

Exposure to tailings dust, the Characterization thereof and the Evaluation of Current Control Measures

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OPSOMMING

Agtergrond

Slikdamwerkers word blootgestel aan stof wat potensiële gesondheidsrisiko's inhou as gevolg van die elemente wat daarin voorkom. Nietemin is die blootstellingsvlak van slikdamwerkers onbekend. In hierdie studie is ondersoek ingestel op die inhoud van die stof, die blootstellingsvlak, die potensiële gesondheidsrisiko's van die elemente, die doelmatigheid en doeltreffendheid van die bestaande beheermaatreëls ten opsigte van wetlike aspekte.

Ontwerp en Metode

Tydens die ondersoek is 69 persoonlike stofmonsters oor drie volle produksieskifte op slikdamwerkers in drie verskillende slikdamomgewings geneem. Die totale stofkonsentrasies is bepaal en statisties ontleed. Massa- en filtermonsters is ontleed met 'n 32-element- en partikelgrootteskandering. Die tussen-dam, tussen-dag en tussen-groepveranderlikes is bepaal.

Resultate

Die slikdamwerkers was nie aan uiterste konsentrasievlakke blootgestel nie. Die gemiddelde blootstellings was onder die OEL vir PNOC, naamlik $0,124 \text{ mg/m}^3$ (TD 1) $0,366 \text{ mg/m}^3$ (TD 2) en $2,956 \text{ mg/m}^3$ (TD 3). Laasgenoemde dam het egter drie uitskieters in die data gehad en die aksievlak vir PNOC oorskry. 'n Groter deel van die partikelverspreiding het uit inasembare groottes bestaan ($>10 \mu\text{m}$). Sikloonslikdamme het oor die algemeen kleiner partikelgroottes as die 'spigot'-slikdamme, alhoewel 85% van die partikelgroottes by al die slikdamme groter is as $10 \mu\text{m}$. Sekere elemente wat in die stof geïdentifiseer is kan potensiële respiratoriese gesondheidsgevaare veroorsaak. Geen betekenisvolle verskil het tussen die drie slikdamme voorgekom ten opsigte van stofkonsentrasies nie ($p=0,527$ op 'n 5% betekenisvolle vlak en $p=0,292$ op 10% betekenisvolle vlak). Daar was wel 'n betekenisvolle verskil op 'n 5% betekenisvolle vlak tussen die dae ($p=0,003$ and $p=0,006$). Die slikdamwerkers op die sikloonslikdamme het 'n kleiner blootstelling gehad as die werkers op die 'spigot'-slikdamme, en die pyplynwerkers was aan 'n hoër blootstelling onderworpe as die slikdamwagte.

Die beheermaatreëls by die slikdamme het aan die wetlike vereistes voldoen. Wat wel in ag geneem moet word is die behoefte aan wasfasiliteite om oorpakke skoon te maak as gevolg van die teenwoordigheid van potensiële gevaarlike elemente soos nikkel, chroom en mangaan, wat in die stof voorkom. Opleiding moet hersien word rondom werkspraktyke en -prosedures, persoonlike higiëne en simptome wat ná blootstelling kan voorkom. Ondersoek moontlike ingenieursbeheermaatreëls soos watersproeiërs regoor die slikdam, die gebruik van

permanente of tydelike windskerms en die bedekking van paaie op slikdamme met gruis of die spuit van water op die paaie.

Gevolgtrekking

Daar kan dus saamgevat word dat die studie sy doelstellings bereik het soos uiteengesit in hoofstuk 1. Hipotesis is aanvaar en verwerp en voorstelle vir toekomstige studies is gemaak.

Sleutelwoorde: Slikdamstof, partikelgrootte, elemente, sikloon, spigoting, tussen-damblootstelling, tussen-dagblootstelling, tussen-groepe blootstelling.

ABSTRACT

Background

Tailings dam workers are exposed to tailings dust that has a potential health risk due to the element contents in the dust. The extent of exposure of tailings dam workers is unknown. Consequently, the elements, level of exposure, the potential adverse effects to health, compliance to legislative requirements and the efficiency of the current control measures were investigated.

Design and Method

During the trials, 69 personal dust samples were collected during three full production shifts from tailings dam workers in three different tailings dam environments. The field filters were weighed to calculate the total dust concentrations. Bulk samples and field filters were analysed using the 32-element and particle size distribution scans. The between-dam, between-days and between-group variances were determined to assess the changes in exposure levels.

Results

The tailings dam workers were not overexposed to tailings dust. Mean exposures were below the OEL for PNOC, measuring 0,124 mg/m³ (TD 1) 0,366 mg/m³ (TD 2) and 2,956 mg/m³ (TD 3). Three outliers in the data were present in TD 3 and exceeded the action level for PNOC. A major part of the particle size distribution consisted of inhalable sizes (>10 µm). Cyclone tailings dams have smaller particle sizes than spigot tailings dams, though 85% of the particles in all tailings dams were larger than 10 µm. Some elements identified in the dust have potential respiratory health effects. No significant differences existed between the three tailings dams regarding tailings dust concentrations (p=0,527 on 5% significant level and p=0,292 on 10% significant level). There was, however, a significant difference on a 5% significant level between the days (p=0,003 and p=0,006). The workers on the cyclone tailings dams had smaller exposures than workers on the spigot tailings dams, and the pipeline labourers were more exposed than the mudguards.

The tailings dams did comply with legislative control measures. However, washing facilities for the cleaning of overalls due to elements in the dust, such as nickel, chromium and manganese need to be considered. Workers need to be educated in work practices and procedures, personal hygiene and symptoms that can be experienced after exposure. Engineering control measures such as water sprayers covering the entire tailings dam, the use of fixed or temporary windscreens in the area where work is done and covering of the roads on the tailings dam with gravel or waterspray can be considered as dust suppressant controls.

Conclusion

The study met the issues set out in chapter 1, hypotheses were rejected and accepted and future studies were suggested.

Keywords: Tailings dust, particle size, elements, cycloning, spigoting, between-dams exposure, between-days exposure, between-groups exposure.

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ABBREVIATIONS

AIHA	-	American Industrial Hygiene Association
ANOVA	-	Analysis of Variance is a test that measures the difference between the means of two or more groups.
DME	-	Department of Minerals and Energy
FFP2	-	Filtering Face Piece with medium efficiency
HCS	-	Hazardous chemical substances
KBC	-	Kruger Benadie Consulting in Health and Safety
L/min	-	litres per minute
MCE	-	mixed cellulose ester
MDHS	-	Methods for the Determination of Hazardous Substances guidance
µm	-	micrometers
mg/m³	-	milligrams per cubic metre
mL	-	millilitres
mm	-	millimetres
MOHAC	-	Mining Occupational Health Advisory Committee
NIOSH	-	National Institute for Occupational Safety and Health
OEL	-	Occupational Exposure Limit means the time-weighted average concentration for an 8 hour work day and a 40 hour week to which nearly all workers may be repeatedly exposed without adverse health effects.
OESSM	-	Occupational Exposure Sampling Strategy Manual.
PM₁₀	-	Particulate matter with a mass median aerodynamic diameter less than 10 µm.
PNOC	-	Particulates not otherwise classified
PPE	-	Personal Protective Equipment
RPE	-	Respiratory Protective Equipment
S.A.N.A.S	-	South African National Accreditation System
SAMOHP	-	South African Mine Occupational Hygiene Programme
TLV	-	Threshold Limit Value

ABBREVIATIONS (continued)

- TUKEY HSD test** - The "Honestly Significantly Different" (HSD) test proposed by the statistician John Tukey. This post hoc test (or multiple comparison test) can be used to determine the significant differences between group means in an analysis of variance setting.
- TWA** - Time-weighted average

Chapter 1 - INTRODUCTION

The idiom 'the straw that broke the camel's back' is a reference to any process by which tragic failure (a broken back) is achieved by a seemingly minor addition (a single straw). This means that there is a limit to everyone's endurance, or everyone has his/her breaking point.

This idiom can be related to the ability of the body to absorb insults from the workplace, which can be any stressor influencing the body's health. In the case of this study the stressor is supposedly inert dust. Most people have an idea what dust is. In the occupational environment dusts are an ever-present nuisance and often a health hazard. Dusts and particulate matter are the most visible atmospheric effects of mining activities. Long-term health effects, such as cancer, or short-term effects, such as dizziness and unconsciousness, can develop from chronic or acute concentrations of dust deposited in the lungs. Often, multiple exposures, and potential multiple adverse health effects, can result. It is therefore essential to know the concentrations of harmful substances in the work environment, their chemical and physical characteristics, as well as their biological actions, in order to be able to establish effective measures to prevent or minimize impairment of the health of workers.

Dust-related lung diseases have progressed to such an extent that it overshadows mine accidents in the numbers of affected workers (White, 2001:121; WHO, 1999). This phenomenon is of particular concern because these airborne dusts are associated with occupational lung diseases such as pneumoconiosis, resulting in various illnesses, premature retirement because of disability, or death. Great humanitarian and monetary costs are experienced by individuals due to a loss of income and medical or related expenses; and by mining companies through the loss of experienced employees and the expense of recruiting and training new employees, direct medical expenses and compensation levies (Calverley & Murray, 2005:109).

Particulate matter is a pollutant suspended in the air and represents a mixture of organic and/or inorganic particles that can be solid, liquid or both, depending on the source of the pollutant (CCOHS, 1999; WHO, 2005). These particles vary in size, composition and origin. Their properties are summarized according to their aerodynamic diameter, called particle size and heaviness, because large and heavy particles settle more rapidly (CCOHS, 1999; Stern & Mansdorf, 1999:103; WHO, 2005). Chemical composition is important because some substances in particle form can destroy the cilia (hair cells lined in the nose, trachea and bronchi). Cigarette smoking may alter the ability of the lungs to clear themselves.

Dusts are solid airborne particles, created through mechanical actions, such as mine activities from quarries, grinding, crushing, milling, during the transfer of finely divided material or occur naturally (Stranks, 1995:39; White, 2001:121). When dust clouds are visible in the air, it is almost certain that dust of potentially hazardous quantity is present. However, even if no dust cloud is visible, there may still be dangerous concentrations of dust present with a particle size invisible to the naked eye under normal lighting conditions (Unsted, 2001:100; WHO, 1999). Dusts with the same visual appearance can differ in their health significance, depending on the toxicity of their components. A growing body of evidence suggests that some airborne particles previously considered inert or as only a nuisance, may have the potential for biological activity after being sequestered in the human lung for many years. Damp materials are less likely to release airborne dust, but of course, this does not apply if they dry up later.

Quantitative evaluations of airborne dust may be performed for a number of reasons, for example to characterize the exposure conditions in relation to an adopted standard, to determine whether the contamination represents a potential or a real hazard, and to establish the need for control measures or to assess the effectiveness of control strategies (WHO, 1999).

The mining industry is being subjected to increasing public scrutiny, particularly because of its record in environmental degradation and impacts on human health and safety (Fourie, 2003). The industry is often seen as exploitative, dirty, dangerous, having no regard for human health and the environment. This scrutiny can and does lead to legislation that makes mining more expensive. The Occupational Health and Safety Act (85/1993), Mine Health and Safety Act (29/1996) and the Hazardous Chemical Substance Regulations (R.1179/1995) all relate to the safety of workers and the public.

Platinum mining in South Africa has experienced a significant growth over the last 10 years, making the country the largest platinum producer in the world (Boshoff, 2000). This positive trend has created the opportunity to improve tailings storage facility design and operations to meet ever-increasing environmental performance standards.

1.1 Problem Statement

Although many studies had already been performed on coalmine workers and animals and the effect dust has on the lungs, none were found on the subject of the tailings dam worker's exposure to dust. One study on rats suggested that the Threshold Limit Value (TLV) for nuisance dust (10 mg/m^3) was too high, because the results indicated that accumulated particles led to pulmonary inflammation and the impairment of the lung's clearance mechanism.

These particles were of relative low toxicity (Henderson *et al.*, 1992). In another study on rats the particles were poorly soluble leading to fibrosis, alveolar inflammation and mutational events (Oberdörster, 2002). Many studies on particulate matter reported significant associations between the inhalation of particulate matter and cardiovascular health. Exposed workers are at risk to develop cardiovascular diseases and having their bone marrow reacting to acute exposures, which eventually can lead to premature death (Gardner *et al.*, 2000, Medeiros *et al.*, 2004; Rivero *et al.*, 2005; Schwartz, 2001).

It is therefore important to study all areas in the mining industry, especially because of legislative requirements and respiratory health effects suggested in dust exposure studies. The dust exposure of employees working at tailings dams is unknown. Consequently, the following are unknown:

- Elements in the exposure dust;
- level of exposure;
- potential adverse effects;
- compliance to legislative requirements;
- the efficiency of control measures.

1.2 Issues to be addressed

The purpose of this mini-dissertation is:

- To introduce the subject of tailings dams;
- to determine the particle sizes in the bulk samples from the three tailings dams;
- to determine occupational dust exposures of workers at different tailings dams through personal dust sampling;
- to identify the elements present in the tailings dust and their physiological effects on the human body;
- to evaluate these results with the different tailings dams and between the workers in order to determine whether there is a correlation in dust concentrations between the different tailings dams and the intensity of exposure of workers at these different tailings dams;
- to provide feedback by way of dust monitoring results. This will determine the effectiveness of current control measures, and facilitate as a warning mechanism should the control measures be insufficient or unsuccessful;
- to compare the different tailings dam control measures and dust exposures to each other, and to the legislative requirements. This step is necessary to

determine whether changes are called for to reduce the workers' dust concentration exposures.

1.3 Hypothesis

The following hypotheses were formulated:

1. The larger percentage of the tailings dust will consist of respirable fractions ($<7\ \mu\text{m}$).
2. Personal dust exposures will increase with an increase in wind speed.
3. Dust exposure between the different days per tailings dam will not differ significantly.
4. Dust exposure between the three different tailings dams will not differ significantly.
5. There will be a significant difference in the concentrations between Mud Guards and Pipe Line Labourers
6. Workers on cyclone tailings dams will have statistically significant lower dust concentrations than workers on spigot tailings dams.

1.4 Summary

In this chapter, an introduction was made to the reader on the subject of dust and tailings dams and the necessity for this study. Furthermore, issues to be addressed were identified and hypotheses were made on the problem statement.

Chapter 2 forms a literature study on the following issues:

Legislation applicable to the mine will only be mentioned. There will not be a discussion in broad terms. Tailings dams are then discussed in order to understand what this subject is. A description of the process to form slurry, methods of tailings disposal and deposition forms part of this section. A discussion of the physical and chemical properties of airborne particulates follows the tailings dam discussion, integrating it with toxicology and the anatomy of the respiratory system. The physiological consequences of airborne particulates for respiratory health are discussed to highlight manifestation of certain respiratory illnesses. Finally, there is a literature study on the respiratory effects elements identified in the samples may have on the human body.

Chapter 3 describes the methodology. This includes a study design, measurements taken, and the analysis methods used for the bulk and filter samples. The method for calculating the dust concentrations and the statistical analysis used for interpretation of the results is described.

A discussion follows in Chapter 4 of all results found from the measurements taken. The particle size distribution in bulk samples and the elements identified in the bulk and filter samples are presented. From the TWA dust concentrations, a comparison was made between tailings dams, between days and between two occupations, i.e. Pipe Line Labourer and Mud Guards. The control measures at each dam were discussed and compared to legislative requirements.

A conclusion is made on all three tailings dams in Chapter 5.

Chapter 2 LITERATURE STUDY

2.1 TAILINGS

Slurries are to be found throughout the mining process – underground, in surface mines, in process plants and, perhaps the most important, flowing from process plants to tailings facilities elsewhere (Chadwick, 2005).

Tailings disposal is a significant part of the overall mining and milling operation at most hard rock mining projects. The ultimate purpose of a tailings impoundment is to contain fine-grained tailings, often with a secondary or co-purpose of conserving water for use in the mine and mill, with minimal environmental or social impact. This has to be accomplished in a cost-effective manner that provides for long-term stability of the embankment structure and the impounded tailings and the long-term protection of the environment (EPA, August 1994).

Impoundment of slurry tailings is the most common method of disposal. Impoundments are favoured because they are economically attractive and relatively easy to operate. Tailings impoundments can be and are designed to perform a number of functions, including treatment functions. These include:

- Removal of suspended solids by sedimentation;
- precipitation of heavy metals as hydroxides;
- permanent containment of settled tailings;
- equalization of wastewater quality;
- stabilization of some oxidizable elements (e.g., thiosalts, cyanides, flotation reagents);
- storage and stabilization of process recycle water;
- incidental flow balancing of storm water flows (EPA, August 1994).

There are, however, a number of disadvantages to tailings impoundments requiring attention in design, including:

- Difficulty in achieving good flow distribution;
- difficulty in segregating drainage from uncontaminated areas;
- difficulty in reclamation, particularly with acid-generating tailings, because of the large surface area and materials characteristics;
- inconsistent treatment performance due to seasonal variations in bio-oxidation efficiency;
- costly and difficult collection and treatment of seepage through impoundment structures;

- potentially serious wind dispersion of fine materials unless the surface is stabilized by revegetation, chemical binders, or rock cover (EPA, August 1994).

2.1.1 What are Tailings?

Tailings are discarded materials resulting from the concentration of ore through various beneficiation operations, such as the milling and flotation process used to extract metals of interest from the mined ores (EPA, June 1994; Wiseman Uranium Project, 2003). During this process, ores are first milled and finely ground, and then treated in a hydrometallurgical plant. Crushing and grinding methods are used to reduce the mined ore to sand and silt sizes, and then the concentrating process can begin (Engels, 2005).

A range of different techniques can do storage of tailings. The most common technique used today is 'flotation', which has been used to separate minerals since the early 1920s. The process treats the ground ore in a bubbling mixture of water and chemical elements, to which the sort metallic minerals stick to, and rise to the surface of the flotation tank. The concentrate is either scraped or poured off for further processing or drying. As ore bodies are extracted only a small percentage of the whole ore mass consists of valuable minerals. The remainder of the mass is uneconomic material that needs to be separated in a concentrating process, and ends up as fine slurry. Tailings are characterized by fine particle sizes of varying mineralogical and chemical compositions, among them, heavy metals and other toxic substances that were added during the milling process (EPA, June 1994; Wiseman Uranium Project, 2003).

There has been an evolution of the terms used for the various disposal facilities, for example, tailings dams, tailings impoundments, tailings management facilities and tailings storage facilities (MMSD, 2002). Tailings dams are similar to conventional water dams in that they are designed to be a retaining structure. However, a tailings dam is designed to retain water and solids, whereas a conventional dam retains only water (Engels, 2005).

2.1.2 Methods of Tailings Disposal

There are four main types of slurry impoundment layouts: variations of the valley impoundments, ring dikes, in-pit impoundments, and specially dug pits. In some cases, tailings are dewatered or dried prior to disposal. The efficiency and applicability of using thickened or dry tailings depends on the ore grind and concentrations of gypsum and clay as well as the availability of alternative methods (EPA, Aug 1994).

2.1.3 Methods of Tailings Deposition

Tailings are generally composed of fine sand- or silt-size particles, typically deposited as slurry, and, depending upon the method of deposition, may be graded so that coarser material is nearer to the point of discharge. Gradients in grain size occur both vertically and horizontally (Norman, 1998).

Tailings dams are an expensive liability to a mining company, and so generally the embankments are built with material that is available locally at the proposed construction site. In areas where borrowed materials are not available (particularly in the required quantities), then the embankments are constructed and raised by the sand fraction of the tailings (Engels, 2005).

The vast majority of surface tailings storage facilities today are constructed using the tailings material itself to raise the height of the retaining perimeter of the tailings storage facilities. The manner of construction may differ, e.g. downstream, upstream or centreline, but the use of tailings as a construction material is widespread (Fourie, 2003).

The slurry is facilitated via a pipeline where it is deposited via a single point discharge, spigots or a cyclone, when the sand fraction is being used to construct the embankment (Engels, 2005; MMSD, 2002). In single point discharge and spigot systems, the tailings are usually deposited to form a beach against the embankment with the liquid collecting away from it. This reduces the seepage and increases the stability. The level of the tailings pond is controlled by decanting any surplus liquid also referred to as supernatant. This is done through an embankment drain, decant towers or a floating pump. The liquids return to the processing plant or are discharged (Engels, 2005; MMSD, 2002).

Generally, *cyclones* separate the sand and slimes from the tailings feed delivered to the dam. The sand fraction is deposited on the embankment (for raising purposes), and the slimes are piped out to the centre of the impoundment (see Figure 1 in Annexure A.)

If perimeter *spigoting* is used, the natural segregation of sands and slimes develops (course fraction settling near the spigoting), allowing the sand portion to be dug up and placed behind the perimeter tails line for rising. This can be seen in Figure 2 in Annexure A (Engels, 2005).

