LEAD EXPOSURE OF WORKERS EMPLOYED AS TAPPERS IN A PLATINUM-SMELTING ENVIRONMENT

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CHAPTER 6: RECOMMENDATIONS AND CONCLUSIONS

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AFRIKAANSE TITEL

Loodblootstelling van werkers werksaam as tappers in 'n platinumsmeltingsomgewing.

OPSOMMING

Die studie was onderneem nadat aanvanklike ondersoeke getoon het dat lood (Pb) teenwoordig is in konsentrasies hoër as die Beroepblootstellingsdrempel (BBd) op die matte tapvloer (MTF). 'n Opvolgstudie is ontwerp in ooreenstemming met die *Occupational Exposure Sampling Strategy Manual*(OESSM) om vas te stel wat die persoonlike blootstellingsvlakke van die tappers, werksaam op die MTF, aan Pb is.

Nadat die aanvanklike statiese monsters gedurende die indentifikasie fase geneem is, is verdere monsters geneem tydens die daaropvolgende persoonlike blootstellingsondersoek. Hieruit kon bepaal word of daar enige noemenswaardige kondisie veranderinge was tussen die aanvanklike- en statiese monsters. Persoonlike monsters, van 'n verteenwoordigende groep van die 30 tappers wat in die oondgebou op die twee onderskeidelike tapvloere werksaam is, is gelyktydig geneem. As gevolg van die duur van skofte deur die tappers gewerk, is monsters geneem oor 'n 12 uur periode. 'n Besluit is geneem om die MTF en die slak tapvloer (STF) te vergelyk, aangesien daar ooreenkomste bestaan tussen die prosesse wat gebruik word op die twee vloere.

'n Groep van 30 mans, werksaam as "tappers" in die oondgebou op die tapvloere van die Polokwane Smelter, is geëvalueer . Hierdie groep bestaan uit 30 mans uit 'n stedelike omgewing. Persoonlike monsters is geneem van 16 werkers uit die groep. Hierdie werkers is onwillekeurig gekies om 'n bloodstelling van die top 10 %, met 'n 90 % vertrouensvlak, soos voorgeskryf deur OESSM, te verseker.

Volgens die Loodregulasies van die Wet op Beroepsgesondheid en Veiligheid (OHS wet), Wet 85 van 1993, is die BBd vir Pb (anders as tetra-etiel Pb) 0.15 mg/m^3 vir 'n 8 uur skof. 'n Kort berekening het aangedui dat die BBd vir Pb sal verlaag na 0.1 mg/m^3 vir 'n 12 uur skof. Hierdie waarde is daarna gebruik om die blootstellingsvlakke te vergelyk met die aangepasde statutêre drempels.

Lood dien geen nuttige doel in die menslike liggaam nie en die teenwoordigheid daarvan in die liggaam kan lei tot toksiese effekte, ongeag van die roete van blootselling. Daar kan verwag word dat die bloedloodvlak (verwys as BLL) tussen 1 en 5 µg/dL is vir mense van buitestedelike afkoms en ongeveer 13 µg/dL vir dié van stedelike afkoms.

Die resultate van die BLL-toets gedoen tydens die studie dui egter dat alle vlakke onder 10 µg/dL was. Hierdie waarde dui daarop dat die huidige beheer maatreëls die blootstelling van tappers aan Pb laag hou. Die tydsduur wat per individu op die MTF spandeer word, word tot 'n minimum beperk deur die 30 tappers op 'n skofbasis te roteer. Dit beteken dat elke betrokke werker slegs vir een skof op die MTF werk voordat hy roteer word na 'n ander werksarea.

Die resultate wat verkry is toon dat daar statisties geen betekenisvolle verskil is tussen die aanvanklike- en statiese monsters, wat geneem is op die MTF en STF, nie. Die BLL-toets wat op die groep tappers uitgevoer is, is daarna vergelyk met die risiko faktore wat geïdentifiseer is as moontlike nie-industriële bronne van blootstelling aan Pb. Geen noemenswaardige resultate is verkry met hierdie vergelyking nie. Dit dui daarop dat daar geen effekte is op die BLL as gevolg van die nie-beroepsblootstelling aan Pb nie.

Laastens was daar 'n betekenisvolle verskil tussen die persoonlike blootstelling gemeet by die MTF en die STF, wat daarop dui dat daar 'n hoër loodkonsentrasie is in die lug van die MTF.

Hierdie bevinding is verwag, want aangesien Pb 'n swaarmetaal is, het dit 'n neiging om te groepeer en sorteer met die res van die waardevolle metale wat op die MTF te vinde is. Die elektriese boog oond is ontwerp om afwaarts te loop vanaf die STF na die MTF, wat die STF dus hoër plaas as die MTF. Gedroogde konsentraat word neumaties in die oond in verplaas. Die temepratuur van die konsentraat word dan verhoog na ongeveer 1500°C. In die tyd wat dit neem on na die vloeibare fase om te sit, verkry die konsetraat genoeg tyd om toe te laat dat die swaarmetale afwaarts kan beweeg na die MTF, waar dit versamel om gegiet te word deur die tapopening van die MTF te open. 'n Klein hoeveelheid Pb en ander swaarmetale (bv. platinum, goud, rodium, rubidium, silwer, ens.) bly egter in die mengsel agter en beweeg dus uit saam die afvalprodukte op die STF.
Hieruit word verduidelik waarom klein hoeveelhede Pb ook gevind is in die omliggende atmosfeer van die STF.

Aanbevelings is gemaak om die huidige ekstraksie ventilasiesisteem te verbeter. Sodoende verseker dit die effektiewe opname van Pb vanuit die omliggende atmosfeer op die MTF, terwyl die gesmelte metaal na die smeltpotte beweeg. Ook deur die skof rotasie rooster te optimaliseer, kan verseker word dat elke individu die absolute minimum tyd op die MTF spandeer. Tesame met 'n verhoogde bewustheid van persoonlike higiene en standaard werksprosedures, kan verdere persoonlike blootstelling aan Pb verminder word. Die probleem is egter om die hoeveelheid Pb in die lug op die MTF te verlaag tot onder die BBd. As 'n interim is hierdie area verklaar as 'n respiratorsone. Persoonlike Beskermde Toerusting (PPE) was die enigste effektiewe vorm van beskerming aan die tappers gebied ten tye van die studie. Half-gesig respirators met chemise magasyne met bykomende stof filters word deur tappers gebruik, om n die longe van die uitwendige atmosfeer van die MTF te beskerm. Soos gesien sal word met die resultate verkry is dit hoogs effektief, maar bykomended beheer maatreëls word voorgestel om die vlak van beskerming te verhoog soos verwag word in die OHS wet.

ABSTRACT

The study was undertaken after initial surveys indicated that lead (Pb) was present at concentrations in excess of the occupational exposure limit (OEL) on the matte tapping floor (MTF). A follow up study was designed in accordance with the Occupational Exposure Sampling Strategy Manual (OESSM), to determine personal exposure levels of the tappers to Pb whom are employed on the MTF.

Following the initial static samples taken during the identification phase, follow up static samples were taken during the follow up personal exposure survey. This enabled us to determine if there were any significant changes in conditions between the initial and static samples. Simultaneously personal samples were taken on a representative group of the 30 tappers employed in the furnace building on the two tapping floors. Samples were taken over a 12 hour period due to the shift duration worked by the tappers. A decision was taken to compare the MTF and the slag tapping floor (STF) due to the similarities in the processes used on both floors.

In order to evaluate the possible effect of lead on the workers employed as "tappers", a group of 30 workers employed in the furnace on the tapping floors of the Polokwane Smelter building were evaluated. The group consists of 30 men from multicultural urban environments. This group was further divided into smokers and non-smokers. Personal samples were conducted on 16 of the workers in the aforementioned group of "tappers",

who were randomly selected to ensure a top 10% exposure, with a 90% confidence level as prescribed by OESSM.

A short calculation gave an indication that the exposure to Pb according to the Lead Regulations of the Occupational Health and Safety Act (OHS Act), Act 85 of 1993, the OEL for Pb other than tetra-ethyl Pb is 0.15 mg/m^3 for an 8-hour shift would decrease to 0.10 mg/m^3 for a 12-hour shift. This value was then used to compare exposure levels to the adapted statutory limits.

Lead serves no useful purpose in the human body, and it's presence in the body can lead to toxic effects, regardless of the exposure pathway. The blood lead level (BLL) could be expected to be between 1 and 5 μg/dL in rural people and around 13 μg/dL in urban people.

The results of the BLL tests performed during the study however indicated that all BLL were under 10 μg/dL, which indicated that the current control measures that are in place are keeping the exposure of the tappers to Pb down. The amount of time per individual spent on the MTF is being kept to a minimum by rotating the 30 tappers on a shift basis, which means that a particular employee will only work for one shift on the MTF before being rotated to another area within the plant.

The results obtained showed that there is no significant difference between the initial and static samples taken on the MTF and STF. The BLL tests performed on the group of tappers were cross-referenced against the risk factors that were identified, as being possible sources of non-occupational sources of exposure to Pb. No significant results were obtained for this comparison showing no effect on the BLL's due to non-occupational exposures to Pb. Lastly there was a significant difference between the personal exposures measured at the MTF and the STF, indicating that there is a higher level of Pb in the ambient atmosphere of the MTF.

This was expected, due to the fact that Pb is a heavy metal and would tend to group and sort with the rest of the valuable metals, which are found on the MTF. The electric arc furnace is designed to incorporate a slant downward from the STF to the MTF. Bone dry concentrate is fed pneumatically into the furnace. The concentrate which is in powder form is then smelted and reaches a temperature of approximately 1500°C. In the time it takes for this concentrate to be smelted and reach a fluid state, the valuable heavy metals, including lead, move down the slope toward the MTF and to accumulate where it can then be "tapped" out by opening the tap hole on the MTF. However a small amount of Pb and other heavy metals like: platinum, gold, rhodium, rubidium, silver, etc., remain caught up in the mixture and are passed out along with the waste product slag, on the STF. This explains why small amounts of Pb were also found in the ambient atmosphere of the STF.

Recommendations were made to improve on the current extraction ventilation system, to increase the effective uptake of Pb from the ambient atmosphere on the MTF whilst the molten metal is being allowed to run along the launder to the ladle. By optimising the shift rotation roster it could be ensured that the minimum amount of time is spent on the MTF by each individual. An increased awareness of personal hygiene, and standard operating procedures could further decrease personal exposure to Pb. The problem however lies in decreasing the amount of airborne Pb on the MTF to below the OEL, and as an interim this area has been declared a respirator zone. Personal Protective Equipment (PPE) was the only effective form of control at the time of the survey. Half mask respirators with chemical cartridges, which along with dust filters present a barrier between the lungs and the ambient atmosphere of the MTF.

ABBREVIATIONS

The following abbreviations were used in the text, listed alphabetically.

- ATDSR - Agency for Toxic Substances and Diseases Registry.
- BLL - Blood lead level.
- EP - Erythrocyte protoporphyrin.
- EPA - Environmental Protection Agency.
- ISMS - Isotope dilution mass spectrometry.
- MTF - Matte tapping floor.
- NHANES II - The National Health and Nutrition Examination Study.
- NIOSH - National Institute of Occupational Safety and Health.
- ODIMWA - Occupational Diseases in Mines and Works Act.
- OEL - Occupational Exposure Limit.
- OESSM - Occupational Exposure Sampling Strategy Manual.
- OHS Act - Occupational Health and Safety Act, Act 85 of 1993.
- Pb - Lead
- PPE - Personal Protective Equipment
- RPE - Respiratory Protective Equipment
- SANS - South African National Standards.
- STF - Slag tapping floor.

