NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT

Exposure of Tanzanian gold mine refinery workers to hydrogen cyanide

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BSc.(Honn)

Mini-dissertation submitted in partial fulfilment of the requirements for the degree Master of Science (Occupational Hygiene) at the Potchefstroom Campus of the North-West University.

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December 2008

Acknowledgements

I would like to thank the following people and companies for their contributions in making this project possible:

- My supervisor Mr. J.L. du Plessis, NWU-Potchefstroom campus, for his guidance, help and support
- My assistant supervisor Prof. F. C. Eloff for his help in the formulation of the project and valuable feedback
- Gijima AST for giving me the opportunity to conduct my project under their supervision and guidance especially Mr. Jaco van Rensburg, Mr. Johan Cornelius and Mr. Donovan Govender.
- Mr. Morgan Caroll and his Safety Team for all their help, Asante Sana.
- Dr. J. Howard Bradbury form the Australian National University, Canberra Australia and Dr. Gerhard Scherer from the Analytisch-biologisches Forschungslabor, München Germany for providing valuable information and assistance.
- Dr. Suris Ellis from the Statistical consultation service for her help with the statistical analyzes of the data.
- Ms. Thea de Villiers for help with the language and technical editing
- Ms. Anneke Coetzee, information specialist at the NWU (Potchefstroom campus) for her help in the search for scientific articles
- My friends and family for their direct and indirect help. Without them I wouldn't have been able to take this project on and finished it.

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Author's contribution

This study was planned and carried out by a team of researches. The contribution of each researcher is given in Table 1.

Table 1. Research team

NAME	CONTRIBUTION
Ms. K. Linde	Responsible for: ▪ Personal monitoring ▪ Literature research and writing of the article and the biological monitoring program
Mr. J.L. Du Plessis	▪ Supervisor ▪ Assisted with the design and planning of the study, approval of the protocol used in the study, review of the dissertation and interpretation of the obtained results.
Prof. F. C. Eloff	▪ Assistant-supervisor ▪ Assisted with the planning and design of the study, with the approval of the protocol and review of the article
Mr. J. van Rensburg	▪ Assistant-supervisor ▪ Assisted with the design and planning of the study

The following is a statement from the co-authors each individual's role in the study:

I declare that I have approved the article and that my role in the study as indicated above is a true reflection of my actual contribution and that I hereby

give my consent that it may be published as part of Karlien Linde's M.Sc (Occupational Hygiene) dissertation.

Mr. J.L. Du Plessis	*Prof. F. C. Eloff*
(Supervisor)	*(Assistant-Supervisor)*

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(Assistant-Supervisor)

List of Abbreviations

ATP	- Adenosine 5' triphosphate
ATSDR	-Agency for Toxic Substances and Disease Registry
°C	- Centigrade degree
Ca^{2+}	- Calsium
cGMP	- 3'5 ' cyclic Guanosine Monophosphate
CN^-	- Cyanide
ECG	- Electrocardiogram
H^+	- Hydrogen
HCN	- Hydrogen Cyanide
HIF-1α	- Hypoxia inducible factor -1 alfa
Km	- kilometer
L/min	- litre per minute
Mg^{2+}	- Magnesium
mg/L	- miligram per litre
mg/m^3	- milligram per cubic meter
ml	- milliliter
µmol/L	-micromole per liter
µM	-micromolar
µg	-microgram
NIOSH	-National Institute for Occupational Safety and Health, United States of America
OSHA	- Occupational Safety and Health Administration, United States of America
pH	- negative logarithm of the H^+ concentration
pK	- dissociation constant
ppm	- parts per million
ROS	- Reactive oxygen species
TWA-OEL	- Time weighted average- Occuaptional exposure limit

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Preface

The mini-dissertation is written in the form of an article according to the requirements of the journal that the article will be submitted to namely Annals of Occupational Hygiene. The references used in the literature study in Chapter 2 are given at the end of Chapter 2 in the Vancouver style as required by the journal.

Abstract

Hydrogen cyanide gas ($HCN_{(g)}$) is formed during the process of extracting gold from ore and may pose a risk to the health of the workers at the gold refinery (Mill/plant), especially the risk of detrimental effects on the central nervous system and the cardiovascular system. The measurement of the personal airborne $HCN_{(g)}$ exposure of a worker using sorbent tubes, provides the concentration of the chemical that the worker breaths in. The measurement of the urinary thiocyanate (SCN^-) concentration provides the total HCN exposure experience by the worker through all possible routes of exposure. The study's aim was to determine if the workers were exposed to $HCN_{(g)}$ concentrations that was higher than the occupational exposure limit (OEL) , which would mean that the workers are exposed to excessive and possibly harmful levels of HCN. The monitored workers were divided into three homogenous exposure groups or HEGs, according to the their potential level of exposure. The results were compared between the three HEGs and between three work description groups, namely the Mill/plant workers, SGS laboratory assistants and members of the environmental department. The study found that all the workers were exposed to personal airborne $HCN_{(g)}$ concentrations below the OEL. A statistical significant difference was found the personal airborne exposure experienced by the three HEGs and between the Mill/plant workers and the members of the environmental department. No statistical significant difference was found between the urinary SCN^- concentration found in the three HEGs or the between the three work description groups. Confounding factors such as smoking, the consumption of cassava, the exposure to fire smoke and the amount of time worked at the mine did not influence the urinary SCN^- concentration. The implementation of a biological monitoring program would enable the identification of any worker that is exposed to excessive levels of HCN.

Keywords: Hydrogen cyanide; gold mine; Tanzania; biological monitoring; occupational exposure.

Opsomming

Waterstof sianied gas ($HCN_{(g)}$) word gevorm gedurende die ontginning van goud uit erts en mag 'n risiko vir die gesondheid van die goud raffinadery werkers inhou, met veral die sentrale senuwee stelsel en die kardiovaskulere stelsel wat beskadig kan word. Die monitering van die persoonlike blootstelling aan $HCN_{(g)}$ teenwoordig in die lug d.m.v die gebruik van adsorpsie buise het die konsentrasie van die chemikalieë bepaal wat die werker inasem. Die bepaling van die tiosianaat (SCN^-) konsentrasie in die urine verskaf die werker se totale blootsteling aan HCN, ongeag van die roete van blootstelling. Die doel van die studie was om te bepaal of die werkers blootgestel word aan $HCN_{(g)}$ konsentrasies wat hoër is as die beroepsblootstellingsdrempel (BBD), wat sou beteken dat die werkers blootgestel word aan te hoë en moontlik skadelike HCN konsentrasies. Die werkers wat gemonitor is, is ingedeel volgens hulle moontlike blootstelling in drie homogene blootstellingsgroepe of HBGS (homogene blootstellingsgroepe). Die resultate is vergelyk tussen die drie homogene blootstellingsgroepe en tussen die drie werksbeskrywings groepe naamlik die Meul/aanleg werkers, die SGS laboratorium assistente en die lede van die omgewings departement. Die studie het gevind dat al die werkers persoonlik blootgestel is aan $HCN_{(g)}$ konsentrasies in die lug wat onder die agt uur BBD is. 'n Statistiese betekenisvolle verskil is gevind tussen die persoonlike blootstelling aan $HCN_{(g)}$ konsentrasies in die lug ondervind deur die drie blootstellingsgroepe en tussen die blootstelling ervaar deur die Meul/aanleg werkers en die lede van die omgewings departement. Daar is geen statistiese betekenisvolle verskil gevind tussen die SCN^- konsentrasies in die uriene van die werkers van die drie blootstellingsgroepe of tussen die drie werksbeskrywings groepe nie. Omgewings faktore wat moontlik die SCN^- konsentrasies in die uriene kon verhoog soos sigaret rook, die inname van cassava, blootstelling aan vuur rook en die hoeveelheid tyd wat die werker by die myn gewerk het, het geen invloed gehad nie. Die implementering van 'n biologiese moniteringsprogram sal die identifisering van enige werker wat blootgestel word aan oormatige hoë vlakke van HCN moontlik maak.

Sleutelwoorde: Waterstof sianied; goudmyn; Tanzanië, biologiese monitering; beroepsblootstelling.

Chapter 1

General introduction

1.1 Introduction

Cyanide is a chemical with a sinister reputation. It has been used in history as a chemical warfare agent as far back as the Romans and Napoleon III and in more recent time in the Nazi gas chambers and planned terrorist attacks by Al-Qaeda (Baskin and Rockwood, 2002). If used in high concentrations it is a deadly poison to humans. However it is normal for individuals to be exposed to a very small amount of cyanide in their daily lives (Nelson, 2006). What is more, the body itself produces its own endogenous cyanide by an oxidative reaction in the white blood cells and neural cells (Billaut-Laden *et al.*, 2006, Jones *et al.*, 2003)

There are numerous ways that a person can be exposed to cyanide, including the industrial environment, medicine that contains cyanide, cigarette smoke and the food that he or she eats (Lindsay *et al.*, 2004). These foods for example cassava contain cyanide compounds that are released when the food is ingested and hydrolysed in the digestive system (ATSDR, 1993; Haque and Bradbury, 1999; Baskin and Rockwood, 2002; Cardoso *et al.*, 2004, Lindsay *et al.*, 2004).

The heart and nervous system are especially sensitive to the toxic effect of cyanide because these organs function with a high aerobic respiration rate and cyanide disrupts the aerobic metabolism (Thompson *et al.*, 2003; Porter *et al.*, 2007; Baud, 2007). Symptoms experienced by individuals exposed to cyanide include headaches, nausea, vomiting, weakness, an initial increase in the respiratory rate followed by a decrease and abnormal thyroid functioning in cases of chronic exposure (NIOSH, 2005).

Biological monitoring is used to determine the total amount of the chemical in the body because it takes all routes of exposure into consideration in order to establish overall exposure (Klaassen and Watkins, 2003:460). Personal airborne monitoring is used to establish the extent of the ambient exposure of the individual to the hazard (Unsted, 2001). Biological monitoring and environmental or ambient monitoring should be used together to ensure an effective monitoring program to guarantee the health of the exposed individuals (Klaassen and Watkins, 2003:460).

The safe use of cyanide in the gold mining industry is an important issue as shown by initiatives such as the International Cyanide management code, drawn up as a voluntary way of ensuring proper cyanide management (Anon, 2006). The health of

the workers, exposed to cyanide must be protected by evaluation of the effectiveness of the measures put in place to ensure the workers' health (Anon, 2006).

One of the countries in Africa where gold is being mined, is Tanzania (Müezzinoğlu, 2003). There has not been a great amount of research carried out on gold mines in this country, as the gold industry in Tanzania is relatively young. Tanzanian legislation does not contain regulations for the control of cyanide or hydrogen cyanide. Niosh does however have an eight hour OEL-STEL value of 11 mg/m^3 (NIOSH, 2005).

Hydrogen cyanide gas is formed during the extraction of gold from ore. There is a large risk that workers working around the Carbon-in-Leach tanks may be exposed to excessive amounts of the gas (Stanton and Jeebhay, 2001: 291)

1.2 Aims and Objectives

The aims of this study are:

- to determine the personal airborne HCN gas exposure experienced by the workers at the gold refinery.
- to determine the total exposure to hydrogen cyanide as shown by biological monitoring.
- to develop a biological monitoring program that can be used to determine the total exposure of workers to $HCN_{(g)}$.
- to provide recommendations for the effective control of exposure to $HCN_{(g)}$
- to determine the correlation between the results for personal airborne exposure and biological monitoring

1.3 Hypothesis

The workers at the Mill/plant of a gold mine in Tanzania are exposed to a $HCN_{(g)}$ concentration that is below the Occupational Exposure Level (OEL) of 11 mg/m^3.

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Chapter 2

Literature study

The literature presented in the following literature study will discuss the ways that people may be exposed to cyanide, the characteristics of cyanide, its method of action and the health consequences of exposure. Legislation put in place to protect against dangerous cyanide exposure and controls that may minimize this exposure will also be discussed. There will be focused on the use of cyanide in the gold mining industry to extract gold and the potential exposure of this industry's workers.

1.1 The chemical and physical characteristics of hydrogen cyanide

Cyanide consists of a carbon connected by three molecular bonds to a nitrogen atom and can be man-made or occur naturally (ATSDR, 2006). The main form of cyanide that is involved in exposure through inhalation, is hydrogen cyanide gas ($HCN_{(g)}$) (Lindsay *et al.*, 2004, ATSDR, 2006). $HCN_{(g)}$ is colourless when at room temperature and has a faint smell of almonds (ATSDR, 1993; NIOSH, 2005; Varone, 2006). About 50% of the population can't detect this smell, so it can't be used as a definitive method to detect $HCN_{(g)}$ that may be present in the atmosphere (Porter, 2008).

$HCN_{(g)}$ can form simple salts such as sodium cyanide and potassium cyanide (Hurtung, 1982: 4845). If the cyanic salts come in contact with acid solutions it will dissociate to form $HCN_{(g)}$ (Piccinini *et al.*, 2000; Guidotti, 2006). It has a pK of 9.2, meaning it will dissociate to H^+ and CN^- if the pH of the solution is equal or below 9.2 (ATSDR, 2006).

1.2 Toxicology

1.2.1 Routes of exposure

The route of exposure can be via absorption through the skin, mucous membranes and eyes, inhalation or ingestion with inhalation as the most significant route (OSHA, 1995; Baud, 2007).

