ASSESSMENT OF NOISE LEVELS IN WORK AREAS AT THE POLOKWANE PLATINUM SMELTER, SOUTH AFRICA

by

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RESEARCH DISSERTATION

Submitted in fulfilment of the requirements for the degree of

MASTERS OF SCIENCE

in

Physiology

in the

FACULTY OF SCIENCE & AGRICUTURE

(School of Molecular & Life Science)

at the

University of Limpopo, Turfloop Campus (Sovenga)

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2015

DECLARATION

I declare that the "***Assessment of noise levels at work areas of the Polokwane Platinum Smelter, South Africa"*** dissertation, hereby submitted to the University of Limpopo for the degree of Master of Science has not been previously submitted by me for a degree at any other university. That it is my own work in design and execution, and that all material contained therein has been duly acknowledged.

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T.C. Mdaka (Mr) Date: 28 July 2014

DEDICATION

I dedicate this study to my family, friends and everyone who supported and encouraged me.

ACKNOWLEDGEMENTS

The support and assistance given in this study was tremendous due to such factors as patience, love and dedication of time, resources and selflessness of many people whom I would like to acknowledge thus:

- Dr van Staden and Prof. Mulder, for their professional leadership and mentorship, academic input and technical guidance and the interest they had shown;

- My parents, Mr and Mrs. J. Mdaka, who made sure that I attend school up to the level where I am today, with their parental guidance;

- My brothers, sisters, family and friends, for their support and motivation;

- Members of the Student Christian Organization (SCO) at the University of the Limpopo, for support and prayers;

- SKC Safety Health and Environment South Africa (Pty) Ltd for the financial and technical assistance;

- Linde Karlien, for the technical assistance;

- Sincere thanks to staff at the Polokwane Platinum Smelter, for their expertise, advice and support on all operations and the measurements of all the occupational hazards;

- University of Limpopo, for the financial assistance and all the necessary academic support; and

- The staff of the Department of Physiology, for guidance and administrative support.

FOREWORD

This mini-dissertation is meant to assist the Polokwane Platinum Smelter to decide on the Occupational Health and Safety aspects of all workers.

SUMMARY

Objective

This study assesses whether noise levels above legal limits of 85 dB(A) that can result in noise-induced hearing loss are present in areas where employees are supposed to work and to verify that such areas are demarcated as noise zones at the Polokwane Platinum Smelter.

Background and motivation

Excessive noise is a global health hazard with considerable social and physiological impact, including the development of noise-induced hearing loss (NIHL). Noise is a major hazard in many workplaces. It is estimated that more than 30 million workers (almost 1 in 10) are exposed to unsafe noise in their work places. NIHL is the second most self-reported occupational illness or injury in the United States. Amongst miners, more than 90% of the population reports hearing problems by the age of 55 years. Noise exposure is prevalent in construction, foundries, agriculture, transport, industry and mining-related activities. The prevalence of NIHL has not changed much in the past two decades. Therefore, a hearing conservation programme is an important issue in the smelter as certain areas are denoted as noise areas.

Study design

A cross-sectional study design with a group of utility workers at the Polokwane Platinum Smelter, as the experimental group, and a group of undergraduate Bachelor of Science students at the University of Limpopo (Turfloop Campus) served as a control group.

Method

A sound level meter was used to measure the noise levels where the utility group performs their technical work. Data were analysed using the Statistical Package for the Social Sciences (SPSS) computer program.

Results

The average noise measured in various locations of the Polokwane Platinum Smelter was between 62.6 dB(A) and 105.1 dB(A). The results indicated that workers at the Polokwane Platinum Smelter are over exposed to noise in certain work areas if they work eight hours in the area. Areas where the average noise level was above noise rating limit of 85 dB(A) were demarcated as noise zones as an additional protective measure. Employees also use hearing protective devices, when they are working in noise zones, to control personal noise exposure. This is in accordance with the Occupational Health and Safety Act No. 85 of 1993 as amended eleventh edition (OHS Act 85/93).

Conclusion

In the present study, noise levels in certain areas exceeded the noise rating limit of 85 dB(A). However such areas are clearly demarcated as noise areas and employees accessing those area must wear earmuffs or earplugs. Possibilities of employees developing hearing loss overtime exist, if employees work for eight hours or longer in demarcated areas and do not adhere to the existing Hearing Conservation Program (HCP) implemented at the Polokwane Platinum Smelter. Noise levels at the Polokwane Platinum Smelter should be monitored regularly.

TABLE OF CONTENTS

List of Figures

List of Tables

List of Appendices

List of Abbreviations/Acronyms

AIDS	: Acquired Immune Deficiency Syndrome
ACOEM	: American College of Occupational and Environmental Medicine
COIDA	: Compensation for Occupational Injuries and Diseases Act
CNS	: Central Nervous System
dB	: Decibels
dB(A)	: A-weighted scale used to asses noise exposure as per the human ear. A-frequency-weighting is mandated to be used for the protection of workers against noise-induced hearing loss
HCP	**:** Hearing Conservation Program
HPD	: Hearing Protective Devices
HPDs	: Personal Hearing Protective Devices
HPE	: Hearing Protective Equipment
HIV	: Human immunodeficiency virus
HL	: Hearing Loss
HTL	: Hearing Threshold Level
NIDCD	: National Institute on Deafness and Communication Disorders
NIHL	: Noise-induced hearing loss
NIOSH	: National Institute for Occupational Safety and Health
OHC	: Outer Hair Cells
ONS	: Occupational Noise Survey
OHS Act (85/93)	: Occupational Health and Safety Act, N0. 85 of 1993
OSHA	: Occupational Health and Safety Association
PEL	: Permissive Exposure Level
PLH	: Percentage Loss of Hearing
PPE	: Personal Protective Equipment
PTS	: Permanent Threshold shift
SANS	: South African National Standard
SASCOM	: South African Society of Occupational Medicine
SPSS	: Statistical Package for the Social Sciences
TB	: Tuberculosis
TTS	: Temporal Threshold Shift

CHAPTER 1
INTRODUCTION

1.1 Introduction

Noise is one of the major threats to industrial workers. Since the period of industrialization began, workers have been suffering from different occupational diseases such as occupational hearing loss (Meyer-Bisch, 2005). Before the mid-1960's, there were no laws mandating the use of devices to protect hearing, and many people working before the mid-1960's have been exposed to dangerously high levels of noise (Danielle et al., 2002). Occupational safety and health issues are great concerns to developing countries aiming at industrialization (Daniel, 2005; Nuwayhid, 2004; and Christiani, & Durvasula 1990). Noise and hearing loss problems have been well documented in many developing countries, including India, Thailand, and Singapore (Nuwayhid, 2004; and Öhrström & Björkman, 1998). Studies conducted in these countries have revealed that workers are often exposed to dangerous levels of noise (Nuwayhid, 2004). Occupational noise is also prevalent in developed countries. Twenty-five percent of the work force in the United States is regularly exposed to potentially damaging noise (Suter, 2002). Furthermore, hearing loss affects the ability of one in ten Americans to understand normal speech (Higgins et al., 2005; and Christiani & Durvasula 1990). Thus, NIHL is a real problem in both developing and developed countries.

In the field of occupational health, noise-induced hearing loss (NIHL) can be defined as a permanent hearing impairment resulting from prolonged exposure to high levels of noise or as a condition caused by occupational and environmental factors that damage the structures involved in hearing (Daniel, 2005; Prince, *et al.,* 2004; Prince, *et al.,* 2003; Joshi, *et al*., 2003; and Allen, 2001). Hearing loss has many consequences, including poor communication and deafness (NIDCD, 2010; Clark & Bohne, 1999; and Steffen & Jaggy, 1998). Because of the risk of occupational noise-induced hearing loss, government standards regulating allowable noise exposure in occupational situations have been developed. These standards aim to control excessive noise exposure (NIOSH, 1998). However, in many cases, such occupational laws are neglected (McCall & Horwit, 2004).