DEFINITIONS

- Action level - The level at which action needs to be taken to prevent exposures to stressors. The level is 50 % of the OEL.
- OEL-TWA - Occupational exposure limit – time weighted average.
- Personal sample - Samples taken on the employees body, as close to the employees breathing zone as is possible.
- Static sample - Samples taken in a static position in the area being sampled, in a position representing the worst case scenario.
- Tapper - Employee responsible for the opening and closing of the furnace tap holes in order to control the level of the bath of molten metal within the furnace.

CHAPTER 1: INTRODUCTION

1.1 Introduction

In the platinum smelting industry, raw materials are smelted to obtain platinum and numerous other valuable metals including chromium, iron, cobalt, nickel, copper, ruthenium, rhodium, palladium, silver, iridium and gold. This group of "valuable" metals are found in the concentrate received from the mines in the Anglo Platinum group. These "valuable" transition metals are found along with other elements in the closely associated groups 3A and 4A of the periodic table. One such element is lead, which is found in the same period of the periodic table with elements like iridium, platinum and gold. The heavy metals are separated from "waste" ground in the mining process and the platinum smelter is provided with a concentrate of these heavy metals for separation and ultimately the removal of platinum and the other valuable heavy metals mentioned above. Unfortunately most industrial processes have unwanted by-products. In some instances these by-products can have serious health effects if an individual is exposed to them. One such by-product is the heavy metal lead (ATDSR, 2000).

Occupational exposure to lead has been on the decrease since the nineteen hundreds (Anon., 2004a). This, however, does not mean that exposure to lead has been eliminated from the work environment. Instead there are a number of industries in which exposure to airborne lead is unavoidable (Gerhardsson, *et al.*, 1995). It is as a result of the fact that the exposure to lead is unavoidable, the monetary gain and the well documented health effects of lead on the human body, that stringent regulations have been adopted in the Occupational Health and Safety Act, Act 85 of 1993, namely the Lead Regulations. These regulations set a stringent set of guidelines which aid the employer in controlling unavoidable exposures to lead in such a manner as to ensure that the majority of the work force will not be adversely affected by a prolonged exposure to lead (ATDSR, 2000).

The Lead Regulations of the Occupational Health and Safety Act (85 of 1993) call for an intimate and structured approach to any suspected exposure to airborne lead between occupational hygiene and occupational medicine. A structured risk based approach to lead exposure means that clear guidelines will aid this interaction between the occupational hygienist and the occupational medical practitioner, and give meaningful results both to the occupational hygienist and the occupational medical practitioner. It gives an indication to the relationship between the amount of airborne lead an employee is exposed to, the amount of lead absorbed by the employee in his work environment and the effectiveness of control measures put in place by the employer to protect the employee from an over exposure to airborne lead.

This paper gives a complete discussion of a survey undertaken within a platinum smelting furnace, to determine the levels of airborne lead, the occupational exposure to airborne lead and the lead uptake by employees working as tappers within the furnace building. As well as the effectiveness of current control measures that have been put in place, by the employer, to prevent excessive exposures of employees to airborne lead within the working environment of the furnace building.

1.2 Aim

To quantify the occupational exposure of a group of tappers employed in a platinum smelting environment to airborne lead and using blood lead levels to determine the effectiveness of current control measures.

1.3 Hypothesis

The following hypothesis was formulated: Employees employed on the matte tapping floor will have a higher exposure to airborne lead than the slag tapping floor.

1.4 Structure of dissertation

The dissertation is composed of a literature study on the ill-health effects associated with excessive exposure to lead. Strict occupational hygiene procedures, namely:

- A walk through survey in which the presence of lead was suspected.
- Fixed samples to quantify the lead levels as part of a formal risk assessment.
- Follow up samples, both personal and static, based on the findings of the formal risk assessment.
- Biological monitoring based also on the results of formal risk assessment.

The methodology explains the methods used to obtain the results. These results are then presented in the form of graphs, and the statistically treated results in table format. A discussion of various comparisons, using the results obtained as well as statistical proof that the results are significant follows. Recommendations are made on the findings, taking into consideration the effectiveness of current controls that are in place within the furnace building. Finally, a short conclusion summarises the findings of the survey.

CHAPTER 2: LITERATURE SURVEY

Lead has been used for at least 6000 years and is a most attractive metal for cultures that employ simple technology. It is easy to extract from it's principle ores, has a low melting point so that it can be cast and moulded with ease, is malleable and so can be worked without undue effort (Morgan & Scott, 2000:7).
According to Sanborn *et al.* (1999) lead serves no useful purpose in the human body, and it's presence in the body can lead to toxic effects, regardless of the exposure pathway. Therefore, lead toxicity can affect every organ system in the human body. Exposure to lead and lead chemicals occurs when lead dust or fumes are inhaled, or when lead is ingested via contaminated hands during eating, drinking, smoking or getting dressed (New York State Department of Health, 2001).

The National Health and Nutrition Examination Study (NHANES II) held between 1976-1980 found the median blood lead level for the entire US population to be 13,0 μg/dL with African Americans having a higher blood lead level (BLL) than Caucasians, adult men having a higher BLL than adult women and younger children having higher levels than older children. The population with the lowest BLL, 1-5 μg/dL, live in rural areas far from urban centres (Miller, 1999).

According to the Agency for Toxic Substances and Diseases Registry (ATDSR) (1999) lead is an environmental toxicant that may affect the nervous, haematopoietic, endocrine, renal and reproductive systems in the human body negatively. The human body may be exposed to lead by the following routes of exposure:

- Inhalation
- Ingestion
- Absorption

ATDSR (2000) states that practically all inhaled lead is absorbed into the body, whereas 20 % - 70 % of ingested lead is absorbed into the human body.

Inhalation

Industrially inhalation is by far the most important route of exposure, according to Morgan and Scott (2000:7). Once inhaled, air follows a pathway from the nose to the windpipe (trachea), which in turn forms two passages (bronchi) - one to each of the two lungs. The bronchi branch extensively and end in clusters of tiny air sacs called alveoli. Millions of alveoli in the lungs provide an enormous surface area for the exchange of gasses. This surface area, combined with the delicate cells of the alveoli, allows oxygen to pass readily into the blood stream (Leff & Schumacker, 1993). Unfortunately, it also gives any contaminant easy access. The body does have some defences to protect the delicate lung tissues. These defences include nose hairs to filter out large particles and a mucociliary system in the bronchi to trap medium sized particles. These defences are not very effective in the removal of very small particles, which pass quite freely on to the terminal bronchioles and alveoli (Leff & Schumacker, 1993).

At the point of transition between the conducting airways and the alveoli, there is a change in the mechanism used to clear the area of particles. This transition area is characterized by the change from ciliated columnar epithelium in the terminal bronchioles to non-ciliated epithelium in the alveoli. Goblet cells and sub-mucosal glands are common in the conducting airways although none are found in the alveoli. This transition therefore signals a change in the mechanism of particle clearance, from mucociliary clearance in the conducting airways to alveolar macrophages in the alveoli and interstitial space. This area of transition is the area with the weakest clearance effectiveness. The highest concentration of particles is usually found beyond the terminal bronchioles, as in patients with lung diseases such as pneumoconiosis. It could be that the slow clearance rate in this area provides an opportunity for the material to leave the airway (absorption) and enter the interstitial space where clearance is extremely slow. This is frequently the primary site of airway damage in occupational lung disease (Leff & Schumacker, 1993).

Hu (1998) claims that it is from these interstitial spaces that lead is absorbed into the blood stream. Absorption of lead from the lungs is very efficient, especially where the particles are less than 1 micrometer in diameter, as may be the case with lead fumes.

Ingestion

In the past it was customary to give workers exposed to heavy metals in the workplace, a pint of milk a day, as it was commonly believed that the milk protected the workers from the toxic effects of heavy metals (Morgan & Scott, 2000:7). This is still found to be a common belief amongst workers exposed to lead. Milk however, has little protective effect, as the presence of calcium in the gut cannot influence the uptake of lead from the lungs. Large amounts of lactose present in the milk might actually increase the uptake of lead from the gut. The false impression that milk prevents the harmful effects of exposure to heavy metals, might be attributed to the fact that these workers follow a poor diet, and that the milk increases their dietary intake, explaining the improved "state" of health (Morgan & Scott, 2000:7).

Ingestion could be the principal route of uptake into the body, especially where high standards of personal hygiene are not insisted upon. Lead workers who smoke and who are allowed to eat without first washing their hands run the highest risk of being exposed to lead in this fashion, says (Morgan & Scott, 2000:7).

Absorption

Absorption takes place when a substance passes through the skin into the body. Organic lead compounds e.g. tetraethyl lead, may be absorbed by skin contact and often are the most toxic. Inorganic lead compounds are less toxic and are believed not to be readily absorbed through the skin (Hu, 1998).

The pathway of lead in the body

Lead is absorbed slowly and incompletely from the gastrointestinal tract and almost completely from the respiratory tract after being inhaled. Once in the blood, lead is distributed mainly between two pools: the blood and soft tissues, and bone. Once in the blood, the majority of inorganic lead is associated with erythrocytes (Essa, 1999). Directly after absorption, lead is distributed to the soft tissues via the blood, with the highest concentration normally going to the kidneys. Over time, lead is again distributed across the body to all organs and ultimately to bone. Lead then accumulates in the bone, teeth, hair and a small amount of inorganic lead is deposited in the brain. Since lead is excreted very slowly from the body, it tends to accumulate in the body (Essa, 1999).

Most of the lead that is absorbed into the human body, is excreted by either the kidney (via urine) or by biliary clearance (ultimately via faeces). The amount excreted and the timing of the excretion, however, depends on a number of factors: the physiological characteristics of the exposed individual, nutritional status, age, general health and the chemical form of the lead or lead compound absorbed. Organic lead compounds are metabolized in the liver, whilst inorganic lead, the most common form of lead, undergoes no transformation (ATDSR, 2000).

Once in the blood, the lead that is not excreted circulates bound to haemoglobin molecules, and less than 5 % of the total blood lead is found in the plasma. Lead has a long biological half-life, estimated at between 28 and 36 days in the blood, and the total body burden (total amount of lead in the body) thus increases with time (ATDSR, 2000). The total body burden can be considered to consist of two pools: a rapidly exchangeable pool in the blood and soft tissues (liver, kidneys, lungs, brain, spleen, muscles and heart) and a long term skeletal pool. The mineralising tissues (bones and teeth) contain the vast majority of the total body burden, with the rapidly exchangeable pool in the blood being toxicologically the most important (ATDSR, 2000).

Despite the fact that blood only carries a tiny percentage of the total body burden of lead, it serves to initially receive the absorbed lead and transports blood throughout the body, making it available to other tissues in the human body and for excretion. The fact that blood plasma transfers lead between the blood, soft tissues and mineralizing tissues makes it biologically important. The higher the concentration of lead in the blood, the greater the percentage found in the blood plasma (ATDSR, 2000).