Typically, the spigot line is positioned on the crest of the tailings dam (see Figure 3 in Annexure A). With each deposition, a section of the spigot pipe is dismantled and moved to one side to allow the rising of the perimeter bund, which is usually constructed of the beach tailings (Boshoff & de Koning, 2004:12). In the course of a deposition cycle, a batch of adjacent spigots is

opened, sufficient to cater for the slurry flow rate. As the beach falls, spigots at one end of the batch are opened while the equivalent number at the other end is closed so that the deposition gradually moves along the spigot pipe and around the tailings dam. Deposition is achieved through a delivery pipe acting as a ring main on the embankment crest. The pipe is fitted with spigot outlets and discharges directly into the paddock system inside the dam. Discharge at any time, is controlled by opening or closing the spigots such that deposition occurs only on a limited portion of the dam perimeter. Deposition proceeds in a cyclic manner around the tailings dam to ensure uniform material deposition and pool control. A takeoff is installed at each paddock cross wall which feeds the spray bar on the inner paddock wall.

Since large particles require more energy to maintain in suspension than smaller particles, large particles tend to be deposited close to the discharge point, while finer particles tend to be transported further down the beach towards the pool area (Boshoff & de Koning, 2004:12). Once tailings have been deposited in an area and have gained adequate strength, the material from within the paddock area is used to mechanically construct an upstream lift to the outer embankment and the paddock system inside the dam. The spigot piping is then relocated onto the crest of the new embankment raise in preparation for the next deposition cycle.

Materials discharging from the spigots beach away from the discharge point into the paddock area. Coarse material settles out inside the paddock area with the vent pipes drawing supernatant water into the basin as well as some fines. On the inside of the dam a uniform beach is created. Beaching of the tailings, however, result in a large proportion of the tailings dam beach being maintained wet.

2.2 PHYSICAL AND CHEMICAL PROPERTIES OF AIRBORNE PARTICLES

The behaviour of particles in air and in the human body is dependent on their physical and chemical properties (Schaper & Bisesi, 2003:32; Stranks, 1995:39). Particle size, defined by its diameter, is the most important physical characteristic of airborne particulate matter. This is because particles with a diameter of $<2,5\text{ }\mu\text{m}$ are able to penetrate into the deepest regions of the lung where they may cause the most severe health effects (Pooley, 2006; Schaper & Bisesi, 2003:32). Effects of irritant particles in the respiratory tract vary from simple temporary irritation (upper respiratory tract irritation), to chronic illness (bronchospasm), to terminal disease (pulmonary oedema).

The size, density and shape of the particles, and the mineralogical and chemical form are of prime importance because these factors influence the settling rate of the particles, the time they

remain airborne, and their penetration and deposition in the respiratory system. The health hazards presented by particles will depend on their solubility, biological activity and whether the particles can pass into the blood stream and act as systemic poisons. Lead and manganese are a case in point (Schaper & Bisesi, 2003:32; Williamson *et al.*, 2004).

Metals such as iron, copper, nickel, vanadium and cobalt can generate reactive oxygen species (ROS) and reactive nitrogen (RNS) species by a catalytic process such as hydroxyl radical (Knaapen *et al.*, 2004; Veranth *et al.*, 2000). Hydroxyl radical may result in direct cell damage and may also activate biochemical reactions that indirectly cause cell damage. The oxidant-generating particles are determined by the physiochemical characteristics of the particle surface and by the ability of particles to stimulate cellular oxidant generation.

2.2.1 Composition

Solubility is the major factor determining the bioavailability of potential toxins (Williamson *et al.*, 2004). The solubility of particulate matter in aqueous media or in lipids is of great biological significance because it influences the rate of absorption in the body (Nims, 1999:27). For substances that present a hazard of irritation or systemic poisoning, the speed with which they dissolve in tissue liquids may be of critical significance. On the other hand, for fibrogenic particles acting directly in the pulmonary cavities this may be of less significance. Silica quartz, for instance, commonly regarded as insoluble, is highly harmful (Nims, 1999:27).

2.3 TOXICOLOGY REVIEW

Occupational exposure is defined as any contact between the human body and a potentially harmful agent or environment in the workplace causing undesirable disturbances of physiological function. Exposure to a small amount of a specific substance can theoretically be tolerated without effect at some lower exposure. However, an excessive level of exposure may cause severe detrimental effects to health and even be fatal when a susceptible place in the human body is reached (Ayres, 2005:47; Kelly, 2002:169; Nims, 1999:27).

Specific exposures are related to the chemical composition, particle size, the individual dose, the occupation, the activity area of the workplace, the individual response to the agent and measures taken to limit exposures (CCOHS, 2002; Driscoll *et al.*, 2004).

Many hazardous substances encountered in the workplace gain entry into the body through inhalation of a dust, gas, mist, fog, fumes or vapour. In one study it was found that approximately 90 percent of all ill health resulted from inhaling hazardous substances in an occupational environment (Ayres, 2005:47; Stranks, 1995:39).

2.3.1 Classes of Toxins and Toxic Responses

General toxic effects are divided into three stages, namely primary, secondary and tertiary, each with a stimulating or inhibiting cause and permanent or temporary health effects. Furthermore, simultaneous exposure of two or more toxins can have synergistic or antagonistic effects. Long-term exposures to toxins, even at mild concentrations, will cause the development of symptoms of poisoning due to the effect of the toxin on a molecular-cellular level (Nims, 1999:27).

2.3.2 Routes of Exposure

Chemicals enter the body through a variety of routes: inhalation, ingestion, or absorption through the skin; less common routes include injection and absorption through moist surfaces surrounding the eyes and in the ear canal (Nims, 1999:27; Kelly, 2002:169; Stranks, 1995:39).

Inhalation is the most important and most common route to toxic exposure in the industrial work setting. Depending on the substance and its specific properties, however, entry and absorption can occur by more than one route. The lungs are covered by a very thin respiratory membrane, consisting of epithelial cells, and are designed to provide efficient gas exchange between the air and blood (Lipmann, 1998:10.2; Nims, 1999:27; Stranks, 1995:39). Deadly amounts of chemical molecules can be absorbed into the bloodstream where the toxicant may elicit general effects or, the critical injury will be localized in specific tissues or organs. Molecules can also be absorbed in the digestive system when it is swallowed after being deposited in the nose and throat. The chemical and physical properties of a given compound will largely determine the route by which exposure occurs (Nims, 1999:27; Stranks, 1995:39).

2.3.3 Exposures

Levels of exposure to air contaminants can also be referred to in terms of acute and chronic exposure. Acute exposure generally refers to exposure to very high concentrations during very

short time periods; chronic exposure involves repetitive or continuous exposure during long periods of time (Delic *et al.*, 2005:67; ILO Safework, 2005; Kelly, 2002:169).

Both types of exposures can be measured for degree of toxicity, based on local or systemic damage to the biological system (Delic *et al.*, 2005:67; Kuempel, 2000; Stranks, 1995:39).

2.3.4 Distribution of Inhalable Particles

The four mechanisms by which particles are deposited in the respiratory system are:

2.3.4.1 Sedimentation

Inhaled particles will fallout of the air stream when the gravitational forces on a particle are greater than air resistance. The deposition of the inhaled particles is proportional to the density of the particle and its aerodynamic diameter squared (Hayes, 2001:680; Johnson & Vincent, 2003:207; Schaper & Bisesi, 2003:32; Stern & Mansdorf, 1999:103). The aerodynamic diameter is a measure of the inhalability of a particle and is defined as the diameter of a sphere of unit density that would sediment at the same velocity as the particle. As the particle diameter gets smaller than 1 μm in diameter it deposits rapidly because the particle tends to slip between the air molecules (Ayres, 2005:47). Sedimentation tends to be most effective in the regions of the respiratory tract where air velocities are low, particle residence times are high, and the airway diameters are small.

2.3.4.2 Inertial impaction

When airflow changes direction, the inertia of any suspended particle will cause it to continue in its original direction for some finite time before changing direction or deposits when a change in direction of airflow occurs (Hayes, 2001:680). Deposition by this mechanism is also proportional to particle settling velocity and air velocity (Hayes, 2001:680; Johnson & Vincent, 2003:207). Particles larger than 1 μm will be deposited in regions of the respiratory tract where air velocities are high and air stream directional changes are abrupt, such as the nose, the glottis and the larger bronchial bifurcations (Ayres, 2005:47; Hayes, 2001:680).

2.3.4.3 Brownian displacement (Diffusion)

The gas molecules that surround aerosols continuously bombard airborne particles, inducing random particle movement. When particles are in random motion, they deposit on the lung walls mostly by chance. This movement is also known as the Brownian motion. The smaller the particle sizes, the more rapid the diffusion movement is (CCOHS, 1999; Hayes, 2001:680; Wang, 2006). Brownian displacement is also called diffusion. Diffusion is the most important mechanism for deposition of small particles ($<0,5\ \mu\text{m}$) in the pulmonary compartment and alveoli (Ayres, 2005:47; CCOHS, 1999; Hayes, 2001:680; Johnson & Vincent, 2003:207). This mechanism is responsible for the net displacement of a particle.

2.3.4.4 Interception

Interception occurs when the trajectory of the particles brings them sufficiently close to airway walls such that the particle contacts the airway walls. Interception may thus provide dimension barriers to the penetration of particles, in addition to the aerodynamic barriers provided by the other mechanisms (Hayes, 2001:680; Johnson & Vincent, 2003:207).

Inside the body, several mechanisms come into play for movement of materials from the site of initial entry to the site of action. The tissues of the lungs are delicate and provide direct contact with the blood (Nims, 1999:27:27; Stranks, 1995:39). Inhaled substances may exert their toxic effect directly on the lungs; examples include irritation, scarring, or oedematous reactions, or it can affect multiple organs and tissues after absorption through the thin cells lining the lungs to enter the bloodstream (Nims, 1999:27:27). The toxic substance is bound to the haemoglobin and erythrocytes; or on the erythrocyte membrane and its compounds; or onto several plasma fractions. Electrolytes are carried in the form of ions in the plasma. An alternative is the hydrolysis of the substance to form colloids, in order to stay in the blood or to form complex combinations with organic acids in the plasma form. Ions can be evenly distributed through the body, or they can accumulate in one organ for which they have a greater affinity, e.g. the kidneys or other specific organs for which they have a greater affinity, or they can deposit in the bone structure. Fat-soluble substances have a greater affinity to fatty substances and will therefore be absorbed in fat tissue (Nims, 1999:27).

2.3.5 Effects of Exposure

The lung is a common site of occupational disease. Particles can enter the human body through the respiratory system, causing a few familiar patterns of disease, which can be non-injurious, slight, serious, or even fatal (Ayres, 2005:47; Nims, 1999:27; Stern & Mansdorf,

1999:103). The site of deposition of the hazardous chemical, the dose and duration of exposure, the susceptibility of lung cells, and the interaction between the chemical and local host defence mechanism, states the specific type of response (Stern & Mansdorf, 1999:103).

A worker can be exposed in an acute or chronic way. An *acute exposure* is short-term high concentration exposures, while a *chronic exposure* relates to continued exposures to substances of low concentrations, presumably throughout a working lifetime (Delic *et al.*, 2005:67; Kelly, 2002:169). Acute effects include upper airway obstruction, bronchoconstriction, alveolitis, and pulmonary oedema; and chronic effects include asthma, fibrosis, and cancer (Stern & Mansdorf, 1999:103).

In addition to acute (short term) and chronic exposures (long-term), a distinction can be made between the toxic actions of a substance that is acute and chronic effects. An *acute effect* is induced by a single, short-term high concentration exposure with immediate reversible effects that follows, such as illness and irritation; in some cases death may occur, which are dependent on the dosage, concentration and the sustained damage to biological matter. In contrast to acute effects, *chronic effects* are characterized by symptoms or diseases developing after a prolonged or cumulative exposure or repeated exposure of long durations to low level concentrations of an agent, and are irreversible in effect or damage (Delic *et al.*, 2005:67; Kelly, 2002:169; Stranks, 1995:39).

Chronic and acute effects may have an impact on different sites of the human body. A *local effect* is an effect usually confined to the initial point of contact. The site may be in the skin, mucous membranes of the eyes, nose or throat, the liver or bladder. On the other hand, a *systemic effect* is generalized and changes the normal functioning of affected organs operating as a system e.g. respiratory system or the central nervous system. Such effects occur in parts of the body other than at the initial point of contact (Kelly, 2002:169; Stranks, 1995:39).

Chronic effects can be more serious than acute effects even though they result from lower concentrations of toxic materials – in fact, the onset of damage to health can be slow, but the ultimate effect can be quite serious and irreversible (Kelly, 2002:169).

2.3.6 Protective Mechanisms within the Human Body to Inhaled Particles

Particles that are inhaled and absorbed from the lungs, passing into the blood stream and being distributed to other organs whose function may adversely be affected either directly or after metabolic transformation, may cause systemic intoxication by, e.g. lead, manganese, or

cadmium (Ayres, 2005:47; CCOHS, 1999; Schaper & Bisesi, 2003:32; Van Eeden & Hogg, 2002).

The protective mechanisms within the different areas of the respiratory system respond largely according to the shape and size of particulate matter, which may be inhaled. Inhaled dusts may elicit little or no reaction of any kind. Particle sizes can be captured or removed by nasal filtration. Peristaltic movements of the terminal bronchioles, coughing and sneezing can remove particles from the air-conducting channels. At other times the particles can stimulate an increase in the production or secretion of mucus, sometimes accompanied by an enlargement of the cells that produce the mucus. Another possible response is the engulfment of particles by macrophages (phagocytosis). Irritating substances may cause an inflammation of tissues, sometimes accompanied by oedema. Some dusts stimulate the formation of fibrous tissues, such as reticulin or collagen; the resulting growths or lesions can be benign (CCOHS, 2002; Hayes, 2001:680; Nims, 1999:27; Stranks, 1995:39).

The upper or **nasopharyngeal region**, the first line of defence, is comprised of the head, nose and nasal passages, sinuses and mouth, and all associated features such as the tonsils and epiglottis, including the back of the throat (Hayes, 2001:680; Nims, 1999:27). This region, and in fact nearly the entire respiratory tract, is lined with specialized skin tissue called a mucous membrane. The mucous membrane produces a layer of mucus, a moist, sticky substance that captures many of the materials inhaled. The many small hairs in the nasal passages also help to trap particles that enter along with inhaled air (Hayes, 2001:680; Nims, 1999:27; Stranks, 1995:39).

Particles are deposited in the nose by filtration (nasal hairs) and changes of direction, causing many particles to hit the walls of the air passage. The retention is favoured by mucus that lines the nose, so the particles deposit or settle in this region. Ciliated epithelium, covered by mucus in the nasal passages contributes to the removal of particles by propelling them towards the pharynx. Particles are then removed through swallowing, sneezing or blowing the nose. These swallowed particles are significant when dealing with agents that can cause systemic intoxication. The larger particles, in the range of 10 µm and larger, are removed in the nose and upper airways (CCOHS, 1999; Nims, 1999:27; Pooley, 2006; White, 2001:121). Some of the smaller particles succeed in passing through the nose to reach the windpipe and the dividing air tubes (bronchi) that lead to the lungs.

Particles ranging from 1 to 5 µm are captured in the **tracheobronchial region**. The middle or tracheobronchial region of the respiratory system is generally considered to be the trachea, or windpipe, and the larger air passages, called bronchi of the lungs. The trachea and bronchi are

constructed of rings of cartilage and muscle (CCOHS, 1999; Hayes, 2001:680; Nims, 1999:27; Stranks, 1995:39). The cartilage supports the windpipe and helps maintain its tubular shape. The muscles contract and can assist in forcing air out, and with it the contaminants, out of the lungs through the cough reflex. The trachea and bronchi are lined with a mucous membrane and fine hairs (called cilia), which help capture and remove foreign particles. Sedimentation is the most common method because at this point the air has slowed enough for particles to settle. The cilia push the mucous, and any particles it may contain, upward and toward the larger air passages in a continuous and synchronized wavelike manner. These peristaltic movements propel the particle-laden mucus toward the epiglottis and where it is either coughed up and spat out, or swallowed. This system, known as the mucociliary escalator is the mechanism whereby particles deposited on the airway surface are removed (CCOHS, 1999; Hayes, 2001:680; Nims, 1999:27; Stranks, 1995:39). Beyond the terminal bronchiole the surface lining of the airways is no longer ciliated.

In the lower, **distal region** of the lungs, the bronchi split into two smaller branches, which split repeatedly about seventeen times, creating passages with increasingly smaller diameter. The rings of the cartilage disappear altogether to form tiny air passages (bronchioli), which are quite small. The airways end in clustered microscopic sacs called alveoli, the shape of which resembles clusters of grapes (Hayes, 2001:680; Nims, 1999:27). The alveoli are very important because through them the body receives oxygen and releases carbon dioxide into and out of the blood through the mechanism of passive diffusion. In this region, the body's primary defence is provided by specialized white blood cells (macrophages), wandering scavenger cells able to move freely through body tissue, engulfing bacteria and dust particles. The epithelium of the pulmonary spaces is not ciliated; however, the macrophage cells (phagocytes) engulf the insoluble particles deposited in this area in the process of phagocytosis (Ayres, 2005:47; CCOHS, 1999; Kuempel, 2000; Stranks, 1995:39; White, 2001:121). Certain particles such as silica-containing dusts, are cytotoxic, i.e. they destroy the macrophage cells.

After engulfing the foreign particle, the macrophage carries the particles to the ciliated epithelium (tracheobronchial region) and then transports it upwards and out of the respiratory system. The particles that escaped macrophage-mediated clearance remain in the pulmonary space, or are slowly cleared to enter the lymphatic system. This is the drainage system, which acts as a clearance channel for the removal of foreign bodies, many of which are retained in the lymph nodes throughout the body. In certain cases, a localised inflammation will be set up in the lymph node (Kuempel, 2000; Stranks, 1995:39).

Only particles 1 μm or less penetrate to the unciliated airways (alveolar region), but only a fraction of these, due to the body's efficient mechanisms for removing inhaled particles, have a

small enough aerodynamic diameter to reach into the deep region of the lungs (the periphery of the lungs) to have a reaction (CCOHS, 1999; Kelly, 2002:169; Nims, 1999:27; Pooley, 2006; Schaper & Bisesi, 2003:32). Particles that evade elimination in the nose or throat tend to settle in the sacs or close to the end of the airways. If the amount of dust is large, the macrophage system will fail, causing injury to the lungs.

Most particles in the size range of 3 to 5 μm eventually make contact with the walls of the airways and stick in the mucus lining of the tracheal region. This capturing system is enhanced by the many branches and splits of the smaller airways, which force the air into diverging paths and provide, collectively, a relatively large surface on which the particles can impact. Once the particles are stuck in the mucus, their removal is performed through the ciliary's action as described earlier. The cough reflex is another possible way for irritating gases and particulates to be removed. These particulates cause the muscles surrounding the bronchi to contract, which forces the air, along with the contaminant, out of the lungs (CCOHS, 1999; Nims, 1999:27; Schaper & Bisesi, 2003:32).

2.4 PHYSIOLOGICAL IMPLICATIONS

Presently, little is known about the potential health effects of mineral particles other than asbestos and quartz (Øvrevik *et al.*, 2005). Airborne dusts are of particular concern because they are associated with classical widespread occupational lung diseases such as pneumoconiosis, as well as with systemic intoxications such as lead poisoning, especially at higher levels of exposure. According to Pooley (2006) respirable fractions of dust smaller than 7 μm comprise a high-risk respiratory threat that is responsible for 90% of respiratory problems experienced. There is, however, an increasing interest in other dust-related diseases which may occur at much lower exposure levels, such as cancer, asthma, allergic alveolitis and irritation, as well as a whole range of non-respiratory illnesses (WHO, 1999).

Schwartz (2001) did a study on particulate matter with a mass median aerodynamic diameter less than 10 μm (PM_{10}). He reported a significant association between PM_{10} and the increase in serum fibrogen, platelet and white cell counts, affecting the cardiovascular health. Various research projects confirmed this conclusion (Gardner *et al.*, 2000; Kodavanti *et al.*, 2002; Rivero *et al.*, 2005; Seaton *et al.*, 1999). Such changes imply that cardiovascular factors could be modified by airborne particles at commonly occurring concentrations. Studies done in European cities, Mexico City, United States of America and São Paulo linked air pollution to premature cardiovascular deaths and hospital admissions for cardiovascular diseases (Schwartz, 2001:405).

It was suggested that particles activate reflexes that affect the cardiovascular function. Some cardiovascular reactions include disruption of the autonomic nervous system that will increase and decrease heart rate variability, pulmonary inflammation, cardiac oedema, induced vasoconstriction and changes in blood homeostasis favouring blood coagulation (Rivero *et al.*, 2005).

Recent studies have indicated that bone marrow can react to inhaled particles (Goto *et al.*, 2004; Medeiros *et al.*, 2004; Rivero *et al.*, 2005; Van Eeden & Hogg, 2002). Bone marrow is stimulated by a systemic inflammatory response, called leukocytosis, to release immature granulocytes into the circulation. This systemic response is induced after acute exposure to air pollution.