1.2.2 Metabolism

About 80% of a cyanide dose will be converted to thiocyanate (SCN^-) (Carlsson *et al.*, 1999). The conversion to SCN^- is estimated to be about 40 µmol/hour for a

healthy 70 kg individual (Carlsson, et al., 1999). This detoxification product is less toxic than the cyanide itself (Valdes & Díaz-Garcia, 2004; Cipollone *et al,* 2006).

$$CN + S_2O_3^{2} \xrightarrow{\text{rhodanese}} SCN + SO_3^{2} \qquad \text{Equation 1 (Lindsay } et\ al.\text{, 2004)}$$

The detoxification enzyme, rhodanese also called thiosulfate sulfurtransferase, is synthesized in both the liver and the kidneys and is found in the matrix of the mitochondria (Billaut-Laden *et al.,* 2006; Nelson, 2006; Valdes & Díaz-Garcia, 2004). Rhodanese catalyses the irreversible binding of a sulfur atom to form SCN^- in the detoxification process (Soto-Blancco *et al.*, 2002). The sulfur atom is obtained from a donor such as thiosulfate (Cipollone *et al.,* 2006; Billaut-Laden *et al.,* 2006). This enables humans to tolerate the chronic exposure to low HCN concentration (Scherer, 2006).

The cyanide also binds with cystine to form cysteine and B-thiocyanoalanine, which converts to 2-iminothiazolidine-4-carboxylic acid. This metabolic pathway metabolizes about 15% of the total cyanide dose (ATSDR, 2006).

It can also be metabolized by being oxidized to formate (Hurtung, 1982: 4847). A small amount of the free HCN is excreted through the individual's saliva, sweat, urine and exhaled breath (Hurtung, 1982: 4847; Guidotti, 2006). Cyanide is also oxidized to cyanate (OCN^-) (Lindsey *et al.,* 2004). This may be the main method of cyanide detoxification instead of conversion to SCN^- if there is an insufficient source of sulfur containing amino acids (Sabri, 1998).

1.2.3 Mechanism of toxicity

Cyanide is able to change the functioning of the cells due to its ability to move easily across the membranes in the body (Porter, 2008:564). HCN binds and inhibits cytochrome C, which is a mitochondrial enzyme that forms part of the oxidative phosphorylation process. (Thompson *et al.*, 2003; Porter *et al.*, 2007; Garrett & Grisham, 2005:663; Turrina *et al.*, 2004). It is able to do so because its chemical structure is similar to the structure of oxygen (Nelson, 2006). Oxidative phosphorylation forms ATP, which is a special energized biomolecule that captures energy and functions as the cells' main energy source. (Garrett & Grisham, 2005:3,640; Nelson, 2006).

The function of cytochrome C oxidase is to impel protons to move across the inner membrane of the mitochondria and act as one of the final receivers of the electrons formed by oxidation in the mitochondria (Garrett & Grisham, 2005: 654). This results in the conversion of oxygen to water (Nelson, 2006).

The decrease in aerobic metabolism caused by cyanide means that the cell has to rely on anaerobic respiration, which doesn't form enough ATP for effective cell functioning and survival (Nelson, 2006). The increase in anaerobic metabolism also means an increase in the lactic acid production causing acidosis (Nelson, 2006). Baud (2007) found that an increase in the cyanide concentration is coupled with an increase in the lactate concentration in the plasma, especially in cases of acute poisoning.

Complexes I and III, in the oxidative phosphorylation chain in the mitochondria, produce a large amount of ROS when stimulated by cyanide (Zhang *et al.*, 2002). Cyanide also activates phospholipase A_2 that metabolise arachidonic acid, increasing the ROS concentration even further (Zhang *et al.*, 2002, Mills *et al.*, 1999).

The overproduction of ROS may trigger cell death through causing cellular damage by oxidizing the cellular macromolecules or by the activation of the HIF-1α death signaling cascade (Zhang *et al.*, 2002). The increase in HIF-1α results in an increase in BNIP3, a Bcl-2 protein that is involved in the apoptosis process caused by hypoxia-iscemia in cortical cells (Prabhakaran *et al.*, 2007). In the substantia nigra cell destruction may be induced by dopamine (Jones *et al.*, 2003). When these cells are exposed repeatedly to cyanide they are more sensitive to the dopamine induced cell death (Jones *et al.*, 2003).

Together with the increase in ROS there is a Ca^{2+} influx that increases the free Ca^{2+} in the cytosol in response to the cyanide stimulation (Zhang *et al.*, 2002). Cyanide causes the Ca^{2+} influx by inhibition of the voltage-dependant Mg^{2+} block of the N-methyl-D aspartate (NMDA) receptor and so activates the voltage-sensitive calcium channels of the intracellular calcium stores (Jensen *et al.*, 2002, Mills *et al.*, 1999). This elevation of intercellular Ca^{2+} may cause tremors and stimulate presynaptic terminals to release neurotransmitters that activate the nervous system. The abnormal functioning of the Ca^{2+} neuronal regulation may promote the neurotoxic effect of cyanide. It may also have an effect on the vascular smooth muscle and the cardiac muscle that may cause cellular damage (ATSDR, 2006).

Other cellular effects are on the various neurotransmitter systems such as the glutamatergic and dopaminergic pathways that enhance the toxicity of cyanide (Nelson, 2006). Some studies have suggested that the toxic effect of cyanide on the central nervous system is actually due to the direct action of the chemical on the glutamate acid receptors or the central nervous system cells (Baskin & Rockwood, 2002). Cyanide- induced Ca^{2+}-dependent and independent mechanisms mediate the release of glutamate that may cause brain injury (ATSDR, 2006).

1.2.4 Symptoms of exposure

1.2.4.1 Acute exposure

Acute symptoms include respiratory distress, olfactory failure and in extreme cases death (Porter *et al.*, 2007). Cyanide can cause death within minutes after exposure to the chemical (Baskin and Rockwood, 2002). Acute symptoms were not found by Porter *et al.*(2007) at a leach field, where the cyanide process takes place.

The inability of the cells to use the oxygen supplied by the arterial system leads to a higher concentration of oxygen in the venous blood than normal. The difference between the arterial and venous blood oxygen content is only a volume % where it would be 4-5 volume % under normal circumstances. This gives the blood a distinctive bright red color (Hurtung, 1982:). The time between a lethal acute exposure and death is determined by the concentration of the cyanide and the route by which the individual is exposed (Uhl *et al.*, 2006). Some systems are particularly affected by excessive exposure such as the central nervous system, the cardiovascular system and respiratory systems and the health effects are discussed below.

Central nervous system

At low doses symptoms such as headache, anxiety, weakness, confusion, asphyxia, increased respiration rate and vertigo can be found (Hurtung, 1982: 4848 ;OSHA, 1995). Large doses may cause instantaneous unconsciousness and convulsions that are followed closely by death (Osha, 1995). Lesions in the substantia nigra have been found in individuals who survived potentially lethal acute cyanide poisoning that results in Parkinson-like symptoms (ATSDR, 2006).

Cardiovascular system

Patients who have suffered severe acute cyanide poisoning have experienced abnormal heart rate and low blood pressure (ATSDR, 2006). Salkowski and Penney (1994) found that cyanide caused bradycardia in rats, but didn't affect the PR and QT intervals or T wave of their ECG. Bradycardia means that the individual has a slow heart rate lower than 60 beats per minute (Guyton & Hall, 2000:134). A long-term effect of acute cyanide exposure at a potential lethal dose is ultrastructural changes of the myocardium (Salkowski & Penney, 1994).

Respiratory

Cyanide activates a reflex respiratory gasp by stimulating the aortic arch's chemoreceptors. The stimulation of the chemoreseptors leads to the development of tachypnea and dyspnea (Baskin and Rockwood, 2002). Dyspnea is defined as mental distress caused by an inability of the body to satisfy its demand for air (Guyton and Hall, 2000:491). This is seen as the first phase of the respiratory symptoms while during the second phase the respiration rate decreases and progresses to apnea. This progression may be the result of the hypoxic influence of the cyanide on the medulla's respiratory centre (Baskin and Rockwood, 2002).

1.2.4.2 Chronic exposure

Symptoms such as headache, weakness and an enlarged thyroid gland have been found due to chronic exposure (OSHA, 1995; Orloff *et al.*, 2006; ATSDR, 1993). Other symptoms are vertigo, fatigue, dermatitis and itching (OSHA, 1995). HCN can also have an effect on hearing as it enhances the effect of noise on hearing, causing noise induced hearing loss. The mechanism is thought to be through the production of radical oxygen species (ROS) (Fechter, 2004).

The heart and nervous system are sensitive to the toxic effect of HCN because these organs function with a high aerobic respiration rate (Thompson *et al.*, 2003; Porter *et al.*, 2007; Baud, 2007). The endocrine and gastro-intestinal systems are also targeted and are discussed with the cardiovascular and central nervous systems in the following paragraphs.

Central nervous system

Examples of neurological disorders found in cases of chronic exposure to non-lethal cyanide levels are progressive Parkinson-like syndrome, dystonia and tobacco amblyopia (Jensen *et al.*, 2002). Tobacco amblyopia is characterized by central vision failure and a gradual loss of the ability to distinguish between colours (Soto-Blancco *et al.*, 2002; Freeman). Another disease attributed to chronic consumption of the cyanide-containing cassava is konzo. Konzo is a disease where the individual experiences spastic paraperesis, specifically of the lower extremities (Ludolph and Spencer, 1996, Cardoso *et al.*, 2004; Mudder & Botz, 2004).

In cases where the nervous system is exposed to HCN, there is a decrease in compound action potentials and conduction velocities (Thompson *et al.*, 2003). The chemical inhibits electron transport in the nerves (Thompson *et al.*, 2003).

The nerves are selectively destroyed by cyanide through apoptosis and necrosis in different areas of the brain. This may be due to the activation of toxic pathways that are specific to the area (Mills *et al.*, 1999). The level of the oxidative stress and the type of cell determines the type of cell death (Mills *et al.*, 1999). Cell death due to apoptosis occurs in the cortex while in the substantia nigra and mesencephalic cells it occurs through necrosis. An increase in ROS in the neurons and ionic imbalance caused by the cyanide triggers the pathways for cell death (Zhang *et al.*, 2002; Jensen *et al.*, 2002). A mechanism that increases the oxidative stress, specific to the mesencephalic cells is the decrease of the cellular antioxidant defense component, mitochondrial reduced glutathione (Zhang *et al.*, 2002). The functioning of other antioxidant defense enzymes such as superoxide dismutase and catalase are also interfered with and so increase oxidative stress (Tulsawani *et al.*, 2005).

The destruction of the dopaminergic neurons can result in the development of Parkinson-like syndrome or dystonia (Mills *et al.*, 1999). Dystonia is a condition characterized by twisting movements caused by continuous muscle spasms (Albanese *et al.*, 2006).

Cases of cytotoxic hypoxia such as the type created by cyanide, may lead to behavioral changes, alteration of brain neurotransmitters and defective functioning of the memory takes place. Another neurotransmitters that may be affected are the

adrenergic hormones, whose dysfunction contributes to the memory defects and also causing a decrease in locomotor activity (Mathangi & Namasivayam, 2000).

Cardiovascular system

Cardiac irregularities such as palpitations were noted (Osha, 1995; ATSDR, 1993). A study done at a silver reclaiming plant, found that about 14 % of the workers who were exposed to 15 ppm $HCN_{(g)}$ complained about palpitations and about 31% complained about chest pains. Another study performed on rats, however, found no cardiovascular effects after they exposed the animals to 17.7 ppm cyanide for 6 months (ATSDR. 2006).

Endocrine system

The chronic exposure to the biomarker SCN^- is possibly the cause of enlargement of the thyroid gland (Orloff *et al.*, 2006; ATSDR, 1993). The high level of SCN^- can cause abnormalities of the thyroid gland by inhibiting the transport of iodide into the gland (Erdoğan, 2003; Gibbs, 2006). Experimental evidence has shown that the predisposition that smokers have in developing goiters is due to the SCN^- in the tobacco smoke (Erdoğan, 2003).

A SCN^- concentration of approximately 100 to 200 µmol/L in the blood can cause serious negative effects on the thyroid accompanied with a severe deficiency of iodine in the body, while the negative thyroid effects without the iodine deficiency can by found if the SCN^- concentration increases above the 200 µmol/L mark (Gibbs, 2006). A likely mechanism for this inhibition may be that SCN- competes with thyroid peroxidase's normal substrate and hinders normal functioning .The T4 form of the thyroid hormone is displaced by the SCN^- from the plasma proteins that binds it. If the balance of the SCN^- and the iodine received from dietary intake is below 13 µg iodine/SCN^-, then a goitre may possibly form (Erdoğan, 2003).

Gastro-intestinal system

Nausea, nervousness and a loss of appetite were also found in cases of subchronic exposure (Obiri *et al.*, 2006). A study conducted at a silver reclaiming facility found that 50 % of the workers experienced a weight loss of 8% on average, after an exposure of 15 ppm for an unspecified time period (ATSDR, 2006).

1.2.5 *Hazardous concentrations of HCN*

In the case of acute cyanide poisoning, cyanide levels of about 1mg/L or 39 µmol/L have been found to be toxic while 2,7 mg/L or 100 µmol/L has been found to be potentially lethal (Baud, 2007). A low level cyanide concentration of about 0.22 ± 0.08 µM is normal in the blood, as some cells produce cyanide (Billaut- Laden *et al.*, 2006). A lethal cyanide exposure concentration (LC_{50}) of 50-135 ppm and an immediate danger to life and health level (IDLH) of 50 ppm has been found for cyanide (Piccinini *et al.*, 2000). This is used to determine the potency of the chemical's acute toxicity (Klaassen and Watkins, 2003:18).