The Blood Lead Level (BLL) test is thus the most widely used measure of lead exposure. There is a less sensitive erythrocyte protoporphyrin (EP) assay that is also used to measure blood lead levels. Both tests do not, however, give an indication of total body burden, but instead reflect recent or ongoing exposures to lead (ATDSR, 2000).

The effects of lead exposure

The toxic effects of lead can be broadly classified into two categories: acute (short-term) effects and chronic (long-term) effects (Anon., 2004a). Some substances, like asbestos, do not display short-term effects, and as a result the diseases caused by asbestos may take years to develop. On the other hand, lead displays short-term as well as long-term effects, despite the fact that there is no clear dividing line between the two (Anon., 2004a).

Acute effects of lead

Acute effects tend to show up relatively soon after an exposure has occurred. Lead, a systemic poison, as stated previously, serves no known useful function once in the human body. Very low lead exposures generally do not have any effect. Excessive exposures on the other hand, can lead to one or more of the following symptoms in the human body: metallic taste in the mouth, stomach pain, vomiting, diarrhea and black stools (Anon., 2004a).

Severe exposures are known to damage the nervous system and symptoms include intoxication, coma, respiratory arrest and, in extreme cases, death (Anon., 2004a).

Chronic effects of lead

Chronic effects tend to show up a relatively long time after exposure to lead has occurred. The chronic carcinogenic effects of asbestos can take 20 years or longer before they show up. In the case of lead, a wide variety of chronic effects can start showing up after continued exposure - a problem which is intensified by the fact that lead also accumulates in the body (Anon., 2004a). Symptoms which show up over a relatively short period of chronic exposure include loss of appetite, constipation, nausea, stomach pain (called lead colic), pallor (a yellowing of the skin), excessive tiredness, weakness, weight loss, insomnia, headache, nervous irritability, fine tremors, numbness, dizziness, anxiety and hyperactivity (Stanton, *et al.,* 2001).

Due to the fact that these symptoms are common to a number of other health problems, the exposed worker is often overlooked. In some cases these symptoms may cease once exposure stops. In other cases, however, these symptoms may progress to the problems associated with classic lead poisoning. These problems are more obvious, and include severe stomach pain, extreme weakness, tremors, gum discolouration, wrist drop, foot drop, convulsions and kidney failure (Anon., 2004a).

These symptoms are often referred to by doctors as "clinical signs" due to the fact that they are readily recognisable by the doctor during a physical examination. Lead can, however, at low dosages cause damage to a persons health without any noticeable symptoms (Anon., 2004a). In order to better understand the chronic effects of lead, we need to look in depth at some of the specific body systems that are affected by lead.

Effects of lead on the blood

Erythrocytes carry oxygen to the body's tissues. Within the erythrocyte is a blood protein called haemoglobin, which serves as a transport site for oxygen as well as giving blood it's red colour. Lead affects the ability of the body to produce haemoglobin (ATDSR, 2000). The decrease in haemoglobin levels decreases the ability of the blood to transport oxygen to the tissues within the body. This lack of oxygen is commonly known as anaemia. Anaemia is linked to symptoms such as tiredness, weakness, headache and irritability, and in severe cases has been known to cause heart failure (Anon., 2004a).

Effects of lead on soft tissue

Blood is responsible for the distribution of oxygen and various other essential elements and food stuffs to the various organs and tissues of the body (Leff & Schumacker, 1993). Unfortunately, blood also distributes lead to the organs and tissue. Animal studies have shown that the lungs, liver and the kidneys display the greatest levels of lead immediately after an acute exposure (ATDSR, 1999). The brain has also been found to be a site of lead storage within the human body. Autopsies have revealed the build-up of lead in the following organs: liver, kidney, lungs and brain (Gerhardsson, *et al.,* 1995).

Effects of lead on the nervous system

The nervous system is the most sensitive organ in the human body, and is also a target of lead exposure (CDC, 1997). The exact mechanism is not well understood, but chronic lead exposure can cause serious problems in the nervous system and the brain. This may manifest itself in the form of fatigue, nervousness, anxiety and sleeplessness, which could ultimately lead to behavioural problems such as poor memory, visual disturbances and confusion. In the worst exposure cases, encephalopathy (a degenerative brain disease) and serious physiological problems can occur (Anon., 2004a). Lead encephalopathy may occur at extremely high blood lead levels (BLL's), e.g. 460 μg/dL. Less severe and behavioural effects have been documented in lead-workers with BLL's ranging from 40 – 120 μg/dL. These effects include malaise, forgetfulness, irritability, lethargy, impaired concentration, depression and mood changes, increased nervousness, headache, fatigue, impotence, decreased libido, dizziness, weakness and paresthesia, as well as diminished reaction time, visual motor performance, hand dexterity, IQ scores and cognitive performance (ATDSR, 1999). Historical data shows that lead exposure could affect peripheral nerve function and, as a result, postural balance (ATDSR, 1997).

In addition to the central nervous system, lead also affects the peripheral nervous system that controls the hands, fingers and feet. Severe exposure to lead can cause damage to the peripheral nerves resulting in paralysis of the hands and legs, leading to "wrist drop" and "foot drop". This condition is commonly known as "peripheral neuropathy" amongst doctors. Some of the less severe problems do sometimes clear up if they are mild, but in other cases the symptoms might be irreversible (Anon., 2004a).

Effects of lead on the Kidneys (Renal System)

Numerous studies have shown a relationship between the exposure to lead and the effects on the renal system. Most of the renal effects associated to lead, are a result of ongoing chronic or current high level exposures (ATDSR, 1999). The level at which lead starts having negative effects on the renal system is not known. Most of the renal effects for workers exposed to lead have been observed in acute high-dose exposures and moderate-to-high chronic exposures (BLL>60 μg/dL) (ATDSR, 2000). There are no early or sensitive indicators (biomarkers) of renal damage due to lead exposure. Serum creatinine and creatinine clearance are used as lagging indicators. Some urinary biomarkers found in the proximal tubule (e.g. N-acetyl-β-D-glucosaminidase) have shown elevations with current exposures. BLL's lower than 60 μg/dL, and population-based studies have shown accelerated (i.e., greater than that for formal ageing) increases in serum creatinine or decreases in creatinine clearance, even at BLL's below 60 μg/dL (Kim, *et al.*, 1996).

Renal diseases associated with exposure to lead can be asymptomatic until the late stages and may remain undetected if not specifically tested for. If picked up early and treated, the progression of renal failure may be slowed or even stop, but is not reversed. Past or ongoing excessive lead exposure may cause kidney disease-associated essential hypertension (ATDSR, 1999).

Exposure to lead can also contribute to the onset of "saturine gout" as a result of lead-induced hyperuricemia, due to decreased renal excretion of uric acid (Batuman, 1993).

Effects on the Cardiovascular System

Hypertension has many causes and risk factors, including old age, obesity, poor diet and exercise habits, and excess alcohol intake (ATDSR, 2000). Exposure to lead is another factor that may contribute to the development of hypertension. Studies have shown that greater, mainly occupational exposures to lead, increase the risk of hypertension, with lower level exposures having little or no effect. Heart disease and cerebrovascular disease are thought to be additional latent effects of such high occupational exposures to lead (Hu, 1991).

Effects on the Reproductive System

According to Lerda (1999) reproductive function studies in humans have shown that ongoing occupational exposures to lead, decrease the total amount of sperm produced and increase the frequency of abnormal sperm. These effects may become evident at BLL's of 40 μg/dL. Long-term lead exposure has caused The Environmental Protection Agency (EPA) to classify elemental lead and inorganic lead compounds as Group 2B: probable human carcinogens (ATDSR, 1999).

Prenatal Effects

Prenatally, a number of health problems have been associated with the exposure of the foetus to lead. It is important to take note of the fact the health effects observed result from lead levels well below those that are toxic to the mother. These include: premature birth, decreased gestational maturity, decreased birth weights, reduced postnatal growth if exposure continues, increased probability of minor congenital abnormalities, and early deficits in postnatal neurological and neurobehavioral status (Dietrich, 1991).

Carcinogenic Effects

As stated above, lead has been declared a probable human carcinogen. This is due to the fact that relatively little data is available concerning the carcinogenic effect of lead in humans (ATDSR, 1999). Lead acetate and lead phosphate are classified by the National Toxicology Program of the Environmental Protection Agency (EPA) as "may reasonably be anticipated to be carcinogens" (ATDSR, 2000). Information on the occupational exposure to lead with an increased risk, is questionable and limited because the actual compound of lead, the route of exposure and the level of lead to which the worker is exposed, is usually not documented. Additionally the occupational exposure studies concentrate mainly on lead smelter workers usually exposed to lead in combination with a number of other chemicals, which include arsenic, cadmium, antimony, as well as toxicants from fellow workers smoking habits (Cooper, 1976; IARC, 1987).

The role of medical testing in control of lead exposure

The presence of lead in the human body can be tested for, using short-term blood tests. Whilst these tests do have limitations, the test can be used by a doctor as an indication, of the body burden of lead (Essa, 1999).

Blood lead level (BLL) test

The BLL test is used as the main index of determining lead exposure. "Lead levels of 10 µg/dL or less are acceptable, while levels of 15 µg/dL is a warning sign and repeated testing should be done once a month for three months. BLL of 20 µg/dL is interpreted as an action level and levels of 40-45µg/dL is clinical lead poisoning and chelation treatment is warranted. The definitive method of assessing lead in blood is isotope-dilution mass spectrometry (ISMS) with ultra clean procedures and facilities." (Miller, 1999).

The BLL test gives an indication as to the level of lead present in the blood, known as the blood lead level. Results, in either micrograms per deciliter (µg/dL) of whole blood, or micrograms of lead per 100 milliliters of whole blood (µg/100ml) are used internationally. Because lead is found in all spheres of the environment, the average urban dweller has BLL's ranging between 12-15 µg/dL (Anon., 2004a). Internationally the average BLL is decreasing as the usage of leaded gas declines (Anon., 2004a). At a BLL of approximately 40µg/dL human health damage starts to occur, although this differs from one person to another. Many will not experience any symptoms at this level. From 60 µg/dL upwards, health damage occurs in most people. Levels of 80 µg/dL will, in all probability, cause serious lead poisoning (Anon., 2004a). The OHS Act's Lead Regulations Occupational Exposure Limit (OEL) was implemented to phase in a removal from work at a BLL threshold of 60 µg/dL, by 30 June 2005 (OHS Act, 1993).

The value of the BLL test lies in its simplicity. All that is required is a tube of blood from a worker suspected of being exposed. As previously stated, the BLL test provides proof that exposure has occurred and can be used to estimate how serious the exposure has been, should there have been an exposure, compared to asbestos, for which there is no short-term test to determine whether a person has been exposed. The test, if carefully interpreted, reflects recent exposure to lead (Essa, 1999). It unfortunately does not measure the body burden of lead directly, nor can it be used as a measure of the health damage caused by lead, should an exposure to lead have occurred. In short, the BLL test is used to identify the amount of lead present in the blood of a person at the present time (Anon., 2004a).

Medical treatment of lead poisoning

Medical treatment of workers with lead poisoning involves removal from further exposure and sometimes involves administration of special drugs, called chelating agents. *Chelate* is the Latin word for claw and these drugs work by latching on to lead in the body (Anon., 2004a).