Hearing Loss can also result from non-occupational activities such as leisure, and entertainment activities (Clark & Bohne, 1999). Typically, this occurs in individuals who are exposed to gunfire or firecrackers, and hear ringing in their ears after the event (this is known as tinnitus) (Dias et al., 2006; and Cunningham & Eavey, 1993). A hypothetical relationship between smoking and hearing loss has been proposed because nicotine reduces blood supply to the cochlear organs (Graham et al., 2010; Boggia et al., 2008; Namura, 2006; Friedman & Griffith, 2003; and Furuta et al., 2000).

There are also other causes of hearing loss. According to Petit *et al*., (2001) hundreds of genetic diseases cause hearing loss and this is called familial sensorineural hearing loss (Steel & Kros, 2001). A brain tumour can also result in hearing loss (Camp *et al.,* 2003). According to Evans and Lepore (1993), a decline in hearing ability with advancing age and is called prebycusis (Martini, 2006; and Gates & Mills, 2005). Males are exhibiting a higher Hearing Threshold Level (HTL) at the higher frequencies, and are susceptibility to the effect of occupational noise (Landon *et al*., 2005). The term socioascusis has been applied to an increase in HTL resulting from exposure to non-occupational noise (Martini, 2006). It is clear that hearing loss does not only result from noise exposure, but from many other non-occupational factors.

The aetiology of NIHL is simple: prolonged exposure to excessive noise results in a permanent hearing disability (Heggins, 1998). The hearing loss usually develops over a period of several years (Chung *et al*., 2005). Since it is painless and gradual, it is often not noticed (Min-Yong, 2003). Many people are not aware of the dangers associated with loud noise; therefore they do not seek protection against it (Camp *et al*., 2003). Excessive noise exposure is the most common cause of hearing loss (Camp *et al.,* 2003). According to Chung *et al.,* (2005), habitual exposure to noise above 85 dB(A) causes a gradual hearing loss in a significant number of individuals. Exposure to noise above 85 dB(A) damages hair cells in the inner ear (Petit *et al.*, 2001; and Alford *et al.*, 2000). As noise exposure increases, more and more hair cells are destroyed (Wu *et al*., 2004; and Pye *et al.,* 1984). As the number of hair cells decreases, the hearing ability also decreases. There is no way to restore life to dead hair cells; therefore the damage is permanent (Davidovits, 2008). Noise can also cause reversible hearing loss, called a temporary threshold shift (Allen, 2001; and Kraener, *et al*., 1995). Tinnitus can develop as a result of long-term exposure to noise that has damaged hearing (Martines *et al.,* 2010; and Kaltenbach, 2006). However, the diagnosis is not always straightforward, especially when more than-one-pathology is present (Min-Yong, 2003).

Besides hearing loss, loud noise may also lead to systemic symptoms (Prince et al., 2003). These include anxiety and irritability; an increase in pulse rate and blood pressure; and an increase in the secretion of stomach acid (Ahmed & Dennis, 2001). Very loud noise can reduce efficiency of performing difficult tasks by diverting attention from the task (Reid et al., 2004; and Ahmed & Dennis, 2001). Individuals differ in their sensitivity to noise (Clark & Bonhe, 1999). Thus noise does not only affect the hearing of workers, but also their health in general and their ability to perform tasks.

Noise levels in the workplace should be below the noise rating limit of 85 dB(A) as stated in the Occupational Health and Safety Act No. 85 of 1993 as amended eleventh edition (OHS Act 85/93). The OHS Act (85/93) (NIHL regulations) regulates noise exposure levels in South African industries. Statutory occupational noise exposure limits vary from country to country. The variation levels are from 85dB(A) to 90dB(A), however, acceptable levels in South Africa as per OHS Act (85/93) is an 8 hour time weighted average of 85 dB(A) as legislated in Noise Induce Hearing Loss Regulations (2003) (SIMRAC, 2001; OHS Act 85,1993).

Habitual noise exposure above 85 dB(A) causes a gradual HL in a significant number of individuals, and louder noises accelerates this damage. In addition, the duration (how long an employee is exposed to a noise) can affect the extent of noise-induced hearing loss. The longer you are exposed to a loud noise, the more damaging it may be. For unprotected ears, the allowed exposure time decreases by one half for each 5 dB(A) increase in the average noise level. The alternative of 3 dB(A) is used in other countries than the USA. For instance, exposure is limited to 8 hours per day at 85 dB(A), 4 hours per day at 90 dB(A), and 2 hours per day at 95 dB(A) (Camp *et al.,* 2003). The highest permissible noise exposure for the unprotected ear is 115 dB(A) for 15 minutes per day. Any noise above 140 dB(A) is not permitted (Goyal *et al.,* 2010; Dicke, 2005; and Camp *et al.,* 2003).

It is obvious that noisy machinery at workplaces should be engineered to be quieter or the worker's time in the noisy environment should be reduced. As an alternative, individual hearing protectors can be used when noise averages more than 85 dB(A) during an 8hour day (Opperman *et al*., 2006; Chung *et al*., 2005; and Camp *et al.,* 2003). In South Africa, medical surveillance has to take place annually according to the (OHS Act 85/93). This includes routine audiometric tests and medical examinations. The cost associated with these actions is often prohibitive (Melnick, 2004; and Katz, 1994). When noise measurements indicate that hearing protectors are needed, the employer must offer at least one type of earplug and one type of earmuff without cost to employees (OHS Act 85/93). If annual hearing tests indicate hearing loss of Percentage Loss of Hearing (PLH) shift of 10% or more in higher pitches in either ear, the worker must be informed to undergo numeral medical tests in order to determine if there is permanent hearing loss. The worker must wear hearing protectors when noise averages more than 85 dB(A) for an 8 hour day or be moved to an non noisy area (Daniel, 2007; and OHS Act 85/93). It is the employer's obligation to protect workers against factors that may be harmful to their health (OHS Act 85/93).

Occupational hearing loss is commonly caused by work-related hearing disabilities amongst workers in mining, construction, manufacturing, agriculture, foundries and other similar industries (Neitzel & Seixas, 2005; and Bies & Hansen, 2009). According to the research conducted by Landon and colleagues in 2001, during the past years there have been an indication of an increase in the prevalence of NIHL among foundry and similar industries. This is at least partly due to the effect of an increase in noisy machines industries (Rabinowitz, 2000). It affects millions of workers and inflicts high costs to society (Landon *et al*., 2005; and Rabinowitz, 2000). NIHL in at the Polokwane Platinum Smelter have not been studied since the inception of the Smelter as often as other industries (Goncalves & Iguti, 2006; and

Landon *et al*., 2005; McReynolds, 2005; Seixas, 2004; Beckett *et al*., 2000; and Shakhatrek *et al*., 2000). The study is one of the few studies in South African Smelters. Therefore, research is necessary in the area of occupational hearing loss especially in Smelters.

It is important for the Polokwane Platinum Smelter to comply with safety measures as stipulated in the (OHS Act 85/93) and noise regulation within the Act. The monitoring of noise at regular intervals may assist in ensuring that occupational noise does not affect employees.

The aim of this study was to assess noise levels in various work areas at the smelter and further verify whether areas with high noise levels are demarcated as noise zone areas at Polokwane Platinum Smelter, Limpopo Province, South Africa.

1.2 Research Questions of the Study

- What are the noise levels in the work areas of a group of utility workers at the Polokwane Platinum Smelter?
- Do the noise exposure levels in these areas at the Polokwane Platinum Smelter comply with the 85dB(A) noise rating limit according to the Occupational Health and Safety Act No. 85 of 1993?
- Are the present control measures at the Polokwane Platinum Smelter for control and prevention of noise hazards sufficient?
- Are any changes in measures for the control and prevention of noise hazards, at the Polokwane Platinum Smelter, needed?

1.3 Limitations of the Study

The following are limitations of the study:

- Selection of the a experimental group was not done randomly but was limited to one specific group of utility workers and it influences the study group size;
- The control group was chosen as a random but convenient group from students at the University of Limpopo;

- Study was limited to this one Smelter and to utility workers at the Polokwane Platinum Smelter;
- The study was not intended to be a full occupational report to the Polokwane Platinum Smelter, but simply investigates those aspects listed under the questions of the study;
- The study is limited to occupational noise levels, it does not include leisure time noise exposure or hearing loss due to other causes as it was not feasible and extremely difficult to monitor employees outside working environment; and
- The researcher was not able to access the medical records of the employees due to confidentiality; hence medical history was not discussed in the results. This includes the results of audiograms for the experimental group.