The levels given above should not be taken as the absolute, as they can vary from person to person and variations in the method of sample collection, the storage of the sample and the final analyzes (Lindsey *et al.*, 2004).

1.2.6 *Treatment of acute cyanide toxicity*

The administration of methemoglobin inducers, dicobalt edentate (EDTA), hydroxycobalamin, sodium thiosulfate, alfa-ketoglutarate and sodium thiosulfate and sodium nitrate are ways of treating cyanide toxicity (Baud, 2007). Some researchers have found that a combination of alfa-ketoglutarate, thiosulfate and hydroxocobalim is more effective as antidote than any one of the substances on its own (Hume *et al.*, 1998).

One example of a methemoglobin inducer is amyl nitrite (Lindsay *et al.*, 2004; Baud, 2007). The functional mechanism consists of the transformation of the ferrous iron portion of the hemoglobin to ferric iron, which will turn it into methemoglobin. The formed molecule will compete with cytochrome oxidase to bind the cyanide molecule and so decreases the amount of cyanide that the cytochrome oxidase binds. It is speculated that it may also decrease the toxicity of cyanide through inducing vasodilation (Baum, 2007). It causes the relaxation of the smooth muscle of the blood vessels through the activation of cyclic guanosine monophosphate (cGMP)) and subsequently produces nitric oxide (NO) (West, 1999, Sanders *et al.*, 2000). However, treatment with methemoglobin inducers can cause abnormal cardiovascular functioning (Satpute *et al.*, 2007). The elevation of the amount of methemoglobin leads to a decreased ability to carry oxygen enhanced by the

vasodilation action (Tulsawani *et al.*, 2005; West, 1999; Bradbery , 2007; Guidotti, 2006).

Dicobalt EDTA binds two cyanide molecules, but has dangerous cardiovascular side effects (Baud, 2007). It can cause severe hypotension in patients with already inadequate oxygen available for cellular function. This is found especially in patients who are misdiagnosed as being exposed to cyanide and then treated with dicobalt EDTA (Guidotti, 2006).

Hydroxycobalamin, a natural form of vitamin B_{12}, binds cyanide to form cyanocobalamin (vitamin B_{12}) and so decrease the amount of cyanide that binds to cytochrome oxidase (Lindsay *et al.*, 2004, Guidotti, 2006). The cyanocobalamin is removed from the body through urine (Hall *et al.*, 2007, Guidotti, 2006). It increases blood pressure and improves hemodynamic stability by an unknown mechanism, possibly through the scavenging of nitric oxide (Uhl *et al.*, 2006). Hydroxycobalamin has shown to be an effective cyanide antidote with few side effects (Baud, 2007, Guidotti, 2006). It can also cross the blood-brain barrier and is therefore also effective in the brain (Hall *et al.*, 2007).

Rhodanese, the enzyme that converts cyanide to thiocyanate, uses sodium thiosulfate as a substrate (Baud, 2007). When the sodium thiosulfate concentration is increased, the rate of enzyme function will also increase, which will decrease the cyanide concentration (Baud, 2007). It is together with sodium nitrate, the most widely used antidotes (Tulsawani *et al.*, 2005). It has however a lengthy onset time and it is not efficiently distributed into the brain and mitochondria, lowering its ability to have an effect (Hall *et al.*, 2007, Guidotti, 2006).

Research has also been done on the use of alfa-ketoglutarate as an oral antidote to cyanide exposure (Tulsawani *et al.*, 2005, Satpute *et al.*, 2007). The CN^- is thought to interact with the alfa-ketoglutarate's ketone group that is next to the carboxylic group forming a cyanohycfin intermediate and so reduce the free cyanide ions (Tulsawani *et al.*, 2005). Because the treatment is oral, it can be used effectively in occupational situations such as those of fire fighters (Tulsawani *et al.*, 2005, Satpute *et al.*, 2007).

1.3 Occupational exposure to hydrogen cyanide

1.3.1 Industries where exposure take place

Individuals may be exposed to cyanide and in particular $HCN_{(g)}$ in a number of ways (Thompson *et al.*, 2003). One of the major means of exposure is through their work (Nelson, 2006, Lindsay *et al.*, 2004). $HCN_{(g)}$ together with potassium cyanide and sodium cyanide are the types of cyanide mainly released into the environment by industrial actions (ATSDR, 2006). In 1995 approximately 20,000 tons was released worldwide from the cyanidation processes used to extract precious metals (ATSDR, 2006).

Many of the modern day materials found in buildings, for example, fiber based materials, acrylic plastics, synthetic rubber, melamine, polyurethane, asphalt, nitriles and nylon, release $HCN_{(g)}$ when burned (Hillson and Manhemius, 2006; Walsh, Varone, 2006). The possibility of the release of $HCN_{(g)}$ is enhanced if there are conditions of low oxygen and high temperature present (Turrina *et al.*, 2004). This creates a chance that firefighters and fire survivors can inhale this chemical, which is a great danger especially when coupled with exposure to carbon monoxide (ATSDR, 1993; Baud, 2007, Varone, 2006). The two gasses have a synergistic action as they have a similar toxic mechanism (Turrina *et al.*, 2004).

Workers in the factories that manufacture these materials such as nylon and plastics, may also potentially be exposed to cyanide (Hillson and Manhemius, 2006). Other industries that use cyanide in the production of products are the manufacturers of fire retardants, cosmetics, paints, pharmaceuticals, adhesives and computer electronics (Mudder & Botz, 2004). Approximately 50% of the HCN that is produced, is used in the manufacturing of the organic frontrunner of nylon, namely adiponitrile (Mudder & Botz, 2004).

Cyanide is used in the electroplating industry, manufacturing of steel and mining (Baskin & Rockwood, 2002). The hydrocyanic salts are used in the electroplating industry to form a thin coating made of fine crystals and keep cations of deposited metal in an aqueous solution (Piccinini *et al.*, 2000). A survey done by NIOSH found $HCN_{(g)}$ concentrations of 4 ppm at a university art department foundry while another study done at a plating facility showed that the workers were exposed to a concentration of about 1.6 ppm or 1.7 mg/m^3 (ATSDR 2006).

1.3.2 *The use of cyanide in gold extraction*

A large portion of the world's gold is in the form of tiny particles and has to be recovered from ore (Woollacott & Eric, 1994:365). It is estimated that about 90% of gold worldwide is recovered with the use of cyanide (Mudder & Botz, 2004; Ackil, 2006). According to the Gold Institute, 27% of the all mines that use cyanide in their production, are located in Africa (Mudder & Botz, 2004). The number of fatalities attributed to cyanide per decade in mining is only one or two which indicates that acute cyanide exposure doesn't pose a great risk to the workers' health (Ackil, 2006).

Hydrometallurgical methods are used to extract the gold from the ore. This means that gold is chemically processed in an aqueous or water environment. Hydrometallurgy consists of three phases. The first phase is the transferring of the metal from the solid feed material, namely the ore, to an aqueous solution. The second phase is the processing of the metal-bearing solution to an appropriate degree of purity, while the third phase consists of the recovering of the metal in a solid state from the purified solution (Woollacott & Eric, 1994:321,365).

The extraction of the metal from the ore to the aqueous solution is called the leaching process (Woollacott & Eric, 1994:329). Cyanide's ability to dissolve gold makes it suitable for use as a leaching agent to recover gold from ore (Hillson and Manhemius, 2006; Akcil, 2002). The extraction process involves interaction between the sodium cyanide solution and the ore that results in the sodium cyanide forming a complex with the gold (Orloff et al,. 2006; Müezzinoğlu, 2003). One of three types of leaching systems, namely agitated leaching, leaching without agitation and high-temperature and pressure leaching, can be used (Woolacott & Eric, 1994:337).

In the agitated leaching systems, the crushed ore is mixed with the cyanide solution and forms slurry in the tank. The slurry has to be in constant motion to keep the solids in suspension. The constant agitation increases the speed of the leaching reactions, making this a much faster process than the leaching without agitation methods, which can take from 10 days up to 20 years, depending on the method. The operation time of the agitating leaching system is about two days. The solution can be agitated either by mechanical action or by air injection, called pneumatic agitation (Woolacott & Eric, 1994:338). The specific mine site where the study was conducted, uses the mechanical agitation method.

The methods for leaching without agitation are less expensive and less complicated than the other methods. Two types of leaching without agitation that may be used, are the vat-leaching and heap-leaching systems (Woolacott & Eric, 1994:339-340). Vat-leaching is carried out in big reactors where the cyanide solution is introduced to the ground ore and flows through the ore. The ore is crushed and piled into large pits and the cyanide is sprayed over the ore in the heap-leaching process (Müezzinoğlu, 2003).

Leaching can also be performed under high temperature and pressure conditions that promote leaching. In some cases the leaching rate is adequate without the enhanced temperature and pressure, making the cost of maintaining the required temperature and pressure too high. The temperature can be raised by using electricity or injection of steam, while the pressure can be raised by elevating the temperature or pressuring the atmosphere using an autoclave (Woolacott & Eric, 1994:341).

In the Carbon-in-pulp (CIP) or Carbon-in-leach (CIL) methods, activated carbon is used to adsorb the desired metal from the leaching solution carrying the metal, also called the pregnant solution. This concentrates and purifies the solution. Activated carbon is a granular solid with a great affinity for gold that is used as a carrier phase (Woolacott & Eric, 1994:360). In order for the carbon to be reused a step is required to regenerate the carbon after it has been used (Woolacott & Eric, 1994:361, Müezzinoğlu, 2003).

The CIL method is used at the specific mine site in Tanzania where the study was conducted. In this method the carbon is added to the leached circuit, thus combining the leaching and adsorption of gold by the carbon. This means the same vessels can be used for the leaching and elution function and because of improved leaching kinetics there is a smaller chance of any loss of the unleached gold (Woolacott & Eric, 1994:362). The metal is removed from activated carbon in a process called elution. Elution is the stripping of the metal from the loaded carbon to another aqueous phase, called the eluant (Woolacott & Eric, 1994:353). The gold is removed from the eluant by a process called electrowinning. An electrical current is passed through the eluant, which causes the depositing of the gold on the catode (Woollacott & Eric, 1994:17).

Hydrogen cyanide gas is formed during the leaching process (Heath *et al*,. 2007; Nakeno *et al.*, 1999). The processing of 250 000 tons of ore per year is estimated to produce 22 tons of $HCN_{(g)}$ (Müezzinoğlu, 2003). The cyanidation process requires large tailing ponds where the formed HCN(g) evaporates into the air (Müezzinoğlu, 2003). The gas can remain in the environment for a long time with a half-life in air of 267 days (Müezzinoğlu, 2003). The dissolution of gold in cyanide can be described by the mechanism shown by the following equation.

$$4NaCN + 2Au + 2H_2O + O_2 \longrightarrow 2NaOH + 2NaAu(CN_2) + H_2O$$

(Equation 2) (Guzman *et al.*, 1999)

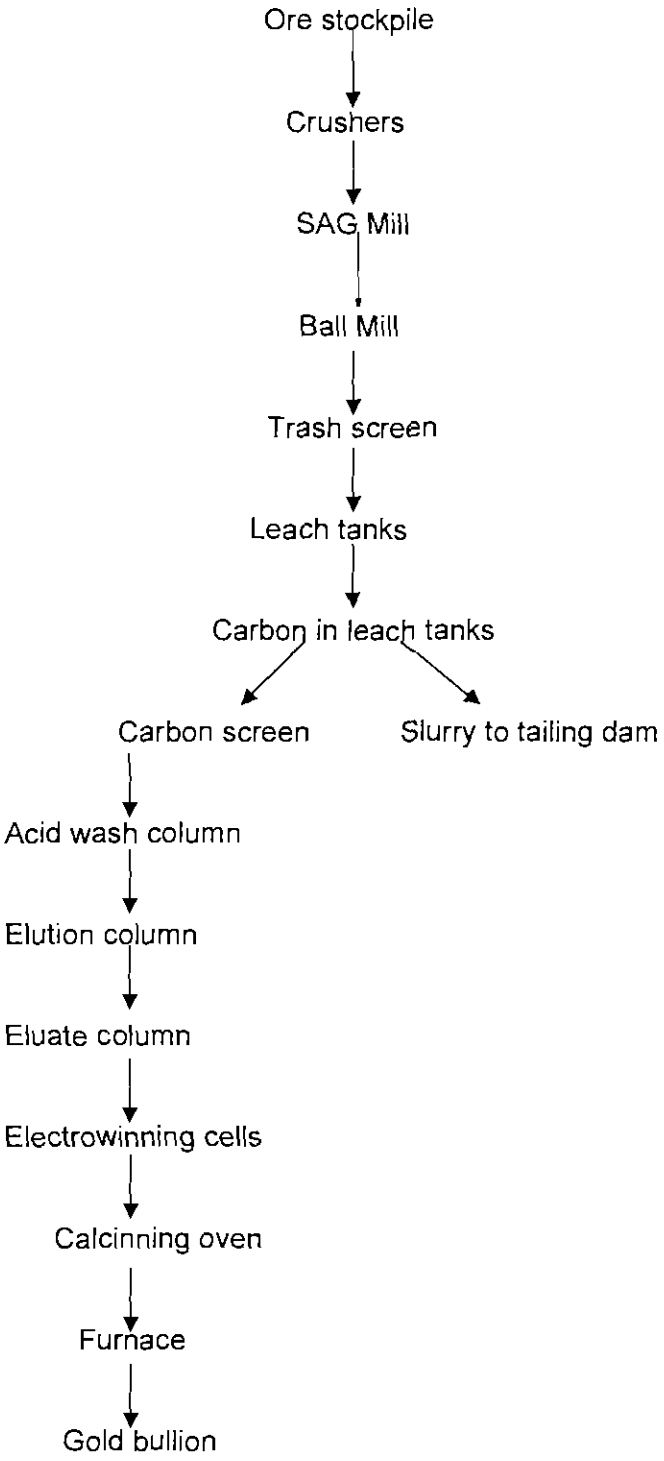

Figure 1: Simplified Mill/Plant Process flowsheet as used by the Barrick North Mara Mine, Tanzania (Provided by the Mill/Plant Supervisor)

1.4 Measurement of HCN exposure

1.4.1 Environmental monitoring

1.4.1.1 General environmental monitoring for gasses

There are two methods for the measurement of gasses, namely using direct reading instruments or, the collection of samples in sorbent tubes or filters. The direct reading instruments work on the principle of grab sampling or spot measurement over a short period of time. The instrument draws air through a collector and the immediate reaction with the collector gives a measurement that is shown on the instrument (Unsted, 2001:107). The gas detector will be a substance specific detector that contains an electrochemical sensor (Heath *et al.*, 2008, Unsted, 2001:108). An electrochemical half reaction takes place in the HCN^- direct reading instrument sensor, namely the formation of a metal cyanide complex by the oxidation of a noble metal, which is responsible for the detection of the specific gas. These monitors are commercially available (Heath *et al.*, 2008). An example is the DrägerSensor HCN-6809650 or the G750 Polytector from GfG Instrumentation.