Calcium disodium ethylenediaminetetraacetate ($CaNa_2EDTA$) and unapproved D-penicillamine (which is used in some centers in the USA) are used for chelation therapy in the case of lead poisoning (Essa, 1999). Patients with blood lead levels higher than 45 mg/dL, should be given chelation therapy immediately. Patients with blood lead levels between 25 mg/dL and 45 mg/dL are tested using the $CaNa_2EDTA$ challenge test to assess the body burden of lead. The ratio of lead excreted in urine versus the dosage of

$CaNa_2EDTA$, are then calculated. A ratio of higher than 0.6 for an 8-hour challenge test is considered positive (Essa, 1999).

The chelating agent, which can be administered orally or by injection, binds to the lead and is excreted from the body in the urine. Chelating agents do however also bind with other mineral nutrients like copper, calcium, manganese, iron and zinc, causing the body burden of these essential elements to decrease (Anon., 2004a).

Because of the fact that a chelating agent binds to other essential mineral nutrients, the chelation therapy must be done under the strict supervision of a medical doctor. In the past, some employers administered prophylactic chelation to employees who were exposed heavily to lead. This is not an accepted medical practice and is forbidden by the OHS Act.

Despite the problems associated with chelation therapy, it is a very important tool used to rid the body of excess lead. It is not a cure to serious lead exposure and the damage inflicted to the human body, but does serve to decrease the amount of lead available to inflict any further such damage. Exposed workers with lead poisoning, or suspected lead induced ailments, should consult with a medical doctor on the suitability of chelation therapy. Due to the complexity and the fact that chelation therapy can be a painfull process, it should always be seen as a last resort (Anon., 2004a).

CHAPTER 3: METHODOLOGY

3.1 Base-line Risk Assessments

Based on the above information, a decision was taken to do an initial base-line risk assessment of the levels of several metals in the atmosphere of the two tapping floors within the furnace building of the Polokwane Smelter, namely the matte tapping flor (MTF) and slag tapping floors (STF). Three static samples were taken on both the MTF and STF. The initial static samples taken during the base-line risk assessment were 8-hour samples. The base-line risk assessment indicated that lead was present in the atmosphere of the matte tapping floor at concentrations in excess of the occupational exposure limit as specified in the Occupational Health and Safety Act, Act 85 of 1993 (OHS Act, 1993), being 0.15 mg/m^3. The OHS Act requires that employees exposed to lead in excess of the OEL have blood lead levels tested. Thus all the employees, employed on the tapping floors as tappers, needed blood lead level tests to determine what the extent of the exposure was to each individual employee.

3.2 Subjects

The group of workers referred to in this document as tappers, are employees that have been trained to open and close the tap holes of the furnace. In short, this means that they are responsible for controlling the levels of molten metal within the furnace, by opening the tap holes to allow the molten metal to flow out of the furnace in a controlled fashion. Once open, the metal is allowed to run into 45 ton ladles, which is then cast into ingots, or casting pits, on the matte side of the furnace. In direct contrast, the slag side of the furnace is of little value and is constantly opened and granulated before being transported per conveyer to the slag dumps. During this process the metals are heated to approximately 1300 °C, which means that the lead involved could theoretically become airborne to a certain degree for the duration of this process at both ends of the furnace.

In order to evaluate the possible effect of lead on the health of the tappers, the group of 32 tappers employed in the furnace on the tapping floors of the Polokwane Smelter building, were chosen for the study. The number of workers that had to be sampled was determined by following the guidelines of OESSM (1997).

The following procedure was used:

Step 1 – Determine the number of employees to sample using Table 3.1 p. 35 OESSM.

During this study, the equal expected exposure risk group of size $N = 32$ was considered. To be 90 % confident that at least one of the three (i.e. 10 % of 32) individuals with the highest of all exposures was included in the partial sample, 16 workers had to be randomly chosen from the sample group of 32. Thus, it was necessary to sample 50 % of the subgroup to ensure with 90 % probability that at least one worker with an exposure in the highest 10 % of all exposures in the group has been included.

Step 2 – The required number of employees was randomly selected by using the random numbers given in Table 3.2 p. 36 OESSM.

3.3 Personal Sampling

Representative samples were taken in the employees breathing zone, using NIOSH method 7300, to represent as closely as possible the air that would be inhaled by the employee whilst performing his/her everyday task. The sampling pump was attached directly to the employee and worn for an entire shift - during work and during breaks.

"Casella Apex" series sample pumps were used to take the samples. The pumps were pre-calibrated using a blank filter of the same type as the filters used to take the personal samples. The pumps were set as close to 2,2 l/min for all samples taken. Following the sampling the pumps were post calibrated and the time and volumes recorded were carefully noted. A DryCal DC-Lite flow meter, calibrated 26 May 2004 – certificate number FL\G-0413, was used to pre and post calibrate the pumps. In each case the calibrator was allowed to run for a cycle of at least 10 readings and an average of the 10 readings was taken as the calibrated flow rate. This information for each individual sample was captured and sent along with the samples to the laboratory for analysis.

Full period single sample measurements were taken. The sample was taken for the full duration of the shift. This would be 8 hours for an 8 hour TWA standard and 15 minutes for a ceiling standard (OESSM, 1977). Since the tappers work 12 hour shifts, a 12 hour TWA needs to be calculated.

Calculation of an 12 hour TWA Occupational Exposure Limit (OEL) value, as specified in the Lead Regulations, of the Occupational health and Safety Act, Act 85 of 1993.

The 8 hour TWA OEL for lead, other than "tetra-ethyl" lead, is set at 0.15 mg/m^3.

Therefore the 12 hour TWA OEL for lead, other than "tetra-ethyl" lead, is:

$$\text{12-hour TWA} = \underline{C^1T^1}$$

$$= \frac{\dots}{12 \text{ hours}}$$

$$= \frac{(0.15 \text{ mg/m}^3)\ (8 \text{ hours})}{12 \text{ hours}}$$

$$= 0.1 \text{ mg/m}^3$$

Where:

C = is the occupational exposure value (concentration).
T = associated exposure time in hours in any 24 hour period.

Exposure measurements for an 8 hour TWA standard

According to OESSM (1977) there is no such thing as a best strategy for all situations, instead, some strategies are just better than others in certain situations. Below is given a list of considerations that need to be taken into account when comparing strategies:

- Equipment available for the survey (number of pumps, cost, filter availability, analysis, etc.).
- Shifts and available personnel for sampling.
- Occupational exposure variations (intraday and interday).
- The location of the exposed workers.
- Number of samples that need to be taken, as required to attain the level of accuracy required.
- Precision and accuracy of sampling and analytical methods needed or available.

The variations of any exposure in any operation simply cannot be predicted. The only general guideline that can be used for intraday and interday variation, is that the geometric standard deviation (GSD) will lie between 1.25 and 2.5 (Leidel, 1975).

NIOSH (National Institute of Occupational health and Safety) sampling and analytical procedures have total coefficients of variation ranging between 0.05 to 0.10 (5% to10%).

After careful consideration regarding precision and accuracy of the sampling and analytical methods, as well as the occupational variation, the following general guidelines are given:

The Full Period Single Sample Measurement (one 8-hour sample) is next to best if an appropriate sampling analytical method is available. Due to the shift duration of the tappers 12 hour samples were taken.

Sample train and Sampling Method

OSHA Method ID 121 (SKC, 2002) can be used to determine amounts of specific metal and metalloid particulates in the workplace atmosphere. The analytical method is specific for the element metal itself but does not distinguish between compounds. For some metals, alternative methods exist that may be more accurate, sensitive, or specific.

Equipment Required

1. Sampler: cellulose ester membrane filter, 0.8 µm pore size, 37 mm diameter, in cassette filter holder.
2. Personal sampling pump, 1 to 4 L/min, with flexible connecting tubing.

Sampling and Analysis

1. A filter cassette sampling train, consisting of a preloaded filter cassette, sealed with a sealing band, and an inserted filter cassette within a filter case holder. The sampling train was then attached with the cassette inlet facing down with the outlet plug removed. The end of the rubber tube was attached by means of an adapter to the filter cassette holder, on the outlet end. Flexible rubber tubing was used to connect the filter cassette holder to the pump inlet.
2. For calibration of the pump, the sampling train as described in 1 was used and connected via the inlet of the filter cassette to the calibrator with flexible rubber tubing. The pump was calibrated to the specified rate (2,2 l/min for airborne particulate sampling). Upon completion of the calibration, the filter cassette was removed, the plugs reinserted, and the filter cassette saved for re-use.
3. During the actual sampling, a sampling train was set up as explained above except a new filter cassette was used and the inlet plug on the filter cassette inlet was not removed until the actual sample was taken. Care was taken to ensure that the filter cassette was facing down. The cassette holder clip was then attached to the workers collar and the pump to the workers belt. The filter cassette inlet plug was then removed and the pump switched on, whilst taking note of the time.
4. A sample was then taken accurately at a known flow rate for the duration of the shift.
5. At the end of the sampling period, the pump was turned off and a note taken of the ending time. The inlet to the filter cassette was plugged. A note was then made of all the relevant information.
6. The pump was then calibrated to ensure that the flow rate had not changed by more than 5%.
7. All sample filters, field blanks, and all pertinent information was then securely packed for shipment to a SANS accredited laboratory for analysis.

Analysis of Samples

Analysis was performed by a SANS accredited laboratory, using NIOSH Method 7300. The samples were prepared as follows:

1. The cassette filter holders were opened and the samples and blanks transfered to clean beakers.
2. Five millilitres of ashing acid was added. Covered with a watch glass, and allowed to stand for 30 minutes at room temperature. NOTE – the reagent blank was started at the same time.
3. The solution was heated on a hot plate (120 °C) until ca. 5 ml remained.
4. Two millilitres of ashing acid was added and step 3 repeated. This step was then repeated until the solution was clear.
5. The watch glass was removed and the solution rinsed into the beaker using distilled water.

6. The temperature was increased to 150 °C and the samples taken to near dryness (ca. 5 ml).
7. The residue was dissolved in 2 to 3 ml dilution acid.
8. The solutions were then transferred quantitatively to 10 ml volumetric flasks.
9. The solution was then diluted to volume with dilution acid.

The spectrometer was then calibrated according to manufacturers specifications.

Calculations

1. The solution concentrations for the sample, Cs (g/mL), and the average media blank, Cb (µg/mL), from the instrument, were obtained.
2. The solution volumes of the sample, Vs (mL), and the media blank, Vb (mL), were used to calculate the concentration, C (mg/m^3), for each of the elements in the air volume sampled, V (L):

$$C = \frac{CsVs - CbVb}{V}, mg/m^3$$

Evaluation of Method

Method P&CAM 351 was evaluated in 1981. The precision and recovery data were determined at 2.5 and 1000 µg of each element per sample on spiked filters. The precision and recovery data, instrumental detection limits, sensitivity, and analytical wavelength for lead are given below:

- Precision – 0.011 (1000 µg/filter)
- Recovery - 105 (2.5 µg/filter) and 95 (1000 µg/filter)
- Instrumental detection limit - 17 (ng/mL)
- Sensitivity - 0.42 (µg/mL)
- Analytical wavelength - 220.4 (nm)

3.4 Biological Sampling – Acquisition of samples

Venepuncture was used to obtain blood from a tappers arm. The aim of the venepuncture was to obtain a blood sample of sufficient volume for the blood lead level (BLL) test. The blood was obtained from a vein in the patient's arm, the most common area being the antecubital fossa, the area in front of the elbow. Veins do vary in position, the veins move around within the arm. The vein selected for venepuncture could be anchored by pressing down on the vein an inch or so below the venepuncture site. Important was to note that the brachial artery and the medial nerve are situated in close proximity to each other and care was taken not to insert the needle too deeply in the antecubital fossa area (area in front of the elbow).

