be implemented such as the use of vacuum-equipment with a filtration system. Any person executing cleaning needs to wear protective clothing such as approved gloves, overalls and goggles and approved respiratory equipment. The lead powder is then discarded in a suitable container as postulated in the lead regulations.

4.1.4. Limitations and future prospects

There are some limitations in this study. The main limitation is the relatively small number of the study group. It is recommended that a larger study needs to be done to increase the number of samples and therefore broadening the extent of known dermal exposure levels. The presence of high levels of airborne nickel as indicated by the personal total inhalable samples recommend further studies to fully evaluate the extent of the nickel airborne exposure. It is recommended that a larger study is done to gather a greater amount of data to examine the possibility of a correlation between copper personal inhalable exposure and copper dermal exposure.

To conclude: through the use of occupational hygiene methods and observations the exposure of workers to lead fumes in an assay laboratory, nickel sulfate powder at a crystallizer circuit and packing site and copper dust whilst executing copper stripping was measured and the extent of their exposure was established.

Hypothesis 1 comprises of the dermal exposure of workers at each of the working sites monitored to each siteǒs possible contaminant which includes lead in an assay laboratory, nickel sulfate powder at a crystallizer circuit and packaging site and copper dust whilst executing copper stripping. Because of the sampled nickel and copper dermal concentrations it was determined that there was dermal exposure to nickel sulfate powder at the crystallizer circuit and packaging site and copper at the copper stripping site. Therefore hypothesis 1 has been accepted regarding nickel and copper dermal exposure. Dermal lead sampling revealed that no measurable dermal exposure to lead occurred in the fire assay laboratory and therefore hypothesis 1 regarding the lead exposure has not been accepted.

Hypothesis 2 comprises of the exposure of workers to airborne contaminants at each of the working sites monitored which includes lead in an assay laboratory, nickel sulfate powder at a crystallizer circuit and packaging site and copper dust whilst executing copper stripping. The sampling results of nickel and lead respiratory exposure showed that there was exposure to airborne nickel sulfate powder at the crystallizer circuit and packaging site and airborne lead at the fire assay laboratory. Therefore hypothesis 2 has been accepted regarding nickel and lead respiratory exposure. Sampling of airborne copper revealed that none of the results were above the occupational exposure limit given in the South African Mine Health and Safety Act (Act 29 of 1996, Regulation 22) for copper. Therefore hypothesis 2 regarding the copper exposure has not been accepted.

Dermal exposure results obtained through this study contribute in the process of filling existing dermal data gaps such as the development of standard dermal sampling methods. Inhalation results confirmed the importance of measuring personal inhalation levels to ensure the health and safety of workers being exposed to metals. It is strongly advised that recommendations made are implemented to lower exposure levels as far as reasonably possible.

CHAPTER 5

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