1.4.1.2 Personal air sampling

Air is collected by a sampling device worn by the monitored worker that is placed as close as possible to the worker's breathing zone. This will ensure that the data collected is representative of the concentration of the chemical breathed in by the worker. The sampling device consists of an air inlet opening, a collection device, a valve controlling the flow-rate by which the device functions, and a suction pump (Huye, 2002:523).

The type of adsorption tube that is used to measure exposure to $HCN_{(g)}$ is a soda lime sorbent tube (NIOSH, 2005). Adsorption tubes are used to sample gasses and vapors. These tubes are filled with a sorbent material. It is a granular material and can be activated carbon or a material that is specific for the chemical that is being sampled (Huye, 2002:524-525, Unsted, 2001: 111). The pump draws the air containing the gas or vapor through the sorbent tube (Unsted, 2001:111). The vapor or gas is captured on the surface of the specific material or adsorbed without undergoing a physical or chemical change. The chemical is extracted and analyzed

in a laboratory to determine the concentration of the chemical present in the tube (Huye, 2002:524-525).

1.4.1.3 The influence of environmental factors on the airborne $HCN_{(g)}$ concentration

The ambient air temperature determines the liquid-vapor equilibrium and so the concentration of $HCN_{(g)}$ (Piccinini, 2000). Researchers found the highest concentration when the air temperature was low, and *vice versa*. The $HCN_{(g)}$ concentration at the level of the nose and chest were the highest at sunrise. It was also found that the $HCN_{(g)}$ concentration was high when the wind speed was high (Heath *et al.*, 2008). Natural airflow such as wind influences the movement and concentration of $HCN_{(g)}$ in the atmosphere (Orloff *et al.*, 2006). However Müezzinoğlu (2003) found that calm weather conditions can lead to problems if the levels of the $HCN_{(g)}$ in the air increase, as it will not be dispersed after release from the tailing pond surface as under other circumstances. An increase in the pH of the slurry/tailing will result in the increase of the amount of $HCN_{(g)}$ that is released (Heath *et al.*, 2008).

1.4.2 Biological monitoring

Biological monitoring consists of the measurement of indicators of exposure, called biomarkers, in biological media such as urine, blood and expired air. The substance itself, its metabolites or reversible biochemical and physical chances can be measured and used as biomarkers. The environmental or occupational exposure and danger to health is determined by comparing the results obtained by this measurement to established reference values or standards. The reference values are formulated by using the association between the exposure and the health effects caused by the exposure (Menditto and Turrio-Baldassasrri, 1999). Biological monitoring is also used in the determining the effectiveness of Personal Protective Equipment such as respirators in protecting the individual against exposure to contaminants (Klaassen and Watkins, 2004:460)

When one of the routes of exposure is via the skin, as is the case with cyanide, the exposure can't always be determined by using only airborne monitoring (Bolt and Thier, 2005). Biological monitoring can give a better indication of the total exposure to the chemical than environmental monitoring can alone, because biological

monitoring describes the exposure obtained from all exposure routes (Klaassens & Watkins, 2003:460). The measurement of the chemical or metabolite in the urine samples mirrors the mean level in the plasma that existed during the time that the urine was formed (Bolt and Thier, 2005).

Cyanide itself does not have a long half-life in blood, as it is an unstable molecule that breaks down quickly (Baud, 2007). A half-life of about 20 minutes to an hour in plasma has been suggested after exposure to a non-lethal dose (Hurtung, 1992: 4849). SCN^- is used as the biomarker for HCN exposure as it is the main cyanic metabolite (Scherer, 2006; Soto-Blanco *et al.*, 2002). SCN^- concentrations in the body can, however, not be used to determine acute exposure to cyanide, as the metabolic conversion of cyanide to SCN^- takes too long to be used in situations where the person has to be treated immediately or they will die (ATSDR,2006).

The SCN^- levels in workers exposed to cyanide in the working environment are higher than normal (Tulsawani *et al.*, 2005). The formed SCN concentration can be determined in urine, blood or saliva with the excretion of SCN mainly in the urine (Scherer, 2006). SCN has a half-life of several days in plasma, 10 to 14 days according to Bliss and O'Connell (1984), or 6 days according to Junge (1985) (Scherer, 2006). It was found that SCN^- concentration in the urine samples remained stable for up to 6 months when it was frozen at -20 °C (Haque & Bradbury, 1999). Therefore, SCN^- in urine shows the exposure to $HCN_{(g)}$ of the individual over one to two weeks because of the long half-life of the biomarker (Scherer, 2006). There are no significant changes in the concentration of SCN^- in the body fluids because of this long half-life and the SCN^- concentration can be accurately determined (Erdoğan, 2003).

A SCN^- concentration of 4.4 mg SCN^-/L in urine was found in smokers who had no known cyanide exposure, while a concentration of about 0.17 mg/L for non-smokers was found. Concentrations of 2.1 to 2.9 mg SCN^- /100 ml were found in the blood plasma of smokers (Hartung, 1982:4848).

1.4.3 Confounding factors

Confounding and interference factors can give incorrect results and result in faulty conclusions of the cyanide exposure. It impedes effective interpretations of the results (Schaller *et al.*, 2002).

1.4.3.1 Food

Some foods like cassava, lentils, lima beans and almonds have cyanogenic properties and the consumption of these foods may elevate cyanide levels in the body (Schaller *et al.,* 2002; Mudder & Botz, 2004). Cassava, in particular, can release cyanide in the body if not prepared correctly (Oluwole *et al.,* 2002; Mudder & Botz, 2004; Erdoğan, 2003). There are two main varieties of cassava, called the sweet and bitter varieties (Maziga-Dixon et al., 2007). The bitter variety contains higher levels of cyanogenic glucoside than the sweet variety with levels of about 138-203 mg HCN/kg cassava (Mudder & Botz, 2004; Maziga-Dixon et al., 2007).

The cyanogenic glycoside in cassava is mainly linamarin and the cassava itself doesn't contain the sulphur amino acids methionine and cysteine (Ngudi et al., 2003; Carlsson, et al., 1999). These amino acids are used in the cyanide detoxification process as a sulfur donor (Ngudi et al., 2003). The difference in the digestion rate and absorption of the food between individuals is the possible reason for the large variation between individuals in the percentage of the cyanide released from food in their systemic circulation (Oluwole et al., 2002). When the cassava is incorrectly processed, an endogenous enzyme is released and the linamarin is hydrolyzed to acetate cyanohydrins. If the temperature is too high and the moisture too low, the cyanohydrins will break down to HCN (Carlsson, et al., 1999).

Malnourished individuals who are chronically exposed to cyanide are more likely to exhibit health problems caused by cyanide toxicity (Mathangi & Namasivayam, 2000). This can be attributed to a deficiency of sulfur containing amino acids in their diet. The sulfur-containing amino acids provide the sulfur that is used in the cyanide detoxification process (Soto-Blancco *et al,*. 2002).

1.4.3.2 Smoking

Smoking can be a confounding factor in the measurement of SCN^- concentrations due to occupational exposure, as the SCN^- concentrations in smokers have been found to be two to three times the concentration found in non-smokers (Scherer, 2006). The concentrations found in individuals who are light smokers don't differ much from non-smoking individuals (Scherer, 2006). The biomarker has a limited use

to determine environmental second hand smoke exposure, because it is usually low-dose exposure (Husgafvel-Pursiainenm 2002).

A smoky environment would result in a higher cyanide level in the blood of workers working in this type of environment and individuals who live there (Lindsay *et al.*, 2004).

1.4.3.3 Biological variability

Some individuals may exceed the Biological Limit Values (BLV) during the biological monitoring measurements, but show no increased health risk due to biological variability according to Bolt and Thier (2005). As with other chemicals, the factors that can affect the toxicity of cyanide are the health and age of the exposed individual, the chemical form of the cyanide and method of exposure (Baskin & Rockwood, 2002).

1.5 Occupational exposure limits (OEL's)

The occupational exposure level (OEL) stated by OSHA is a time weighted average (TWA) over 8 hours of 10 ppm or 11 mg/m^3, while NIOSH gives a recommended short term exposure level (STEL) of 4.7 ppm or 5 mg/m^3 (Niosh, 2005). A OEL is a time weighted average concentration of a stress factor given for an eight hour day to which an individual may be repeatedly exposed without experiencing an harmful effect on his or her health while a STEl refers to a 15 minute time weighted average exposure which should not be exceeded during a work shift at any point in time (South Africa, 1996). The South African Regulations for Hazardous Chemical Substances 1995 and the Mine Health and Safety Act, 29 of 1996 don't provide a TWA that must be adhered to, but only a STEL value of 10 mg/m^3. A ceiling value of 4.7 ppm is set by the government of Ontario, Canada for exposure to HCN while a ceiling value of 5 mg / m^3 is given for sodium cyanide exposure (Ontario, 1990). A ceiling value is a concentration of the chemical that may not be exceeded at any point in time and is put in place to protect against acute effects of short- term exposure to a high concentration of the chemical (Klaassen and Watkins, 2003:362).

1.6 The International Cyanide Management Code

The International Cyanide Management Code was drafted as a voluntary initiative to enhance the cyanide regulations already in existence in the gold mining industry. Its aim is to ensure the safe management of cyanide in the industrial environment, which

in the mining industry is related to the use of cyanide in the recovery of gold. This includes both the cyanide producers and the gold mines (Anon, 2006).

Companies that wish to be signatories to this code, have to adhere to certain standards of operations or SOP's. These SOP's include SOP's for production, transportation, and handling of cyanide. Other SOP's in the Code are for operations using cyanide, decommissioning of cyanide facilities, ensuring worker safety, emergency response, training and public dialogue (Anon, 2006).

Independent professionals audit the signatories every three years to ensure that the company, in this case a gold mine, is compliant with the Code (Anon, 2006).

The SOP for operations states that there must be systems in place to ensure the type of management and operations that will not put the health of the workers or the environment in jeopardy. These systems include preventative maintenance, inspection of facilities and efforts to minimize the amount of cyanide that is used. It must be certain that the cyanide facilities comply with acknowledged engineering specifications to ensure safe operations (Anon, 2006).

The health of the cyanide-exposed workers must be protected, according to the SOP for worker safety, by the evaluation of the effectiveness of the measures put in place to ensure the workers' health. Any potential way that the workers may be exposed to cyanide must be established and measures taken to eliminate, or if that isn't possible, to reduce or control the potential threat (Anon, 2006).

A company that wishes to be a signatory can either comply fully or substantially to the Code (Anon, 2006).

1.7 Control measures

The concentration of the $HCN_{(g)}$ released from the slurry increases when the pH is too low, creating the need for the control of the pH (Heath *et al.*, 2008).

Floating barriers can reduce the release of this chemical from the surfaces of the slurry of tailing dams (Heath *et al.*, 2008). Barriers that float on the gold leach tanks and so reduce the amount of $HCN_{(g)}$ released from the tanks, are being developed by

a number of industrial companies including the Parker Center in Australia. These barriers are manufactured from cross-linked polyethylene foam. In a study done by the Parker Center hexagonal panels made from Trocellen ® were used which had a life of about six months. It was found that the panels reduced the average $HCN_{(g)}$ above the leach tanks and in addition it also reduced the number and size of the periodical spikes in the release of the gas (Humphries, 2008).

Local exhaust ventilation, general dilution ventilation, process enclosure and personal protective equipment (PPE) such as full-face respirators and chemical resistive clothing consisting of encapsulating suits and gloves, are ways of effective control of $HCN_{(g)}$ exposure (OSHA, 1996). An effective exhaust ventilation system is able prevent the diffusion of the chemical into the atmosphere (Piccinini *et al.*, 2000).

The mezzanine floor is a mesh floor above the leach tanks through which gasses from the open leach tanks can escape into the atmosphere. The CIL operators and Mill/Plant Day crew frequently work in this area and there is a large possibility that the workers will be exposed to $HCN_{(g)}$. Controls can be implemented in this area to minimize exposure (Heath *et al.*, 2008).