In the event of a vein not being found in the antecuital fossa area, the forearm and the back of the hand was examined for an obvious vein. On rare occasions venepuncture was carried out on the foot or the femoral vein in the groin region.

To find a suitable vein a tourniquet was used to "bring up" veins by restricting the flow of blood up the arm through the veins. Care was teken not be place the tourniquet to close to the site of venepuncture, but approximately 5 cm away from the venepuncture site. When applying the tourniquet, care was taken not to pinch the skin. The tourniquet was also not pulled too tight, as this could have caused the patient discomfort, and the release of the pressure that built up could have lead to the leaking of blood in the vicinity immediately surrounding the insertion of the needle point, or even the spurting of blood out of the vein. Before piercing the skin, the skin was sterilised by wiping the area identified for venepuncture with a isopropyl alcohol swab. This removed all dirt and oil from the skin, and also decreased the amount of bacteria in the area. The skin was the dried with cotton wool, to prevent any unpleasant stinging sensation as a result of the alcohol on the needle when the skin was pierced in the presence of the alcohol.

The combined needle and valve system was used. This entailed a needle screwed into an open ended plastic cylinder. The needle was inserted at between 20 – 40 degrees. Inserting the needle at a too shallow angle would cause pain and also cause the vein to roll away. Inserting the needle at too great an angle may have caused the vein to become transfixed. Care was taken not to bend the needle before venepuncture. A tube was inserted into a plastic cylinder, and blood was drawn automatically into the cylinder due to the presence of a vacuum within the tube. Once removed, the valve seals the needle.

Upon removal of the needle firmly press a piece of cotton wool on the venepuncture site. Serious bruising in the area of the venepuncture should have been avoided if pressure was maintained on the venepuncture site for an adequate period of time after the needle was removed from the arm.

Samples were carefully marked and transported by the staff members of the laboratory responsible for the analysis. An analysis was performed by an approved laboratory, using the following procedure:

According to Poongavanum (2004) the following procedure was followed in analysis of the blood samples, for blood lead levels:

1. All samples and controls were brought to room temperature and mixed thoroughly.
2. A x 10 dilution of samples was prepared using 0.5 % $(NH_4)_2HPO_4$.
3. The mixture was vortexed thoroughly.
4. All samples (EDTA) and controls were treated in exactly the same manner.
5. The standard was prepared using stock standard, Spectrascan Certified Element Standard – Lead ± 3 µg/ml.
6. A 10 µg/dl standard was prepared using the working stock standard, by using 100 µl of sheep blood plus 800µl of diluent plus 100 µl of working stock standard, which was capped and vortexed
7. Analysis was then performed using a Varian Spectra AA 220Z.
8. The technique used was Atomic Absorption with Zeeman background correction.
9. Calibration was automatically done by the instrument.
10. The curve used ranged between 2.0 and 10.0 µg/dl.

The results were then printed on individual sheets for each of the employees of the sample group. Permission was obtained by the occupational hygienist from each individual to make use of their results, after these were made known to each employee individually.

3.5 Questionnaires

A questionnaire was designed using a number of international questionnaires. Numerous discussions were held with tappers employed at the smelter. In the discussions the various questions contained in the questionnaires were discussed briefly with the tappers. The questions to which all answered no were omitted from the questionnaire to be used in the study. Of all the original questions only 4 questions, called risk factors, gave varying results when discussed with tappers. For example, all the tappers use electricity at home, and do not have to use fossil fuels. This resulted in a very simple, short questionnaire, which was explained to each individual before being asked to complete it. Each question was given three answer options: yes, no and not sure. The "not sure" option was included in the event of any employee not being absolutely sure as to what he feels regarding the question. For example, someone who has the occasional social cigarette: does he class himself as a smoker or a non-smoker?

An example of the questionnaire is attached in appendix B.

3.6 Statistical analysis

The statistical analysis of the results was performed by the statistical department of the University of the North's Mrs. Rita Olwagen. Due to the nature of the sampling process, a small amount of initial samples are taken to give an indication as to the presence and levels of the contaminant concerned. The Man-Whitney test is used in place of a two sample *t* test when the population being compared is not normal (Lethen, 1996). This gives a statistical significance, in the form of a P-value, along with a standard deviation for the results obtained. "In a statistical hypothesis test, the P-value is the probability of observing a test statistic at least as extreme as the value actually observed, assuming that the null hypothesis is true. This probability is then compared to the pre-selected significance level of the test. If the P-value is smaller than the significance level, the null hypothesis is rejected, and the test result is termed significant." (Anon., 2004b) A P-value of below 0.05 indicates statistical significance, and a P-value of above 0.05 indicates no statistical significance for the data concerned.

The Chi-Square Goodness-of-Fit Test is used in testing data with a specific distribution. The attractive feature is that the Chi-Square test can be applied to any univariate distribution. The Chi-Squared Test is usually used for data that is into classes. The effectiveness of the test however lies in the choice of classes for the data. In combination with Fisher's exact test a P-value for statistical significance was again given along with standard deviation for the classes of data used and grouped together (Anon., 2004b)

Lastly the *t* test is used and run between all variables. Essentially test are run between all sets of variables that need to be compared to each other. This is done by comparing the means of the data with each other. Again a P-value indicates whether or not there is a statistically significant difference between the data being compared, along with a standard deviation for each of the sets of data being compared. Ultimately in our study we compared the means of the slag tapping floor (STF) with the mean of the matte tapping floor (MTF), after numerous other test were run on data comparing aspects such as BLL with risk factors, stemming from a questionnaire (Hopkins, 2000).

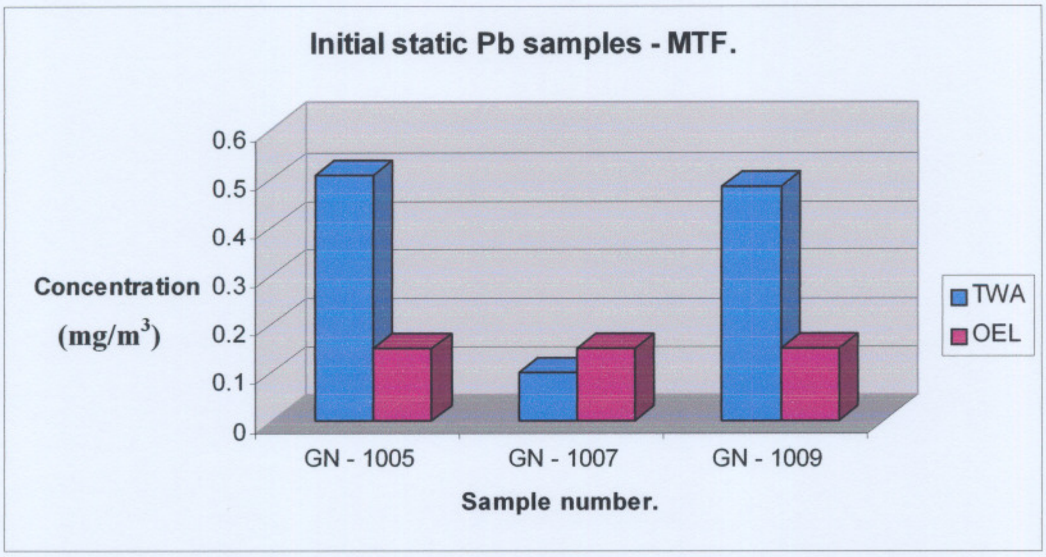

Figure 1 – Initial static Pb samples taken on the Matte Tapping Floor (taken as part of the base-line risk assessment).

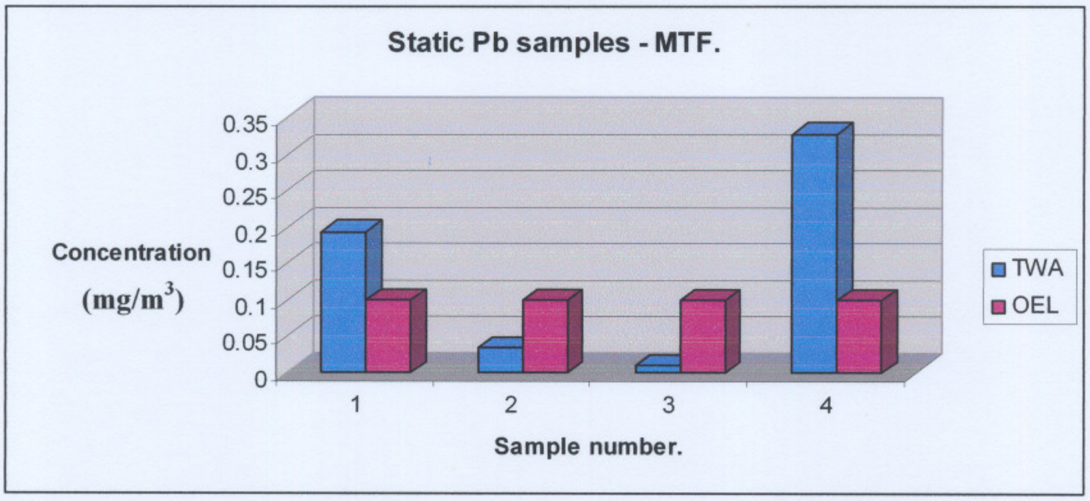

Figure 2 – Static Pb samples taken on the Matte Tapping Floor.

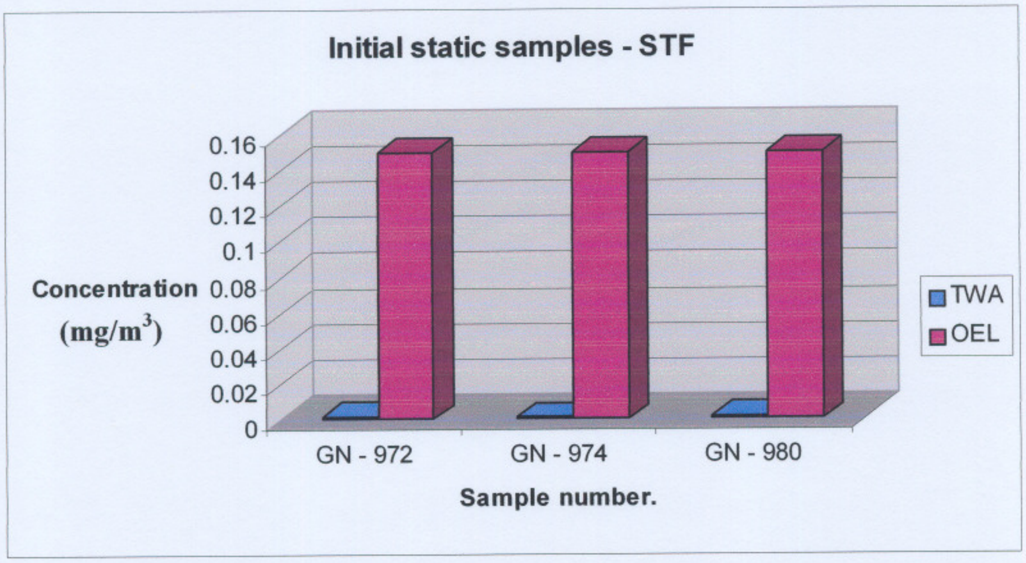

Figure 3 – Initial static Pb samples taken on the Slag Tapping Floor.