1.4 Conclusion

The Polokwane Platinum Smelter is still in its early stages of operation and is using advanced technology. Therefore, the level of noise experienced by the workers is less in certain areas (Plant Cooling and Ventilation Fans, Casting Platform and Larox Filter Press) within the Polokwane Smelter. The study concluded based on the results that not all areas workers experienced high noise levels. The study, further observed that Smelting operations are inherently noisy due to the large amount of mechanical equipment, physical activities, and energy usage, notably furnaces, Flash Dryer and Storage Silo were noise levels exceeded legislated noise exposure limit of 85dB(A).

The aim of this study was to assess noise levels in certain areas at the Polokwane Platinum Smelter, Limpopo Province, South Africa and verify if these areas with excessive noise levels comply with legislative requirements (i.e., zoning of noise areas, putting relevant signage and implementing a hearing conservation program).

The objectives of the study were to:

1. determine which areas where the experimental group are supposed to work have noise levels above legal limits that can result in hearing loss;

2. determine if all such areas with high noise levels are demarcated as noise zones;
3. determine if such areas has relevant signage as required by legislations and access is controlled; and
4. verify if any of the experimental subjects are suffering from noise-induced hearing loss.

1.5 Content and Planning

In Chapter Two, the literature pertaining to the anatomy and physiology of the ear, the effects of noise (both auditory and non-auditory), and NIHL and its effects on workers in the mining industry are discussed in detail. The methodology used to capture, analyse and present the data is described in Chapter Three. Chapter Four encompasses the results of the research. The results are discussed in the light of previous literature findings and the research questions are answered. Conclusions regarding the aims and objectives of the study are made in Chapter Five. Limitations of the project are discussed and further possible avenues of research are suggested.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

Noise is an intense sound capable damaging the inner ear (Rosen *et al*., 2001). Noise-induced hearing loss (NIHL) is permanent hearing damage, caused by noise, to the outer hair cells of the cochlea, resulting in a decrease of the amplification ability of the cochlea (Ou *et al.,* 2000; and Reshef *et al.*, 1993). The development of NIHL depends on the characteristics of noise, that is, its temporal patterns, spectral distribution, overall sound level and the duration of the noise exposure (Katz, 1994). Loud noise may cause tinnitus (ringing in the ear). This commonly occurs after noise exposure, and often becomes permanent (Ludman & Wright, 1998). Exposure to continuous noise is more damaging than to intermitted noise, with sound levels exceeding 75-85 dB(A) beginning to stress the auditory system (Chen & Henderson, 2009; Björk, 2002; and Kvaerner *et al.,* 1995).

Individuals who are exposed to noise while working can be affected in a variety of ways. Annoyance, decreased productivity, psychological distress and physiological changes are only a few of the effects that have been reported (Lepage, 1998; and Katz, 1994). A more direct and permanent consequence is the development NIHL (Casali *et al.,* 2000). NIHL occurs slowly over time, and the full effects thereof are generally only realized after 10 to 15 years of chronic exposure to excessive noise (Rosen *et al.,* 2001).

An estimated 60-80% of mineworkers are exposed to 85 dB(A) or more noise during their work shift (a shift is averaged at eight hours per day) (McBride, 2004; and Hermanus, 2007). Agriculture, construction, engineering, woodworking, and foundry workers are therefore significantly at risk for developing NIHL (Neitzel & Seixas, 2005; and Rowlinson, 2004). In South Africa, more than R448 million in settlement was paid to over 43 000 employees within the mining industry between 1998 and 2003 (Giuld *et al.*, 2001). Direct costs include compensation costs, costs associated with interruption of production. Indirect costs include the costs of livelihoods lost, income to dependents, and the cost associated with caregiving by families and the community (Rikhardsson, 2004). Poor communities tend to bear the brunt of externalized indirect costs, but mining companies can also suffer loss of reputation and withdrawal of investment capital (Hermanus, 2007; and Rikhardsson, 2004). These amounts exclude the amount equated to loss of skills and rehabilitating injured employees (Rikhardsson, 2004).

The potential of NIHL to disrupt ordinary lives justifies the research and other efforts that have been made in the last 20 years to try to understand it, with the ultimate goal of protecting the workers from getting this disease. It is appropriate therefore to look briefly at the sequence of events at cellular level that can lead to the development of NIHL (Martini, 2006).

There is no treatment, no medicine, and no surgery, not even a hearing aid that corrects hearing once it is damaged by noise (Fowler & Leigh-Paffenoth, 2007; Lynch & Kil, 2005; and Katz, 1994). Therefore, it is important to take precautionary measures to avoid hearing loss within the society in general, but also in occupational settings.

Although NIHL is often caused by occupational noise, researchers (Lynch & Kil, 2005; Murray-Johnson *et al.,* 2004; Bluestone & Klein, 2001; and Horne *et al.,* 1994) agreed that non-occupational noise is regularly encountered during recreational activities and is also a source of premature hearing reduction.

This chapter gives an overview of the, properties of sound, physiological and anatomy of the ear, hearing loss/deafness, sources of noise, effects of noise, both auditory and non-auditory, hearing loss, consequences, prevalence of NIHL, legislation and Hearing Conservation Programs.

2.2 Sound

2.2.1 The Physical Principles of Sound

- *Introduction*

Sound is the form of energy which is detected by the ear (Martini, 2006). In physical terms, it is the mechanical vibration of an elastic medium, causing the transmission of energy away from the source by a series of successive changes in pressure, known as sound waves (Martini, 2006; and Michael & Byrne, 2000). Sound is propagated through materials by the longitudinal oscillation of individual molecules and interaction with adjacent molecules; therefore, it cannot pass through a vacuum (Gardiner, 1996). The characteristics of a particular sound depend on the rate at which the sound source vibrates the amplitude of the vibration and the properties of the conducting medium (Michael & Byrne, 2000). Air, the medium through which sound generally reaches the ear, has both mass and elasticity; and the transmission of sound can be described in terms of momentum and the recovery of elastic forces (Martini, 2006).

Sound may be described in terms of three variables: amplitude (perceived as loudness), frequency (perceived as pitch) and time pattern (Botteldooren *et al*., 2006). Physical properties of sound include wavelength, frequency, loudness, speed of sound, sound power, and intensity of sound and will be discuss below.

- *Wavelength*

A single compression, which is transferred in the medium, is known as a wave, and the distance between two consecutive wave fronts is known as a wavelength. Wavelength is indicated by the symbol 'λ' (Martini, 2006).

- *Frequency*

The rate at which a sound source vibrates, or makes the air vibrate, determines the frequency of the sound (Rabinowitz, 2000). Thus the frequency of sound can be defined as the number of pressure changes moving past a definite point per second (Martini, 2006). Frequency is indicated by the symbol 'f' and measured in Hertz (Hz) (Martini, 2006; Michael & Byrne, 2000; and Rabinowitz, 2000). The unit of time is usually one second (Rabinowitz, 2000).

Humans can identify sounds with frequencies from about 16Hz to 20,000 Hz (Novitski *et al.,* 2007; and Rabinowitz, 2000). Sound with a long wavelength has a low frequency whilst sound with a short wavelength has a high frequency (Martini, 2006). The simplest form of sound, known as a pure tone, consists of waves having the same frequency (Botteldooren *et al*., 2006). Pure tones are relatively rare in real-life situations. Most sounds, including industrial noise, consist of a complex mixture of many frequencies, and are generally known as broad-spectrum noise (Botteldooren *et al*., 2006; and Martini, 2006).

- *Loudness*

The frequency response of the ear is most sensitive to sounds in the 1-5 kHz frequency range and particularly insensitive at low frequencies (Martini, 2006; Botteldooren *et al*., 2006; and Gardiner, 1996). Loudness is the subjective assessment of sound quantity and has a complex relationship with the sound pressure level actually presented to the ear. Loudness level depends on both frequency and sound pressure level (Gardiner, 1996).