Decreasing the amount or substituting the material that releases the toxic gas can reduce the amount of $HCN_{(g)}$ that the workers are exposed to. One method of decreasing the amount of the toxic substance, is to consume the toxic intermediate substance immediately after it has been formed. The use of process conditions or forms of the material that is less hazardous than the toxic substance will decrease the hazard (Maxwell *et al.*, 2006).

The negative impact of accidental release of the hazardous substance can be lowered if the area where the substance is used, is designed in such a way that the exposure to the substance is minimal. The training of the workers in the correct working and emergency response procedures that will minimize their exposure can also be used to protect the workers. The installation of $HCN_{(g)}$ sensor alarms can be used to reduce the chance of exposure of the workers to $HCN_{(g)}$ (Maxwell *et al.*, 2006).

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The paper must be in English with the use of either the British or the American style and spelling.

The paper should consist of an Introduction, Methods, Results, Discussion and Conclusions with an abstract of the argument and findings as preface. The abstract may be arranged under Objectives, Methods, Results and Conclusions. After the list of authors, keywords should be given. The length of the paper may vary according to the subject but if it is longer than 5000 words a statement must be included that justifies the extra length. The paper must be as succinct as possible.

The figures should be on separate pages at the end of the text and the each tables typed on a separate page. The tables must be consecutively numbered, given a suitable caption and any footnotes typed below the table in subscript.should be submitted on separate pages at the end of the text. [1]

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Chapter 3

Exposure of Tanzanian gold mine refinery workers to hydrogen cyanide

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ABSTRACT

Objectives: To determine HCN exposure of refinery workers at a Tanzanian gold mine.

Methods: Personal airborne $HCN_{(g)}$ exposure was measured using a personal air pump with a soda lime sorbent tube. Urine samples were collected from the workers and the SCN^- concentration was measured in each urine sample by an accredited pathology laboratory. The differences between the exposures experienced by the different HEGs and work description groups were investigated.

Results: All of the workers' personal airborne $HCN_{(g)}$ exposures were below the TWA-OEL of 11 mg/m^3. No statistical significant correlation was found between the personal airborne $HCN_{(g)}$ exposure of the workers and the SCN^- concentration in their urine. There was a statistical significant difference between the personal airborne $HCN_{(g)}$ exposure experienced by the Mill/plant workers and the members of the environmental department ($p = 0.0142$). Confounding factors didn't have a statistical significant influence on the urinary SCN^- concentrations of the workers.

Conclusions: The workers were not exposed to airborne $HCN_{(g)}$ concentrations higher than the TWA-OEL. The Mill/plant workers were exposed to the highest concentration of $HCN_{(g)}$ of all the work description groups.

Keywords: Hydrogen cyanide, occupational exposure, biological monitoring, gold mine, Tanzania

Introduction

A large part of the gold that is being mined in the world is tiny particles that have to be extracted from the ore, mostly by a process called leaching (Woolacott and Eric, 1994:365). Cyanide is used as a leaching agent in many of the gold mines (Hillson and Manhemius, 2006; Ackil, 2002). In the Carbon-in-pulp (CIP) or Carbon-in-leach (CIL) methods, activated carbon is used to adsorb the desired metal from the leaching solution carrying the metal, also called the pregnant solution (Woolacott & Eric, 1994:360). $HCN_{(g)}$ is formed in these Carbon-in-pulp (CIP) or Carbon-in-leach (CIL) tanks and inhaled by workers working around these tanks (Stanton and Jeebhay, 1994:291).

Hydrogen cyanide gas ($HCN_{(g)}$) is a form of cyanide used in a variety of industries such as the electroplating, plastic manufacturing and mining industries (Cipollone *et al.*, 2005; ATSDR, 1993). It is also found in foods like cassava, bamboo sprouts and lima beans, cigarette smoke and fire smoke (ATSDR, 1993; Soto-Blanco *et al.*, 2000). These other sources of cyanide may act as confounding factors that may influence the SCN^- concentration found during biological monitoring (Schaller *et al.*, 2002). The body itself also produces its own endogenous cyanide. This is done through production by colon bacteria and an oxidative reaction in both white blood cells and neural cells (Billaut-Laden *et al.*, 2006; Jones *et al.*, 2003; Erdoğan, 2003).

The $HCN_{(g)}$ molecule binds and inhibits the mitochondrial enzyme cytochrome C, causing a disruption of the oxidative phosphorylation process and aerobic metabolism (Thompson *et al.*, 2003; Porter *et al.*, 2007). In other words, cyanide prevents the cells of utilizing the oxygen provided by the circulation and thus reduces the amount of energy produced by cells (Nelson, 2006). The central nervous system and cardiovascular system are particularly susceptible to damage caused by cyanide exposure, resulting in many of the symptoms associated with cyanide exposure. This is because of the dependence that these two systems have on aerobic metabolism (Thompson *et al.*, 2003; Porter *et al.*, 2007; Baud, 2007).

Symptoms experienced by individuals exposed to excessive HCN concentrations include weakness, an increase in respiration rate and abnormal heart rate (NIOSH, 2005). Thyroid abnormalities have been found in some cases of chronic exposure but other studies have found no such abnormalities in individuals who have ingested

cassava over long periods of time (Linday *et al.*, 2004; Erdoğan, 2003; Hurtung, 1992: 4849).

Humans can endure a certain level of cyanide exposure because they posses an effective detoxification mechanism, namely the enzyme rhodanese also called thiosulfate sulfurtransferase, that converts cyanide to thiocyanate (SCN^-) (Soto-Blanco *et al.*, 2000). SCN^- is used as a biomarker for cyanide exposure as it is the main metabolite of cyanide (Scherer, 2006; Soto-Blanco *et al*, 2002). This biomarker is mainly excreted in the urine (Scherer, 2006). Biomarkers are used in biological monitoring, which can provide a complete reflection of an individual's total exposure from any exposure route (Klaassens and Watkins, 2003: 460; Stanton and Jeebhay, 2001:276). A level of 0.17 mg/L for non-smokers and 4.4 mg/L for smokers that has not been exposed to cyanide can be considered normal, according to Hartung (1982:4848).

$$CN + S_2O_3^{2-} \xrightarrow{\text{rhodanese}} SCN + SO_3^{2}$$

Equation 1 (Lindsay *et al.*, 2004)

OSHA provides a time weighted average (TWA) of 10 ppm or 11mg/m^3, while NIOSH gives a short term exposure level (STEL) of 4.7 ppm or 5 mg/m^3 as limits for airborne $HCN_{(g)}$ exposure (NIOSH, 2005). The Regulations for Hazardous Chemical Substances found in South African legislation gives a STEL value of 10 mg/m^3 (South Africa, 1995).

Extensive research has been done regarding cyanide exposure in Africa due to the consumption of poorly processed cassava (Hague and Bradbury, 1999). However the exposure of workers to cyanide due to industrial exposure has not been researched in such detail. The impact of cyanide on the environment has been studied in South Africa by Hudson and Bouwman (2008) and the concentration of cyanide and cyanate in the effluent of a Zimbabwean mine was determined by Zvinowanda *et al.* (2008). There have been several studies concerning the effect of acute exposure to cyanide, but a lack of research on chronic exposure, possibly due the fact that acute poisoning can be severe and quick (Soto-Blanco *et al.*, 2000).

The aim of the study is to determine the concentration of $HCN_{(g)}$ that workers at a Tanzanian gold mine are exposed to through personal airborne $HCN_{(g)}$ monitoring,

biological monitoring that consisted of analyses of the workers' urine samples to determine the SCN^- concentration and the evaluation of the workers' medical records for symptoms of exposure to excessive cyanide concentrations such as headaches.

MATERIALS AND METHODS

Study design

Informed consent

Ethical approval was obtained for the project from the Ethics Committee of the North-West University (NWU-0067-08-S1). Informed consent was obtained from all participating workers.

Workers

Workers at the Mill/plant of a Tanzanian opencast gold mine, who are potentially exposed to HCN were selected from the following groups of workers: the SGS laboratory assistants that took the cyanide and slurry samples to be analysed in the laboratory (n = 5); environmental scientists that collected samples from the tailing dam to determine the cyanide content (n = 2); environmental assistants who worked around the tailing dam (n = 2); the Mill/plant Day crew that performed the cyanide dozing itself (n = 4); the Mill/plant day operators who worked on the elution circuit, Carbon-in-Leach (CIL) floor (above the leaching tanks), the gold room or around the plant (n = 10) and the Mill/Plant shift supervisors and trainers who move around the whole Mill/plant as needed including the CIL (n = 2). The workers were divided into HEGs or homogenous exposure groups according to the workers' predicted exposure.

Sampling strategies

Description of the work area of potentially exposed workers

The CIL of the Mill/plant consisted of a mezzanine floor above eight open leach tanks from which gasses may evaporate. The Day crew who were responsible for the cyanide dozing and the Mill/plant operators worked on the CIL area itself. The elution circuit was located to the side of the CIL and is where the process technicians worked. The slurry was pumped to the tailing dam approximately one km away.

Personal ambient sampling of $HCN_{(g)}$

The NIOSH method 6010 was used to determine the $HCN_{(g)}$ present in the breathing zones of the workers for a full eight hour (NIOSH, 1993). Air was drawn through a SKC soda lime solid sorbent tube (ST 226-28) by a Gilian Gilair personal air sampling pump. The sampling train was assembled before each monitoring with the pump calibrated with a Bios DryCal flow calibrator before and after the sampling at a flow rate of 0.2 L/min. The sorbent tube was sealed after monitoring and stored at -4 °C. Sorbent tube samples were analysed by an accredited laboratory.

Biological sampling

The workers were monitored on days that it was anticipated that they would be exposed to $HCN_{(g)}$. Urine samples, consisting of 50 ml of urine, were collected from the workers at the clinic on the mine site at the end of the work shift, on the same day as personal air sampling. The samples were immediately frozen and kept frozen during transport. The analyses of the samples for SCN^- was done by an accredited laboratory in South Africa.

Questionnaires

Lifestyle factors that may influence the results were determined using questionnaires that were filled out by the workers. These included dietary factors and environmental factors such as smoking, consumption of cassava, exposure to fire smoke and the number of years worked at the Mill/plant.

Statistical analysis of results

The statistical analysis of the results was carried out using Statistica 7.1 (Statsoft Inc.). Basic descriptive statistics including the calculation of the mean, standard deviation and variation on the personal airborne $HCN_{(g)}$, the urinary SCN^- concentration. The Spearman correlation and the Pearson product-moment correlation coefficient was used to calculate the correlation between the personal airborne $HCN_{(g)}$ concentrations and the urinary SCN^- concentrations. The influence of smoking, consumption of cassava, the length of time worked at the plant and exposure to fire smoke on both the personal airborne $HCN_{(g)}$ concentrations and the urinary SCN^- concentrations were determined using the Mann-Whitney U test.

Medical records of workers

The Medical records of participating workers were searched for prior symptoms such as headaches, dizziness, weakness and nausea that can be attributed to excessive cyanide exposure. The occurrence of these symptoms in the Mill/plant department was obtained from statistical data compiled by the mine. Individual records were not used.

RESULTS

The personal exposure of employees of a gold refinery to HCN was determined through personal air monitoring and biological monitoring of the employees. In total 25 personal air samples and 18 urine samples, which were analyzed for the urinary SCN^- concentration were collected from workers potentially exposed to $HCN_{(g)}$.

The information given in Table 1 was obtained from questionnaires completed by the workers with regard to potential confounding factors that may influence the monitoring results. Eighty eight percent of the workers were non-smoker while 76 % consumed cassava. Fifty six percent of the total workers consumed cooked cassava, while 20 % consumed raw cassava. Just over half of the workers, namely 52 %, had worked at the plant for a period of between one and three years. The rest of the workers were divided almost evenly between a period of less than a year (28 %) and a period of more than three years (20 %). The participating workers were predominately males with only 8 % being female, which is consistent with the overall demographic division of the mine employees. Sixty eight percent of the participating workers are not exposed to fire smoke every day.

Table 1: Characteristics of the study population obtained from workers' questionnaires

		Number	% of whole population
Number of workers (*N*)		25	
Gender	Male	23	92
	Female	2	8
Smoking habits	Smokers	3	12
	Non-smokers	22	78
Dietary habits	Eats cassava	19	76
	Cooked	14	56
	Raw	5	20
Length of time working at plant	< 1 year	7	28
	1-3 years	13	52
	> 3 years	5	20
Regularly exposed to fire smoke	Yes	8	32
	No	17	68

Table 2: $HCN_{(g)}$ concentrations, the adjusted occupational exposure limit for airborne $HCN_{(g)}$ exposure and SCN^- concentrations in urine samples

Work title	Concentration (mg/m^3)	Adjusted TWA-OEL *(mg/m^3)	Urine sample analyses (mg/L)	Measurement time period (min)
Mill/Plant outside operator	0.0987	10.667	0.48	495
Mill/Plant outside operator	0.0408	11.707	0.48	451
Mill/Plant process technician	0.9057	10.776	0.48	490
Mill/Plant process technician	1.0269	10.667	0.48	475
Mill/Plant process technician	0.534	11.116		475
Mill/Plant process technician	0.4917	10.776	0.48	495
Mill/Pant supervisor	0.1034	11	4.69	480
Mill/Plant supervisor	0.2556	10.887		485
Mill/Plant operator	0.021	10.019		475
Mill/Plant operator	0.4346	10.560	1.49	500
Mill/Plant operator	0.218	11.116	0.48	527
Mill/Plant operator	0.1668	11.186		472
Mill/Plant Day crew	0.0217	10.798		489
Mill/Plant Day crew	4.17	10.153	0.48	520
Mill/Plant Day crew	0.056	10.353	0.48	510
Mill/Plant Day crew	0.5084	11.355	4.51	465
SGS lab technician	0.0295	10.977	0.99	481
SGS lab technician	0.1846	10.154		520
SGS lab technician	0.3251	9.869	0.48	535
SGS lab technician	0.0772	10.776	0.48	490
SGS lab technician	0.2277	10.776	0.48	490
Environmental assistant	0.0288	10.887	0.48	485
Environmental assistant	0.0182	11		480
Environmental scientist	0.034	11.503	1.49	459
Environmental scientist	0.0094	10.864	1.65	486

*The TWE OEL was adjusted, as sampling was not precisely 480 minutes or 8 hours.