2.4.1 Occupational diseases related to the inhalation of airborne particles

The way the respiratory system responds to inhaled particles depends on where the particle settles. For example, irritant dust that settles in the nose may lead to rhinitis, an inflammation of the mucous membrane. If the particle attacks the larger air passages, inflammation of the trachea (tracheitis) or the bronchi (bronchitis) may be seen (CCOHS, 1999). The most significant reactions of the lung occur in the deepest parts of the lung.

2.4.1.1 Pneumoconiosis

The accumulation of certain inorganic and organic dusts and the reaction of pulmonary tissue to the dusts cause pneumoconiosis, an occupational disease of the lungs (Nims, 1999:27; Stern & Mansdorf, 1999:103; Stranks, 1995:39).

Pneumoconiosis can be divided into the collagenous and non-collagenous forms. Collagen is a protein-based substance, which forms the principle component of connective tissue. The collagen disease or connective tissue diseases have as their common factor a disorganisation of collagen strands. In all collagen diseases there is inflammation without infection (Brunekreef & Forsberg, 2005; Stranks, 1995:39).

The first simple collagenous pneumoconiosis, cause scarring and damage of varying degree throughout the lung and with varying degrees of fibrosis leading to serious impairment of the respiratory function or to the development of a reactive condition that is associated with the inhaled fibrogenic dust. Its characteristics are authenticated damage to alveolar architecture,

appreciable supporting tissue reaction and irreversible scarring of the lung. Silicosis, asbestosis, and coal miner's pneumoconiosis is examples of this progressive massive fibrosis (Brunekreef & Forsberg, 2005; Stern & Mansdorf, 1999:103; Stranks, 1995:39). Silicosis is the most significant form of pneumoconiosis and claims the largest number of victims on a global basis.

The most serious pneumoconiosis lead to appreciable fibrotic changes and affects a small percentage of persons with pneumoconiosis. Fibrotic nodules coalesce and encompass blood vessels and airways. In the past, tuberculosis was a common accompaniment of this condition (Stern & Mansdorf, 1999:103).

However, not all dust inhaled, cause an identifiable disease. Non-collagenous pneumoconiosis is caused by non-fibrogenic, inert dust inhalation, depositing in the lung tissue. They may be detectable using x-rays but without any resulting pulmonary tissue reaction or functional impairment to deposition of the dusts, even when there are large accumulations in the lungs. Non-collagenous pneumoconiosis has characteristics such as intact alveolar architecture, minimal supporting tissue reaction and potentially reversible effects (Brunekreef & Forsberg, 2005; Stern & Mansdorf, 1999:103; Stranks, 1995:39).

Other forms of pneumoconiosis may be produced by inhalation of excessive amounts of the following dusts: beryllium (berylliosis); kaolin (kaolinosi); barium (barytosis); tin (stannosis); iron oxide (siderosis); stone particles (lithosis); talc; graphite and mica. Long-term, repeated exposure can cause premature death, cancer and an increase in hospitalizations for respiratory and cardiac disease (Brunekreef & Forsberg, 2005; Stranks, 1995:39).

2.4.1.2 Systemic poisoning

The respiratory system provides a very effective entrance for fine particles of certain chemicals to enter the bloodstream and be circulated to various organs, which can be damaged, or cause poisoning or have a systemic effect. Manganese, lead, cadmium and their compounds are examples of toxic systemic agents occurring in particulate form (Kennedy & Hinds, 2002; Lipmann, 1998:10.2).

2.4.1.3 Cancer

There are approximately 20 established occupational carcinogenic agents and mixtures in the industrialized countries (Bofetta *et al.*, 1998:2.2). Cancer can develop after a long-term exposure to carcinogenic substances (Brunekreef & Forsberg, 2005; Stranks, 1995:39). Examples of airborne particles that can produce cancer of the lung after inhalation are arsenic and its compounds, chromates and certain nickel-bearing dusts (ATSDR, 2005; Driscoll *et al.*, 2004; Bussi eres, 2004; HSE, September 2002).

Occupational cancer is, however, a preventable disease (Bofetta *et al.*, 1998:2.2).

2.4.1.4 Irritation of inflammatory lung injuries

Pulmonary inflammation, as an acute health effect, has a direct link to ambient particles (Veranth *et al.*, 2000). Exposures to high concentrations of an irritant, such as zinc chloride or vanadium pentoxide dusts, may cause a burning sensation in the nose, throat and eyes. A pain sensation in the chest can be experienced together with coughing that leads to inflammation of the mucosa such as tracheitis and bronchitis, pneumonitis, and pulmonary oedema and sinusitis (CCOHS, 1999; Lipmann, 1998:10.2). Airborne irritant particles include cadmium fumes (pneumonitis, pulmonary oedema), beryllium (acute chemical pneumonitis), vanadium pentoxide, zinc chloride, boron hydrides, chromium compounds, manganese, cyanide, dusts or mists of some pesticides (pulmonary oedema), acid mists and fluorides (Rivero *et al.*, 2005).

2.4.1.5 Allergic and other sensitivity responses

The deposition and retention of inhaled sensitising substances may produce allergic reactions or other sensitivity responses, such as a runny or stuffy nose, sore throat, hay fever, burning or red eyes and shortness of breath (Lipmann, 1998:10.6; White, 2001:132). The two main respiratory diseases of allergic type caused by occupational exposure to particles (such as chromium and nickel), are occupational asthma and extrinsic allergic alveolitis (lung inflammation).

2.4.1.6 Infection

Particles containing fungi, viral, or bacterial pathogens may play a role in the transmission of infectious diseases (Todd & Carman, 2001:362). Some examples of such infectious agents are tuberculosis, anthrax, ornithosis, brucellosis, histoplasmosis and Legionnaires' disease (Lipmann, 1998:10.2).

2.5 HEALTH EFFECTS OF CHARACTERIZED ELEMENTS

According to Kelly (2002:169) inhalation forms the most significant route of entry to occupational airborne hazards. The effects associated with inhalation of dust depends on where in the respiratory tract the inhaled particles are deposited and vary from local skin irritation to systemic effects including cancer or nervous system damage. Many chemicals, such as zinc, manganese, copper, chromium, nickel and potassium, essential for health in small quantities are highly toxic in large quantities (Kelly, 2002:169).

Following below is a discussion of hazardous substances present in the analysed bulk and filter membrane samples and their physiological health effects.

2.5.1 Aluminium

Aluminium occurs naturally in the environment and is found combined with other elements such as oxygen, silicon, and fluorine. It consists of a mixture of minerals formed by the weathering of aluminium-bearing rocks. Bauxite is the principle source of aluminium.

Breathing aluminium dusts irritates the respiratory tract, which may lead to manifestations like coughing and asthma (ATSDR, 2005; ILO Safework, 2005; Nims, 1999:27). The water-soluble form of aluminium causes the harmful effects. They are usually found in a solution of aluminium in combination with other ions, for instance as aluminium chloride. Particles of aluminium that are deposited in the eye can cause mild eye irritation that can damage the cornea (Lenntech, 2005). Long-term exposures can develop into pulmonary alterations, clinically characterized by minor, predominantly asymptomatic restrictive pulmonary function changes. Chest x-ray examinations of workers engaged in the metal working industry with more than twenty years of exposure revealed small, scanty, irregular opacities, particularly at the lung base. These clinical responses have been attributed to deposition of dust in the lung parenchyma, which was the result of very high occupational exposures (ILO Safework, 2005). Inhalation of aluminium

oxides is capable of producing alveolar oedema following acute exposures (Nims, 1999:27; Olson, 2004:536).

A progressive and often fatal, non-nodular interstitial fibrosis, known as Shaver's disease, was reported in the aluminium industry (ILO, 2005). Shaver's disease is complicated by the presence of silica and iron oxides in the inhaled air (Lenntech, 2005; Nims, 1999:27). The particulates were of a size range that made them highly respirable.

Chronic inhalation of significant concentrations of aluminium can lead to serious health effects, such as:

- Damage to the central nervous system;
- dementia;
- loss of memory;
- listlessness;
- severe trembling;
- may also be implicated in Alzheimer's disease (Lenntech, 2005; Nims, 1999:27).

Other problems that may occur from aluminium exposure is:

- Problems for kidney patients when it enters the body during kidney dialyses (Lenntech, 2005; Nims, 1999:27); and
- skeletal problems (ATSDR, 2005).

2.5.2 Arsenic

Arsenic, a metalloid, is one of the most toxic elements that can be found widely distributed in the earth's crust as inorganic arsenic bonds. It occurs in trace quantities in all rock, soil, water and air (Lenntech, 2005; Ng *et al.*, 2001).

Human inhalation exposure to inorganic arsenic can occur as a consequence of industrial activity (e.g. smelting of ores) and energy production (e.g. coal-fired power plants), and during cigarette smoking (HSE, September 2002). It is extremely rare for workers to be exposed to arsenic combined with other elements, but ingestion and dermal exposure may be significant in particular situations (e.g. preparation of CCA-treated timber). Respiratory absorption of arsenic is thus a two-stage process, involving deposition of the particulates in the airway and on lung surfaces, followed by absorption of arsenic from deposited particulates. The extent of deposition of inhaled arsenic will depend largely on the size of the inhaled particulates, and

absorption of deposited arsenic is highly dependent on the solubility of the chemical form of arsenic (HSE, September 2002).

Exposure to inorganic arsenic can cause infertility and miscarriages, skin disturbances, heart disruptions and brain damage with both men and women and in high doses it may cause certain effects to human health, such as nerve injury and stomach aches (Lenntech, 2005).

Some short-term effects include:

- Stomach upsets;
- irritation of the eyes and nose;
- skin damage and inflammation; and
- internal bleeding from the stomach and intestines leading, in extreme cases, to death (HSE, September 2002).

Long-term effects include:

- Damage to the inside of the nose;
- skin colour changes, dermatitis, skin lesions and skin cancer;
- irritation of the lungs;
- stomach disturbances; and
- cardiovascular diseases (Bussi eres, 2004; HSE, September 2002).

Arsenic is a known human carcinogen causing lung cancer when inhalation of high levels of arsenic trioxide dust occurs (Bussi eres, 2004; HSE, September 2002).

2.5.3 Barium

Barium combines with other chemicals such as sulphur or carbon and oxygen to form barium compounds (ATSDR, 2005; Lenntech, 2005). Exposure to barium may occur by breathing dust, eating soil or plants, or drinking water that is polluted with barium or through skin contact. These dusts are irritating to the eyes, skin, and respiratory tract (Olson, 2004:536). The toxicity of barium compounds depends on their solubility (Eaton & Klaassen, 2001:11).

Concentrated solutions of barium oxide or barium hydroxide are strongly alkaline and corrosive to the skin and eyes. Breathing barium sulphate or barium carbonate causes most of the health risks (Brown, 2005).

Like calcium, barium accumulates in bone (ATSDR, 2005; Choudhury & Cary, 2001). It is deposited in the most active areas of bone growth, primarily at the periosteal surfaces. Inhaled barium can be absorbed through the lung or directly from the nasal membrane into the bloodstream. Barium possesses chemical and physiological properties that competes with and replace calcium in processes mediated normally by calcium. Clinical features of barium poisoning include acute gastroenteritis, loss of deep reflexes with onset of muscular paralysis and progressive muscular paralysis. The muscular paralysis appears to be related to severe hypokalemia. There is no evidence that barium is carcinogenic. A benign pneumoconiosis, known as baritosis, can be produced after inhalation of sufficient quantities of barium compounds deposited in the lungs (ATSDR, 2005; Choudhury & Cary, 2001; ILO Safework, 2005).

The health effects of barium depend upon the water-solubility of the compounds. Barium compounds that dissolve in water can be harmful to human health (ATSDR, 2005; Brown, 2005; IRIS, 1998; Lenntech, 2005). The uptake of very large amounts of barium that are water-soluble may cause paralysis and in some cases even death. Small amounts of water-soluble barium may cause a person to experience breathing difficulties, hypertension (high blood pressure), stomach irritation, muscle weakness, changes in nerve reflexes, swelling of brains and liver, kidney and heart damage (Brown, 2005; IRIS, 1998; Lenntech, 2005).

2.5.4 Boron

Boron occurs naturally in the environment due to the release into air, soil and water through weathering (Lenntech, 2005). It is often found combined to form compounds called borates, which includes boric acid, salts of borates, and boron oxide (ATSDR, 2005). The concentrations of boron that are to processes are smaller than concentrations formed through weathering (ATSDR, 2005; Lenntech, 2005).

Direct eye or skin contact with boron oxide dusts is irritating (ATSDR, 2005; Brown, 2005). Lenntech (2005) and Olson (2004) have shown that when animals absorb large amounts of boron over a relatively long period of time, the male reproductive organs were affected. The offspring of animals exposed to boron during pregnancy may suffer from birth defects or delayed development. Furthermore, animals are likely to suffer from nose irritation when they inhale boron.

Occupational inhalation has shown to cause eye irritation, dryness of mouth, nose or throat, sore throat, productive cough, conjunctivitis and skin erythema to a significant extent in exposed workers (ACGIH, 2001; Brown, 2005).

2.5.5 Calcium

Calcium is most commonly found in milk and milk products, but also in vegetables, nuts and beans. It is an essential component for the growth of the human skeleton and teeth. It also assists the functions of nerves and muscles. However, the use of more than 2,5 grams of calcium per day without a medical necessity can lead to the development of kidney stones and sclerosis of kidneys and blood vessels (Olson, 2004:536).

Calcium oxides are corrosive and have exothermic reactions with moisture (Olson, 2004:536). Calcium dusts are highly irritating to the skin, eyes, and respiratory tract.

2.5.6 Chromium

Chromium is present in the environment in several different forms (ATSDR, 2005; HSE, 2001). The most common forms are chromium metal(0), chromium(II), chromium(III), chromium(IV) and chromium(VI). Of these, chromium(VI) compounds have the most significant effects on health. Exposures to chromium and its various compounds can occur during smelting, roasting and extraction of chromate from ore, chemical and refractory processing, and in the manufacture of alloys containing chromium (Lenntech, 2005; Nims, 1999:27). Chromium salts are used in pigments, wood preservatives, photographic chemicals, and as anti-corrosive additives in boilers and cooling systems. Chromium targets the kidneys, bladder, skin, and respiratory system (White, 2001:132).

The health hazards associated with exposure to chromium are dependent on its oxidation state. Trace amounts of chromium(III) are essential for normal metabolic processes, and are less hazardous than chromium(VI). However, the hexavalent chromium(VI) has corrosive and irritating effects, which occurs readily after uptake through mucous membranes after ingestion as well as during inhalation, causing danger to human health with various health effects (ILO Safework, 2005; Lenntech, 2005). People who smoke tobacco also have a higher chance of exposure to chromium (Lenntech, 2005). Work-related exposure to chromium(VI) compounds may induce adverse health effects on the skin, which include ulcerations, dermatitis, and allergic skin reactions (ATSDR, 2005; Brown, 2005; HSE, 2001; ILO Safework, 2005). Inhalation of

dust containing chromium(VI) compounds can result in ulceration and perforation of the mucous membranes of the nasal septum, irritation of the pharynx and larynx, asthmatic bronchitis, bronchospasms and oedema. Sensitisation has also been reported, resulting in typical asthmatic attacks, which may recur on subsequent exposure. These respiratory symptoms may include coughing and wheezing, shortness of breath, nosebleeds, difficulty and pain in breathing. Exposure to too much chromium(III) can cause health effects as well, for instance skin rashes. Other health effects are headaches, fever and weight loss (ATSDR, 2005; Brown, 2005; HSE, 2001; ILO Safework, 2005).

Respiratory tract irritation may persist after the other symptoms disappear. In numerous studies on the exposure to chromium compounds from France, Germany, Italy, Japan, Norway, the United States and the United Kingdom, an increased risk of trachea, bronchus, and lung cancer were reported. Liver and kidney damage may also occur (Driscoll *et al.*, 2004; HSE, 2001; ILO Safework, 2005; Nims, 1999:27; Schairer & Schöniger, 2001). Chromium intake may increase insulin sensitivity, glucose intolerance, and the ratio of high-density lipoprotein cholesterol to low density lipoprotein cholesterol. Epidemiological evidence on the association between chromium and cardiovascular disease is very limited (Guallar *et al.*, 2005).

Chromates of zinc and calcium appear to be among the most potent carcinogenic chromates, as well as among the most potent human carcinogens (ILO Safework, 2005). Chromium is an IARC Category 1 carcinogen, with many cohort studies showing a dose-response relationship. Chromium trioxide is a teratogen in test animals. Certain hexavalent chromium compounds are carcinogenic in test animals and humans (ATSDR, 2005; Driscoll *et al.*, 2004).

Other health problems that are caused by chromium are:

- Glomerulonephritis;
- tubular necrosis;
- skin burns/rashes;
- a weakened immune system;
- upset stomach;
- alteration of genetic material;
- occupational asthma;
- hypersensitivity pneumonitis;
- chronic obstructive lung disease;
- pneumoconiosis;
- mesothelioma;
- death (White, 2001:132).

There is no firmly established “safe” level of exposure. However, most of the reports on association between chromium(VI) exposure and cancer of the respiratory organs and exposure levels report on air level exceeding $50\text{mgCr}^{\text{VI}}/\text{m}^3$ air (ILO Safework, 2005).

2.5.7 Cobalt

Cobalt is a naturally occurring element in rocks, soil, water, plants and animals, both beneficial and harmful to human health. At high levels it may harm the lungs and heart and cause dermatitis (ATSDR, 2005; HSE, 1998). Cobalt dust is mildly irritating to the eyes and to a lesser extent to the skin. One of the main target organs is the respiratory tract. Bronchial asthma and allergic contact dermatitis may be caused by cobalt, presumably on the basis of allergic sensitisation. Sensitization may drive a granulomatous reaction. Cobalt is the suspected agent of hard metal lung disease, a fibrosis characterized by desquamative and giant cell interstitial pneumonitis (Brown, 2005). The disease progresses from chronic airway obstruction to interstitial lung fibrosis, causing increasingly severe dyspnea. This is characterized by cough, wheezing and shortness of breath – microscopic examinations of exposed lungs showed interstitial infiltration and fibrosis. Other potential symptoms as a result of exposure to cobalt dust are: decreased pulmonary function, weight loss, nausea, abdominal pains, loss of appetite, cough, and a deterioration of the sense of smell and respiratory hypersensitivity. Some workers had decreased hemoglobin levels and red blood cell counts, liver and spleen enlargement, and dermatitis.

2.5.8 Copper

Copper is a very common substance that occurs naturally in the environment and spreads through the environment through natural phenomena. Humans use copper extensively. For instance, it is applied in industry and agriculture and can be found in many kinds of food, in drinking water and in air. The absorption of copper is necessary, because copper is a trace element that is essential for human health. Although humans can handle proportionally large concentrations of copper, too much copper causes health problems (ATSDR, 2005; Lenntech 2005).

Most copper compounds will settle and be bound to either water sediment or soil particles. Soluble copper compounds form the largest threat to human health. Usually water-soluble copper compounds occur in the environment after release through application in agriculture (Lenntech 2005).

Occupational exposure to copper often occurs. The inhalation of dusts containing copper salts can cause congestion of the nasal and mucous membranes and ulceration with perforation of the nasal septum. Copper exposure can lead to a flu-like condition known as metal fume fever with atrophic changes in the nasal mucous membranes that disappear after two days and is caused by hypersensitivity to copper dust (ATSDR, 2005; ILO Safework, 2005; Lenntech 2005).

Chronic toxic effects in humans appear to be found only in individuals who have inherited a particular pair of abnormal autosomal recessive genes and in whom, as a consequence, hepatolenticular degeneration (Wilson's disease) develops. This disease is characterized by hepatic cirrhosis, brain damage, demyelisation, renal disease, and copper deposition in the cornea. Furthermore, it can cause irritation of the nose and mouth, headaches, stomachache, dizziness, vomiting and diarrhoea (ATSDR, 2005; ILO Safework, 2005; Lenntech 2005). Primary chronic copper toxicity has never been found in any individuals except those with Wilson's disease.

Intentionally high intakes of copper may cause liver and kidney damage and even death. Irritation upon direct contact varies with the compound (Olson, 2004:536). The salts are more irritating than dusts and is known to cause corneal ulceration. Allergic contact dermatitis is rare. Dusts and mists can be irritating to the respiratory tract, knowing to cause nasal ulceration. Ingestion can cause severe gastroenteritis and hepatic injury.

2.5.9 Iron

Iron is an essential part of haemoglobin. If inhaled, iron is a local irritant to the lung and gastrointestinal tract. Long-term exposure to a mixture of iron and other metallic dusts may impair pulmonary function (ILO Safework, 2005). Exposure causes conjunctivitis, choroiditis, and retinitis. Chronic inhalation of excessive concentrations of iron oxide fumes or dusts may result in development of a benign pneumoconiosis, called siderosis, which is observable as an x-ray change. Siderosis is pneumoconiosis with little or no fibrosis, causing the reddish discoloration from deposits of iron oxide in the lungs. Many dusts, when inhaled, can cause changes in lung tissue that affect the lung's breathing or gas exchange functions. The most severe response would be changes in the tissues that lead to severe lung damage or enhance the development of cancer when combined with exposure to carcinogenic substances (Brown, 2005; ILO Safework, 2005; Lenntech, 2005; White, 2001:132).