- *The speed of sound*

The tempo at which pressure transfer takes place determines the speed of sound (Martini, 2006). The speed of sound is indicated by the symbol c (Michael & Byrne, 2000; and Martini, 2006). It is dependent on the density and elasticity of the medium and on the temperature (Michael & Byrne, 2000). In a homogeneous, medium sound of all frequencies is transmitted at the same speed (Martini, 2006; and Michael & Byrne, 2000).

- *Sound power*

Any source of sound has a characteristic sound power, which is determined by the rate at which sound energy leaves its source (Martini, 2006; Michael & Byrne, 2000; and Gardiner, 1996). It is measured in watts (W) (Botteldooren *et al*., 2006). A source of sound approximating a point will produce a spherical sound field, so that the sound power is dissipated over an ever-increasing area (Botteldooren *et al*., 2006; and Gardiner, 1996). The sound pressure level that reaches the ear depends on many external factors, such as the temperature of the medium, the distance from the source and obstructions in the transmitting path of the sound wave (Martini, 2006; Michael & Byrne, 2000; and Gardiner, 1996). Sound power is merely a physical characteristic of the source of sound and is often used to compare sources of sound with one another (Martini, 2006).

Measured sound pressure is a result of the amount of sound power generated by a source (Michael & Byrne, 2000). There is a cause-and-effect relationship between sound power and sound pressure: Sound power is the cause of a noise, and sound pressure is the resulting effect (Martini, 2006; and Michael & Byrne, 2000). Sound pressure levels can be predicted from known sound power levels, depending on the environment in which the sound source is located, the exact distance from the source and other variables (Michael & Byrne, 2000).

- *The intensity of sound*

The average tempo, at which energy is transmitted per surface unit over an area at right angles to the direction of transmittance, is known as the intensity of the wave (Martini, 2006). The intensity of a sound wave is related to the size of the pressure change that takes place in the medium (Michael & Byrne, 2000). This deviation is known as amplitude (a) and it is measured in watts per square meter (w/m^2) (Michael & Byrne, 2000).

2.2.2 Types of Sound Sources

Sound is caused by various noise sources (Miglani, 2010). The three types of sound sources are the point source, plane source and line source (Martini, 2006). The point source is the simplest source of sound (Michael & Byrne, 2000), and is regarded as a pulsating sphere producing a series of consecutive wave fronts, which are steadily transmitted from the centre in all directions (Russell, 2009). Examples of point sources include individual machines, steam leaks and hammer blows (Miglani, 2010).

2.2.3 Types of Sound

Sound can be divided into a number of types depending on how it varies over time in terms of continuity, fluctuation, impulsiveness and intermittency. These are, namely, continuous sound, fluctuating sound, interrupted noise and impulse sound (Martini, 2006). Intermittent sound, such as hammering, is more harmful than continuous sound and a single very loud noise (e.g., a shot or an explosion) can damage the hair cells in the cochlea immediately (Harding, *et al.*, 2005; and Kroemer &

Grandjean, 2000). Continuous and intermitted sound is the most common causes of hearing loss in the construction, foundry and similar industries (Pourbakht & Yamasoba, 2003).

- *Continuous sound*

Continuous sound is produced for relatively long periods at a constant level (Martini, 2006; and Prasher, 1998). Examples of continuous sound include the noise of a waterfall, turbines, fans, and electronic motors (Martini, 2006).

- *Fluctuating sound*

Fluctuating sound refers to sound whose intensity varies considerably over a given period of time (Martini, 2006; and Rahman, 2006), such as a machine that runs continually, but whose engine runs at different speeds depending on the load it has to carry (Botteldooren *et al*., 2006). There is no evidence in the literature that fluctuating sound contributes to the development of NIHL (Rabinowitz, 2000).

- *Interrupted or intermittent sound*

Interrupted or intermittent sound is noise which is interrupted at intervals, producing great variations in sound intensity from a given background noise (Russell, 2009; Martini, 2006). Examples of interrupted sound are the switching on and off of equipment, such as hand-drills and grinding-wheels (Martini, 2006).

- **Impulse sound**

Impulse sound is momentary noise with a duration of less than 0, 5 seconds (Martini, 2006; and Starck *et al*., 2003). Impulse noise may be repetitive, or a single event (as with a sonic boom) (Balough & Jackson, 2010; Martini, 2006; and Zhao *et al*., 2006). Such an impulse may be heard under normally quiet conditions or it may be superimposed on a background of continuous or fluctuating noise (Martini, 2006; and Starck *et al*., 2003). Examples of impulse sounds are a pistol shot and the hammer blows in the workshop of a boilermaker (Martini, 2006). If the impulses occur in very rapid succession, such as jackhammers, drills, the sound would not be described as impulsive (Fletcher *et al.,* 2002; and Starck *et al*., 2003).

Impulse sound may damage the structures of the inner ear severely (Kardous & Willson, 2004). The effect from impulse sound can be instantaneous and can result in immediate hearing loss that may be permanent (Hong, 2005; and Kardous *et al*., 2005).

The total noise level existing in any location is made up of noise from many different sources. For example, in a Smelter there will be a certain sound level when the plant is turned on. This is known as the background noise. When measuring sound in industrial settings, background noise has to be taken into account including selection of the equipment for measuring noise as it can influence the results (Gardiner, 1996).

2.2.4 Noise

The terms noise and sound are often used interchangeably. However, sound is normally used to describe useful communication or pleasant audible signals such as music, individual discussion (Martini, 2006; Rosen *et al*., 2001; Michael & Byrne, 2000). It is any pressure variation that the human ear can detect and can also be defined as a stimulus that produces a sensory (auditory) response in the human brain (Weiten, 1992).

Noise is defined as sound that bears no information, whose intensity varies randomly in time and it is also regarded as unwanted, undesirable or annoying sound, capable of producing damage to the inner ear and cause hearing loss. Excessive noise or loud noise may cause hearing loss (Michael & Byrne, 2000). For the purpose of this study the above definitions for sound, music and noise will be used.

2.2.5 The Transmission of Sound

Apart from the decrease in the intensity of noise with distance, other factors also influence the transmission of sound. These factors include noise fields, absorption, and diffraction (Martini, 2006; and Gardiner, 1996).

In an enclosed noise field where many hard, reflecting surfaces are found, two noise fields are distinguished, namely the near field and the far field (Martini, 2006). The near field is characterised by temperamental changes in the noise levels with changes of position and is generally avoided in noise measurements (Earshen, 2000; Morse, 1981). The far field is divided into the free field and the reverberant field (Russell, 2009; Martini, 2006). The free field travels from source to listener by the shortest route without encountering any room surface (Gardiner, 1996). Thus in the free field, noise is transmitted as if in the open air with no reflecting surfaces interfering with its transmission, and the intensity of the sound decreases at a tempo which is characteristic of the properties of the source (Miglani, 2010; and Martini, 2006). The size of the free field depends on the acoustic power of the source, the distance between the source and the listener and the position of the source in the space (Gardiner, 1996).

The reverberant field reaches the listener after at least one reflection from a room surface (Gardiner, 1996). The reverberant field is often dominated by reflections so that the intensity of sound is greater than in the free field (Martini, 2006). The size of the reverberant field depends on the amount of sound reflected at each reflecting surface and the number of reflections that each individual sound wave undergoes before reaching the listener (Gardiner, 1996).

When a sound wave meets a surface, a part of its energy is lost (Martini, 2006). This phenomenon is known as absorption. The absorptive power of a surface depends on many variables including its porosity, flexibility and roughness (Martini, 2006; Gardiner, 1996). Some materials are well known for their sound-absorbing qualities and can be used effectively to "soften" any "hard" surfaces in the environment (Davidovits, 2008; and Martini, 2006). Obstacles are often used to bring about a decrease in the intensity of noise (Martini, 2006). The phenomenon of diffraction, however, plays an important role in the effectiveness of an obstacle. When the wavelength of a sound is longer than the dimensions of the obstacle, the obstacle will have little effect on the transmission of the sound because the sound waves can merely bend around it. Sound waves that have a wavelength shorter than the dimensions of the obstacle will, depending on the acoustic properties of the obstacle be reflected or absorbed thus forming a sound shadow behind the obstacle (Davidovits, 2008; and Martini, 2006). A small opening in the obstacle often results in the obstacle having little effect on altering the sound (Martini, 2006; Berglund &

Nilsson, 1997). The reason for this is that sound with a long wavelength is transmitted through the opening as if the opening formed a new point source (Martini, 2006).