Table 3: The airborne $HCN_{(g)}$ concentration from the three HEGs

HEG	*N*	Mean	CI -95%	CI +95%	Min	Max	SD
60	12	0.358	0.147	0.569	0.021	1.027	0.332
61	4	1.189	-1.993	4.371	0.022	4.170	2
62	9	0.104	0.016	0.191	0.009	0.325	0.114
Total	25	0.400	0.056	0.743	0.009	4.170	0.832

HEG- Homogeneous exposure group; *N*-number of samples; CI-confidence interval; Min-minimum; Max- maximum; SD-standard deviation.

Table 4. The SCN^- concentration in urine samples from the three HEGs

HEG	*N*	Mean	CI -95%	CI +95%	Min	Max	SD
60	8	1.133	-0.105	2.370	0.480	4.690	1.48
61	3	1.823	-3.957	7.603	0.480	4.510	2.327
62	7	0.864	0.384	1.334	0.480	1.650	0.519
Total	18	1.143	0.486	1.801	0.480	4.690	1.322

HEG- Homogeneous exposure group; *N*-number of samples; CI-confidence interval; Min-minimum; Max- maximum; SD-standard deviation.

The mean personal airborne $HCN_{(g)}$ exposures experienced by the monitored workers was 0.400 ± 0.832 mg/m^3. A HEG is a homogenous exposure group which means that all the workers that are put in this group experience a similar level of exposure to the hazard, in this case $HCN_{(g)}$. The respective mean personal airborne $HCN_{(g)}$ exposures from the workers in HEG 60 and HEG 62 are less than the mean found from the workers HEG 61. A comparison between the concentrations found a difference of p = 0.0970 in the different HEGs with the use of Analysis of Variance (ANOVA). There is also a difference in the maximum values found in the HEGs with the most considerable difference being between the maximum value in HEG 61 and the maximum value in HEG 62.

The mean airborne $HCN_{(g)}$ concentration that the different work description groups was exposed to is shown in figure 1. . A statistical significant difference was however found between the Mill/plant workers and the members of the environmental department using the Kruskal-Wallis test (p = 0.0142) but not between the Mill/plant workers and the SGS laboratory assistants (p = 1.0000) or the SGS laboratory assistants and the members of the environmental department (p = 0.2004).

If the workers are grouped, not according to HEGs, but according to work description groups the mean airborne $HCN_{(g)}$ concentration is shown in Figure 1, a statistical significant difference was found between the Mill/plant workers and the members of the Environmental department using the Kruskal-Wallis test (p = 0.0142) but not between the Mill/plant workers and the SGS laboratory assistants (p = 1.0000) or the

SGS laboratory assistants and the members of the Environmental department (p = 0.2004)

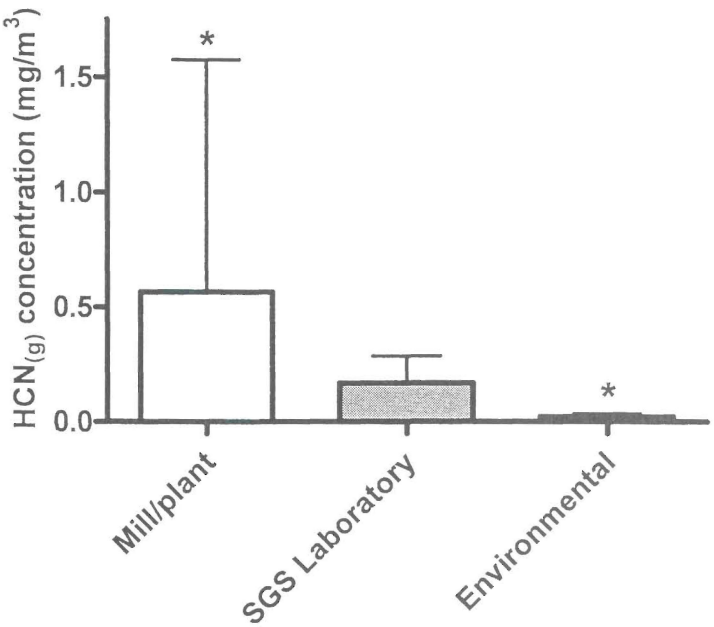

Figure 1 $HCN_{(g)}$ exposure of the different work description groups

The SCN^- concentrations in some of the urine samples were below 0.98 mg/L, which is the biological detection limit (BDL) of the method used by the pathology laboratory. Half of the BDL value i.e. 0.48 mg/L was used as the SCN^- concentration of each of these samples. The total mean of the SCN^- concentrations monitored workers was 1.143 ± 1.322 mg/L (Table 4). There was no statistically significant difference found between the mean SCN^- concentrations in the urine samples from the three HEGs (p = 0.5518). The maximum values in two of the HEGs namely HEGs 60 and 61 were 4.690 mg/L and 4.510 mg/L but the maximum of HEG 62 was 1.650. The mean and standard deviation found in HEG 60 and HEG 61 was respectively 1.133 ± 1.480 mg/L and 2.327 ± 2.327 mg/L that indicates a large variance in the samples. The mean and standard deviation found in HEG 62 was 0.864 ± 0.519.

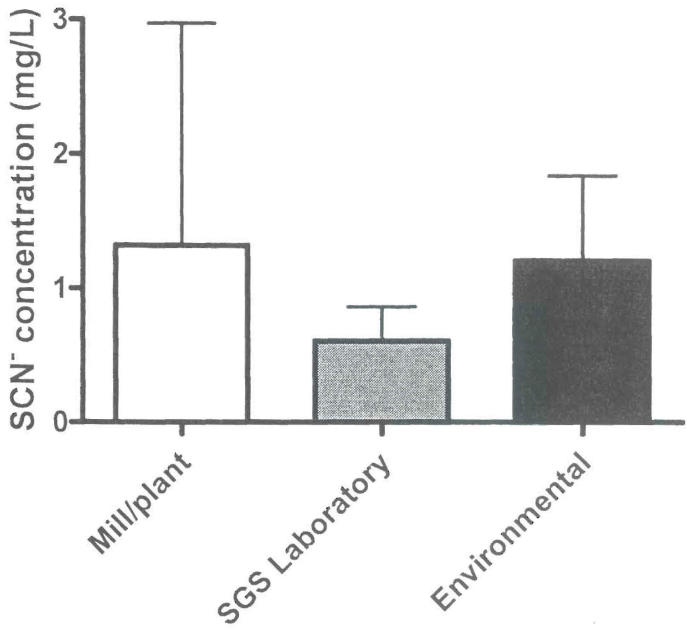

Figure 2: The mean urinary SCN- concentrations of the different work description groups.

There wasn't any statistical significant difference found between the mean urinary SCN^- concentrations between the Mill/plant workers and the SGS laboratory assistants ($p = 1.0000$), the Mill/plant workers and the members of the environmental departments ($p = 1.0000$) or the SGS laboratory assistants and the members of the environmental department ($p = 0.9061$) when the Kruskal-Wallis test was used (Figure 2).

A correlation between the airborne $HCN_{(g)}$ concentrations and the SCN^- concentrations in the urine samples was calculated using the parametric Pearson product-moment correlation coefficient. Although a negative correlation (-0:1309) was found between the two variables, it wasn't a statistical significant correlation. A negative correlation means that as the airborne $HCN_{(g)}$ concentration increases the SCN^- concentration will decrease. The non-parametric Spearman correlation also found a correlation of -0.2140 between the two variables, also indicating a negative correlation.

There are confounding factors that may influence the SCN^- concentration namely smoking, eating cassava, the years working at the Mill/Plant and exposure to fire smoke. None of these factors have shown a significant statistical influence on the

SCN^- concentration except the combined influence of smoking and cassava, which has a negative influence according to parametric tests. The workers that only ate cassava had a higher SCN^- concentration than workers who ate cassava and smoked. The Mann-Whitney U test showed no significant difference between the SCN^- concentrations if the confounding factor was present and the concentrations if the confounding factor was absent in the case of smoking ($p = 0.357$), consumption of cassava ($p=0.57$) and regular exposure to fire smoke ($p = 0.4106$). No statistical significant difference was also found between the workers working at the Mill/plant less than a year, workers working there between one and three years and the workers working at the Mill/plant longer than three years ($p = 0.1493$).

The medical records of the monitored workers were evaluated and no significant mention was made of any neurological symptoms such as headaches, confusion, exhaustion, abnormal vision, hearing loss and weakness.

DISCUSSION

In the past more extensive research has been done on the health effects caused by acute exposure to cyanide than the effects of chronic exposure to the chemical (Mathangi and Namasivayam, 2000). The focus has shifted to chronic low levels of cyanide exposure, as the current perception is that its chronic effects are more far-reaching and significant (De Sousa *et al.*, 2007). Mining is one of the industries where employees may be exposed to cyanide (Baskin and Rockwood, 2002). This is why the personal airborne $HCN_{(g)}$ exposure of gold refinery (Mill/plant) workers were measured over the full shift and biological monitoring was carried out on the same group of workers at the end of the shift.

All of the personal airborne $HCN_{(g)}$ measurement obtained from the workers showed exposure below the OEL for eight hours. This would also indicate that the controls in place to reduce the airborne $HCN_{(g)}$ at the Mill/plant was effective. A statistical significant difference was not found between the three HEGs. The workers were sorted in the HEGs according to the type of work they perform an the similar predicted airborne $HCN_{(g)}$ exposure which should have resulted in statistical differences between personal airborne exposure found in the three HEGs. The HEGs should possibly be reformulated.

A member of the Day crew showed the highest personal airborne $HCN_{(g)}$ exposure when monitored. The members of the Day crew are responsible for adding the sodium cyanide to the CIL tanks, so it was expected that the members of the Day crew would experience high exposure. However, the other three members of the Day crew that were monitored showed much lower exposure levels. This value could be the reason that the mean value of HEG 61, which the Day crew are part of, is significantly higher than the mean concentrations of the other two HEGs. The maximum concentration found in HEG 61 was substantially higher than the maximum concentrations of HEG 60 and HEG 62. As the sampling group is small, one extreme concentration may provide an incorrect representation of the data. The Mill/plant workers may be exposed to excessive $HCN_{(g)}$ concentrations for short periods of time which would not be identified by eight hour monitoring.

The process technicians had the highest mean airborne $HCN_{(g)}$ of the different work groups which can be the result of their work near the CIL tanks. There is a risk that employees may be exposed to $HCN_{(g)}$ in the air when they work near the CIL tanks (Stanton and Jeebhay, 1994:291). The Mill/plant operators experienced the highest personal airborne exposure to $HCN_{(g)}$ which could be due to the fact that they physically work with the sodium cyanide and spend their working day in the vicinity of the CIL tanks that emit the chemical gas. The SGS laboratory assistants, who spend their work shift in a laboratory on the Mill/plant site and take samples from the CIL tanks once in the morning have the second highest $HCN_{(g)}$ exposure. A statistical difference was found between the exposure experienced by the Mill/plant workers and the members of the environmental department which was expected before the study was carried out as the Mill/plant workers are in direct contact with the sodium cyanide and work their whole shift in the area where the $HCN_{(g)}$ is emitted from. The only potential exposure that the members of the environmental department may experience is during the collecting of samples from the tailing dam and while working near the tailing dam.

The monitored members of the environmental division of the mine were exposed to the lowest mean $HCN_{(g)}$ exposure. The low exposure concentrations would indicate that the $HCN_{(g)}$ emissions from the tailing dam are low enough not to be a risk to the health of the employees who work around the dam especially when compared to the emissions from the CIL tanks at the Mill/plant. The analyses of the SCN^- concentration in the urine samples obtained from the two environmental scientists however showed values that were higher than some of the other groups that had

higher personal airborne $HCN_{(g)}$ of. The monitoring of these workers for eight hour exposure may not be the right strategy as their exposure is only for short periods. The eight hour concentrations could show that they are exposed to low $HCN_{(g)}$ concentrations but they may be exposed to high concentrations on an acute basis. A better strategy may be to determine their short-term exposure to HCN for 15 minutes at a time.

No statistical significant difference was found between the SCN^- concentrations in the urine samples obtained from the three HEGs. It was assumed that there would be a difference as the different HEGs should be exposed to different $HCN_{(g)}$ concentrations that would lead to different SCN^- concentrations in the body. There was also no statistical significant difference between the concentrations found in the different work description groups.