Iron-loaded dust increased procollagen gene expression and tissue hydroxyproline and produces airway wall fibrosis, which in turn leads to chronic obstructive pulmonary disease (Dai

et al., 2002). Inhalation of excessive concentrations of iron oxide may enhance the risk of lung cancer development in workers exposed to pulmonary carcinogens (Lenntech 2005).

2.5.10 Lithium

Industrial exposures to lithium occur during extraction of lithium from its ores, welding, brazing and enamelling. Despite the widespread use of lithium and its compounds, reports of toxic responses in workers are rare (Zenz *et al.*, 1994:605). Acute toxicity of lithium salts is difficult to assess. Most poisonings have occurred to chronic intake, not from single ingestion episodes. Inhalation exposure to lithium causes a burning sensation, cough, laboured breathing, shortness of breath and a sore throat. It can produce upper airway oedema, respiratory failure, wheezing, pulmonary oedema and pneumonitis. Exposure to the eyes and skin causes redness and burns (Lenntech, 2005).

Vomiting, profuse diarrhoea, coarse tremor, ataxia, coma, and convulsions characterize acute intoxication. Symptoms of milder toxicity are most likely to occur at the absorptive peak of lithium and include nausea, vomiting, abdominal pain, diarrhoea, sedation, and fine tremor (Hardman *et al.*, 2001:448; Zenz *et al.*, 1994:605). The more serious effects are primarily neurological and range from fine tremors and muscle weakness in mild cases, to dysarthria, hyperreflexia, coma and collapse. It also includes mental confusion, hyperreflexia, gross tremor, dysarthria, seizures, and cranial nerve and focal neurological signs, progressing to coma and death; neurological damage may be irreversible. Other toxic effects are cardiac arrhythmias, hypertension, and albuminuria (Hardman *et al.*, 2001:448; Hayes, 2001:680). Lithium has properties similar to sodium, and substitution for body cations (sodium, potassium) may account for these effects. Renal symptoms of intoxication include polyuria, polydipsia and renal failure. Lithium has been associated with development toxicity after exposure during pregnancy in animals and humans (Hayes, 2001:680).

2.5.11 Magnesium

Magnesium is found in rock-like dolomite, magnetite, olivine and serpentine. It is the third most abundant structural metal in the earth's crust, only exceeded by aluminium and iron (Lenntech, 2005). The following forms of magnesium are found: dolomite, magnesite, brucite, periclase, carnallite and kieserite (ILO Safework, 2005).

Magnesium has a low toxicity and is not considered to be hazardous to health (Lenntech, 2005). Experimentally produced magnesium deficiency in rats leads to a dilation of the peripheral blood vessels and later to hyperexcitability and convulsions (ILO Safework, 2005). Inhalation of the dust may irritate mucous membranes or the upper respiratory tract and the eyes and nose (HSDB, 2005; ILO Safework, 2005, Lenntech, 2005). The embedding of magnesium particles can cause mechanical injury to the eye. Conjunctivitis, nasal catarrh, and coughing up of discoloured sputum was cited after industrial exposures (HSDB, 2005). Exposure to air polluted with particles <2,5 micron in size is associated epidemiologically with adverse cardiopulmonary health consequences in humans (Kuschner *et al.*, 1997).

Magnesium has not been classified as a carcinogen, mutagen or teratogen (HSDB, 2005; Lenntech, 2005).

2.5.12 Manganese

Manganese is a very common compound that can be found in many ores of rocks. Manganese is one out of three toxic essential trace elements, which means that it is not only necessary for humans to survive, but it is also toxic when too high concentrations are present in a human body. At high levels, it can cause damage to the brain, liver, kidneys, and the developing foetus. Manganese was historically established as a neurotoxin (ATSDR, 2005; Lenntech, 2005).

In occupational situations manganese is primarily absorbed by inhalation (ILO Safework, 2005). Considering the dependence of deposition sites and solubility rate of particle size, the dangerous effect of exposure is closely related to the particle size composition of manganese aerosol. Only particles small enough to reach the alveoli are absorbed in the blood. Large inhaled particles may be cleared from the respiratory tract and swallowed. After inhalation, the absorbed manganese is rapidly eliminated from the blood and distributed mainly to the liver (ATSDR, 2005; ILO Safework, 2005; White, 2001:132). Manganese effects occur mainly in the respiratory tract and in the central nervous system, which may result in permanent disability. Excess metal may be distributed to other tissues such as kidneys, small intestine, endocrine glands and bones. Manganese preferentially accumulates in tissues rich in mitochondria. It also penetrates the blood-brain barrier and the placenta. Biliary excretion is the main regulatory mechanism in the homeostatic control of manganese in the body (ILO Safework, 2005).

Chronic manganese exposure can take either a nervous or pulmonary form. Symptoms of manganese exposure are hallucinations, forgetfulness and nerve damage. Some individuals

chronically exposed to very high levels of manganese, developed a combination of symptoms called “manganism”, which includes mental and emotional disturbances and slow and clumsy body movements (ATSDR, 2005; ILO Safework, 2005). Other chronic overexposure results in the central nervous system toxicity, manifested as psychosis, which may be followed by a progressive toxicity similar to Parkinson’s disease (Brown, 2005; Olson, 2004:536). Symptoms include languor, sleepiness, weakness, emotional disturbances, spastic gait, recurring leg cramps, and paralysis. A high incidence of pneumonia, lung embolism, bronchitis and other upper respiratory infections has been found in workers exposed to dust or fume of manganese compounds. Manganese compounds increased incidence of pancreatic tumours in male rats and thyroid tumours in male and female mice (ATSDR, 2005; Brown, 2005; ILO Safework, 2005; Olson, 2004:536).

There may be difficulty in distinguishing between manganese poisoning and the following diseases (ILO Safework, 2005): nerve syphilis, Parkinson’s disease, disseminated sclerosis, Wilson’s disease, hepatic cirrhosis and Westphal-Strümpf’s disease (pseudo-sclerosis).

Some other symptoms after chronic manganese exposure are:

- Abnormal tension of arteries or muscles, muscle rigidity;
- anxiety, depression, emotional setback, fatigue, confusion, impaired memory, insomnia, irritability, lassitude, lethargy, malaise, nervousness;
- flu-like fever, low-back pains;
- metal fume fever;
- cough, decreased pulmonary function, dry throat, increased pulmonary infections, laboured or difficult breathing (MIWA, 1999).

The Department of Minerals and Energy are currently in the process of compiling a Mandatory Code of Practice for Manganese (Doyle, 2006).

2.5.13 Nickel

Nickel is a naturally occurring compound that targets the skin and respiratory system at very low levels. It can combine with other elements such as chlorine, sulphur and oxygen to form nickel compounds. Humans may be exposed to nickel by breathing air, drinking water, eating food or smoking cigarettes (ATSDR, 2005; HSE, February 2002; ILO Safework, 2005). Human health hazards from occupational exposures to nickel compounds can generally be divided into four major categories:

- Allergy;

- rhinitis;
- sinusitis and respiratory diseases such as asthma; and
- cancers of the nasal cavities, lungs and other organs.

The most common harmful effect of nickel in humans is an allergic reaction. Over-exposure in humans can result in dangerous health effects, with the following consequences:

- Higher chances of development of lung, nasal, larynx and prostate cancers;
- lung embolism;
- irregular breathing;
- respiratory tract irritation and respiratory failure;
- birth defects;
- occupational asthma and chronic bronchitis;
- allergic reactions such as skin rashes;
- heart disorders, e.g. cardiac arrest;
- contact allergic and irritant dermatitis;
- skin burns;
- ulcers;
- hypersensitivity pneumonitis;
- chronic obstructive lung disease;
- pneumoconiosis;
- Mesothelioma;
- abdominal cramps;
- chromosomal aberrations;
- convulsions (ATSDR, 2005; Driscoll *et al.*, 2004; ILO Safework, 2005; Lenntech, 2005; Olson, 2004:536).

More symptoms that can be experienced are a lowered body temperature, cough, cyanosis, death, delirium, diarrhoea, emphysema, epigastric pain, excessive salivation, fatigue, giddiness, headaches, in coordination, increase in blood reticulocytes, increased leukocytes in the blood, increase in serum bilirubin, increased rate or depth of respiration, and interaction with the DNA (MIWA, 1999).

Nickel is one of the most common causes of allergic contact dermatitis known as “nickel itch” in sensitised individuals. Once the worker is sensitised to nickel, the sensitivity persists indefinitely. The first symptom to nickel sensitivity is usually itching, which occurs up to 7 days before skin eruption occurs. The primary skin eruption is erythematous, or follicular, which may be followed by skin ulceration (ATSDR, 2005; Brown, 2005; ILO Safework, 2005; Olson, 2004:536).

Adverse effects on fetal development in test animals have been observed. While rats and mice breathing nickel compounds, developed lung and nasal cavity cancers (ATSDR, 2005; Brown, 2005; Grimsrud *et al.*, 2002). The International Agency for Research on Cancer has classified nickel compounds as carcinogenic to humans, but the form of nickel is still not known with certainty (ATSDR, 2005; Grimsrud *et al.*, 2002). Nickel is an IARC Category 1 carcinogen (Driscoll *et al.*, 2004; Olson, 2004:536).

2.5.14 Phosphorus

Phosphorus is a highly reactive, poisonous, non-metallic element occurring naturally as phosphates. Due to its high reactivity, it is never found as a free element in nature. As phosphate ion, it is abundant and widely distributed in apatite, phosphorite and combines with many other non-metals and metals (Britannica, 2006; Columbia University Press, 2003; Lenntech, 2005). Phosphorous exists in three allotropic forms: white, red and black (Britannica, 2006; Lenntech, 2005). White phosphorus is manufactured industrial, red phosphorus vary in colour due to slight variations in its chemical structure, and black phosphorus is made under high pressure, looks like graphite and has the ability to conduct electricity (Lenntech, 2005).

Phosphate is a key element in plants, animals and the human body, because they are a part of DNA materials and they take part in energy distribution via a component called adenosine triphosphate (Columbia University Press, 2003; Lenntech, 2005). Too much phosphate can cause health problems, such as kidney damage and osteoporosis. Phosphorus is a potent hepatotoxin causing systemic symptoms like abdominal pain, jaundice, and garlic odour in the breath.

Phosphorus in its pure form has a white colour (ATSDR, 2005; Lenntech, 2005). White phosphorus is the most dangerous form of phosphorus. When white phosphorus occurs in nature this can be a serious danger to health. Chronic breathing of white phosphorus has lead to jaw bone necrosis (also known as 'phossy jaw'). This involves poor wound healing of the mouth and breakdown of the jawbone. White phosphorus is extremely poisonous and in many cases exposure fatal. Death following white phosphorus exposure has in the past mostly been brought on by the accidental (or otherwise) swallowing of rat poison. Before people die from white phosphorus exposure, they experience nausea, stomach cramps and drowsiness (ATSDR, 2005; Lenntech, 2005).

White phosphorus can cause severe, penetrating skin burns upon direct contact. These skin burn injuries result because of the highly lipophilic properties of white phosphorus and as such,

is believed to have rapid dermal penetration once particles are embedded under the skin (Keim *et al.*, 2005). While burning, white phosphorus may cause damage to the liver, the heart or the kidneys (Lenntech, 2005; Olson, 2004:536).

Systemic toxicity causes changes in the liver and kidney of animal models. These changes result in the development of progressive anuria, decreased creatinine clearance, increased blood phosphorus levels and electrocardiographic changes (Keim *et al.*, 2005).

2.5.15 Potassium

Potassium plays an important role in the physical fluid system of humans and it assists nerve functions. When the kidneys are malfunctioning an accumulation of potassium will consist, leading to palpitations. Inhalation of dust can irritate the nose, throat, and lungs causing symptoms like sneezing, coughing and a sore throat. Higher exposures may cause a build up of fluid in the lungs that can lead to death (Lenntech, 2005).

Skin and eye contact can cause severe burns leading to permanent damage (Lenntech, 2005).

2.5.16 Silica

Crystalline silica is solid naturally occurring minerals (also known as quartz) found almost everywhere in varying amounts in the earth's crust. It is present in the soil in quarries and mines (Brown, 2005; CCOHS, 1997; HSE, 2005). Quartz, cristobalite and tridymite are the three most common crystalline forms. These forms are interrelated and can change their form under different conditions of temperature and pressure. There are two different forms of quartz that are designated by the prefixes alpha and beta. The most common form is alpha-quartz, which is a major component of igneous rocks, such as granite and pegmatite, but is also found in sandstone and sedimentary rock such as slate and shale. Beta-quartz is less common. Many synthetic forms of quartz also exist. Quartz silica is also known as crystalline quartz silica, crystallized silicon dioxide, free crystalline silica, alpha-quartz, silica, silica flour, silicon dioxide, crystalline silica (non-specific name), and silica.

Crystalline silica (silicon dioxide) is a potent respiratory hazard. Cancer of the trachea, bronchus, or lung is associated with occupational exposures to crystalline silica, specifically quartz and cristobalite. An exposure-response relationship has been reported in studies amongst miners, diatomaceous earth workers, granite workers, and pottery workers.

On the basis of detailed reviews, silica has been classified as an IARC Category 1 carcinogen (Brown, 2005; Driscoll *et al.*, 2004; HSE, 2005; White, 2001:121). Several cohort studies in silica-exposed and silicosis cases show a dose-response relationship between silica exposure and lung cancer relative risk, which has been confirmed by meta-analyses and a pooled study. Animal and cellular studies provide supporting evidence.

Epidemiological studies have reported statistically significant numbers of excess deaths or cases of renal diseases, subclinical renal changes, immunologic disorders and autoimmune diseases in silica-exposed workers, leading to mycobacterial infections (tuberculous and nontuberculous) or fungal, especially in workers with silicosis. These diseases and disorders include scleroderma or progressive systemic sclerosis (PPS), rheumatoid arthritis, systemic lupus erythematosus, and sarcoidosis (CCOHS, 1997; Lenntech, 2005; White, 2001:121).

Occupational exposure to breathable crystalline silica is associated with irritation to the skin and eyes on contact. Irritation to the eyes will cause watering and redness. Reddening, scaling, and itching are characteristics of skin inflammation. Inhalation will cause irritation to the lungs and mucus membrane, occupational asthma, hypersensitivity pneumonitis, pneumoconiosis, mesothelioma, bronchitis, chronic obstructive pulmonary disease (COPD), emphysema and silicosis (Brown, 2005; Lenntech, 2005; MIWA, 1999; WHO, 2000).

Silicosis is one of the oldest occupational diseases and is the key health hazard from exposure to respirable silica dust. It is an incurable disease, scarring the lungs. This is caused by the inhalation of dust containing free crystalline silica. It is irreversible and even progresses when exposure stops (CCOHS, 1997; HSE, 2005; Nims, 1999:27; WHO, 2000). The condition is characterized by the development of nodules that form in response to the dust. The nodules form when macrophages, containing silica particles, die and release their digestive enzymes into the delicate lung tissue. The silica particle, released from the now-dead macrophage, is phagocytized by another macrophage, and the cycle begins again. The nodules form throughout the lungs, but many leave large areas of lung tissue unaffected (HSE, 2005; Nims, 1999:27). As more nodules are formed, they may become larger and clump together, causing localized areas of damage, which impair lung function. The main symptoms in affected people are difficulty in breathing and cough. People who have silicosis are more susceptible to opportunistic infections such as tuberculosis and pneumonia. In some cases the development of tuberculosis may go unnoticed by the doctor since the physical symptoms associated with the disease are masked by silicosis. Other complications associated with silicosis include hypertension (high blood pressure), and cor pulmonale, a disease of the heart characterized by an enlarged right ventricle (HSE, 2005; Nims, 1999:27).

The extent to which silicosis develops is proportional to the amount of crystalline silica present in the dust. These crystalline formations can occur as different minerals; quartz, tridymite; cristobalite; coesite, and stishovite. All of them contain silicon dioxide, SiO_2 . Dusts containing more than two percent quartz tend to produce lesions similar to the nodules associated with silicosis. Dusts that have small amounts (less than two percent) or no crystalline quartz, such as clay (kaolin), talc, and iron oxide, are associated with the formation of lesions that are more like coal macules. These lesions seem to occur in proportion to the amount of dust present; they contain small amounts of reticulin but do not necessarily impair lung function. Such dusts are called nonfibrogenic, since they do not cause a fibrotic response when deposited in the lungs (Nims, 1999:27).

Some epidemiological studies suggest that these health effects may be less frequent or absent in non-smokers (MIWA, 1999).

2.5.17 Sodium

Sodium is the sixth most abundant element in the earth's crust, which contains 2,83% of sodium in all its forms. It is necessary for humans. Sodium is required to maintain the balance of the body's physical fluids system and also necessary for nerve and muscle functioning. Too much sodium can damage the kidneys and increases the chances of high blood pressure (Lenntech, 2005).

Sodium coming in contact with water, for instance like perspiration, causes formation of sodium hydroxide fumes, which are highly irritating to the skin, eyes, nose and throat. This may cause sneezing and coughing. Over-exposures may result in difficult breathing, coughing and chemical bronchitis. Contact with the skin may cause itching, tingling, thermal and caustic burns and permanent damage. Contact with eyes may result in permanent damage and loss of sight (Lenntech, 2005).

2.5.18 Strontium

Strontium is a naturally stable occurring element, not radioactive and is found in rocks, soil, dust, coal and oil. Radioactive strontium is much more of a health risk than stable strontium. Strontium compounds that are water-insoluble can become water-soluble, as a result of chemical reactions. The water-soluble compounds are a greater threat to human health than the water-insoluble ones (ATSDR, 2005; Lenntech, 2005).

Exposure to low levels of stable strontium has not been shown to affect adult human health, but may harm children, impairing bone growth. When the intake is very high, it may cause anaemia and oxygen shortages, and at extremely high concentrations it is even known to cause cancer as a result of damage to the genetic materials in cells. The only strontium compound that is considered a danger to human health, even in small quantities, is strontium chromate. This mainly causes lung cancer due to the chromium (ATSDR, 2005; Lenntech, 2005). Strontium salts are not known to cause skin rashes or other skin problems of any kind. When strontium intake is extremely high, it can cause disruption of bone development. But this effect can only occur when strontium intake is in the thousands of parts per million (ATSDR, 2005; Lenntech, 2005).

2.5.19 Sulphur

Sulphur is found as sulphides in nature. Several processes in nature and in the industry adds sulphur bonds to the environment that are damaging to animals and humans (Lenntech, 2005). These sulphur bonds are unwanted because of their unpleasant smells and are often highly toxic, which targets the respiratory system, skin and eyes. About 10-20% of humans are estimated to be hypersensitive to the adverse respiratory effects of sulphur. Sulphuric substances can have the following effects on human health:

- Neurological effects, and behavioural changes, agitation and fatigue;
- disturbance of blood circulation;
- heart damage;
- effects on eyes and eyesight, e.g. corneal damage and blindness, inflammation of the iris;
- reproductive failure and menstrual disorders;
- damage to immune systems;
- stomach and gastrointestinal disorder, abdominal pain and diarrhoea;
- damage to liver and kidney functions;
- hearing defects;
- disturbance of the hormonal metabolism;
- dermatological effects;
- suffocation and lung embolism (Lenntech, 2005).

Other symptoms include: eye, nasal, throat, and skin irritation, altered sense of taste and smell, asphyxia, bronchial asthma, bronchial spasms, bronchitis, chemical bronchial pneumonia, chemical sensitivity, chest pains and constriction, choking, cough, cyanosis, death, tooth decay, dysphagia, emphysema, eye and skin burns, fever, skin rash, inhibition of thyroid function,

difficult breathing, laryngeal swelling, loss of smell, metabolic acidosis, mouth and pharyngeal redness (Lenntech, 2005).

2.5.20 Titanium

Elemental titanium and titanium dioxide is of a low order of toxicity, considered to be a nuisance dust. Studies on rats exposed to titanium dioxide via inhalation have shown them to develop small localized areas of dark-coloured dust deposits in the lungs. The rats developed neutrophilic inflammation within five hours after exposure (Yuen *et al.*, 1996). In another inhalation study, rodents developed lung cancer after exposure to titanium dioxide (Borm *et al.*, 2004).