2.2.6 Acoustical environments

According to Berglund & Nilsson (1997), many acoustical environments consist of sounds from more than one source. For these environments, health effects are associated with the total noise exposure, rather than with the noise from a single source (Ahmed *et al.,* 2001). Environmental noise is often temporal in nature, for example an aircraft flying over a certain area or a motorcar driving past an individual (SANS 10117:2008; Bohnker *et al*., 2002). Some disturbances (for example speech interference and sleep disturbance) may more easily be attributed to specific noises (Higgins *et al*., 2005; Miedema, 2004; Horne *et al*., 1994).

There is no consensus on a model for assessing the total annoyance due to a combination of environmental noise sources. This is partly due to a lack of research into the temporal patterns of combined noises (Joshi *et al*., 2003; Ahmed *et al.,* 2001; Suter, 2002; Henderson *et al*., 2001; WHO, 2001; WHO, 1999; and Miedema, 1996). It is important to keep in mind that the effects of noise on the human body are subjective in nature and depends largely on the individual that is affected (Nagamine *et al*., 2002).

Noise affects humans physiologically, psychologically and sociologically (Clark & Bohne, 1999). It can impair hearing, intrude in communication, be disturbing, lead to fatigue, and reduce effectiveness and productivity (Ahmed *et al.,* 2001; Beckett *et al*., 2000; and Clark & Bohne, 1999). Noise also has an effect on person's blood pressure, level of alertness, blood composition (e.g. lipid level), and stress level. Furthermore, noise contains an accident risk because warnings and signals cannot be heard properly. It is for this reason that it is necessary to quantify the noise level in the work environment (Attais *et al.,* 1998).

2.2.7 Measuring of Sound

The most common method of sound measurement is to determine the pressure changes transmitted by the medium as sound waves (Martini, 2006). Sound pressure is the amplitude of a sound wave (Powell *et al*., 2005). The human ear has an extremely wide range of response to sound amplitude (Rabinowitz, 2000). Sharply painful sound is ten million times greater in sound pressure than the least audible sound (Ahmed *et al*., 2001). The unit of sound pressure is the decibel dB(A). The decibel scale is a logarithmic scale (Rabinowitz, 2000). A logarithmic scale is used because the range of sound intensities is so great that it is convenient to compress the scale to encompass all the sounds that need to be measured (Baccus, 2006). Thus decibel is a dimensionless unit that describes the logarithm of the ratio of two power-related quantities (Michael & Byrne, 2000). It is normally defined as ten times the logarithm of the ratio of a measured quantity to a reference quantity (Michael & Byrne, 2000). When measuring sound, different reference values have been arbitrarily established, depending on whether sound power, sound intensity or sound pressure is to be measured (Michael & Byrne, 2000). Instrumentation and measuring parameters for the evaluation of noise exposure are discussed below:

- *The sound level meter*

There are a variety of instruments commercially available to measure sound. They differ in application and appearance (Martini, 2006). A sound level meter is the basic instrument used for measuring noise. It consists of a pressure sensitive microphone, an electronic circuit, and a detector indicator (Martini, 2006; Michael & Byrne, 2000; SANS 656:2008). The sound level meter measures the root mean square (r.m.s.) sound pressure level in dB(A) (Martini, 2006). This is proportionate to the flow of sound energy (Martini, 2006). Several different types of sound level meters are available which have different facilities and levels of accuracy and precision (Gardiner, 1996). The type of sound level meter selected should be suitable and sufficient to enable the assessment that is required (SANS 658: 2008).

Attempts to give the sound level meter a similar frequency response to that of the human ear resulted in the weighting networks A, B, and C (Michael & Byrne, 2000; Gardiner, 1996). These are based on the response of the ear at 40, 70 and 100 phone (Gardiner, 1996). When the A, B and C networks are used the particular weighting network used must always be indicated, therefore the meter readings are quoted as dB(A), dB(B), and dB(C) respectively (Michael & Byrne, 2000; Gardiner 1996). The B weighting network has fallen from general use (Gardiner, 1996). The A-weighting scale is used most often, since it imitates the sound encountered by the ear the best (Martini, 2006; Michael & Byrne, 2000). OHS Act (85/93) and SANS 10083 (2004) specify that the A-weighting scale shall be used to measure sound level in industrial noise measurements. The result of this measurement is then also called the sound level (or noise level) to distinguish it from the direct sound pressure measurement (Martini, 2006). The C and A scales of sound level measurements were specifically developed to appropriately weigh the actual sound level in terms of the equivalent ability to hear sound and probability of the sound to cause damage (NIHL). Additional weighting networks have been added namely: D-weighing scale is for aircraft noise only and the E-weighing scale which is another attempt at a loudness level measurement (SANS 10117: 2008; and Martini, 2006).

Variations in the sound pressure level may in time, result in significant measuring errors due to the slowness of the detector (Martini, 2006). However, sound level meters have three detector-indicator characteristics F, S and I (fast, slow and impulse respectively), which are built into the electric circuit and which can be selected alternatively to influence the action of the detector according to the time-varying characteristic of the sound that is being investigated (Michael & Byrne, 2000; and Martini, 2006). International and national standards usually prescribe the detector to be used in a particular situation, but in general the F-characteristic is used for measuring continuous noise or when the highest value during the period of measuring is important (Martini, 2006; and Michael & Byrne, 2000). The S-characteristic is used to measure fluctuating noise, and the I-characteristic is used for impulse noise (Balough & Jackson 2010; Martini, 2006l and Zhao *et al*., 2006). The OHS Act (85/93) (NIHL regulations: 2003) states that the slow response setting is to be used for industrial noise monitoring purposes in situations where variations in the noise surpass 5 dB (SANS 10083, 2004). The impulse setting is not suitable for industrial noise measurements, because it is not designed to actually measure the true unweighted peak sound level (Michael & Byrne, 2000).

- *The integrating sound level meter*

Measuring exposure to noise sometimes means that the exposure of workers must be determined for the duration of a full workday or eight hours (Martini, 2006). When the noise level remains constant over the period, the exposure can be determined with a basic sound level meter, but when the noise level varies a lot during the measuring period an integrating sound level meter should be used (Martini, 2006). The integrating sound level meter integrates sound energy over a relatively long time and divides the measured values by the period of the measurement to provide a direct reading, known as the equivalent noise level (L_{eq}) (Martini, 2006; and SANS 10103:2008). The equivalent noise level is defined as the continuous noise level, which, over a given time, has the same total energy as the actual fluctuating noise (Martini, 2006). Usually, an A-weighted L_{eq} is used, indicated as L_{aeq} (Martini, 2006; SANS 10083:2004;).

- *Noise dosimetry*

Workers sometimes move around a lot in a plant and are thus exposed to varying noise levels, making it difficult to determine the worker's exposure accurately with the aid of environmental readings (Martini, 2006). In such cases portable personal dosimeters can be used to give a more accurate reflection of the individual's exposure to noise (Miglani, 2010; and Martini, 2006). The noise dosimeter is carried in the worker's pocket with the microphone attached to his lapel for all or part of the shift (Martini, 2006; Michael & Byrne, 2000). The dosimeter then directly measures the exposure, expressed as a percentage of the acceptable exposure (Michael & Byrne, 2000). The use of dosimeters is not appropriate in the demarcation of a work area as a noise zone according to SANS 10083 (2004).

- *Calculations*

If the noise levels of two or more machines have been measured separately, the total noise level when the machines work together cannot be determined by adding up the individual noise levels, because the decibel unit is in logarithmic quantities (Martini, 2006). First the antilogarithm must be found and these antilogarithms are then added up. The antilogarithm of the sum of antilogarithms then represents the total noise level (Martini, 2006; Michael & Byrne, 2000). The level of noise, in proportion to the sound that is being measured, has an influence on the exactness of noise measurements so that certain adjustments are necessary (Martini, 2006; Gardiner 1996).