There is currently no internationally accepted set biological exposure index (BEI) value for cyanide or HCN. Reference values for normal urinary SCN^- concentration from 1982 were found which gave a reference value of 0.17 mg/L for non-smokers and 4.4 mg/L for smokers (Hartung, 1982:4848). It was decided to use the reference values used by the pathology laboratory to determine if the SCN^- concentration points to occupational exposure to cyanide. These reference values are more recent and part of standardized analytical methods. The SCN^- concentrations in all the urine samples except one were below the reference values used by the pathology laboratory to determine if the workers were occupationally exposed to cyanide. The reference values were 0.98 – 2.7 mg/L for non-smokers and 4.70 - 11.3 mg/L for smokers. The worker's urine sample contained a SCN^- concentration of 4.51 mg/L that was below the reference values for smokers but above the reference value for non-smokers and as the worker has been a non-smoker for two years, the SCN^- concentration, indicates occupational exposure to cyanide. The worker is a member of the Day crew who was expected to have the highest SCN^- concentration, however the other members had very low concentrations in their urine. The highest SCN^- concentration of 4.69 mg/L was found in the urine sample of a Mill/plant supervisor. The supervisors move around the Mill/plant area the whole time and may experience acute exposure to excessive amounts of $HCN_{(g)}$ which would result in a high total amount of cyanide in his body.

According to Haque and Bradbury (1999) the SCN^- content in the urine can be used as an indicator of the exposure to cyanide. This would imply that there would be a

correlation between the concentration of $HCN_{(g)}$ that the worker is exposed to and the SCN^- concentration in the worker's body. A negative correlation that's in direct disagreement with previous findings was found between the two concentrations Tulsawani *et al.*, 2005).

The confounding factors didn't have the anticipated influence on the urinary SCN^- concentrations of the workers. The chronic consumption of cassava and cigarette smoke both should add to the cyanide concentration in the body (Erdoğan, 2003). The HCN found in cigarette smoke would result in substantially higher SCN^- concentrations in smokers than non-smokers (Scherer, 2006). Only three of the workers smoked which could have decreased the statistical impact. Seventy six percent of the workers ate cassava but this may have been predominately cooked and correctly processed cassava which would decrease the amount of cyanide found in the food and its impact on the SCN^- concentration in the urine (Ngudi *et al.*, 2003).

None of the workers had a medical history of headaches, dizziness, nausea, vision abnormalities, hearing loss, exhaustion or weakness but some of the workers have had cases of malaria. Malaria has similar symptoms such as headaches that could have masked cyanide related symptoms.

A study that incorporates a larger sampling population would give a better representation of the mean exposure to $HCN_{(g)}$ and the influence of the confounding factors. The combination of eight hour monitoring to determine the long term exposure and 15 minute monitoring to determine the short term exposure will give a comprehensive and accurate reflection of the workers' exposure.

Laboratory techniques used to determine the urinary SCN- concentration are impractical in remote places such as the mine site in Tanzania. An alternative method of determination of the SCN- in the urine is the semiquantitative picrate method developed by Hague and Bradbury (1999). It uses a color chart or spectrophotometer to determine the approximate concentration and would save time and money on the transport of the urine samples (Hague and Bradbury, 1999)

CONCLUSION

The personal airborne exposure to $HCN_{(g)}$ experienced by workers of a gold mine refinery (Mill/plant) was on average very low which would lower the risk of health problems caused by cyanide's inhibition of cellular aerobic metabolism. Chronic exposure to $HCN_{(g)}$ may lead to problems of the central nervous system, the cardiovascular system and the endocrine system (ATSDR, 1993). Smoking, cassava consumption, exposure to fire smoke and the length of time that the worker has worked at the Mill/plant did not have a statistical significant influence on the SCN^- concentration.

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Chapter 4

Concluding chapter

The $HCN_{(g)}$ exposure of workers at a gold refinery was established with personal airborne sampling and measurement of their urinary SCN^- concentration.

None of the workers were exposed to an airborne $HCN_{(g)}$ concentration higher than the OEL or action level, which is 50 % of the OEL . The OEL was obtained from OSHA as no exposure limit was given by Tanzanian legislation. Most of the exposure limits set for HCN are in the form of a STEL value including the limit given by NIOSH and the South African Regulations for Hazardous Chemical Substances, but OSHA set a TWA-PEL of 11 mg/m^3 (NIOSH, 2005; South Africa, 1995).

A statistical significant difference was not found between the $HCN_{(g)}$ exposure of the different HEGs ($p = 0.0964$). The workers were sorted into the HEGs according to differences in predicted exposure. There was a statistical significant difference between the exposure of the workers working at the Mill/plant itself and the exposure experienced by the members of the Environmental department. The Mill/plant workers are exposed to $HCN_{(g)}$ emissions for the full length of their shift which would result in high exposure levels. The Environmental department members are only exposed to $HCN_{(g)}$ emissions during work around the tailing dam, the collection of samples from the tailing dam and working with these samples in a laboratory. Consequently their exposure doesn't take place over a long period of time. Eight hour monitoring won't show the workers' acute exposure that might by be higher than the STEL value of 5 mg/m^3. Short-term exposure monitoring would consist of a number of 15 minute measurements. According to the results of this study we suggest that the HEGs for workers exposed to HCN be resorted to the workers' job category thereby making the three HEGs more homogenous. Combining the monitoring of short-term exposure and long-term exposure will provide a comprehensive representation of the workers' exposure and any exposure that may pose a risk to the workers' health will be identified.

An international recognized BEI value is not available to evaluate the biological exposure to cyanide or HCN. The urinary SCN^- concentration can be used as an indicator of the total amount of cyanide present in the body (Haque and Bradbury, 1999). Urines samples were collected from the workers as part of biological monitoring. Just one of the workers showed a urinary SCN^- concentration that was over laboratory reference limits set for occupational exposure to cyanide. There was

no significant difference between the urinary SCN^- concentrations found in the three HEGs or between the three work description groups. A statistical significant difference was expected as the workers' exposure to cyanide varied.

Furthermore, the urine samples had to be transported from the mine site in Tanzania to an accredited pathology laboratory in South Africa, which increased the chance of an inaccurate biomarker concentration in the urine samples. It is well documented that the SCN^- concentrations in urine sample remain stable for 14 days at 4°C if the samples are correctly stored and handled. The difficulties with transporting urine samples out of the country can be eliminated by using the picrate kit that allows the determining of the SCN^- concentrations in urine sample on the mine site itself. The picrate test results would also be available in a few days where the results from the pathology laboratory would be available only after two weeks. The picrate kit is also far less expensive than pathology tests.

A negative correlation was found between the subjects' personal airborne $HCN_{(g)}$ exposure concentration and the SCN^- concentration found in the subjects' urine samples. A positive correlation was expected as studies have found that SCN^- can be used as a biomarker for cyanide exposure due to a higher than normal SCN^- concentration in the bodies of cyanide exposed employees (Tulsawani *et al.*, 2005).

The hypothesis of this study stated that the employees at the gold refinery (Mill/plant) were exposed to $HCN_{(g)}$ levels that was below the TWA-OEL as given by OSHA. The hypothesis can be accepted as the personal airborne exposure levels experienced by the employees were all below the OEL.

The mine has instituted administrative controls to decrease the employees' exposure to $HCN_{(g)}$ by rotating the workers on a weekly basis between the Day crew (who physically handle the sodium cyanide), day shift, night shift and a week of R and R (rest and relaxation). This means that every worker's exposure to the chemical is limited. The members of the Day crew who add the sodium cyanide to the CIL tanks wear protective clothing when they are handling the sodium cyanide namely CAT 3 type 5B and 6B overalls and reparatory protection that consists of a full face air-purifying respirator. The existing controls at the mine are sufficient to prevent excessive exposure over a period of eight hours but as the short- term exposure was not measured it can't be confirmed that the controls prevent excessive short-term exposure.

The medical records of the subjects were examined for symptoms attributed to chronic cyanide exposure such as headaches, nausea, confusion, vision abnormalities, hearing loss and weakness. None of these symptoms were found but the fact that the mine is in a malaria area and that a headache is a symptom of malaria could mask cases caused by cyanide exposure. Many of the employees also go to the nearby village or their hometown or city for medical attention, which means that their medical records may not be complete.

A larger sample group would give a more accurate account of the exposure experienced by the workers to $HCN_{(g)}$ and would be especially useful in establishing the correlation between the personal airborne exposure and the urinary SCN^- concentrations.

Recommendations

Recommendations related to biological monitoring, the training of workers to correctly handle cyanide and recognizing the symptoms of exposure to an excessive concentration of HCN or any other form of cyanide are included in the biological monitoring program for HCN. The biological monitoring program also includes a word list, the types of biological monitoring for HCN, the selection of the appropriate testing schedule, employee access to their results and the action that must be taken if the employee is exposed to elevated levels of SCN^-. The biological monitoring program will provide proof that the mine is instituting a program to adhere to the requirements of being signatories to the Cyanide Management Code

The workers' short-term exposure must also be determined as the acute effects of excessive amounts of cyanide are severe. Some of the workers such as the members of the Environmental department are only exposed to cyanide for short periods of time which means that the eight hour monitoring alone would not give an accurate indication of the worker's exposure. The worker could be exposed to extremely high HCN concentrations for short time periods but it would not be indicated by the eight hour monitoring. Workers must be monitored for a number of short periods lasting 15 minutes, which would be compared to STEL values.

The hierarchy of control must be followed which means the first type of control measure that must be considered is engineering controls followed by administrative controls and PPE.

Panels that float on the surface of the CIL tank have shown to reduce the concentration of the average $HCN_{(g)}$ emissions from the CIL tank in similar setups according to Heath *et al.*(2008). These panels can be installed as an engineering control. The installation of local ventilation and the enclosure of the CIL tanks will ensure that the formed $HCN_{(g)}$ is not released into the atmosphere above the CIL tanks and so reducing the concentration of the gas that workers may be exposed to.

The present administrative controls and the culture of personal protective equipment use must be maintained. The training and education of employees must be a priority and commence on a regular basis.

Other measures that must be instituted are:

- regular personal airborne $HCN_{(g)}$ exposure monitoring to become aware of any changes in the level of exposure and to evaluate the efficiency of the control measures that are in place.

- static environmental monitoring that can be implemented by the installation of $HCN_{(g)}$ sensor alarms that are set to inform the relevant individuals if the airborne $HCN_{(g)}$ concentration reaches a level at which action must be taken to prevent a potential health risk.

- the establishment of medical surveillance to ensure complete medical records.

A biological monitoring program for HCN exposure.

The biological monitoring program was drawn up for a gold mine in Tanzania.

Background

Cyanide is a chemical that inhibits the production of energy in the cell's mitochondria by inhibiting enzyme, cytochrome C (Thompson *et al.*, 2003; Porter *et al.*, 2007). Exposure to excessive levels result in health problems, especially in the central nervous system with symptoms such as headaches, weakness, vision abnormalities and hearing anomalies (NIOSH, 2005). Optic pathologies such as retrobulbar neuritis, optic atrophy and Leber's hereditary optic atrophy have been attributed to chronic exposure to excessive cyanide levels (ATSDR, 1993; Soto-Blanco *et al.*, 2000). There is a failure of the individual's central vision (Soto-Blanco *et al.*, 2002).

One of the forms of cyanide, hydrogen cyanide gas ($HCN_{(g)}$) is produced in the extraction of gold from ore in the gold mining industry (ATSDR, 2006). The use and production of $HCN_{(g)}$ is a concern for the gold mining industry which resulted in the International Cyanide Management Code. It is a voluntary initiative where signatories commit themselves to uphold prescribed standards of responsible management of cyanide (Anon, 2006).

Cyanide itself can be used as a biomarker of exposure, but the molecule itself does not have a very long half-life in blood. Cyanide is metabolized to mainly thiocyanate (SCN^-) (Baud, 2007). However, SCN^- can be used as a more effective biomarker for chronic exposure to cyanide as it has a longer half-life and can be measured in blood or urine (ATSDR, 2006; Scherer, 2006). SCN^- is mainly excreted in the urine (Scherer, 2006).

Biological monitoring is the measurement of a chemical or its metabolites, called a biomarker, in biological material such as blood, urine and saliva, to provide an estimate of the exposure of a person or worker to the chemical (Schaller, 2002). HCN can be absorbed into the body via the skin, respiratory system and by ingestion of the chemical. This means that a complete reflection of the exposure regardless of the route of exposure can only be given by biological monitoring (Klaassens and Watkins, 2003: 460; Stanton and Jeebhay, 2001:276). For several potentially hazardous chemical substances there are international reference values called BEIs that is the concentration of the chemical or its metabolites that can be theoretically

found in a worker who inhaled a OEL-TWA concentration of the chemical (South Africa, 1995). There is unfortunately not an internationally recognized BEI specifically for cyanide or $HCN_{(g)}$. The picrate kit protocol or the limits set by accredited pathology laboratories can be used as reference levels.

The determining of the SCN^- concentration in the workers' urine as a reflection of exposure to cyanide may contribute to the upholding of the International Cyanide Management Code. . This can be achieved by using the picrate test or laboratory tests.

Word list

All definitions are according to the Regulations for Hazardous Chemical Substances (1995).

BEI (Biological Exposure Indices): An index that theoretically corresponds to the level of the hazardous chemical or its metabolite that will be observed in a sample collected from a healthy worker exposed to a hazardous chemical at the same levels as a worker who experienced inhalation exposure to the OEL-TWA of the chemical.

Biological monitoring test: A test that consists of the measurement of the concentration of a chemical risk or its metabolite to determine the total exposure experienced by an individual to the specific chemical risk

Employee: Any individual who receives payment for work, is employed by, or works for an employer or performs work under an employer's supervision or direction.

Employer: An individual who provides employment or work to any other individual and pays that individual or clearly undertakes to pay him or her.