Excessive exposure in humans may result in slight changes in the lungs, such as tightness and pain in chest, coughing, and difficulty in breathing, but no clear indication of lung cancer exists in humans (Borm *et al.*, 2004; Lenntech, 2005). Workers chronically exposed to titanium and titanium dioxide dust show a high incidence of chronic bronchitis (endobronchitis and peribronchitis). Electrocardiographic tracings of these titanium workers revealed cardiac changes characteristic of pulmonary disease with hypertrophy of the right auricle (ILO Safework, 2005). Pulmonary fibrosis is occasionally found in subjects exposed to titanium (Mattorano, 1997). Contact with the skin or eyes may cause irritation. Routes of entry are inhalation, skin and eye contact. Titanium dioxide is a mild pulmonary irritant (Olson, 2004:536).

At high lung particle burdens, rats showed a marked progression of histopathological lesions throughout the post-exposure period while mice and hamsters showed minimal initial lesions with recovery apparent during the post-exposure period. Lung neutrophil responses, a sensitive marker of inflammatory changes, reflected the development or recovery of the histopathological lesions (Hext *et al.*, 2005).

The International Agency for Research on Cancer has listed titanium dioxide within Group 3 (ATSDR, 2005).

2.5.21 Vanadium

Vanadium and vanadium compounds can naturally be found in the earth's crust and in rocks, some iron ores, and crude petroleum deposits. It does not dissolve well in water and combines with other elements and particles, and sticks to soil sediments (ATSDR, 2005).

Most people are exposed to vanadium through food. Breathing in high amounts of vanadium can have a number of harmful human health effects, causing lung irritation, chest pain, coughing, runny nose and a sore throat (ATSDR, 2005; ILO Safework, 2005). Similar effects have been observed in animal studies. In some animal studies, the animals had minor birth defects and kidney and liver changes.

The severity of the effects depends on the atmospheric concentration of the vanadium compounds and the duration of exposure. Vanadium pentoxide is a known skin and respiratory irritant and can result in asthma-like symptoms (Brown, 2005; ILO Safework, 2005; White, 2001:132). Sensitisation dermatitis has been reported. The acute effects of vanadium are irritation of lungs, throat, eyes and nasal cavities. When vanadium uptake takes place through air it can cause a burning sensation in the conjunctivae, serous or haemorrhageous rhinitis, coughing and sneezing, profuse lacrimation, sore throat, persistent bronchitis, expectoration, chest pain, asthma-like responses and pneumonia with fatal outcome. Low-level exposure may cause a greenish discoloration of the tongue and metallic taste (ILO Safework, 2005; Lenntech, 2005).

Systemic effects have been observed in the liver, kidney, nervous system, cardiovascular system and blood-forming organs. Metabolic effects include interference with biosynthesis of cystine and cholesterol, depression and stimulation of phospholipid synthesis (ILO Safework, 2005, Lenntech, 2005). Some other health effects of vanadium are:

- Inflammation of stomach and intestines;
- severe trembling and paralyses;
- weakening;
- sickness and headaches;
- dizziness;
- behavioural changes (Lenntech, 2005).

Vanadium is not classified as carcinogenic to humans by the International Agency for Research on Cancer and the Environmental Protection Agency (ATSDR, 2005).

The Department of Minerals and Energy are currently in the process of compiling a Mandatory Code of Practice for Vanadium (Doyle, 2006).

2.5.22 Zinc

Zinc is a natural occurring element in the earth's crust and is essential for human health (ATSDR, 2005; Lenntech, 2005). It is found in air, soil, water and is present in different concentrations in all foods. Too little zinc causes problems, but too much zinc causes serious health problems, such as stomach cramps, skin irritations, vomiting, nausea and anaemia. Chronic exposure can cause anaemia and decrease good cholesterol levels. It is not well known how zinc can affect reproduction in humans, but studies in rats exposed to zinc have shown infertility to occur (ATSDR, 2005). Very high levels of zinc can damage the pancreas and disturb the protein metabolism, and cause arteriosclerosis. Zinc targets the respiratory system and skin (Lenntech, 2005).

In the workplace environment zinc contamination can lead to a short-term, flu-like condition known as metal fume fever (ATSDR, 2005; Brown, 2005; Lenntech 2005; Olson, 2004:536). Symptoms include headache, fever, chills, shortness of breath and muscle aches. This condition will pass after two days and is caused by over sensitivity.

Symptoms of zinc oxide exposure, include a sweet or metallic taste, dry throat, cough, chills, fever, tight chest, laboured or difficult breathing, reduced pulmonary function, blurred vision, muscle cramps and pain, lower back pain, nausea, vomiting, fatigue, lassitude, malaise, metal fume fever, dermatitis, boils, conjunctivitis, gastrointestinal disturbances, pneumonia, increase in leukocytes in the blood (MIWA, 1999).

The International Agency for Research on Cancer (IARC) has not classified zinc for carcinogenicity due to incomplete information from human and animal studies (ATSDR, 2005).

2.6 SUMMARY

Tailings (slurry) are finely grounded discarded waste resulting from the processes followed in mining operations. Tailings are generally composed of fine sand- or silt-size particles, typically deposited as slurry, and, depending upon the method of deposition, may be graded so that coarser material is nearer to the point of discharge. The slurry waste is discharged in retaining structures known as tailings dams by means of either the spigot or cyclone method, separating sand and slimes. Coarse material settles along the perimeter of the dam, while water and some fine material is drawn into the basin in the middle of the dam. A uniform beach is created resulting in a large proportion of the tailings dam beach being maintained wet.

Particles are distributed through any following mechanisms: sedimentation, inertial impaction, Brownian displacement (diffusion) and interception, having an acute or chronic effect, depending on the period of exposure (acute or chronic) and the concentration of the substance. The physiological defence mechanisms include nasal filtration, mucociliary clearance, peristaltic movements of the terminal bronchioles, coughing and sneezing, and phagocytosis.

The potential health effects of different particle sizes in the respiratory system was discussed, indicating that respirable particles sizes ($<7\text{ }\mu\text{m}$) played a significant role in the development of occupational lung diseases such as pneumoconiosis. For example, irritant dust that settles in the nose may lead to rhinitis, an inflammation of the mucous membrane. If the particle attacks the larger air passages, inflammation of the trachea or the bronchi may be seen. The most significant reactions of the lung occur in the deepest parts of the lung.

Lastly, potential respiratory health effects of identified elements in the tailings dust, was discussed. Some elements, such as aluminium, copper, magnesium, manganese, nickel, titanium and zinc had systemic effects. These effects, however, were not discussed because the focus of this dissertation is on tailings dust exposure, and, resulting from that, the potential respiratory effects that can occur.

The study design, methods for monitoring and analysis, statistical analysis and interpretation of calculated data are discussed in the following chapter.

Chapter 3 METHOD

This chapter describes the methodology used for measuring the tailings dust exposure. A 32 element scan was done on the bulk and personal samples according to NIOSH method number 7300. In addition, particle sizes were determined from the bulk samples. The volume of dust on the filters was not enough for determining the particle sizes. The individual total dust concentrations were calculated from the personal sampling data obtained, which was then used for statistical analysis and the interpretation of the statistical results.

3.1 STUDY DESIGN

Forty-seven male workers from three different tailings dams were randomly included in this study, using the 95% OESSM method to determine the participating groups. The Occupational Exposure Sampling Strategy Manual (OESSM), states that such sample size shall be chosen for the top 10% of the group at the 0,95 confidence level for a HCS with a control limit. This implies that at least one individual from the highest 10% exposure group is contained in the sample. The group's average age was approximately 33 years and their working experience varied between one and 14 years in the tailings dam environment. Bulk samples were taken from each tailings dam to be analysed for particle size and a 32 element scan. In order to measure the worst-case scenario of tailings dust exposure, personal dust sampling was conducted during the windiest time of the year. The weather data was obtained from the South African Weather Services. Weather data on the days the measurements were done, was provided by this service.

The foreman or supervisor of the specific tailings dam was asked for assistance in gathering workers randomly for sampling, using the OESSM method to obtain a 95% confidence interval. Personal dust sampling was taken from each subject at each tailings dam, on three consecutive days, in order to determine and evaluate the occupational exposure to airborne particulate matter. This was achieved by drawing breathing zone air through a 0,8 µm mixed cellulose ester (MCE) filter. The samples were sent to a South African National Accreditation System (S.A.N.A.S) laboratory to do the analysis.

3.2 BULK SAMPLING

Three bulk samples per tailings dam were taken from different areas on the tailings' walls, sealed and sent to a S.A.N.A.S accredited laboratory for 32 element and particle size

distribution scans. The particle size distribution was determined by means of x-ray fluorescence. To determine the composition of the tailings dust, the NIOSH 7300 method was used to perform a 32 element scan. The bulk samples were taken as representative of the dust the workers were exposed to.

3.3 PERSONAL SAMPLING

For the purpose of this study, NIOSH 0500 and MDHS 14/3 methods were used for sampling inhalable dusts that are appropriate sampling methods that comply with international best practices.

Air was drawn through a 37 mm diameter 0,8 µm pore sized MCE filter membrane by means of the Gilian GilAir-3 and/or SKC Sidekick air sampling pumps.

The air sampling pumps were pre- and post-calibrated with a Gilibrator bubble generator flow cell and/or a SKC DryCal DC-Lite calibrator.

Respirable dust sampling was not performed due to financial restrictions.

Pre-sampling procedures included the preparation of filters and cassettes, i.e. filter acclimatization overnight, weighing of filters, loading and labelling of filter cassettes. Sampling pumps were pre-calibrated to a volumetric flow rate of 2,0 L/min (see Figures 1 to 3 in Annexure B). All the necessary pre-sampling information, i.e. filter weight and volumetric flow rate, was recorded.

The supervisor assisted in selecting workers for sampling at the tailings dam. It was explained why monitoring was done, as well as when and where equipment would be removed. They were advised not to tamper with the sampling equipment. The workers' details, i.e. name, surname, company number and occupation were recorded on the dust sampling field sheet, matching the filter and pump number allocated to the worker. The filter cassette was placed in the worker's breathing zone (see Figure 4 in Annexure B) and the starting time of sampling period recorded. The sampling pump operated for eight hours after which it was retrieved and the time at which the sampling period ended, recorded.

Post-sampling procedures included the determination of the volumetric flow rate, calculating the average flow rate and sampling period. Used field filters and control filters were acclimatized,

re-weighed and recorded. Field filters that were sent for analysis, were put in petri dishes, sealed and labelled.

3.4 ANALYSIS

The sampled filters were then transported to a laboratory in a container designed to prevent damage in transit and labelled to ensure proper handling. This laboratory was accredited in terms of S.A.N.A.S.

Analysis of these sampled filters was done to determine the elements present in the dust. The laboratory used the NIOSH 7300 method, Inductively Coupled Argon Plasma, Atomic Emission Spectroscopy (ICP-AES), in order to perform a metal scan.

3.5 CALCULATIONS OF DUST CONCENTRATIONS

The total mass of dust on the filter was then determined as (mass of filter + dust) – (mass of filter), allowing for changes to the mass of the filter due to moisture changes. These changes were ascertained by checking changes of the masses of control filters during the period between initial weighing and weighing after sample collection. The average weight change of the control filters was then subtracted from or added to the weight change of each sampled filter, in order to calculate the net weight gain.

The time-weighted average (TWA) exposure was then calculated by determining the volume, the average concentration of exposure and multiplying this value by the sampling period, and then divided by the total duration of the shift of eight hours. These TWA values were compared to the Occupational Exposure Limit (OEL) for particulates not otherwise classified (PNOC) to determine the severity of the workers' exposure.

3.6 STATISTICAL ANALYSIS AND INTERPRETATION

The dust concentration results were used to describe the exposure levels for all workers at the same tailings dam and between the three tailings dams. The Statistical Consulting Services of the North-West University, Potchefstroom Campus, determined variation in exposure. The software programme Statistica was used to analyse the between tailings dams and between day differences by means of various statistical tests: a two-way ANOVA F test and a multiple

comparisons TUKEY HSD test. A Student T test was done for the comparison between Pipe Line Labourers and Mud Guards.

The two-way ANOVA F test compares more than one variance statistically in order to make a general assumption on the populations. The multiple comparisons TUKEY HSD test is a post hoc test in order to compare three or more medians statistically after an ANOVA test was completed. The student T test compares two medians statistically (Steyn, 2006).

3.7 SUMMARY

The methodology was discussed, looking at the study design, bulk and personal sampling, the NIOSH methods used for monitoring and analysis of the samples. The statistical analysis used and interpretation thereof was then discussed.

The following chapter will discuss and reach conclusions on the results found from the metal scan and particle size analysis, calculations of dust concentrations and statistical interpretations

Chapter 4 - RESULTS and DISCUSSION

Results are displayed and discussed in this chapter. The particle size distribution, elements in the bulk and filter samples, and total dust concentrations are reflected in this chapter. The weather's influence on the dust concentrations was considered. Compliance to the Occupational Exposure Limit (OEL) for PNOC was investigated. The between-days, between-dams and between-group variances were determined to assess the contrast in exposure level. Additive respiratory health effects that can occur in the mixture of hazardous substances were identified from the highest dust exposure in each Homogenous Exposure Group (HEG). Conclusions are arrived at regarding the discussed results in this chapter and whether the hypothesis mentioned in Chapter 1 can be accepted or rejected. Existing control measures are discussed and the efficiency thereof analysed by looking at the required control measures as described in the Mine Health and Safety Act (1996). Final conclusions of the points discussed in this chapter are made in the following chapter, Chapter 5.

The South African Weather Services provided weather data. The Statistical Consulting Services of the North-West University, Potchefstroom Campus, did the statistical evaluation on the sample data collected from the personal total dust exposures measured at the three different tailings dams.

4.1 ANALYSIS OF TAILINGS DUST

During the trials, a total of 69 personal dust samples were collected for three full production shifts on tailings dam workers in each of the three different tailings dams. Tailings dam 1 (TD 1) was situated near Rustenburg, TD 2 in Thabazimbi and TD 3 was located outside Potgietersrust. The field filters were weighed to calculate the total dust concentrations. Bulk samples and field filters were sent away for 32 element and particle size distribution scans.

4.1.1 Elemental analysis

The analysis results on the filters and bulk samples are discussed under this heading. These results display in table 1 the elements' percentage found in the samples. Aluminium, barium, chromium, cobalt, copper, magnesium, manganese, nickel, titanium, vanadium and zinc are all systemic toxins found in the bulk samples. All identified elements' health effects are discussed in Chapter 2.

An interesting observation made was that arsenic was identified in the bulk sample of TD 1, but was absent in the filter sample, also, on TD 3, Silica was identified in the bulk sample, but was absent in the filter sample. A possible explanation of this occurrence can be that the particle sizes of these elements were too heavy to become airborne due to their size, or the moisture content of the tailings dam itself caused the particles to be heavy.

Also, some elements identified in the filter samples were not present in the bulk samples. This was the situation at all three tailings dams. A possible reason can be that environmental dusts not coming from the tailings dams were blown across the tailings dams by the wind.

Other reasons may be due to the bulk samples taken at a different period than when the monitoring was conducted. During this time, mining activities could have taken place in different meteorological rock. During this time, mining activities could have taken place in different meteorological rock. However, no mining activity was done in meteorological rock containing silica.

The main elements identified by the Inductively Coupled Argon Plasma, Atomic Emission Spectroscopy (ICP-AES) analysis, are indicated in table 1. The total percentage sum of the ICP-AES analysis on the bulk and filter samples do not add up to 100% indicating that oxides of microelements were also present in the sample. Molecules such as O₂, OH and C are not indicated because samples for the metal scan were burnt in a furnace before being prepared in an acidic solution. During this process organic molecules are destroyed, leaving only the metal molecules behind for analysis.

The silica indicated in TD 3's bulk sample was not analysed to determine the type of silica. Also, no respirable measurements were taken. This was due to a restraint put on the study by the financial provider, which only budgeted for inhalable dust measurements and analysis, the reason being that silica does not occur naturally in this area.

4.1.2 Particle Size Distribution

Results from a particle scan on the bulk samples are indicated in table 2. Particle scans were not done on the filter samples because the volume of dust on the filters was not enough to be subjected to analysis. It is clear that TD 3 has the smallest particle size distribution, and TD 2 has the largest distribution. TD 3 showed 10% of the particles to be smaller than 7 µm, which is a property of respirable dust. TD 1 and 2 indicate particle sizes for inhalable dusts.

Table 1. Elements identified in the bulk and filter samples, described in percentages present in the samples.

% Identified						
Elements	Bulk Samples			Filter Samples		
	TD 1	TD 2	TD 3	TD 1	TD 2	TD 3
Aluminium (Al)	13,891	9,389	7,017	6,80	8,66	25,878
Arsenic (As)	0,001	-	-	-	-	-
Barium (Ba)	0,015	0,01	-	0,04	0,52	0,113
Boron (B)	-	-	-	-	-	0,0032
Calcium (Ca)	9,453	6,631	11,180	21,26	17,07	11,797
Chromium (Cr)	-	-	0,603	0,74	1,16	0,365
Cobalt (Co)	-	-	-	-	-	0,004
Copper (Cu)	-	-	-	0,13	0,14	0,074
Iron (Fe)	-	-	9,497	6,40	8,54	25,949
Lithium (Li)	-	-	-	0,05	0,19	0,167
Magnesium (Mg)	-	-	20,293	1,77	5,67	27,475
Manganese (Mn)	-	-	0,287	0,12	0,19	0,715
Nickel (Ni)	-	-	-	-	0,23	0,125
Phosphorous (P)	-	-	0,020	-	0,03	0,107
Potassium (K)	-	-	0,210	-	0,91	4,647
Silica (Si)	-	-	46,777	-	-	-
Sodium (Na)	-	-	0,120	-	-	1,417
Strontium (Sr)	0,030	0,021	-	-	-	0,013
Sulphur (S)	0,139	0,105	-	-	-	0,913
Titanium (Ti)	0,144	0,070	0,233	0,14	0,23	0,37
Vanadium (V)	0,026	0,012	-	-	-	0,003
Zinc (Zn)	0,006	0,001	-	0,90	0,73	0,057
Total Percentage:	23,344	16,020	94,764	38,35	44,27	97,163

* Part of the above-mentioned samples is bulk samples that have no listed exposure limits for the identified chemicals. It is important that the concentration of the above substances is kept as low as reasonably practicable in a work area where workers regularly have to work.

Table 2. Particle size distribution (µm) of the three tailings dams.

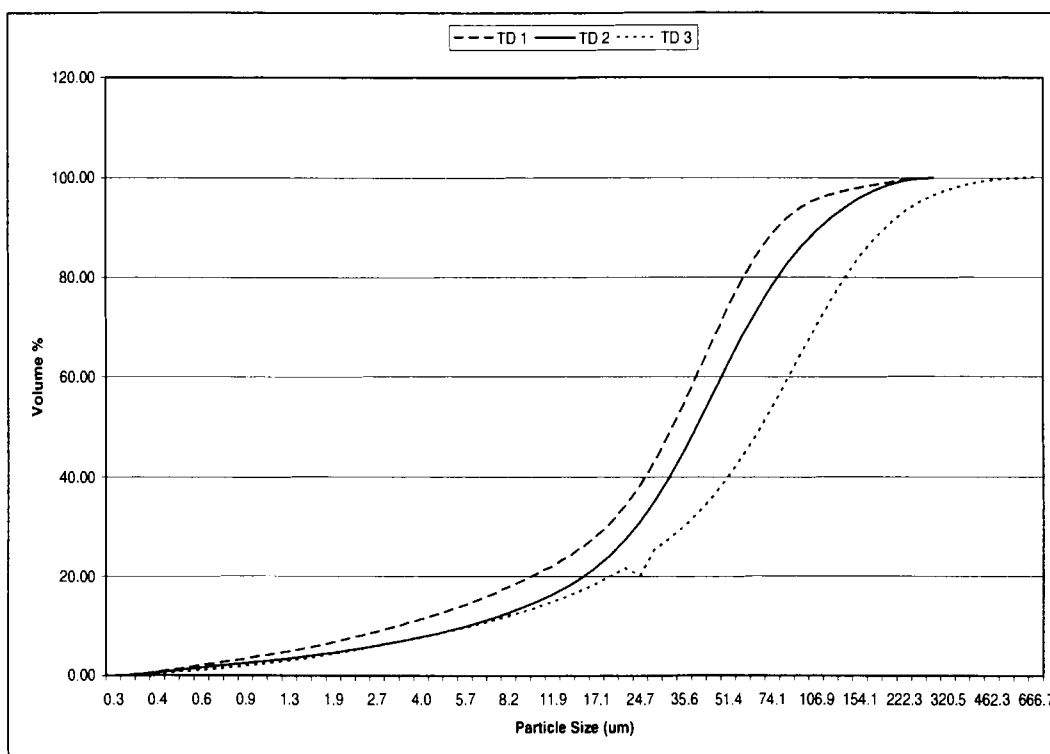
Volume %	Particle size (µm)		
	TD 1	TD 2	TD 3
10 %	< 12,198	< 15,134	< 6,042
50 %	< 66,713	< 98,502	< 68,257
90 %	< 197,593	< 262,628	< 189,125

* TD, Tailings dam.

Table 3. Particle size volume % of particles smaller than 7 μm and particles greater than 10 μm .