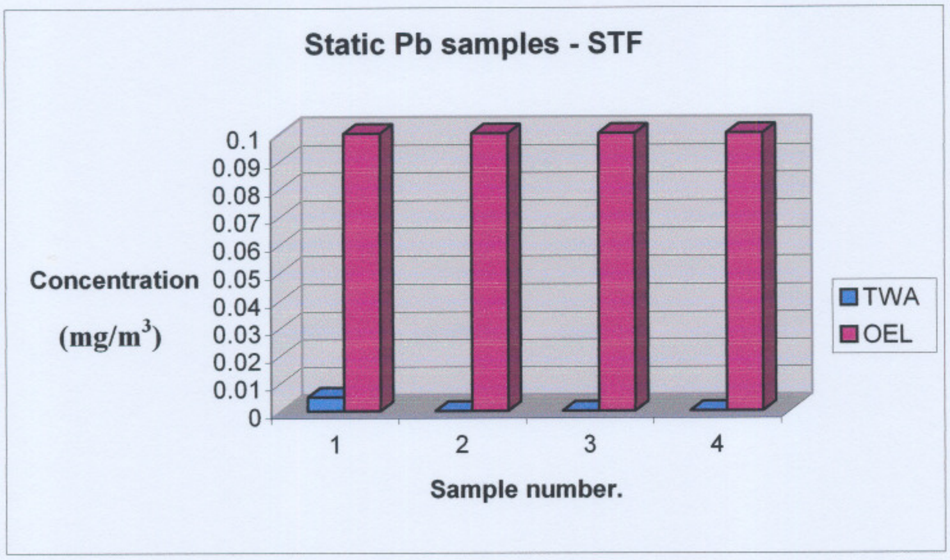

Figure 4 – Static Pb samples taken on the Slag Tapping Floor.

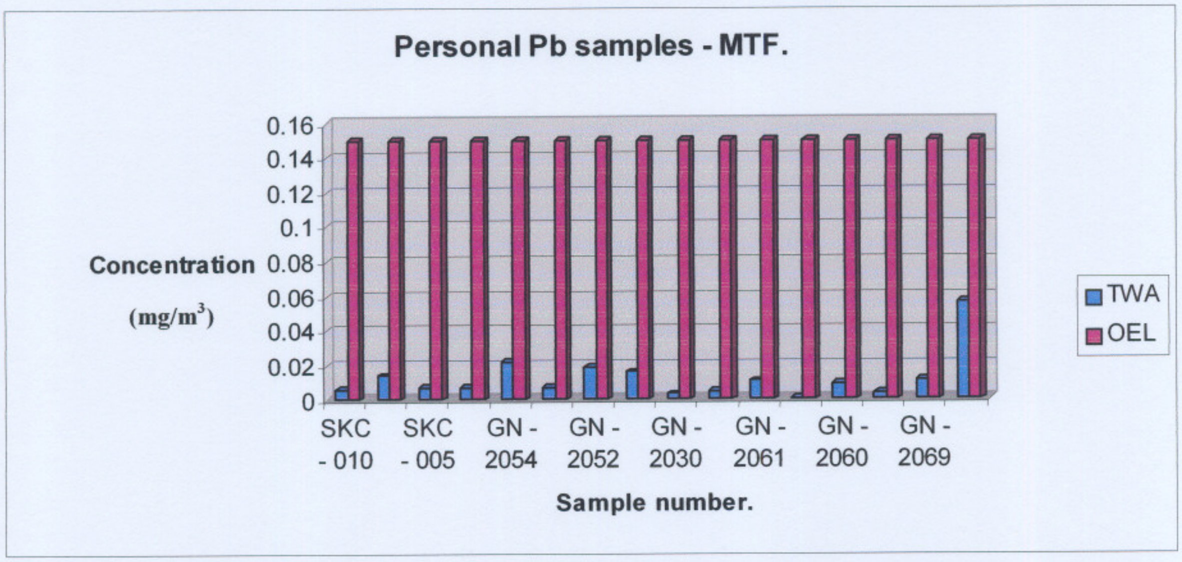

Figure 5 – Static Pb samples taken on the Matte Tapping Floor.

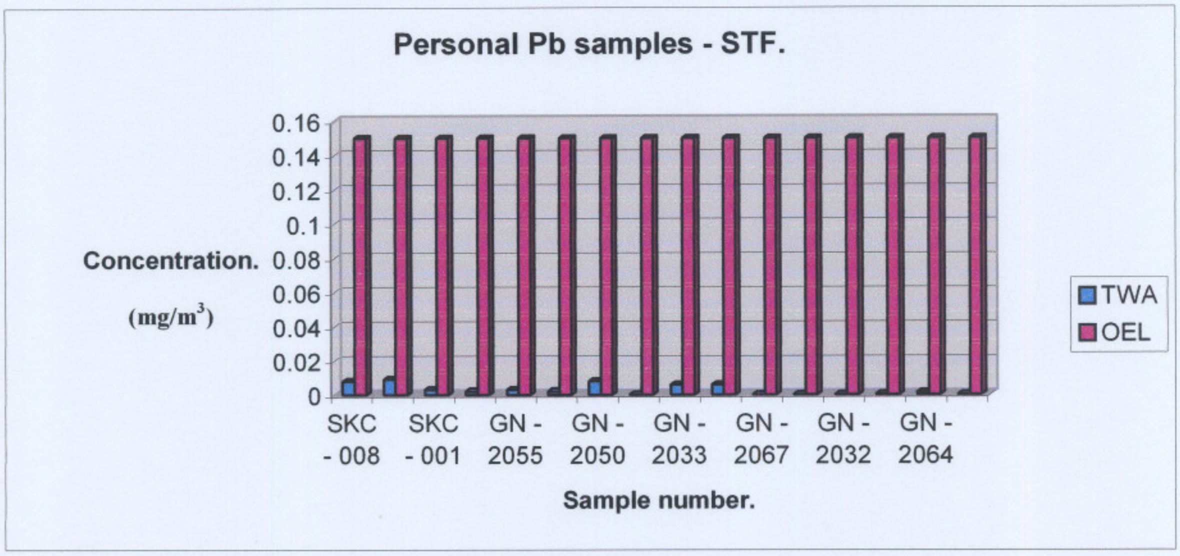

Figure 6 – Static Pb samples taken on the Slag Tapping Floor.

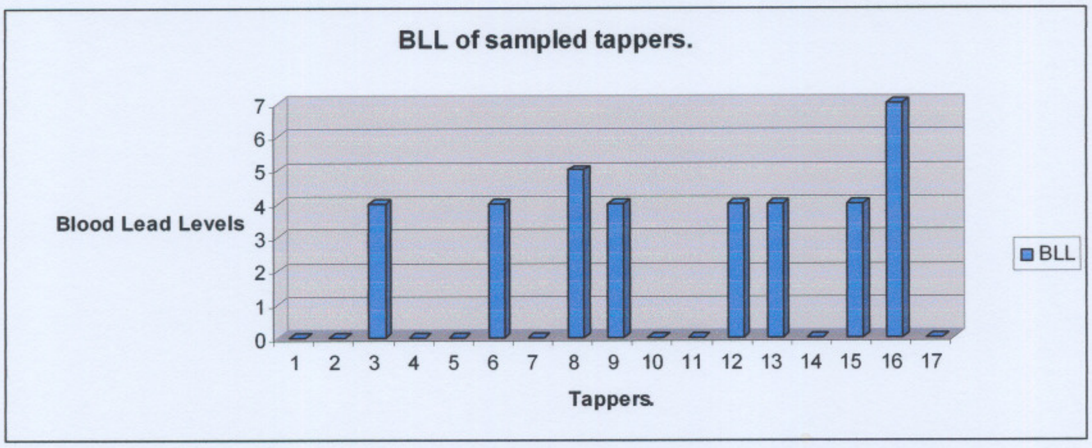

Figure 7 – Blood Lead Levels of sampled tappers.

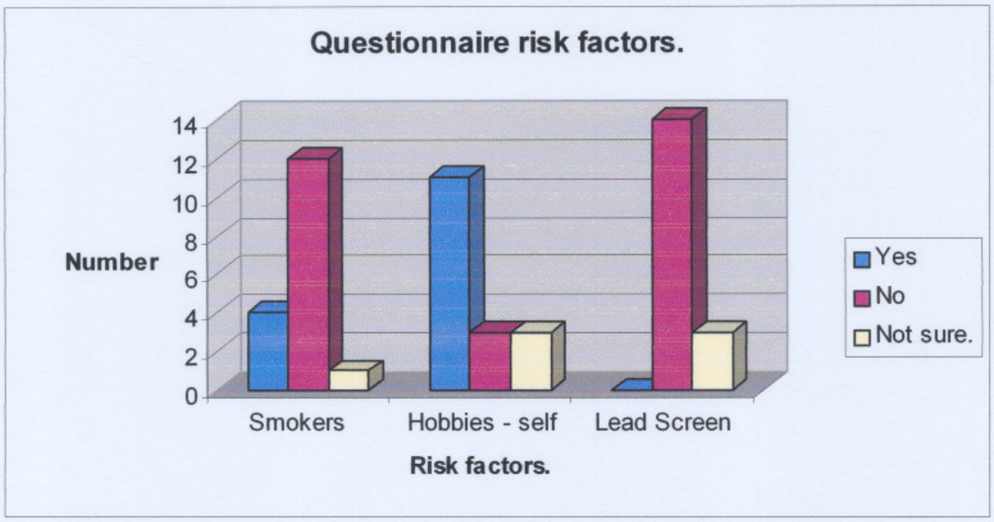

Figure 8 – Results of the questionnaire filled in by all tappers regarding possible non-occupational exposure to lead.

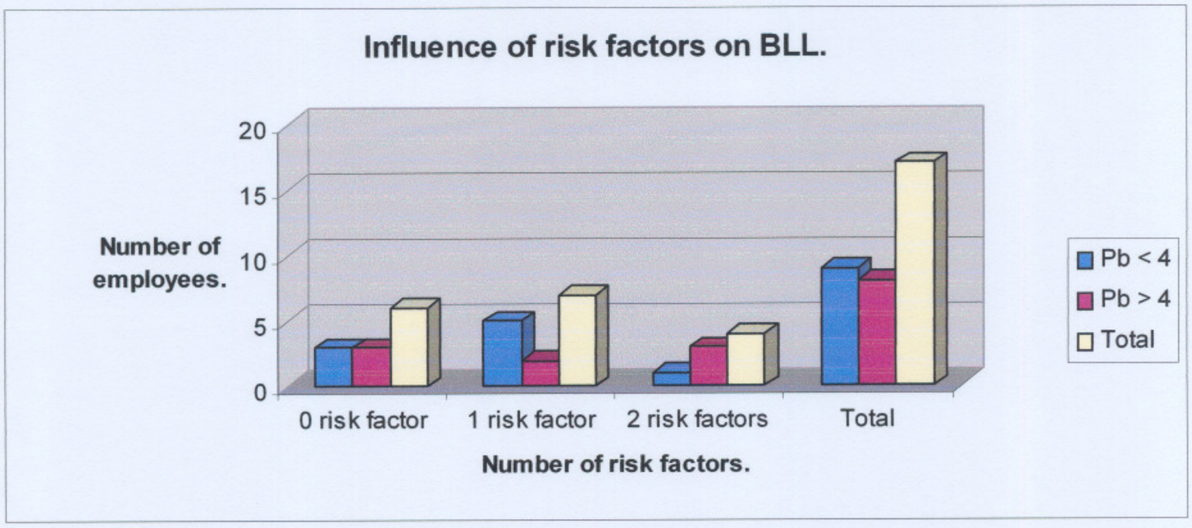

Figure 9 – The influence of the number of risk factors on the BLL of the tappers.