The noise level being measured must be at least 3 dB(A) higher than the background noise. If the noise level to be measured is 10 dB(A) higher than the background noise, no adjustment is necessary (Michael & Byrne, 2000; Gardiner, 1996). Since the background noise cannot be removed, the true level of the plant noise must be calculated from measurements of the background noise alone (with the plant turned off) and the total level of noise (with the plant turned on) (Gardiner, 1996).

2.3 Physiology and Anatomy of the Ear

2.3.1 External Ear

The external ear consists of the visible auricle (pinna) and the external auditory canal (meatus) (Martini, 2006). The pinna collects sounds in the environment in the form of acoustic energy or sound waves and funnels it down the meatus (Michael & Byrne, 2000; and Gardiner 1996). At the end of the meatus, the acoustic energy hits the eardrum (tympanic membrane), which begins to vibrate (Martini, 2006; Catherine & Gary, 2002). The vibration of the tympanic membrane indicates that the acoustic energy has been transformed into mechanical energy (Guyton & Hall, 2010; and Merchant & Rosowski, 2003).

2.3.2 Middle Ear

The middle ear extends from the backside of the eardrum to the oval window of the cochlea (Merchant & Rosowski, 2003). Three tiny bones are found in the middle ear called the malleus, incus, and stapes (Nakajima *et al*., 2005; and Saunders *et al*., 2000). Together, these three bones are called the ossicles. The malleus is attached to the eardrum (Willi *et al*., 2004). The incus is attached to the malleus and the stapes is attached to the incus (Nakajima *et al*., 2005; and Merchant & Rosowski, 2003). The footplate of the stapes is attached to the oval window of the cochlea (Harding, *et al.*, 2000; Merchant & Rosowski, 2003; and Saunders *et al*., 2001). As the eardrum begins to vibrate, the vibrations are passed through the ossicles to the oval window (Merchant *et al*., 2005; and Merchant & Rosowski, 2003). As the footplate of the stapes moves back and forth, it moves in and out of the oval window (Willi *et al*., 2004). The stapedius muscle attaches to the neck of the stapes (Decraemer & Khanna, 1999). This muscle contracts in response to loud sounds and stiffens the movement of the ossicles (Rajan 2006; Ravicz *et al*., 2004; and Decraemer & Khanna, 1999). This stiffening limits the vibrations of the footplate of the stapes, and therefore, also reduces the amount of fluid motion in the cochlea (Priner *et* al., 2003; Decreamer & Khanna, 1999), protecting the inner ear from loud sounds that can cause damage and result in hearing loss (Nakajima *et al*., 2005; Saunders *et al*., 2000; Kozak & Grundfast, 1999*)*. However, this protective mechanism only occurs for low frequency sounds, whereas the traditional NIHL occurs at high frequency sounds (Merchant *et al*., 2005; Merchant & Rosowski, 2003).

2.3.3 Inner ear

The inner ear consists of the cochlea, which is involved in hearing, and the semi-circular canals, which is involved in maintaining equilibrium (Rosen *et al*., 2001). The cochlea is a 30 to 35 cm long, coiled tube embedded deeply in the temporal bone of the skull (Holley, 2005). It is a fluid filled structure completely encased in hard bone with the exception of the oval window and the round window, which are covered by pliable membranes rather than bone (Catherine & Gary, 2002). As the footplate of the stapes moves in and out of the oval window, the fluid of the cochlea is displaced, and a wave is set into motion (Merchant & Rosowski, 2003; and Decreamer & Khanna, 1999).

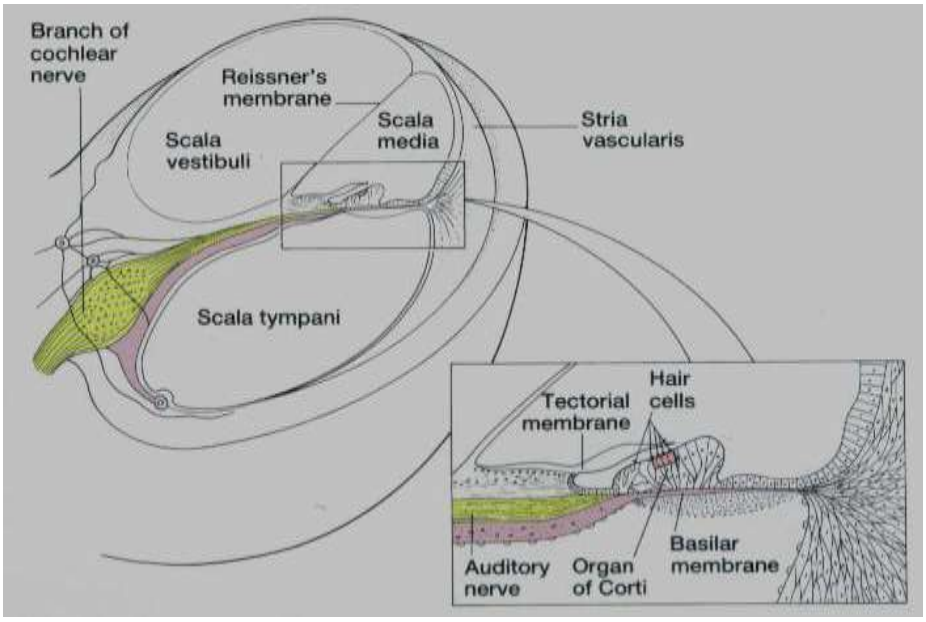

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Figure A: *A schematic representation of the anatomy of the ear. It shows the anatomical relation of the hair cells to other vital tissues that are involved in the hearing mechanism (adapted from Davidovits, 2008).*

The organ of corti is located inside the cochlea (Holley, 2005). It is the hearing organ of the inner ear, and contains three rows of outer hair cells (cilia) and one row of inner hair cells (cilia) (Holley, 2005; and Lynch & Kil, 2005). The cilia are embedded in a collagenous structure called the basilar membrane (Holley, 2005). The tectorial membrane is a gelatinous flap that loosely covers the tips of the cilia (Bluestone & Klein, 2001). When the travelling wave of fluid moves through the cochlea, the motion disrupts the basilar membrane, and causes it to vibrate (Popelar *et al*., 2006). As the basilar membrane moves, the cilia move with it, as they are attached to it. As a result of this up and down movement, the tips of the cilia rub against the tectorial membrane, which is semi-attached to them (Merchant & Rosowski, 2003). As they hit the tectorial membrane, the hair cells bend. As they bend, the cilia release a neurotransmitter substance, which is picked up by sensory nerve cells whose cell bodies are located in the centre of the bony cochlea in the spiral ganglia (Popelar *et al*., 2006). The neurotransmitter causes the nerve cells to send electrical impulses to the brain, where it is interpreted as sound (Merchant & Rosowski, 2003; and Cunningham & Eavey, 1993).

2.3.4 Sound Perception and Interpretation: How Do We Hear?

The primary stimulus for sound perception is a sound wave with an audible frequency and intensity. The frequency spectrum that the ear can perceive is limited and reaches from 20 to 16000Hz in young people (Martini, 2006). The basilar membrane of the human cochlea is relatively narrow and thin at the basal end and increases progressively in width and thickness towards the apex (Holley, 2005). Sound energy is absorbed maximally at the part of the membrane that shares a similar resonant frequency and therefore results in oscillatory motion of the basilar membrane (Merchant & Rosowski, 2003). Hair cells in the inner cochlea detect waves and convert them into nerve signals (Goodhill, 2000).

Therefore the frequency of a sound causes a stimulus at a particular area of the basilar membrane, and the corresponding sensation is known as the pitch of the sound, whilst the intensity of a sound correlates with the loudness of the perceived stimulus (Martini, 2006). Once the sound waves reach the inner ear, they are converted into electrical impulses. The electrical impulses are sent to the brain by the auditory nerve. The brain then translates these electrical impulses into sound (Michael & Byrne, 2000). Thus, the ear is an important organ that transmits sound or makes hearing possible.