Particle Size (μm)	Volume %		
	TD 1	TD 2	TD 3
< 7 μm	11,34	7,72	10,41
> 10 μm	85,73	90,14	86,17

* TD, Tailings dam.

**Figure 1.** Particle size distribution of Tailings dams 1, 2 and 3.

Respirable dust is airborne particulate fractions from 0,1 to 7 microns that can enter the respiratory system and penetrate the gaseous exchange region, i.e. the alveoli, where the molecules get absorbed into the bloodstream, having effects on specific target organs (CCOHS, 1999; Johnson & Vincent, 2003:207; Ayres, 2005:47). It is thus responsible for the development of any form of pneumoconiosis (dusty lung), be it siderosis, silicosis or stannosis, depending on the type of dust. Inhalable dust is the particles sizes 10 μm and greater, which deposits in the nasal region where it is sneezed out or swallowed (CCOHS, 1999; Nims, 1999:27; White, 2001). The respiratory health effects of elements found in the bulk and filter samples were discussed in chapter 2 under physiological implications.

Table 4. Summary statistics of TWA dust concentration (mg/m^3) ratios.

	TD 1	TD 2	TD 3^o	TD 3*
Mean	0,124	0,366	11,519	2,956
Median	0,122	0,154	2,390	1,600
Standard deviation	0,052	0,454	28,520	2,977
Minimum	0,031	0,041	0,031	0,130
Maximum	0,222	1,378	116,240	10,606
Population size (n)	19	18	32	32

^o With outliers; * Without outliers; TD, tailings dam.

Table 3 describes the respirable and inhalable dust particle size volume percentage. Although table 2 indicated TD 3 to have the smallest particle size distribution, TD 1 has however the largest percentage of respirable dust in its bulk samples. TD 2 was also indicated in this table as the tailings dam with the largest particle size distribution.

Figure 1 displays the three tailings dams' particle size distribution in micrometer (μm) against the volume % in which the sizes occur. From this figure it is clear that TD 1 has a larger particle size distribution while TD 3, making use of the spigoting method, showed the smallest particle size distribution.

4.2 TOTAL DUST EXPOSURES

Population sizes were determined by means of the OESSM method. It was found that the Time Weighted Average (TWA) dust concentrations in the sample population ranged from 0,031 to 116,240 mg/m^3 . Table 4 gives descriptive statistics that include the mean, minimum, maximum, median and standard deviation of the workers' dust exposure ratios. Tailings dam 3 is described in two columns, one with its outliers and one without.

No total dust overexposures were found at tailings dams 1 and 2. Tailings dam 3 had three outliers exceeding the OEL of 10,0 mg/m^3 . This deviation causes the mean value, which included outliers to exceed the OEL. Without the three outliers, the mean value would have been within the OEL. These outliers were measured on three different individuals in two different days, i.e. 111,265 mg/m^3 and 116,240 mg/m^3 (on day 2) and 55 mg/m^3 (on day 3). It was decided by the Statistical Consulting Services to do statistical analysis without these three outliers. The dust concentrations of the outliers are suspected not to reflect true exposures, because there are no repetitive concentrations higher than 10,0 mg/m^3 other than the above-

mentioned three outliers. Such outliers have never been found in similar studies done at tailings dam 3.

Possible reasons are discussed for these outliers to have occurred:

- It could be possible for the workers to have deliberately ‘fed’ the samples. This is because sometimes workers have hostile attitudes toward wearing sampling pumps. A comparison between results of measurements taken earlier during the year delivered values smaller than $1,0 \text{ mg/m}^3$, in contrast to this study’s results where no repetitive concentrations higher than $10,0 \text{ mg/m}^3$ other than the above-mentioned three outliers were found. Any suspicious results need further investigation;
- The position of the worker in relation to the wind direction and wind speed could cause outliers. The wind speeds for day 2 and 3 at TD 3 were $3,2$ and $3,0 \text{ m.s}^{-1}$ (table 5c). The workers on Tailings Dam 3 faced the wind while securing the crest of the tailings dam. This involved digging in the dry slurry, causing the tailings dust to blow into the breathing zone of the worker.

It was further observed that some samples over the three-day period at tailings dam 3 exceeded the action level, which is calculated at 50% of the OEL for total dust (i.e. 5 mg/m^3). This indicates that respiratory control measures need to be implemented as a preventative measure. This needs to be done in order to ensure that the exposure of workers do not at any stage exceed the respective OEL’s of substances to which they are exposed.

4.2.1 Weather data and total dust concentrations

An interesting observation was made in the comparison of the data in tables 2 to 4. Workers at TD 3 with the larger particles, showed the highest TWA dust exposures, instead of the expectation that the dam with the largest portion of small particles will show the highest TWA dust exposures.

Weather data and piezometer (water table level) results of each dam were used to search for a possible explanation of this occurrence. Temperature, humidity and air pressure are contributing factors to the atmosphere’s density. From table 5 it is clear that TD 3 had a higher temperature and humidity than TD 1. TD 1 could not provide piezometer results because the tailings dam’s walls were constructed at the point of monitoring. The moisture content between the three tailings dams could therefore not be compared.

Table 5. Descriptive tables (5a – 5c) on weather data at the three tailings dams over three consecutive days.*Table 5a – Weather data at tailings dam 1.*

Tailings Dam 1	Day 1	Day 2	Day 3	Average:
Temperature Maximum (°C)	32,0	31,5	22,5	28,7
Temperature Minimum (°C)	11,0	12,0	9,4	10,8
Humidity (%)	24	56,5	42,8	41,1
Wind speed (m.s⁻¹)	2,1	2,5	2,2	2,3

Table 5b – Weather data at tailings dam 2.

Tailings Dam 2	Day 1	Day 2	Day 3	Average:
Temperature Maximum (°C)	31,8	31,2	30,1	31,0
Temperature Minimum (°C)	7,3	11,5	12,2	10,3
Humidity (%)	44,5	43,4	43,9	43,9
Wind speed (m.s⁻¹)	0,9	1,9	1,0	1,3

Table 5c – Weather data at tailings dam 3.

Tailings Dam 3	Day 1	Day 2	Day 3	Average
Temperature Maximum (°C)	29,8	28,5	31,1	29,8
Temperature Minimum (°C)	14,9	12,7	14,7	14,1
Humidity (%)	52	55	56	54,3
Wind speed (m.s⁻¹)	2,6	3,2	3,0	2,9

°C – degrees Celsius; m.s⁻¹ – metres per second.

Table 6. Two-way ANOVA Test for repeated measures between day and tailings dam as factors with a 5% significant level.

Effect	SS	d.f.	MS	F	p
Tailings Dam	2301,48	2	1150,740	3,350	0,057
DAY	551,09	2	275,543	0,651	0,527
DAY*Tailings Dam	1347,86	4	336,964	0,797	0,535

* SS, Sum of squares; d.f., Degrees of Freedom; MS, Mean squares; F, F-ratio; p, p-value

Table 7. Two-way ANOVA Test for repeated measures between day and tailings dam as factors with a 10% significant level, without outliers.

Effect	SS	d.f.	MS	F	p
Tailings Dam	116,764	2	58,382	10,601	0,001
DAY	8,502	2	4,251	1,278	0,292
DAY*Tailings Dam	12,290	4	3,073	0,924	0,462

* SS, Sum of squares; d.f., Degrees of Freedom; MS, Mean squares; F, F-ratio; p, p-value.

Table 8. Multiple comparisons with TUKEY HSD, without outliers on a 5% significant level.

	p-value		
	Tailings Dam 1	Tailings Dam 2	Tailings Dam 3
Tailings Dam 1	-	0,951	0,003
Tailings Dam 2	0,951	-	0,006
Tailings Dam 3	0,003	0,006	-

Table 9. Multiple comparisons with TUKEY HSD test, without outliers on a 10% significant level.

	p-value		
	Tailings Dam 1	Tailings Dam 2	Tailings Dam 3
Tailings Dam 1	-	0,999	0,155
Tailings Dam 2	0,999	-	0,166
Tailings Dam 3	0,155	0,166	-

Table 10. Two-way ANOVA Test for repeated measures over type and tailings dam as factor, on a 5% significant level, without outliers.

Effect	SS	d.f.	MS	F	P
Type	35,176	1	35,176	3,524	0,078
DAY	9,897	2	4,948	1,428	0,254
DAY*Type	0,956	2	0,478	0,138	0,872

* SS, Sum of squares; d.f., Degrees of Freedom; MS, Mean squares; F, F-ratio; p, p-value.

Table 11. Multiple comparisons with TUKEY HSD test, without outliers on a 10% significant level.

	p-value	
	Mud Guards	Pipe Line Labourers
Mud Guards	-	0,099
Pipe Line Labourers	0,099	-

Table 12. Student T-test on a 10% significant level to compare types for each day, without outliers.

Variable	Mean MG	Mean PLL	t-value	p
Day 1	0,497	2,160	-2,735	0,013
Day 2	0,270	1,642	-1,471	0,160
Day 3	1,548	2,710	-0,767	0,453

* MG, Mud Guards; PLL, Pipe Line Labourers; p, p-value.

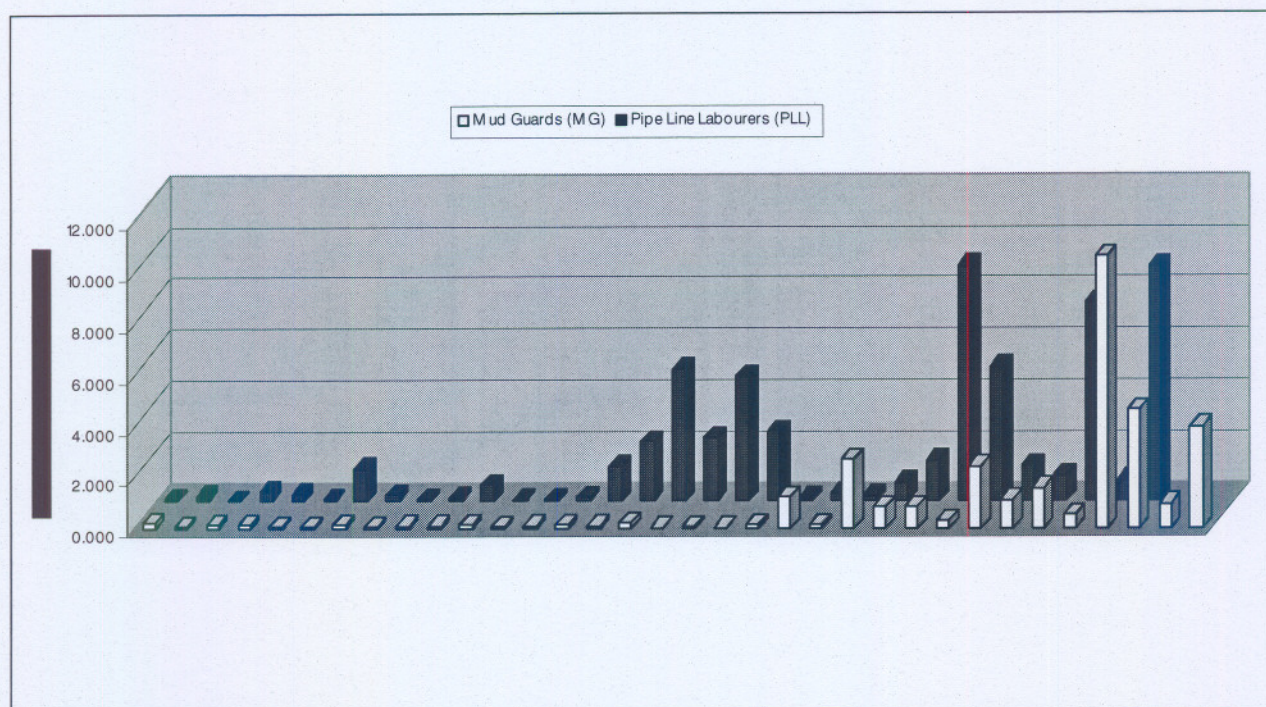


Figure 2. This figure displays the overall TWA dust exposure concentrations (mg/m^3) for the Mud Guards (in yellow) and Pipe Line Labourers (in blue) on the three tailings dams. It is clear that the Pipe Line Labourers had a higher exposure than the Mud Guards.

4.2.2 Compliance to Exposure Limits

Fundamental to any Occupational Hygiene decision is the question: Is there a possibility that the dust exposure can be harmful to the workers? This can be answered by determining whether the concentration is exceeding a certain level or limit. The South African legislation refers to this limit as the health and safety standard. In terms of exposure to hazardous chemical substances it is known as the Occupational Exposure Limit (OEL) or the threshold limit value (TLV), referring to the maximum concentration of a hazardous airborne substance to which nearly all workers may be exposed to, day after day, without adverse effects.

The results of this survey were evaluated against the Occupational Exposure Limits (OELs) prescribed in the Regulations for Hazardous Chemical Substances, 1995, of the Occupational Health and Safety Act No. 85 of 1995. The Mine Health and Safety Act (1996) states that when airborne particulates are one tenth of the OEL for that specific substance, then an airborne pollutant monitoring programme must be implemented. The TWA-OEL for particulates not otherwise classified is $10 \text{ mg}/\text{m}^3$. If one compares the dust TWA mean concentrations with this OEL (see table 4), then it is clear that there is no general overexposure. There are, however, samples exceeding the action limit, which is 50% of the OEL (i.e. $5 \text{ mg}/\text{m}^3$). This implies that a

monitoring programme should be implemented for TD 3, which had an individual maximum concentration of 10,606 mg/m³.

4.2.3 Between days variation

A two-way ANOVA F test was performed to determine whether there was a significant difference in the exposure levels for dust between the measurement days on each of the tailings dams. The test was performed on a 5% and a 10% significant level with day and tailings dam as factors.

A p-value of 0,527 was calculated on a 5% significant level for the different days at each tailings dam. This means that no significant difference exist between the three different days per tailings dams (see table 6).

On a 10% significant level between days (see table 7), no significant effect was found due to days ($p=0,292$) or the day-tailings dam interaction ($p=0,462$).

4.2.4 Between dam variation in TWA personal dust exposure

The possibility for a significant effect between the three tailings dams were examined by means of the two-way ANOVA F test and the TUKEY HSD test on a 5% and 10% significant level, without outliers at tailings dam 3. The two-way ANOVA F test (see tables 6 and 7) does not have a significant difference on a 5% significant level ($p=0,057$). Though, a significant difference was found between the three tailings dams on a 10% significant level with a p-value of 0,001.

Significant differences were found between tailings dam 1 and 3 ($p=0,003$) and between tailings dam 2 and 3 ($p=0,006$) on a 5% significant level (see table 8). However, no significant effect was found on the 10% significant level (see table 9).

4.2.5 Pipe Line Labourers compared to Mud Guards

The two-way ANOVA F test, a TUKEY HSD test and a student T test (see tables 10 to 12), were used for the analysis of the Pipe Line Labourers (PLL) and Mud Guards (MG). The ANOVA F test was done on a 5% significant level without outliers (see table 10). No significant effect was

found ($p>0,05$). The TUKEY HSD test obtained a significant level between the types of work on a 10% significant level, $p=0,099$. A significant level was also found for Day 1 in the student T test where the Pipe Line Labourers were compared with the Mud Guards for each day ($p=0,013$). Day 2 and 3 had no significant effect (see table 12).

The reason why the Pipe Line Labourers and the Mud Guard's exposures differed significantly can be ascribed to the areas and type of work each group performs. The Pipe Line Labourer does more general work, like removing the grass under the pipelines, digging holes and operating the tyre dozer on the tailings dam. They tend to work in areas where the slurry and normal ground has dried. On the other hand, the Mud Guard patrols the benches of the tailings dam and inspects the pipelines on the tailings dam. They are working in areas where the slurry is mostly wet. The difference in exposures is illustrated in Figure 2 where it is clear that the PLLs were subjected to more severe exposure to dust than the MGs.

4.3 CONCLUSIONS RESULTING FROM THE ANALYSIS OF DUST EXPOSURES

The following hypotheses were formulated, each followed by a conclusion:

1. *The larger percentage of the tailings dust will consist of respirable fractions (particles $<7\ \mu\text{m}$).*

This hypothesis is rejected because the larger percentage of tailings dusts, consisted of $10\ \mu\text{m}$ and larger. However, the presence of particles sizes smaller than $7\ \mu\text{m}$ was detected in the tailings dust. This can be seen in tables 2 and 3.

2. *Personal dust exposures will increase with an increase in wind speed.*

TD 3 showed the highest dust exposures as well as the highest wind speed compared to the other two tailings dams. However, TD 2 had the lowest wind speeds, but showed a higher dust concentration than TD 1, whose wind speeds were higher than TD 2 (see table 5). It can be concluded that wind speed does not influence the personal dust exposures. A study done by Wagner and Leith (2001), confirms this conclusion. They concluded that wind speed, relative humidity and the concentration of dust did not influence results.

3. *Dust exposure between the different days per tailings dam will not differ significantly.*

This hypothesis is accepted on a 5% and 10% significant level due to the fact that no significant level was found ($p<0,05$).

4. *Dust exposure between the three different tailings dams will not differ significantly.*

It was found in the results (tables 8 and 9) that a significant difference does exist between the tailings dams in the ANOVA F test on a 10% significant level ($p=0,001$). The TUKEY HSD test on a 5% significant level had a significant effect between TD1 and TD3 ($p=0,003$), and between TD2 and TD3 (0,006). Therefore the hypothesis cannot be accepted as true.

5. *There will be a significant difference in the concentrations between Mud Guards and Pipe Line Labourers*

A significant effect was obtained on a 10% significant level ($p=0,099$) in the TUKEY HSD test between the MG and PLL. The student T test indicated Day 1 to have significant differences between the two occupations, $p<0,1$ (see table 12). On these grounds the hypothesis can be accepted.

6. *Workers on cyclone tailings dams will have a lower dust concentration than workers at the spigot tailings dams.*

TD 2 and 3 were using the spigot method and TD 1 used the cyclone method. It was found that TD 2 and 3 had higher concentrations than TD 1 (see table 4). For this reason the hypothesis can be accepted.

4.4 EXPOSURE CONTROL

The Hazardous Chemical Substances Regulation (1995), states that where there is no indication of the need for a lower value, personal exposure should be kept below 10 mg/m^3 8-hour time-weighted average total inhalable dust and 5 mg/m^3 time-weighted average respirable dust. This level, or greater dust concentrations should be regarded as substantial concentrations.

Not all dusts have been designated occupational exposure limits but the lack of such limits should not be considered an absence of hazard. In the absence of a specific exposure limit for a particular dust, exposure should be adequately controlled. In fact, if a hazardous agent is found to be present in the workplace in concentrations that could cause health effects, it must be controlled. Control means eliminating the hazard or reducing it to a level that protects workers from adverse health effects. To be effective, a control measure must satisfy the following criteria:

- it must adequately control the hazard to eliminate the danger to the worker;
- it must protect all workers who are likely to be exposed;
- it must not create a new hazard in the workplace;

- it must not create an environmental hazard outside the workplace.

Hazards may be controlled at the source, along the path from the source to the worker, or at the worker.

In this section, current control measures are discussed for each tailings dam. Then consideration will be given to the requirements of the Mine Health and Safety Act (1996) regarding airborne pollutant exposures, which will be used to evaluate the current control measures at each tailings dam. Thereafter recommendations are made considering the evaluation of the current control measures and the exposure results.

4.4.1 Required Control Measures in the Mine Health and Safety Act (1996)

The Mine Health and Safety Act (1996) requires an occupational hygiene programme of all working places where the TWA concentration of airborne pollutants exceeds or equals a tenth of the occupational exposure limit. This must be periodically reviewed to determine whether additional elimination, control and minimisation of risk are possible. Records must be kept of the measurements, management and medical examination of these airborne pollutants.

To measure the worst case, guidelines issued in the SAMOHP (2002) codebook by the Department of Minerals and Energy (DME) is followed to measure airborne pollutants (see table 13). It is stipulated that 5% of workers within a HEG or a minimum of five samples per HEG, must be measured, whichever is the greatest. Thereafter, measurements and reporting to the DME takes place according to the HEG category classification band of the personal exposure levels found, i.e. A, B or C. Where A will be quarterly reporting, B is bi-annual, and C is annually reporting (Unsted, 2001:100).

Table 13. Airborne pollutants Classification band, sampling and reporting frequency (Unsted, 2001:100; SAMOHP, 2002:14).

Category	Personal exposure level	Sampling Frequency	Reporting Frequency
A	Exposure exceeding the OEL or mixtures of exposure ≥ 1	Sample 5% of HEG on a three monthly basis	Quarterly reporting
B	Exposure between 50% of the OEL and the OEL or mixtures $\geq 0,5$ and < 1	Sample 5% of HEG on a six monthly basis	Bi-annual reporting
C	Exposure between 10% of the OEL and 50% of the OEL or mixtures $\geq 0,1$ and $< 0,5$	Sample 5% of HEG on a annual basis	Annual reporting

The Hazardous Chemical Substances Regulations (1995) require that an employee must be *trained and informed* regarding potential source exposures, potential risks to health caused by exposure and the measures to be taken by the employers and workers to protect the workers against health risks associated with such exposure, including the wearing and use of protective clothing and respiratory protective equipment.