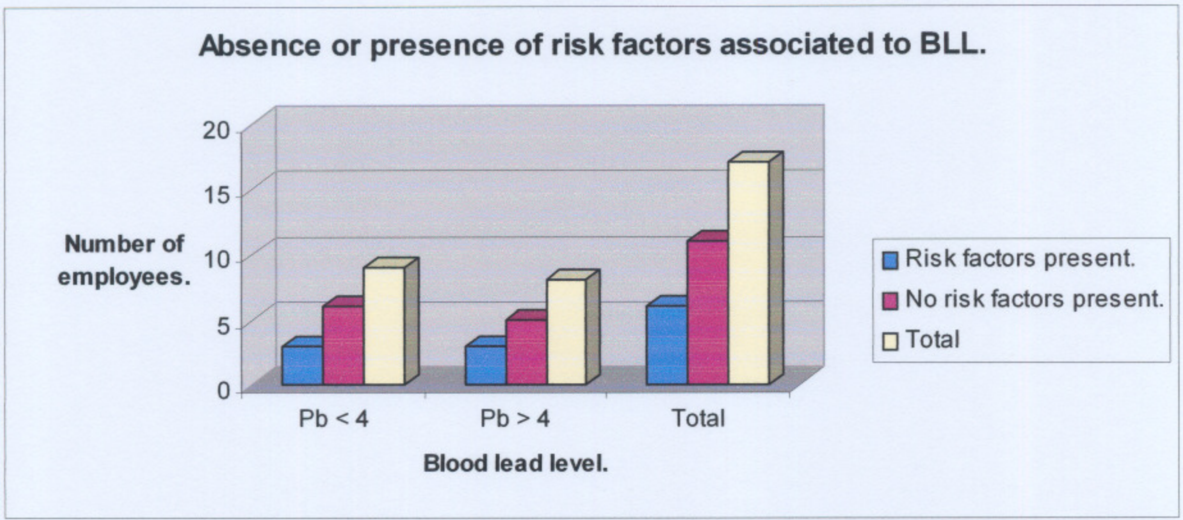

Figure 10 – The influence of the absence or presence of risk factors on the BLL of the tappers.

Table 1:- Non-parametric test comparing the initial static samples to the static samples taken during the personal exposure surveys conducted on the matte and slag tapping floors, within the furnace building.

Time		Site	N	Mean rank	Sum of ranks
Initial	Pb value	STF	3	2	6
		MTF	3	5	15
		Total	6		
Static	Pb value	STF	4	2.75	11
		MTF	4	6.25	25
		Total	8		

Table 2:- Non-parametric test statistics comparing the initial static samples to the static samples taken during the personal exposure surveys conducted on the matte and slag taping floors, within the furnace building.

Time			Pb value
Initial	P - value	(Exact Sig. 1-tailed)	0.1
Static	P- value	(Exact Sig. 1-tailed)	0.057

Table 3:- Group statistics for comparison between the means of Pb levels for the MTF and STF combined.

Site	N	Mean	Std deviation	Std error mean
STF	7	0.00271	0.003251	0.001229
MTF	7	0.22351	0.202609	0.076579

Table 4:- T-test comparing the means of Pb levels for the MTF and STF combined.

	Pb value
P - value (Exact Sig. 1-tailed)	0.028

Table 5:- T-test comparing the means of Pb levels for the MTF and STF.

	Mean	N	Std Deviation	Std error mean
Samples MTF	0.0126	16	0.0131106	0.003278
Samples STF	0.00293	16	0.0033433	0.008358

Table 6:- P-value of T-test comparing the means of Pb levels for the MTF and STF.

	Pb value
P - value (Exact Sig. 2-tailed)	0.007

Table7:- Descriptives for Fisher's exact test.

	Mean	N	Std Deviation	Std error mean
Samples MTF	0.0126	16	0.0131106	0.003278
Samples STF	0.002875	16	0.003245	0.000787

Table 8:- P-value of T-test comparing the means of Pb for the MTF and STF.

	Pb value
P - value (Fisher's exact test).	0.627

Table 9:- Cross-tabulation of risk factors and the BLL's.

Risk factors.		Blood Lead Groups		Total
		Pb < 4	Pb ≥ 4	
0	Count	3	3	6
	% within risk factors.	50	50	100
	% within BLL grp	33.3	37.5	35.3
1	Count	5	2	7
	% within risk factors.	71.4	28.6	100
	% within BLL grp	55.6	25	41.2
2	Count	1	3	4
	% within risk factors.	25	75	100
	% within BLL grp	11.1	37.5	23.5
Total	Count	9	8	17
	% within risk factors.	52.9	47.1	100
	% within BLL grp	100	100	100

CHAPTER 5: DISCUSSION

The sampled Smelter started operation in March 2003. Due to the fact that the Smelter was new and an initial assessment of possible exposures needed to be determined, it was decided to undertake a full scan of the suspected elements present in the ambient atmosphere of the furnace building. A dust scan identified a number of elements, of which the elements that were present in the highest concentrations and those with serious health effects were sampled for in all areas of the furnace.

The results portrayed in figure 1 were obtained for the Matte Tapping Floor (MTF) of the furnace building. These results clearly indicate that lead is present in the ambient atmosphere of the MTF at concentrations that exceed the levels prescribed in the Lead Regulations of the Occupational Health and Safety Act (OHS Act), Act 85 of 1993. The OHS Act specifies an occupational exposure level (OEL) of 0.15 mg/m^3 for lead other than tetra-ethyl lead.
Sample 1 and 3 were in excess of the OEL as prescribed in the OHS Act, which implies that the group of sampled workers need to partake in a medical surveillance programme to determine what the BLL's of each individual worker are. These levels are then studied by an occupational medical practitioner (OMP), who determines what impact the exposure to airborne lead has on each individual workers health. Based on the BLL's the OMP determines whether further steps are required for control or elimination of the exposure to Pb.

Despite the fact that the initial levels on the Slag Tapping Floor did not indicate that Pb was present in significant amounts, figure 3, a decision was taken to measure the STF to allow comparison between the MTF and the STF. This decision was based on the fact that the process on the STF is practically identical to the process on the MTF. Tapping in short involves the opening of a tap hole that is in direct contact with the molten bath of metal. This molten metal is then allowed to flow from the furnace to control the furnace level. As with most processes there is a by-product, which in this case is known as slag. The furnace is sloped downward from the slag end toward the matte end, which allows the heavier metals to "sink" down toward the matte end. On the MTF the molten metal that passes out of the furnace contains the valuable heavier metals like: platinum, gold, silver, iron, copper, iridium, rhodium, rubidium, etc. Along with the valuable heavy metals, Pb, which is a heavy metal, is passed out.

Pb is found in the close proximity to the valuable heavy metals in group 3A and 4A of the periodic table. This explains why Pb is found in concentrations on the MTF that are higher than the levels found on the STF. The Pb moves down the slope of the furnace along with the heavy metals to be concentrated on the MTF and when the furnace is opened in the tapping process, the heated molten metal releases airborne lead in the ambient atmosphere of the MTF. Pb is not the only metal that will become airborne at this temperature, but lead when heated above 530°C releases metallic fumes of fine particle size (Stanton, *et al.*, 2001). The above statement would then raise the question as to why Pb was found on the STF. The slag is the waste products formed from the smelting of the ore containing concentrate. The slag contains small amounts of the valuable metals, and Pb which becomes trapped, cannot move down the slope of the furnace toward the lower lying MTF.

Further static samples were taken along with the personal samples on both the MTF and the STF (figure 2 and 4). These served as indicators that the conditions at the time of the personal sampling undertaken on the MTF and the STF were not significantly different from the conditions during the taking of initial static samples. Table 1 and table 2 indicate that there is no statistical significance between the initial and static samples for both the MTF and the STF. When compared to each other there was not a significant difference between the two sets of measurements and it can be concluded therefore that the conditions were similar in both surveys. P-values of 0.1 and 0.057 indicate that there was no statistically significant difference between the two sets of data. The T-test could not be performed due to the fact that there were too few samples. Instead, the Mann-Whitney test was used to obtain a meaningful result for the comparison between the two sets of data.

Another reason for deciding on taking readings on both the MTF and STF was to allow a comparison between the two floors due to the similarities between the two tapping floors. In this instance the number of samples was increased to provide enough data to make use of the T-test. A comparison of the static and personal samples, table 3 and table 4, taken on the MTF and the STF, reveal as expected, a statistical significant difference. A P-value of 0.028 indicates a statistically significant difference between the MTF and the STF, with a standard deviation of 0.003251 for the STF and 0.202609 for the MTF. This means that a higher airborne Pb concentration is found in the ambient atmosphere of the MTF.

The personal samples depicted in figure 5 taken on the MTF indicate that sample number 16 was in excess of the action level for lead. The rest of the samples were below the action level. The control measures that are in place are lowering the level of airborne Pb, which is indicated by the levels obtained in the personal samples. Therefore the results indicated that a measurement programme must be implemented.

The personal samples depicted in figure 6 taken on the STF indicate that the levels obtained on the STF are even lower than the levels on the MTF. Indicating that the levels of airborne PB in the ambient atmosphere of the STF are low.

When comparing the MTF and STF, personal samples. As in table 5 and table 6, a P-value of 0.007, with a standard deviation of 0.0131106 for the STF and 0.0033433 for the MTF, indicates a statistically significant difference between the levels of airborne Pb in the ambient atmosphere of the MTF and the STF, with the levels on the MTF being far higher than the levels found in the atmosphere of the STF.

The blood lead level (BLL) obtained for each tapper is depicted in figure 7. Despite the fact that numerous of the values in the graph appear to be zero, no values of zero were in fact obtained. The sensitivity of the BLL test indicates BLL that can broadly be divided into two groups for the sake of this study: BLL's of less than 4 μg/dl and blood levels of 4 μg/dl or higher. Due to the fact that no physical value could be attached to the BLL below 4 μg/dl, they appear to be zero. The BLL's were all found to be well below 20 μg/dl, which is seen internationally and in the OHS Act, as the action level. Essentially this means BLL's over 20 μg/dl serve as an indication that action needs to be taken to start decreasing the exposure levels of employees. This serves to prove that the current control measures, which will be discussed in greater detail later, are lowering the levels of airborne Pb to below the action level in the 94 % of the measured employees. Despite these statistics we need to treat the entire sample population as the worst-case scenario, which in our case is the one employee, which was exposed to levels in excess of the action level.