The sensitivity of the ear is not constant over the spectrum of audible frequencies, especially at low sound intensity. Rigidity of the eardrum and oval window muffles the lower frequencies, whilst the mass and inertia of the small auditory bones muffle the transmission of high frequencies (Martini, 2006). The threshold of hearing is defined as the energy threshold where sounds having particular frequencies can only be perceived by people with normal hearing (Gardiner, 1996). The threshold of hearing is very frequency-dependent and the ear is at its most sensitive at frequencies between 1000Hz and 4000Hz (Rabinowitz, 2000). The smallest perceptible sound pressure is in the vicinity of about 0.00002 Pa, a value which is generally used as a reference sound pressure in sound level readings (Rahman, 2006). The speech zone, or the frequencies that are important in speech communication, is given as between 500Hz and 2000Hz and largely coincides with the most sensitive area (Martini, 2006).

At a sound pressure of 20Pa (120 dB(A)) a person experiences discomfort, irrespective of the frequency of the sound stimulus (Davidovits, 2008; and Martini, 2006). This level is known as the threshold of discomfort (Rahman, 2006). When the sound level nears 130 dB(A), pain is experienced (Mizoue *et al.,* 2003). The area lying between the threshold of hearing and the threshold of discomfort is known as the auditory area and represents a wide spectrum of sound pressures (Martini, 2006).

Thus, the effects of noise can be divided into two broad categories: auditory effects and non-auditory effects. The auditory effects include all types and mechanisms of hearing loss and the non-auditory effects include all effects besides hearing loss.

2.3.5 The Auditory Effects of Noise

Noise is capable of producing damage to the inner ear and can cause hearing loss or deafness (Ologo *et al*., 2006; Schneider *et al*., 2002; and Rosen *et al*., 2001). The nature and degree of cochlear damage resulting from noise depend on a variety of both intrinsic and extrinsic factors (Graham *et al.,* 2010; and Merchant & Rosowski, 2003). The intrinsic factors include the individual's susceptibility to noise damage and the physiological changes (Ohinata *et al.,* 2003*;* and Rabinowitz, 2000). The extrinsic factors include the intensity level, wavelength, frequency, speed, spectral content and sound power of the noise, the level and duration of exposure, the types of noise and factors such as environmental influences (Davidovits, 2008; Merchant & Rosowski, 2003; Ahmed *et al*., 2001; Eddins *et al.,* 1999; and Griest & Bishop, 1998). As the intensity and period of noise exposure increases, the more the cochlear hair cells are destroyed (Ahmed *et al*., 2001; and Eddins *et al.,* 1999). After a number of years, hearing loss can be detected audiometrically. Initially, hearing loss occurs in the high frequency rage (Clark & Bohne, 1999).

Hearing damage resulting from excessive noise exposure may be gradual, cumulative and without obvious warning signs, and it may result in permanent hearing loss (Cruickshanks *et al.,* 2010; and Kozak & Grundfast, 1999). The first symptom of NIHL is difficulty in hearing conversation in a noisy environment. The nature of NIHL leads to the initial loss of consonant discrimination (Nash, 2000; and Clark & Bohne, 1999). Maximum hearing losses occur after 10 years of chronic or continuous exposure to noise levels above 75 dB(A) (Min-Yong, 2003). Permanent hearing loss may begin after one or two years of exposure to noise. In susceptible individuals, it may even develop earlier (Prince *et al*., 2003).

Other symptoms of hearing damage include: (Min-Yong, 2003; Prince, 2003; Prince, 2002; Prince *et al*., 2003; and Hetu & Getty, 1993) include the following:

- ringing or buzzing in the ears;
- slight muffling of sounds;
- difficulty in understanding speech in noisy places or places with poor acoustics; and
- difficulty in understanding speech, even under quite circumstances.

2.3.6 The Non-Auditory Effects of Noise

Damaging effects of noise are not only limited to the auditory organs. It also includes a wide range of physiological and psychological changes in the functioning of body systems (Martini, 2006; Hong & Kim, 2001; and Clark & Bohne, 1999). Constant exposure to noise can contribute to deterioration in health, and has a detrimental effect on an individual's life due to amongst other hormonal secretion and damage of the brain, especially in prolonged exposure to noise (Merchant & Rosowski, 2003; and Martini, 2006). After prolonged exposure, susceptible individuals in the general population may also develop permanent effects, such as diabetes, hypertension and ischemic heart disease associated with exposure to high sound pressure levels (Kendi et al., 2004; Muhle et al., 2002; Passchier-Vermeer & Zeichart., 1998; and Berglund & Lindvall, 1995). Excessive noise impairs communication and causes stress (Schapkin *et al.,* 2005; and Clark & Borne, 1999). Unfortunately, no criteria for the non-auditory effects of noise, exists (Katz, 1994).

2.3.7 Effect of Noise on Productivity and Quality of Work

The effect on noise on productivity and quality of work has been closely scrutinized (Marshall & Heller, 1998; and Evans & Lepore, 1993) in both laboratory subjects and in workers exposed to occupational noise. Excessive noise results in a decrease in work performance and the quantity of work completed (Melamed *et al*., 2001). It decreases the coordination function of workers (Seixas *et al*., 2005; and Lusk *et al*., 1998), interrupts an individual's attention processes and reaction time and therefore the accuracy, quantity of the work is affected, and the number of errors increases (Landen *et al.,* 2004). This is common in industries or in areas where continuous noise is common (Landen *et al*., 2004).

Continuous noise levels above 90 dB(A) and intermittent noise, less than 90 dB(A) with a high frequency component, are most likely to affect work performance, with industrial type noise having the most pronounced effect (Seixas *et al.,* 2003; and Golz *et al.,* 2001). Being unable to perform work well reduces the worker's self-esteem, affects personal well-being and creates an aversion to returning to work each day (Mizoue *et al.,* 2003; and Nakaniski *et al.,* 2000).

Studies on the effect of noise on productivity sometimes indicate an improvement, loss or no change in the total productivity (Seixas *et al*., 2005). It seems as if an increase in the intensity of noise may improve productivity during simple routine tasks where alertness of workers is probably below the optimum level (Efferson *et al*., 2004). In contrast, exposure to noise, together with other stimuli, may decrease productivity where the task is complicated, because of over stimulation, with accompanying stress, nervousness, and tiredness (Seixas *et al*., 2003; and Ahmed & Dennis, 2001). Thus, improvement in productivity which is sometimes found with a sudden drop in noise level can be attributed the Hawthorne effect rather than to the decreased noise level. Workers tend to give their best when management is interested in their working conditions, and studies in productivity are often biased by this principle (Horne *et al.,* 1994).

Thus excessive noise may have a negative effect on industries such as the Smelter. It is, therefore, to the advantage of any industry to ensure that noise levels are within acceptable limits or that workers are protected against excessive noise.

2.4 Hearing Loss

2.4.1 Introduction

Hearing loss or deafness is usually divided into two types: conduction deafness and nerve deafness (NIDCD, 2010; Bies & Hansen, 2009; and Baguley, 2002). Nerve deafness can also be divided into two types: sensorineural hearing loss and central hearing loss (Goyal *et al.,* 2010). Prebycusis is the deterioration of auditory sensitivity with age and happens as a result of atrophy, vascular and neural degeneration and other structural changes to the inner ear (Gates & Mills, 2005; and Horne *et al.,* 1994). Certain illnesses, such as hypercholesterolemia and atherosclerosis may also play a role in the development of hearing loss, since the illness interferes with the metabolism of the body (e.g., accumulation of toxic metabolites) (Yoshioka *et al*., 2010; Fowler & Leigh-Paffenoth, 2007; and Casali *et al.,* 2000).

Many treatment options are available for conductive deafness, but treatment options for nerve deafness are relatively limited (Hsien *et al.,* 2009). Because many of these problems become progressively worse, early diagnosis improves the chances of successful treatment (NIDCD, 2010; and Baguley, 2002).