Exposure: Exposure to a hazardous chemical during the execution of their work activities

Monitoring: The planning, execution and recording of the results of a measurement program

OEL (Occupational Exposure Level): A limit value set for a occupational stressor such as a chemical to ensure that exposed individuals aren't harmed by the exposure.

Personal air sampling: The monitoring of the airborne concentration of a hazardous chemical that an individual is exposed to.

TWA (Time weighted average): The highest level of exposure to a hazard that an individual may be subjected to over a specific time period usually eight hours (TWA-8 hours).

Objectives of a biological monitoring program for HCN are:

- to determine the exposure of workers to HCN.
- to identify any workers that are at significant risk of health complications caused by excessive exposure to cyanide.
- to prevent cyanide-induced adverse health effects by enabling the improvement of control measures.

1 Training and education of the employees

All employees that are exposed, or potentially exposed, to the chemical must be informed and trained sufficiently and in detail regarding:

- potential sources of HCN exposure and the health risks associated with exposure.
- the measures implemented by the employer to protect the employee against potential HCN exposure.
- the importance of medical surveillance and personal monitoring to ensure the employees' safety
- the precautions that the employees themselves must take to protect their health, including the correct use of protective clothing and respiratory protective equipment.
- the necessity of good housekeeping and personal hygiene in the workplace.
- the correct use, maintenance and limitations of engineering controls, safety equipment and safety facilities that are in place.
- emergency procedures that should be followed in case of leaks, spills or any similar situations.

Refreshment training must be provided to the employees at least every year or on a more frequent basis if necessary. An individual that is qualified and possesses sufficient practical and theoretical knowledge about cyanide and its health effects must give the training.

1.1 Responsibilities of management

Training sessions must be mandatory and management must participate in every employee training session to explain and outline company policies concerning control of exposure to HCN. Training must be informative and presented in a way that will suit the employees.

1.2 Responsibilities of the employees

Employees must take responsibility for their own health and act according to the company policies concerning the control of exposure to HCN. Employees must also share their concerns and questions with management, inform when the proposed procedures are not practical to implement and suggest alternative procedures.

2 Biological monitoring and medical tests

2.1 General

If any worker fits the following criteria he or she must be included in the biological monitoring program:

- is potentially exposed to $HCN_{(g)}$ or sodium cyanide (NaCN).
- works in any area that has been identified as an area where exposure to $HCN_{(g)}$ is
- probable.
- has a job description that has been identified by the Occupational Hygiene risk
- assessment to be exposed to $HCN_{(g)}$
- if the occupational health practitioner recommends that an employee should be part of the program

The collection of urine samples is less invasive than the collection of blood samples, which is why this type of sample is used in the program.

2.2 The options for analyses of the urine samples

There are two ways whereby the urine samples may be analyzed to determine the level of SCN^- in the samples, namely by an accredited pathology laboratory, or a picrate kit, using a relatively simple semiquantitive method.

The picrate kit can be used on the mine site itself which makes the transport of the urine samples over long distances unnecessary and reduces the time before results would be available to the mine physician and the worker. The kit is however a semiquantitive test, which means that it is not as precise as the method used by the pathology laboratories.

The transportation of the urine samples to an accredited pathology laboratory would increase the chance that the samples may be contaminated or compromised. However, the pathology test would be more accurate. It would also not be possible to collect just one urine sample or even three or four samples at a time as the transportation of the samples would be too expensive to send just a few samples at a time and transportation could only take place on certain days of the week.

An effective method would be to use the picrate kit as a screening test to indicate if there is a significant exposure, after which the urine sample may be sent to the pathology laboratory if further clarification is needed. The preference of the picrate kit for analyzes will ensure that the elevated levels of SCN^- in the individual are determined as fast as possible.

2.3 Analyses by a pathology laboratory

At present there aren't any accredited pathology laboratories in Tanzania equipped with suitable apparatus to analyze samples for the biomarker SCN^-. The urine samples will have to be frozen and transported to an accredited South African pathology laboratory by a courier company to be analyzed. The courier company will have to ensure that the urine samples remain frozen for the duration of transport to South Africa. The samples must be packed in cooler bags with ice. The results of the analyses will usually only be available in approximately two weeks.

2.4 Picrate kit protocol to determine SCN^- in urine.

The method that is generally used to determine the urinary SCN^- concentration is a technique that needs specialized chemicals and equipment that may not be available in developing world countries such as Tanzania. The picrate test kit has been developed to determine cyanide toxicity caused by excessive consumption of improperly processed cassava. Experimental studies have shown that the results obtained with the use of the kit correlates accurately with those obtained from the same urine monsters using the existing column method (Haque & Bradbury, 1999). The Cassava Cyanide Disease Network provides the picrate tests free to impoverished communities and at a minimal fee of approximately $ 350 to corporate organizations such as the mine.

The Cassava Cyanide Disease Network provided the complete protocol. The following is a summary of the protocol: the concentration of SCN^- can be determined

using two methods namely a color chart or by using a spectrophotometer. If the color chart is used, the color change of the picrate paper is compared with shades of color on the reference chart. The shade shows the concentration of SCN^- present in the urine. If a spectrophotometer is available, the picrate paper is placed in water to form a picrate solution. The absorbance of the solution is measured at a wavelength of 510 nm. An equation is used to calculate the SCN^- in ppm or µmol/L. The test will take approximately 16- 24 hours to perform.

The SCN^- concentration can is verified either way by using both methods to ensure that the SCN^- concentration was determined correctly. The concentration found by both methods should be equal.

2.5 Quality control/Standardization of the picrate test method

A 10 ppm standard is provided with the picrate kit and is used, together with a blank picrate paper, to standardize the method.

The method can also be standardized each six months during the evaluation of the program by sending one part of a urine sample to an accredited pathology laboratory and analyzing the other part using the picrate kit. The comparison of the results of the two analyzes methods would indicate if the picrate kit is accurate.

2.6 Medical surveillance tests

The medical history of the worker must be evaluated, and a physical examination performed, to be used as additional information with the biological monitoring when the baseline biological monitoring measurement is determined. A medical examination will determine if the worker has developed symptoms associated with exposure to excessive levels of the chemical such as weakness, nausea, exhaustion, headaches, confusion and enlargement of the thyroid gland. Unfortunately these symptoms can also be attributed to a large number of other medical conditions, which may lead to confusion and misdiagnoses. This means that the focus must be on the testing of the urine samples to determine exposure to HCN.

Medical surveillance tests include:

Testing of the visual field: The area seen by an eye is called the field of vision. The field of vision for each of the eyes is plotted by moving a small point of light or small object back and forth in the areas of the visual field while the subject is looking at a

fixed point straight ahead. The subject indicates when the light or object can be seen and when not (Guyton and Hall, 2000: 595).

Audiometry: an audiogram is a graphic representation of the hearing threshold levels of the individual worker related to frequency of sound. If the auditory nerve, cochlea, or the circuits of the central nervous system for the ear, is damaged, then the inability to hear sound is called nerve deafness. In testing for nerve deafness the ability to hear sound is tested through bone conduction and air conduction. The damage to the individual's hearing is shown by the audiogram (Guyton and Hall, 2000:611).

2.7 Baseline measurement

A baseline measurement for each of the biological monitoring, medical surveillance tests and an overall physical examination should be taken for every worker that fits the criteria provided in 2.1. The baseline measurements enable the physician to determine if there have been any changes in the health of the worker when a follow-up or routine measurement is taken.

The baseline medical examination and biological monitoring should take place immediately, or within 14 days, after a worker commences employment.

In cases where the baseline SCN^- concentration is above the reference concentration of 0.98- 2.7 mg/L for non-smokers and 4.7-11.3 mg/L for smokers, the worker must be prevented from working in the area where the excessive HCN concentration is found. If the baseline alone is elevated above the reference concentration, the worker must be retested after a week after the test has shown excessive exposure to determine if the SCN^- concentration in the worker has decreased which would indicate a decrease in the total amount of SCN^- in the worker's body. The possible causes for the elevated baseline must be determined, as it will be due to lifestyle factors and not occupational factors.

2.8 If personal airborne exposure to $HCN_{(g)}$ exceeds the OEL

If this concentration exceeds the OEL stated by NIOSH, namely 10 ppm or 11 mg/m^3 then the worker is automatically included in the biological monitoring program. If the first biological monitoring test shows a SCN^- concentration that exceeds the reference value, the test must be repeated weekly until the concentration has decreased below the reference concentration. If the worker wasn't already part of

the biological monitoring program the first biological test must be used as a baseline measurement. If this first biological test showed a SCN^- concentration that was below the reference concentration the test must repeated monthly for three months.

The biological monitoring test must be done at the end of the worker's shift on the last day of the shift week.

2.9 Routine monitoring

The next biological monitoring test after the baseline measurement must take place after three months and six months. If below the reference value the next tests must be done every six months. During the collection of the biological sample the medical practitioner that is performing the biological test must ask the worker a number of routine questions. These questions are:

- Have you experienced any headaches or abnormalities with his or her vision or hearing ability during or after you have been in the vicinity of any areas where you could have been exposed to HCN or NaCN ?
- Have you experienced any feeling of weakness, exhaustion or confusion?
- Have you performed work activities that are not part of your normal activities that may be relevant to cyanide exposure during or after you have been in the vicinity of any areas where you could have been exposed to HCN or NaCN ?
- Have your cigarette smoke exposure, fire smoke exposure or cassava consumption increased in the recent past?

When the urinary SCN^- concentration has been measured action must be taken as stipulated in Table 1.

Tabel 1. the action that must be taken if the urinary SCN- concentrations of workers are above certain levels.

Urinary SCN^- concentration (mg/L)	**Action taken**
0-1.35 (non-smoker) 0- 5.56 (smoker)	• No action taken. • Worker remains in routine biological monitoring program.
1.35-2.7 (non-smoker) 5.56- 11.3 (smoker)	• Above action level and below reference concentration. • The personal airborne $HCN_{(g)}$ must be determined in the working area to determine if the airborne $HCN_{(g)}$ concentration is above the OEL. • The worker must undergo biological monitoring again after a week to determine if the urinary SCN^- concentration has decreased to below the action level. • If it has not and the personal airborne $HCN_{(g)}$ exposure is below the OEL, the personal working habits of the worker must be investigated to determine the cause of the excessive exposure. The worker must undergo biological monitoring testing again after a week.
> 2.7 (non-smoker) > 11.3 (smoker)	• The worker must be removed from his/her work area immediately. • After a week the urinary SCN^- concentration must be measured again. The concentration must be measured weekly until the concentration is below the action level. • If the concentration has decreased to below the action level the worker may return to his/her normal work area.

2.10 Responsibilities of management

Management must decide if the biological monitoring will be done on the mine site itself, or sent to the pathology laboratory. They must also ensure that the analyses procedures are followed and carried out by qualified personnel. Personnel must be

made familiar with procedures and equipment. Management must agree on the fundamental strategy that will be followed in the monitoring program.

2.11 Responsibilities of the employees

Employees must give their assistance in the execution of the measurements. The knowledge provided by the employees in regard to the work conditions, work environment and specific jobs, can be invaluable in decisions regarding the employees that should be monitored and any changes that should be made in the monitoring program.

3 Access to results by employees

The employee must have access to his or her personal monitoring results. A personal consultation with the Mine clinic physician must be set up when the results are available, so that the employee may be informed of the results. Results must be reported in an understandable uniform format. A summary of the results of the monitoring program should be presented during the meetings between management and employees.

4 Program evaluation

The components of the program must undergo a thorough evaluation every year to ensure the effectiveness of the program and determine if the program is really working. These evaluations must be conducted periodically to assess compliance with legislative regulations. These may form part of the effort to comply with the International Cyanide Management Code.

4.1 Responsibilities of management

Sufficient resources must be made available by management to ensure a comprehensive evaluation of the program. Management must also ensure that the evaluation is adequately planned and conducted. They must be committed to act upon the findings of the evaluation and be willing to acknowledge and solve problems. This may require the commitment of financial resources and personnel. Disciplinary action must be implemented in cases of non-compliance with the program. The comments of the exposed employees must be taken into account when the program is evaluated.

4.2 Responsibilities of the employees

Employees must communicate with management and act as a means of feedback in the evaluation. They must make their requirements known to management and draw attention to any changes in the workplace that may influence their exposure and so their health.

5 Record keeping

Records of the biological monitoring/medical surveillance should be kept for a period of 30 years.

5.1 Responsibilities of management

Management must provide suitable facilities for the storage of the records and provide the resources necessary for quick and accurate processing. The records must only be accessible to the affected employees, the program implementers and government inspectors. The records must be standardized, integrated and adequately maintained.

5.2 Responsibilities of employees

Employees may check their health status and must provide feedback about the biological monitoring program. Employees should verify the accuracy of their medical history, history of exposure to chemicals and past and current personal and work-related information.

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Annexure

Barrick North Mara Mill/Plant Questionnaire - Lifestyle factors that may influence concentration of cyanide in the body

Name and Surname.....

Work area/ job description.....

HEG number.....

Amount of time worked at mill/plant.....

1. Sex of subject

Male ☐ Female ☐

2. Nationality

Tanzanian ☐ Expatriate ☐

3. Do you smoke?

Yes ☐ No ☐

4. What do you smoke?

Store bought cigarettes ☐ Home made cigarettes ☐

5. How many cigarettes a day do you smoke?

....

6. Do you eat cassava?

Yes ☐ No ☐

7. Do you eat it raw or cooked?

Raw ☐ Cooked ☐

8. Are you regularly exposed to fire smoke?

Yes ☐ No ☐