Due to the fact that it is common practice in occupational hygiene not to sample control groups, a decision was taken to run this study in a similar fashion. An international study performed with a large number of individuals in the US, concluded that the average BLL for urban persons was 13.0 µg/dl and that for rural persons 1.5 µg/dl (Miller, 1999). Despite this not being a local study, paired with the fact that the US has phased out leaded petroleum for a number of years, averaged levels for South African conditions could be expected to be higher than those in the US. This could be attributed to the fact that we still use leaded petroleum, and that a number of rural people still burn fossil fuel like wood and charcoal, which can expose them to airborne Pb. We could therefore expect our average BLL's to be higher, in both urban and rural populations.

The non-occupational exposure to lead questionnaire was filled in by all participants of the study. The questionnaire aimed to identify all non-occupational exposures to Pb, that may play a role in explaining any significant BLL's that might be recorded in the workers. The results of the questionnaire are depicted in figure 8. Four tappers indicated that they are smokers, 12 indicated that they were non-smokers and 1 was not sure. Twelve indicated that they were involved in hobbies that could expose them to non-occupational lead, 2 were not and 2 were not sure. A similar question was asked involving the activities of family members who might have been involved occupationally or non-occupationally in any activities that may lead to possible secondary exposures to lead. All answered no at the time of the questionnaire. Lastly, no tappers had been for a previous lead screen, and 2 were not sure.

The tapper with the highest BLL, namely 7 µg/dl, was one of the tappers who answered no to all the questions on the questionnaire. This means that we need to observe his work habits and procedures to determine if there is something in his daily activities that may expose him to more airborne Pb than any of his colleagues, as the higher BLL cannot be attributed to a possible non-occupational exposure to Pb. Alternately, we could explain this by simply accepting that not all individuals will react in the same way to the same levels of airborne Pb in the same working environment, and that the tapper concerned may not be able to rid his body of Pb in the same way his fellow tappers do.
Table 9 indicates that there is no association between BLL's and the risk factors. Of the tappers that indicated they had no risk factors, 3 had BLL's of < 4 µg/dl and 3 had BLL's of ≥ 4 µg/dl. Of the tappers that indicated they were exposed to one additional risk factor, 5 had BLL's of < 4 µg/dl and 2 had BLL's of ≥ 4 µg/dl. Of the tappers indicating that they were exposed to two additional risk factors, 1 had BLL's of < 4 µg/dl and 3 had BLL's of ≥ 4 µg/dl. In total, 52.9 % of the tappers had BLL's of < 4 µg/dl and 47.1 % had BLL's of ≥ 4 µg/dl.

Of the 52.9 % that had BLL's of < 4 µg/dl, 33.3 % were exposed to no additional risk factors, 55.6 % were exposed to one additional risk factor and 11.1 % to an additional two risk factors. This indicates that the greatest majority of the group < 4 µg/dl were exposed to one additional risk factor. Of the 47.1 % that had BLL's of ≥ 4 µg/dl, 37.5 % had no additional risk factors, 25.0 % had one additional risk factor and 37.5 % had two additional risk factors. Again, this indicates that the majority of the group ≥ 4 µg/dl fell into two categories i.e. 37.5 % with no additional risk factors and 37.5 % with two additional risk factors.

In figure 9 the effect of the risk factors and the effect of those risk factors on the BLL are depicted. From the graph it is clear that there is no direct link in any of the cases between the risk factors and the BLL. Figure 10 depicts the absence or presence of risk factors and the association thereof to BLL. Again there is no link to the absence or presence of risk factors and the BLL. Table 7 and table 8 indicate a P-value of 0.627, with a standard deviation of 0.0131106 for the MTF and a standard deviation of 0.0007870, which means that there is no statistical significance between the risk factors and the BLL's.

CHAPTER 6: RECOMMENDATIONS AND CONCLUSIONS

RECOMMENDATIONS

Despite the fact that 94 % of the sampled tappers, exposure fell below the action level, there was one tapper that was exposed to airborne lead (Pb) levels that exceeded the action level. The action level for any exposure is set at 50 % of the occupational exposure level (OEL) for that substance. This is used as an indication that action needs to be taken to prevent a possible exposure of that employee to the substance concerned. The group of tappers therefore need to be treated in the same way as the worst case scenario, and therefore current control measures and the effectiveness thereof need to be carefully reconsidered.

The most effective of the current controls according to the author of this study is the administrative arrangements that are currently in place. The shifts worked by the tappers are 12 hour shifts, with a cycle of 2 days work, 2 days off and 3 days on , 3 days off. With alternating day and night shift. This means that a tapper will work 1 day as a tapper on the MTF and then be moved to the STF or another area in the plant. By minimizing the time spent tapping on the MTF the exposure to Pb is effectively decreased. By investigating and recommending a minimum time being spent per individual on the MTF exposue levels could possibly further decrease.

Extraction ventilation was installed as a control measure as part of the original project, the effectiveness of which needs to be investigated. The uptake velocities need to be measured and calculated, to determine whether they are sufficient for ridding the atmosphere of airborne substances like Pb. An investigation into extending the uptake area of the extraction ventilation to cover the launders, to remove a greater percentage of the airborne particulates could be undertaken.

The matte tapping floor (MTF) must be declared a respirator zone. This will increase the level of protection of the tappers and any other employees that find themselves in this area in the course of a working day. This measure should remain in effect until the Pb levels are brought down sufficiently to decrease exposure levels to below the OEL for Pb, measured at a static position similar to the measurements taken in this study.

Personal hygiene also needs to be stressed, through education. Simple steps like the washing of hands before eating or drinking, no smoking on the MTF, will significantly decrease personal exposure to Pb.

The control of airborne Pb should however concentrate on decreasing the levels of airborne Pb, preferably at the point of emission. The dlowering of the airborne levels will automatically decrease all other exposures to Pb. Good house keeping would mean keeping the dust levels in the area to a minimum. Standard operating procedures should be observed to ensure that the amount of time spent over or in the immediate vicinity of a launder is kept to a minimum.

According to the Lead Regulations, of the Occupational Health and Safety Act, Act 85 of 1993, a couple of additional control measures need to be introduced to decrease any further exposures and also to ensure that family members are not exposed to Pb once the worker gets home. Clothing should be of such a material that will not trap Pb, and should not have any pockets in which Pb could get trapped. Washing of clothes should be done separately, from other employees clothes that may not have been exposed to Pb. If clothing is sent away for washing, or disposed of it should be handled as hazardous waste, sealed and clearly marked as such. The washing or disposal should be handled by persons who are competent and equipped or trained to do so. No contaminated clothing may be taken home by workers. Change house or cleaning facilities should have a "clean" and "dirty" side. Tappers should enter the "dirty" side after a shift and take off dirty clothes. Upon completion of cleaning under a shower, tappers should move to the "clean" side where the can get into the fresh clothes that were left in a separate locker for this purpose before the shift commenced.

In light of the fact that the OEL for Pb was exceeded the medical practitioner has made a call that a follow up BLL test be performed within the next year. This is to ensure that there is no increase in the BLL due to a change in exposure.

CONCLUSION

Based on the findings of the study it is clear that Pb is present at concentrations in excess of the occupational exposure limit (OEL), in the ambient atmosphere of the matte tapping floor (MTF). Despite the ambient concentrations of Pb in the atmosphere of the MTF, the blood lead level (BLL) tests revealed that the amount of Pb actually being taken up by the tappers being below the action levels as prescribed in the Lead Regulations of the Occupational Health and Safety Act (OHS Act), Act 85 of 1993. An action level of 20 μg/dl, at or over which BLL tests should be performed on a 6 monthly basis, is prescribed in the Lead Regulations of the OHS Act. All tappers BLL's were below 10 μg/dl, indicating that control measures are effective in ensuring that the amount of Pb being taken up by the bodies of the tappers is below the action level.

However even though this is the case, there is still a concern as the ambient concentrations are in excess of the OEL for Pb. This means that additional controls need to be investigated to decrease these levels to below the OEL. This would essentially mean that exposure to Pb would be controlled sufficiently. In order to achieve this it is necessary to consider increasing the extraction ventilation effectiveness currently being used on the MTF. Training and awareness of personal hygiene should also further decrease exposure to Pb as a result of ingestion. The implementation of "clean" and "dirty" change rooms for employees exposed to Pb on the MTF to ensure that no contaminated clothing is taken home, resulting in a possible exposure of family members.

The higher level of Pb found in the atmosphere of the MTF floor can be attributed to the fact that Pb being a heavy metal, and due to the design of the furnace, becomes concentrated along with the other heavy metals on the MTF. The furnace slants down toward the MTF from the slag tapping floor (STF). The MTF is opened allowing the valuable heavy metals to run down a launder into a ladle, a process which lasts about 45 minutes per ladle. During the opening of the furnace, the hot (± 1350°C) molten metal is allowed to run down an open launder. It is during these activities that Pb becomes airborne due to the build up of kinetic energy. The particles then become airborne and as a result of the design of the MTF become entrapped and settle on the MTF again. This explains why the ambient concentration of Pb on the MTF is in excess of the OEL.

The hypothesis that the MTF will have a higher exposure to airborne lead than the STF is proved correct.

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Appendix A

Permission sheet as completed by each employee taking part in study.

Permission to use data from blood lead tests for MSc thesis.

I ______________________ (name and surname), company number ___________ hereby give permission for the results from my personal blood tests to be used in an MSc thesis being undertaken by Morné de Beer. With the understanding that my personal particulars will not be used in doing so, only that the results obtained will be reflected in the results and discussion.

____
Signature

____
Print name.

13. Appendix B

Questionnaire regarding possible non-occupational exposures to lead.

(Point allocation for statistical analysis indicated in red.)

Polokwane Smelter

ABBREVIATED QUESTIONNAIRE

Risk Assessment for Lead Exposure

Guidelines:

- **Target population** – This questionnaire is to be completed by all persons partaking in this study.
- **Assessment of risk** – The questions on this questionnaire should be used for risk assessment of level of exposure to lead.
- **Local community** – Questions specific to situations that exist in the community should be added to the questionnaire and asked of all participants.
- **Negative responses** – If the answer to all the questions are negative, then those persons exposure will be considered a "low risk" for high doses of lead exposure.
- **Positive answers** – If the answer to any question is positive, that person is to be considered a "high risk".
- **" Not sure" answers** – A not sure answer to any question, will result in the question being explained to the participant (re-phrased). If the person remains unsure we will assume the answer is positive.

Name of participant:____

Date questionnaire completed:______________________________

ABBREVIATED QUESTIONNAIRE
Risk Assessment for Lead Exposure

Please fill the questionnaire in as honestly as possible. The answers will be kept confidential, and is only for the purpose of this study.

1. The following possibilities are to be used in answering the questionnaire:

a. Yes
b. No
c. Not sure

1. Do you smoke?

☐ Yes (1) ☐ No (2) ☐ Not sure (3)

2. Does anyone in your family:

- Re-load bullets?
- Make fishing sinkers?
- Make pottery?
- Go to or work at a firing range?
- Make stained glass?
- Re-finish furniture?

☐ Yes (1) ☐ No (2) ☐ Not sure (3)

3. Do you do/participate in one of the following activities, in a full or part time capacity?

- Car workshop? - Radiator repair?
- Spray painting? - Battery replacement?
- Smelting? - Grinding or removing of paint?
- Painting? - Plumbing?
- Petrol jockey? - Refinery?
- Melting down of scrap metal? -
- Disassembling batteries?

☐ Yes (1) ☐ No (2) ☐ Not sure (3)

4. Have you ever been for a lead screen before?

☐ Yes (1) ☐ No (2) ☐ Not sure (3)