Furthermore, periodical *medical surveillance* (chest x-ray and spirometry) must be done when the exposure of the employee to any hazardous substance is such that an identifiable disease or adverse effect may be related to the exposure.

When there is no other way of prevention or managing of exposure, appropriate *PPE* must be provided.

4.4.2 Existing Control Measures at the Tailings Dams

Tailings Dam 1, 2 and 3

- ***Medical surveillance***

The workers undergo an annual chest x-ray and a spirometry test to assess the health of their lungs, which forms part of the medical surveillance. The chest x-ray is taken to look for lung damage (darkened or white spots). The spirometry test includes forced expiratory volume in one second (FEV1), forced vital capacity (FVC) and FEV1/FVC expressed as a percentage. This annual spirometric test is compared to the baseline spirometric test. Clinical evaluation is required when a decline in lung volume occur, an exceeded average of 200 mL between tests.

- ***Respiratory Protective Equipment***

The tailings dam workers are issued with Dräger Piccola FFP2 dust masks because of their exposure to nuisance dust (see Figure 1 in Annexure C). According to a communication by Swanepoel (2006), the reason for these specific masks to be used is because no specific pollutant in the form of gas or vapour is present at the tailings dams.

The Dräger Piccola FFP2 dust mask is a comfortable, lightweight disposable dust mask. This mask is manufactured from Synsafe® material. It combines mechanical and electrostatic filtering for higher filter capacity. It reduces breathing resistance to a minimum and provides improved protection against dusts, including solid and liquid particles. The mask was tested against particle sizes 0,3 µm and above, providing a 94% particle filtration efficiency. It has a tear-resistant harness and can be adjusted to fit different head sizes. The Dräger Piccola FFP2

is available in one size and filters a range of mechanically and thermally generated particles. Each mask is individually packed in a plastic bag. These masks are approved under the protection class in the European Standard EN149:2001 (CE marked). The mask has an adjustable nose clip and forms to the shape of the face because of the flat folded design, creating a comfortable seal even when wearing protective goggles (Dräger, 2006).

This mask is likely to adequately prevent harmful particles from entering the respiratory track of the worker if it is worn correctly.

- ***Occupational hygiene measures***

All the tailings dams are issued with Dräger Piccola FFP2 dust masks. The company decides on the type of mask to wear according to the type of exposure, i.e. dust, fume or mist. The worker is issued with the mask, but is not forced to wear it. Issuing the Respiratory Protective Equipment (RPE) on the worker's company number monitors the utilization of RPE. The RPE is replaced when it is damaged or dirty. Old RPE is given back to the stores when new RPE is issued. Lockers are provided to store issued Personal Protective Equipment (PPE) that includes a dust mask, overall, gloves and boots. The workers use the same locker to store personal clothing and PPE. No showers were available for them to clean themselves after a shift before leaving for their homes. At tailings dam 3, the workers' houses were on site, meaning the workers went home with their dirty overalls.

The Mine Health and Safety Act (1996) stipulates that personal protective equipment must be issued to take care of the workers' health and safety. Furthermore, the worker must use and take care of his/her protective equipment, giving his/her co-operation with the responsible person issuing the PPE in order to comply with the duties and responsibilities of such a responsible person. This means if a worker refusing to wear his mask, he fails to comply with a duty under this Act and can be fined if found guilty.

No formal training is given on the specific respirator the worker is issued with and no respirator fit testing is in place. Should a worker have an issue with his mask, he can take it up with the occupational hygiene department of this company.

No specific cleaning requirements exist for overalls, the reason being that the workers do not work with lead or asbestos or any other chemical that requires special cleaning. However, an observation made was that the tailings dam workers' clothes became very dusty (see figure 2 in Annexure C.)

Some of the tailings dams had grass planted on the tailings dams as a measure to suppress dust emission (see Figure 1 in Annexure C), though it was clear that this measure was not sufficient, because dust was seen blowing from the tailings dam polluting the atmosphere (see Figure 3 in Annexure C.)

- ***Training***

It is compulsory to all contractors at this company to do KBC training (Swanepoel, 2006). These training sessions include general health and safety issues, such as legal liability regarding the Mine Health and Safety Act (1996), hazards and risk identification, personal protective clothing, housekeeping, medical examinations, and health/hygiene, etc. (KBC, 2006). Additionally, the workers undergo induction at the Concentrator site, which includes general health hazards, effects and control measures specific to the concentrator.

Tailings Dam 1

A current control measure to suppress dust emission includes wetting of roads with filtered industrial water to minimise formation of dust. Access to the dam is controlled to minimise traffic on the roads.

Tailings Dam 2 and 3

Currently different grass species is planted on the walls of the tailings dams as a dust control measure. There are a minimum number of paths built to access the top of the dam and the middle of the dam. This will be a road around the dam on each level and a path towards the area where the sludge was poured. This is to minimise the formation of dust on the tailings dam caused by vehicles. Access to the dam is controlled to minimise traffic on the roads.

Tailings Dam 3

An occupational hygiene monitoring programme was in place at the time measurements were taken. Monitoring is conducted annually on this tailings dam's workers because their baseline personal dust exposure was classified in the C band of the South African Mine Occupational Hygiene Programme codebook. This C classification requires annual measurements and reporting, after which the classification is reviewed. If the classification band changes, then recommendations of the specific classification band must be followed. TD 1 and 2 lacked in this respect.

4.4.3 Efficiency of Control Measures

At Tailings Dam 1 and 2, the mean dust concentrations were below the OEL and the action level, and workers were wearing dust masks. Workers were issued with Dräger Piccola FFP2 dust masks and worn them during the course of the working day, especially when the wind was blowing hard. The efficiency of the existing control measures at Tailings Dam 3 can be questioned, due to relative high dust concentrations obtained during the personal monitoring. Workers faced the wind when they secured the crest of the tailings dam, digging in the dry beach areas. Consequently the wind blew tailings dust directly into the workers' faces. This, while no dust mask was worn. Over the course of three consecutive days that the writer did personal monitoring, no workers were seen wearing dust masks.

On all three tailings dams it was observed that the workers' clothes were covered with dust. One can question whether the overalls are cleaned sufficiently, how often and by whom. There are various elements in the tailings dust that should be regarded as potentially hazardous because of their systemic and respiratory effects on health. They include the following:

Barium	Chromium	Iron
Cobalt	Copper	Vanadium
Manganese	Nickel	Aluminium

This is a concern because potential health risks to the worker and the non-workers must be prevented.

4.4.4 Recommended Control Measures

4.4.4.1 Engineering control measures

Beaches of tailings storage facilities contain fine sand or silt size particles that can easily be removed by wind. Elements identified in the dust from the dry beaches of tailings storage facilities are a specific concern for nearby communities. This problem is one of the major ones related to tailings storage facilities and adjacent communities especially in dry and windy climates.

Some engineering control measures are suggested:

- Sprayers can be built covering the tailings dam by spraying water or dust suppressant substances to stabilise the surfaces. In some cases fire fighting foam can be used;
- flooding of the tailings;

- constructing fixed windscreens on the tailings dam walls or making use of temporary windscreens in the area where the workers are working (i.e. digging);
- plant trees as a fixed windscreen. Farmers plant pine trees around their orchards in order to protect their fruit trees from the wind. One can plant trees around the tailings dam, or on the side from where the wind is coming. Water from the return water dam can be used to wet the trees;
- covering problem areas with clean sand and tree branches;
- the occurrence of excessive dust particles on the tailings dam roads can be reduced by irrigation of water or a dust suppressant substance such as Dust-A-Side from South Africa or Dustmatt and Wetless from Australia. The exact frequency of irrigation depends on the moisture content of the tailings dam, the ambient temperature and the degree of wind in the area (World Enzymes Australia, 2006). Inadequate irrigation will not effectively prevent the emission of dust particles. An over supply will be costly and may damage the tailings dam structure (WISE Uranium Project, 2004). It is important that a specialist in dust suppression systems determine the frequency of irrigation;
- suppress dust emission on the tailings dam roads by covering it with gravel.

4.4.4.2 Administrative control measures

When the engineering control procedures are inadequate, administrative control procedures should be introduced. These include:

- Training of workers on proper work practices and procedures, i.e. instead of facing the wind while digging in dry beach sand, the workers can be taught to work facing away from the wind. Effective training programs help workers to fully understand the hazards in the workplace;
- annual exposure monitoring;
- introducing good housekeeping practices by regularly cleaning the changing rooms and throwing waste into specific bins, providing separate storage for personal clothing and PPE, and provide facilities for the drying of wet clothes (South Africa, 1993);
- provision of laundry facilities for overalls and showers for the workers to clean themselves before leaving for their homes;
- introducing job rotation and relief procedures to allow workers time away from certain work, maybe on extremely windy days. These are intended to limit exposure to designated substances when other controls are not effective.

4.4.4.3 Personal Hygiene Practice

Good personal hygiene practices may prevent hazardous agents from being carried outside the workplace. It also reduces the chance of toxic substances being absorbed or ingested into the body. Making sure:

- The workers wash their hands and face before drinking or eating especially when they were on the tailings dam;
- that eating, drinking and smoking is allowed at the workplace only in designated areas, which are isolated from contaminated areas and have been designed for this purpose. They should not be allowed to eat on the tailings dams while doing verifications on the pipelines. They can be allowed to carry water with them, especially in the summer;
- the workers are using moisturising cream on the hands in order to keep the skin healthy and supple;
- workers using personal protective equipment are provided with adequate washing facilities which are readily accessible and located in an area where the facilities will not become contaminated. This will enable the workers to meet a standard of personal hygiene consistent with the adequate control of exposure, and to avoid the spread of an HCS.

NOTE: Though exposure levels might be low it is essential to promote good work practices, to mitigate workers' exposures to as low a level as is reasonably practicable.

4.4.4.4 Personal Protective Equipment (PPE)

As a last resort, respiratory protection, in this case a dust mask can be introduced by protecting the mouth and nose. On rare occasions, skin protection, such as barrier creams and gloves, is needed for skin-sensitised workers. Regarding the issuing of PPE, the following must also be insured:

- The equipment must be correctly selected, i.e. respirators must be selected by means of a respirator fit test, the concentrations to which the worker is exposed and the function of such a specific respirator;
- proper use of PPE is insured when the worker understands his liability towards wearing the PPE, know how to maintain his/her PPE and when to replace his/her PPE, combined with necessary supervision with regard to the use of the equipment (South Africa, 1996; Todd & Carman, 2001:362);
- it must be ensured that no person removes dirty or contaminated personal protective equipment from the premises, which was not the case at tailings dam 3. The workers lived

on the premises taking their overalls to their houses. Provide lockers for their overalls at their gathering area. Ensure that the clothing is kept separately in the lockers concerned (South Africa, 1996; Todd & Carman, 2001:362);

Skin Protection

Appropriate Skin Protection/Gloves, based on AIHA Chemical Protective Clothing Series or CCINFO Data Base are recommended based on elemental skin sensitisers identified in the dust samples, such as chromium and nickel, and personal experience (ATSDR, 2005; Brown, 2005; Driscoll *et al.*, 2004; HSE, 2001; ILO Safework, 2005; Olson, 2004:536). Contact with the dust on the sampling pumps during the post calibration, caused a skin reaction. Blisters formed and the skin itched. A cream containing cortisone and no contact with the dust relieved the symptoms.

Consider lightweight pigskin gloves manufactured for low-cost protection and light handling, i.e. Pigskin Leather Gloves available from MSA South Africa or Execglove and VIP pigskin gloves from Northsafety.

Another option to consider is barrier creams. It maintains skin hydration and preserves skin barrier function. Chemicals are added to inactivate or bind substances such as metals like nickel, in order to prevent interaction with the skin. Some examples of products are 3M™ Cavilon™ Durable Barrier Cream 3392, DeRoyal™ TheraSkin™ Protectant Cream, Hollister™ Restore™ Barrier Crème and Healthpoint Proshield® Plus Skin Protectant (Lutz & LaVoie, 1999).

Respiratory protection

Tailings dam workers are sufficiently protected by the Dräger Piccola FFP2 disposable dust mask. This is based on the level of dust exposure and the type of disposable dust mask the workers are issued with. One recommendation can be made regarding the dust mask, which is to consider the European EN149:2001 approved Dräger Piccola FFP2-V disposable dust mask. This is the same type of dust mask with the same specifications. The difference is that the mask has an exhalation valve. The exhalation valve permits one-way flow of exhaled air to the outside. Also, it reduces the heat and humidity build-up inside the mask, which makes it more comfortable for the worker to wear for longer durations (Dräger, 2006).

NIOSH certified particulate respirators with exhalation valves from 3M can also be considered, such as the 3M 8511 N95 or the 3M 8233 N100 particulate respirators.

4.4.4.5 Medical Surveillance

MOHAC (Mining Occupational Health Advisory Committee) is currently drafting a criterion of the Occupational Health Programme for manganese and vanadium (Doyle, 2006). It will be advisable to consider biological monitoring for manganese and vanadium because of the presence of these two elements in the tailings dust.

Implement medical evaluation to determine the worker's ability to use a respirator. This must be done before the worker is fit tested or insisted on using the respirator in the workplace. The reason for this is that the use of a respirator can put a physiological burden on the worker depending on the type of respirator, the job, workplace conditions and the medical status of the worker (Department of Minerals and Energy, 2003).

A follow-up medical examination must be performed whenever a positive answer arises from the initial medical examination questionnaire. The follow-up medical examination consists of medical tests, consultations or diagnostic evaluations that the occupational health practitioner might find necessary to make a final decision on (Department of Minerals and Energy, 2003).

The employer may discontinue a worker's medical evaluations when he/she is no longer required to use a respirator (Department of Minerals and Energy, 2003).

4.4.4.6 Respirator Fit Testing

It is best practice to have respirator fit testing as part of a respiratory protection programme and should not be overlooked because of the type of mask the worker is wearing or the type of exposure the worker experience. A respirator fit testing is a method to determine that a tight fitting respirator matches the worker's facial features and seals adequately to the worker's face (HSE, 2003). Fit testing and a medical evaluation should be carried out before the respirator is issued to workers on whom no fit testing had previously been done (3M, 2006). Medical conditions such as heart disease, emphysema, asthma or other lung disorders must be taken into account when selecting a respirator, because these conditions may make it difficult to wear a particular type of respirator. Fit testing should be repeated:

- If the wearer has lost or gained significant weight;
- if the wearer develops physiological problems, i.e. respiratory or circulatory problems;
- if the wearer had major dental work;
- if the wearer sustains major facial injury;
- when a different size, style, make or model of RPE is specified;
- annually or when specified by the company policy (HSE, 2003; 3M, 2006).

Whichever part of the respirator that comes into contact with the face, to seal, requires a clean-shaven face. Any facial hair includes any hair on the jawbone, e.g. beards, goatees and longer moustaches. Facial hair interferes with the proper functioning of the mask to seal (HSE, 2003; Kowahl, 2006). There are, however, respirator options for workers wearing beards or interfering facial hair. They can be issued with respirators that operate in a positive pressure mode with a hood headpiece (Kowahl, 2006).

3M provide qualitative and quantitative fit test kits, maintenance free respirators and a range of facemasks (3M, 2006).

HSE (2003) recommended an ambient particle counting (by means of a TSI Portacount fit tester) and a qualitative taste test for FFP2 filtering face pieces. Should the worker taste the aerosol sprayed, then the fit is unsatisfactory and the fit test has failed. A smell fit testing on the current mask will be pointless, because the test media can filter through the Synsafe® material mask. This will cause a worker's mask to fail the smell test. The smell test is only applicable to devices with type A gas/vapour filters. Consider the following when evaluating the sealing of the mask:

- the general appearance of the mask;
- check the straps for loss of elasticity;
- the elastic straps should have the proper length and strength and be able to stretch to any size head without having to tie a knot to shorten them;
- the ease of putting on and removing the mask;
- the method of attachment i.e. staple, fused or stitched;
- an adjustable nose bridge seal clip;
- individual packaging;
- elastomeric or cloth sealing surface;
- universal sizing or individual sizes;
- breathing resistance;
- heat build-up within the mask; and
- durability (Drägersafety, 2006; Zhuang et al., 2005).

4.4.4.7 Respirator Program Requirements

The employer does keep record of respirators issued, but no formal training is given on the type of respirator the workers are issued with. The workers does not undergo respirator fit testing or a medical surveillance specifically for the wear of the respirator beforehand. The employer must make sure he addresses the gaps in the respiratory programme. The respiratory management

programme must address the selection of the respirator, fit testing, inspection and maintenance, training and regular review. The program must be updated to reflect changes in workplace conditions that affect the respirator use.

The following must be included in the program:

- Management responsibilities;
- procedures in the selection of respirators for use in the workplace;
- medical evaluations of employees required to use respirators;
- issue of respirators;
- fit testing procedures for tight-fitting respirators;
- procedures for proper use of respirators in routine and reasonably foreseeable emergency situations;
- procedures and schedules for cleaning, disinfecting, storing, inspecting, repairing, discarding, and otherwise maintaining respirators;
- training of employees in the respiratory hazards to which they are potentially exposed during routine and emergency situations;
- training of employees in the proper use of respirators, including putting on and removing them, any limitations on their use, and their maintenance; and
- procedures for regularly evaluating the effectiveness of the program (Kissane, 1997:249; OSHA, 2004).

4.4.4.8 Information and Training

Training on the use, maintenance and the shortcomings of the specific respirator, must commence before the respirator is issued to the worker. Workers who are assigned respirators must understand in which conditions his/her respirator will not provide respiratory protection, e.g. facial hair that interferes with the respirator seal. The worker should be able to:

- identify when airborne hazards could occur from work operations and workplace conditions, e.g. facing away from the wind when digging in dry sludge;
- identify potential symptoms to dust exposure for the skin, eyes and lungs;
- explain why facial hair is not allowed when wearing a mask;
- properly put on the respirator;
- perform pre-use fit checks. If the worker tastes the dust or have difficulty breathing they should leave their workplace;
- inspect the mask for satisfactory conditions, e.g. elastic straps should be strong and fit around the head without being adjusted;

- inspect the cleanness of the mask;
- explain why the respirator is necessary and how improper fit, usage, or maintenance can compromise the protective effect of the respirator;
- keep the mask clean;
- to store the mask correctly by not storing objects on top of it or hanging the mask in a dusty place;
- understand the importance of good housekeeping at the workplace and personal hygiene;
- How to recognize medical signs and symptoms that may limit or prevent the effective use of respirators; and
- know when to discard the mask, i.e. at the end of the shift or earlier, depending on the degree of contamination of the mask (Kissane, 1997:249; OSHA, 2004).

4.4.4.9 Follow-Up

This survey must be repeated by carrying out representative dust exposure measurements, at least every 24 months for a HCS with a Recommended Limit.

Such Occupational, HCS exposure surveys may only be carried out by an Approved Inspection Authority, or a person whose ability to do the measurements is verified by an Approved Inspection Authority.

4.5 CONCLUSIONS ON THE EVALUATION OF CURRENT CONTROLS

The current control measures regarding *medical surveillance* and *personal protective equipment* provision were in place and comply with the legislative requirements. However, no specific cleaning facilities were provided and some workers did not wear their masks. The reason being put forward was that no chemical exposure exists, (e.g. asbestos) that requires special cleaning and the worker decides when he/she wants to wear the mask. From the results it was clear that elements with potential health risks do exist in the tailings dust. Some were systemic toxins. For this reason washing facilities for the overalls should be provided and biological monitoring needs to be conducted for manganese. The dust masks issued, Dräger Piccola FFP2, do give sufficient protection to the worker if one consider the dust exposures measured were below the OEL and action level for particulates not otherwise classified.

An *occupational hygiene monitoring programme* must be implemented at TD 1 and 2. The elements present in the dust do make it necessary to monitor dust exposures, even though no overexposure was indicated. The same reasoning applies to the cleaning of overalls and the provision of washing bays for the overalls. If the worker takes his overall home, he can expose his family to these metals and cause potential health risks, such as nickel itch or allergic lung reactions.

Workers should be trained in health risks and standard operating procedures at the tailings dams. Health risk training should include possible symptoms after exposure to the elements present in the dust, i.e. nickel and chromium, skin sensitisers causing itching of the hands after contact to the dust.

Another point to consider is reviewing the current standard operating procedures in order to ensure less exposure to dust, i.e. digging in dry slurry facing away from the wind and the use of a temporary windscreen when working on the tailings dam.

The tailings dams had no respiratory mask fit testing programme in place. The company should consider this fit testing, combining it into the annual medical surveillance of the worker. Consider the taste test for the specific mask the workers are wearing in order to be sure that the worker is effectively protected against the dust. During the medical surveillance, the worker can be refreshed on the proper donning and doffing of the mask he/she is wearing, how to check if it fits, maintenance of the mask and positive and negative properties of the mask.

On the subject of tailings dust suppression, improvements can be implemented i.e. the use of temporary windscreens, wetting of the beach or gravel on the roads. Tailings dam 2 and 3 has planted grass on the tailings dam walls, while TD 1 wetted its tailings dam.

Thus, in general the tailings dams do comply with legislative control measures; a few improvements and points to consider were mentioned.

Chapter 5 - CONCLUSIONS AND SUGGESTIONS

In this final chapter an overview on the results and conclusions discussed in the previous chapter will be made. Final remarks are made on the hypotheses and on tailings dust exposures. A few improvements and points to consider were made regarding control efficiency. Gaps in the literature study and in the study design were mentioned for future studies.

It was stated in the first chapter that no dust exposure levels were present for tailings dam workers. The elements in the exposure dust and the compliance and efficiency of control measures were also unknown. Through the literature study, it became clear that dust exposure studies were mostly done on coalmine workers and rats, but no studies were found on tailings dam workers. To a certain extent, studies were done on the construction and maintenance of tailings dams through which methods to control dust was mentioned.

5.1 ISSUES ADDRESSED

The following issues were addressed and met during the process of writing the dissertation:

- The writer became familiar to the subject of tailings dams followed by toxicological terms such as acute and chronic exposure, the different distribution mechanisms and effects of exposure. The normal functioning of the respiratory system together with the defence mechanisms in place, should particles enter the respiratory system, was discussed. Physiological implications to dust exposure and potential lung diseases, such as pneumoconiosis, were mentioned. Respiratory health effects were discussed on all elements identified in the bulk and filter samples;
- particles sizes were identified in the bulk samples and discussed, looking at the respirable sizes;
- personal dust exposures were measured at different tailings dams. The results obtained were compared to the OEL for particulates not otherwise classified (PNOC) and compared with the action level, which was 50% of the OEL for PNOC;
- the data obtained was statistically analysed to evaluate the correlation in dust concentrations between the days, between the tailings dams and between the types of work (the pipeline labourers and mudguards). Adverse health effects were also determined from elements identified in the filter samples in order to evaluate the potential health risks the tailings dust opposed;
- the dust monitoring results provide a feedback mechanism to ascertain the effectiveness of these measurements, and a warning mechanism when the measures are insufficient or unsuccessful. Dust control measures already in place were evaluated along with the results

comparing to legislative requirements. The different tailings dam control measures were also compared to each other. Recommendations were made for gaps found during this procedure.

5.2 FINDINGS ON HYPOTHESES MADE

The following hypotheses were discarded:

1. The larger percentage of the tailings dust will consist of respirable fractions ($<7\ \mu\text{m}$).
2. Wind speed will influence the personal dust exposures to be higher where wind speeds were higher than other days or dams.

The following hypotheses were confirmed:

1. Dust exposure between the different days per tailings dam will not differ significantly.
2. Workers on cyclone tailings dams will have a lower dust concentration than workers at the spigot tailings dams.

The following hypotheses had opposing conclusions:

1. Dust exposure between the three different tailings dams will not differ significantly.
2. There will be a significant difference in the concentrations between mudguards and pipeline labourers

5.3 TAILINGS DUST EXPOSURE

Tailings dam workers are exposed to tailings dust that has a potential risk to their health due to the element contents in the dust. The effects of these identified elements ranged from allergic reactions, i.e. rhinitis, to carcinogenic effects over a long-term exposure period. Some of the elements, which have systemic toxic effects, were aluminium, barium, chromium, cobalt, copper, magnesium, manganese, nickel, titanium, vanadium and zinc. Many of these elements can cause potential respiratory health effects due to its adverse health effects on the lung. It was clear from the three tailings dams, that their particle size distribution were dominantly $>10\ \mu\text{m}$ which were inhalable sizes. However, respirable sizes ($<7\ \mu\text{m}$) were detected varying between 6% and 10% of the total volume per bulk sample. The hypothesis that the larger percentage of tailings dust will consist of respirable dust ($<7\ \mu\text{m}$) was rejected. Respirable monitoring needs to be addressed by the employer in order to determine the respirable exposure of the tailings dam workers.

The dust exposures at each tailings dam indicated that the tailings dam workers in general are not over-exposed to tailings dust. However, TD 3 showed the highest dust concentrations with three outliers and a few samples exceeding the action level concentration (5 mg/m^3), which was 50% of the OEL for PNOC (10 mg/m^3). It is clear that the workers on spigot tailings dams (TD 2 and 3) had a greater exposure than workers on a cyclone tailings dam (TD 1). The hypothesis that cyclone workers will have a lower concentration than workers on spigot tailings dams was accepted. The wind speed did not contribute to significant personal dust exposure correlations. In general there was no significant difference between pipeline labourers and mudguards, though Day 1 had a significant effect. A study in the dust concentration differences between the different types of work are suggested, focusing on the work procedures, weather data (e.g. wind speed) and the moisture content of the tailings dam.

5.4 CONTROL EFFICIENCY

The tailings dams did comply with legislative control measures. A few improvements and points to consider were identified.

Areas of improvement regarding current controls at each tailings dam were the storage of dust masks and overalls, and especially the cleaning of overalls providing washing facilities. The reason for not providing such facilities were that the workers do not work with hazardous chemicals such as lead, asbestos or any other chemical that needs special cleaning. Identified elements, such as nickel, aluminium, manganese, copper, barium and iron, has systemic and respiratory effects, some may even cause skin rashes, i.e. nickel itch. It is thus important to consider washing facilities for the cleaning of overalls in order to prevent exposure to non-workers.

No respiratory fit testing programme was in place. Consider the taste test for the specific mask the workers are wearing in order to be sure that the worker is effectively protected against the dust. This test can be done during the annual medical surveillance where the worker can be refreshed on the maintenance, donning and doffing of the mask and symptoms that can develop after exposure to the tailings dust.

By assuming that all workers within a group have the same mean exposure, some workers with distinctly higher average exposure might not be adequately protected. Consider training in correct work practices and procedures and improvement on personal hygiene. Furthermore, training on the potential health risks and possible symptoms after exposure can be considered.

Effective training programs help workers to fully understand the hazards in the workplace. Introducing job rotation on extremely windy days when other control measures are not effective.

Some engineering control measures suggested to prevent or minimise tailings dust exposures were installing water sprayers covering the entire tailings dam, making use of fixed or temporary wind berms in the area where work is done and covering the roads on the tailings dam with gravel or spray with water.

Other needs identified were an occupational hygiene monitoring programme that needs to be implemented at certain tailings dams where the dust exposure exceeded 10% of the OEL for PNOC.

5.5 FURTHER STUDIES

During the writing of this dissertation, a few gaps and needs for further studies were identified. They are presented below:

1. A study can be done on the reasons why identified elements in the bulk samples are not present in the filter samples, and vice versa. Some explanations for this anomaly are discussed in this study
2. The silica indicated in the bulk sample was not analysed to determine the chemical properties thereof. Another element identified that also needs further analysis is chromium. In future studies there should be a budget included in order to determine the type of element identified.
3. No respirable measurements were taken. This was due to financial restrictions from the source financial provider, which only budgeted for inhalable dust measurements and analysis. In future studies a budget for respirable measurements should be considered.
4. It is suggested doing a study on the dust concentration differences between the different types of work. Focusing on the work procedures, weather data (e.g. wind speed, relative humidity and temperature) and the moisture content of the tailings dam.
5. An occupational health study on tailings dam workers regarding their lung health, skin conditions, and biological monitoring for manganese and vanadium will help to determine whether tailings dam workers work in hazardous environments. Also, consideration should

be given in further studies in biological monitoring, i.e. endocrine studies, because of systemic toxic elements present in the tailings dust.

5.6 CONCLUSIONS

In conclusion, the tailings dam workers were not over-exposed to tailings dust, although some outliers were present. Cyclone tailings dams have smaller particle sizes than spigot tailings dams, though the larger percentage of particle sizes in all tailings dams were larger than 10 μm . No significant effect existed between the different tailings dams regarding tailings dust concentrations. There was however in one instance a significant difference between the days (Day 1). The workers on the cyclone tailings dams had smaller exposures than workers on the spigot tailings dams, and the pipeline labourers were more exposed than the mudguards.

The study met the points set out in chapter one, hypotheses were rejected and accepted, improvements were made on current control measures and future studies were suggested.

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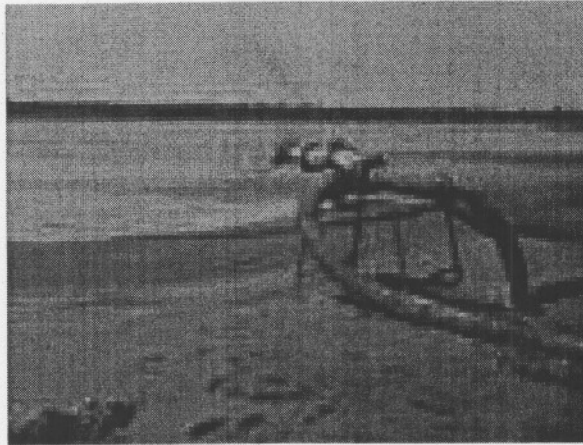
ANNEXURE A**FIGURES**

Figure A1. Cyclones separate the sand and slimes from the tailings feed delivered to the tailings dam (Engels, 2005).



Figure A2. Tailings are excavated to form walls on the tailings dam itself (Engels, 2005). This will serve as berms when the sludge is discharged in this area of the tailings dam.

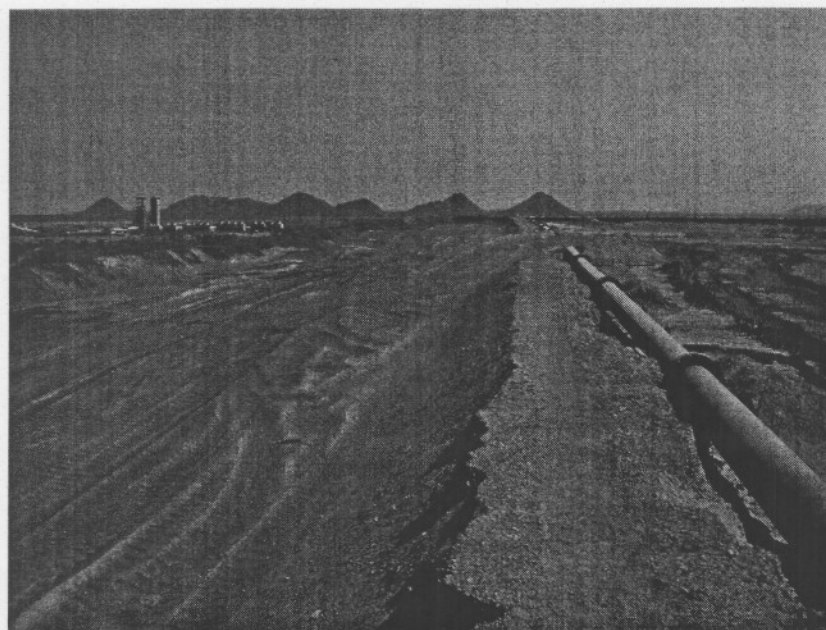


Figure A3. The spigot line is positioned on the crest of the tailings dam (Engels, 2005).

ANNEXURE B

FIGURES

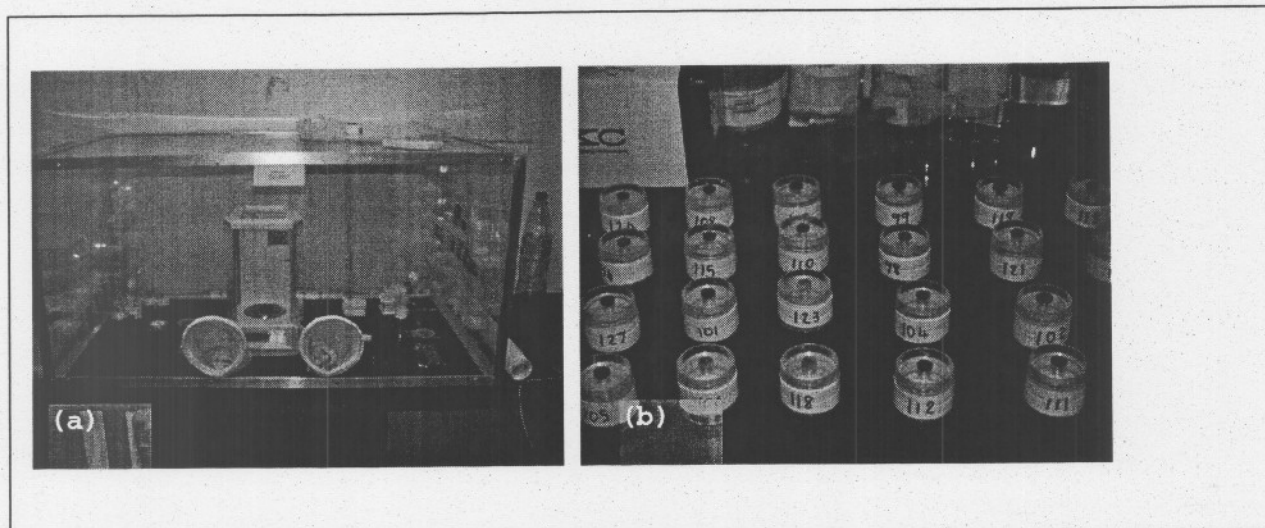


Figure B1. (a) An electronic microbalance in a clean, dust-free environment, and (b) Filter cassettes loaded with the 37-mm three-piece 0,8 μ m pore sized Mixed Cellulose Ester filter; sealed and marked for sampling.

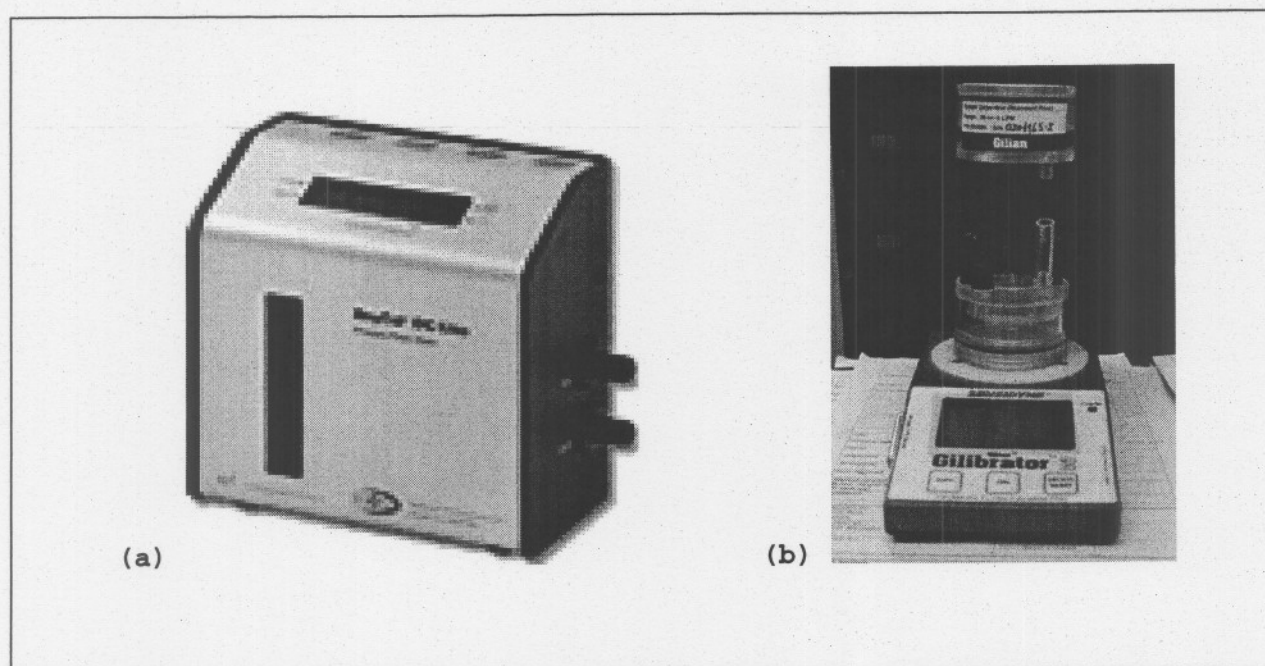


Figure B2. Electronic flow meters, the (a) DryCal DC Lite Calibrator, and (b) the Gilibrator Bubble Generator Flow Cell, used to calibrate the personal air sampling pumps.



Figure B3. The Gilian GilAir-3 air sampling pumps were used during personal dust sampling.



Figure B4. A filter cassette was attached to the shirt's collar within the employee's breathing zone (indicated with a blue dashed circle).

ANNEXURE C

FIGURES

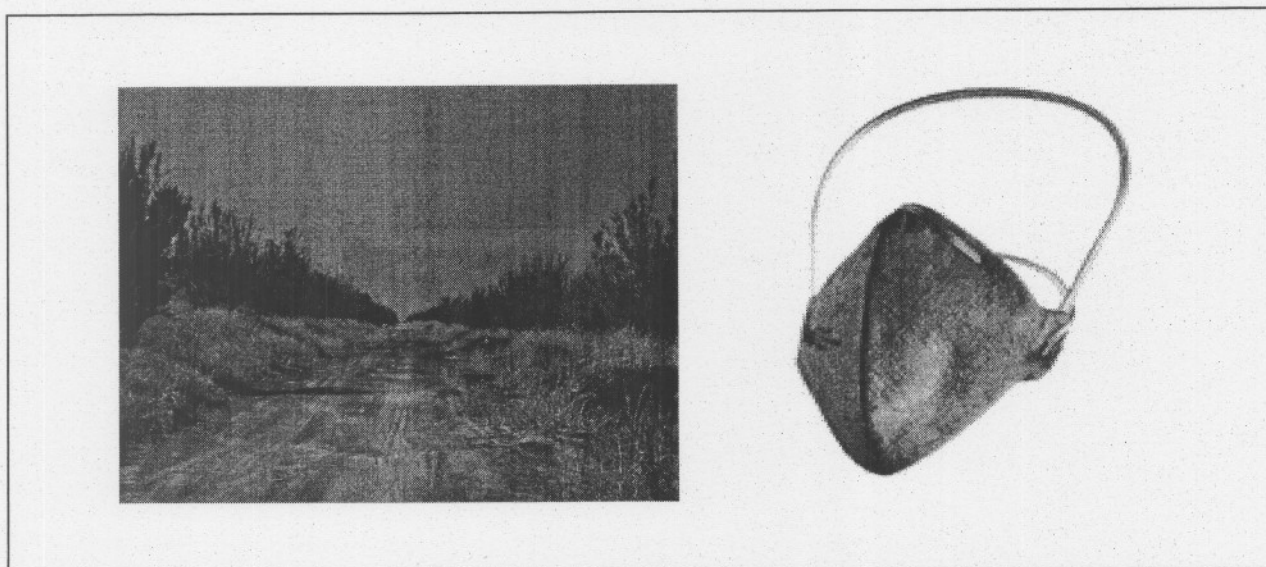


Figure C1. Current control measures include various grass species planted on the tailings dam walls and wearing of Dräger Piccola FFP2 dust masks.



Figure C2. Workers' clothes are full of dust containing i.e. nickel and manganese. The question is: "What control measures are in place for the management thereof?"

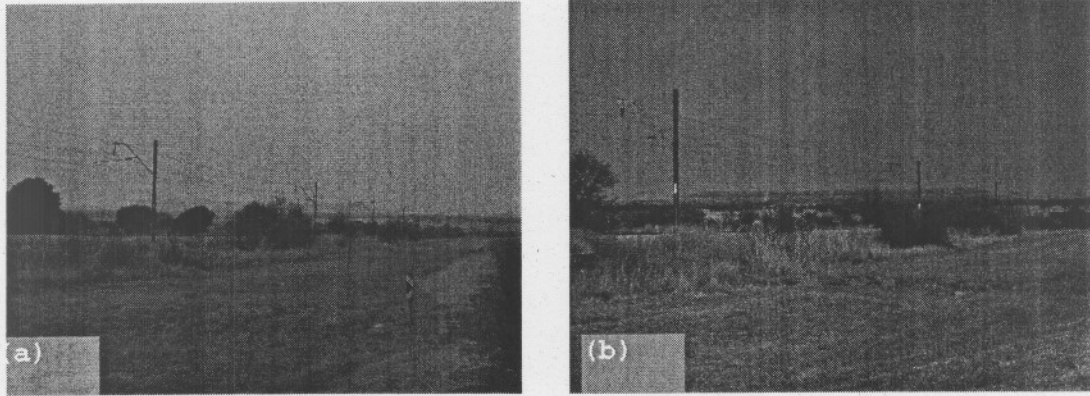


Figure C 3. (a) Visible dust and smoke in the atmosphere. The tailings dam is barely visible; (b) This picture was taken the following day.