2.4.2 Conduction Hearing Loss

Conduction deafness is caused by conditions in the outer or middle ear that impair the normal transfer of vibrations from the tympanic membrane to the oval window (NIDCD, 2010; and Ahroon & Hamernik, 2000). An external auditory canal plugged with accumulated wax can cause a temporary hearing loss (Lynch & Kil, 2005; Ravicz, *et al*., 2004; and Beal *et al*., 2000). Conductive hearing loss produces a general reduction in hearing ability although, hearing by conduction through the skull, however, is still functional (Goudy *et al*., 2006; and Bies & Hansen, 2009).

2.4.3 Nerve Deafness

In nerve deafness, the person has decreased or total loss of ability to hear sound as tested by both air and bone conduction (Martini, 2006). Sensorineural hearing loss is caused by damage to the cochlea, the organ of Corti, or the cochlear nerve fibres of cranial nerve VIII (Laury *et al.,* 2009; and Glastonbury *et al.,* 2002). Thus, the vibrations reach the oval window and enter the perilymph, but the receptors cannot respond to stimulus (Bies & Hansen, 2009). Central hearing loss is caused by defects in the auditory tracts of the brain stem, thalamus, or the auditory cortex of the temporal cerebrum (Martini, 2006; and Rapin & Gravel, 2003). Thus, the vibrations reach the oval window and enter the perilymph, the receptors respond to the stimulus, but the response cannot reach its central destinations (Gardiner, 1996). The causes include malignancies of the brain, cerebrovascular disease, infections of the central nervous system, cerebral concussion and hypoxia (Tomei *et* al. 2010; and Lynch & Kil, 2005).

Deafness for low-frequency sounds is often caused by excessive and prolonged exposure to very loud sounds, because low-frequency sounds are usually louder and more damaging to the organ of Corti (Davidovits, 2008; Hidalgo *et al.,* 2009; and Rajan 2006). The reflex contraction of the tensor tympani and stapedius muscles in response to a dangerously loud noise occurs in less than 0.1 second, but this may not be fast enough to prevent damage (Harris *et al.,* 2005; and Martini, 2006).

The sensory receptor cells (hair cells) of the organ of Corti are the most susceptible to noise damage (Davidovits, 2008; and Grandis *et al*., 2003). A very loud noise can result in sensorineural hearing loss, involving loss of the sensory hair cells and primary sensory neurons in the inner ear (Laury *et al.,* 2009; and Baguley, 2002). A quiet sound has a small amount of acoustic energy, which is transformed to mechanical energy, resulting in a small wave in the cochlear fluid (Holley, 2005). This causes a small displacement of the basilar membrane, resulting in a gentle bending of the cilia and a normal amount of neurotransmitter substance being released (Heinrich *et al.,* 2005). However, very loud sounds, such as loud machinery have a huge amount of acoustic energy that enter the ear and is transformed into mechanical energy (Gale *et al.,* 2004). It causes a huge wave in the cochlear fluid, and extreme displacement of the basilar membrane. As a result, the cilia are repeatedly smashed against the tectorial membrane, causing prolonged and extended bending of the cilia.

This causes too much neurotransmitter substance to be released (Gale *et al.,* 2004; Arhoon & Hamernik, 2000; and Beal *et al.,* 2000), and damage from the repetitive noise is a physiochemical problem that results in permanent or temporal cellular damage (Arhoon & Hamernik, 2000). According to Golz *et al.,* (2001) cilia become damaged mainly for two reasons: Firstly, they experience direct mechanical damage from the severe beating they have received. Secondly, the neurotransmitter substance, which is toxic in large doses, damages them. A diminished blood supply to the ear also occurs and the organ of Corti becomes detached from the basilar membrane, deteriorates and is replaced by the scar tissue (Husbands *et al.,* 1999). In addition, the biochemical processes of the cochlea are altered during noise exposure (Clark & Bohne, 1999). Initially, the cilia are able to repair themselves so that hearing is restored. If the cilia are damaged continuously due to exposure to loud sound, they cannot repair themselves anymore.

Thus, NIHL usually develops as a result of damage to the cochlea due to exposure to loud sounds for a long period (Davidovits, 2008; and Grandis *et al*., 2003). These changes have led researchers to investigate the molecular basis of NIHL. Currently, enzyme therapy is investigated as a possible preventative measure (Kopke *et al*., 2002). Sensorineural hearing loss can also occur due to the destruction of hair cells when the eardrum suddenly is exposed to a loud noise, such as an explosion, which is thought to crush hair cells between the basilar and tectorial membranes (Martini, 2006). It occurs due to strong and repeated stimulation of the ear by intense sound, which leads to the slow but progressive degeneration of the sound-sensitive cells of the inner ear (Catalano & Levin, 2003; and Kroemer & Grandjean, 2000). The more intense the noise, and the more often it is repeated, the greater the damage to hearing (Kroemer & Grandjean, 2000). At first, it is temporary, but it may become permanent with time (Martini, 2006).

Approximately one in seven people suffer from tinnitus, a complex condition involving the endogenous generation of noise from the inner ear and the central auditory pathways (Guyton & Hall, 2010; Ludman & Wright, 1998). Cochlear nerve lesions are known to cause Tinnitus (Martines *et al.,* 2010; Dias *et al.,* 2006; and Kumar & Clark, 2002).

Sensitivity to noise varies greatly from one person to another (Kroemer & Grandjean, 2000). Individuals who are particularly sensitive may suffer permanent deafness after only a few months, whereas less sensitive individuals may not show the first symptoms until after many years' exposure (Bies & Hansen, 2009). NIHL usually starts at frequencies above 4000 Hz and extends gradually to the lower frequencies (Bies & Hansen, 2009; and Kroemer & Grandjean, 2000). At first, the individual is unaware of it and only gradually notices loss of hearing when it begins to involve the lower frequencies (Martini, 2006; and Kroemer & Grandjean, 2000). Noise deafness is progressive and commonly combines with the hearing loss that comes with natural ageing (Bielefeld *et al.,* 2010; Bies & Hansen, 2009; Mizoue *et al.,* 2003; and Gates *et al.,* 1999). In fact, NIHL is often mistaken for the early onset of the latter (Kroemer & Grandjean, 2000). In most industrial countries, noise deafness is one of the occupational hazards of working life (Nuwayhid, 2004).

According to Rabinowitz (2000), NIHL is the major cause of avoidable, permanent hearing loss, accounting in part for about a third of affected people in developed countries (Pujol & Puel, 1999). Although protection from excessive noise is desirable, uncontrolled exposure will remain a serious problem for the near future (Mizoue *et al.,* 2003; and Nakaniski *et al.,* 2000). Despite the fact that the prevalence of hearing loss could be cut in half by responsible care within social and industrial environments, there remain a substantial need for curative as well as preventive treatments (Doswell, 1996).

According to Martini (2006), there are three types of hearing loss because of noise exposure. Firstly, directly after exposure to noise a temporal threshold shift takes place, which entails a short-lived impairment in sensitivity (Chen, 2002). Secondly, after long-term exposure to noise, an irreversible permanent threshold shift takes place. A third type of auditory loss, namely acoustic trauma, follows a single intense exposure to noise, such as an explosion. Acoustic trauma may be reversible (Saunders *et al.,* 2001).

2.4.4 Temporal Threshold Shift

According to Martini (2006), temporal threshold shift depends on the intensity and characteristics of the stimulus and the duration of exposure. It may take minutes, hours or even days before the sensitivity of the ear returns to normal (Guyton & Hall, 2010). This can be attributed to metabolic changes in the auditory receptor cells (as a result of over stimulation) (Kroemer & Grandjean, 2000).

Noise exposure can result in vasoconstriction in the cochlea and it may cause low oxygen availability in the organ of Corti and the auditory nerve fibre (; Martini, 2006). As soon as the noise stops, the blood flow returns to normal followed by the threshold of hearing. It appears that the temporary threshold shift results from excitotoxic damage to the auditory dendrites rather than to the hair cells (Watson *et al.,* 2000; and Zhao *et al.,* 1996). The temporary threshold shift recovers when new dendritic processes grow and reconnect to the inner hair cells (Watson *et al.,* 2000). Thus, temporal threshold shift is not a permanent hearing loss but once prolonged it can result in permanent threshold shift.

2.4.5 Permanent Threshold Shift

According to Martini (2006), if exposure to noise, which causes a major temporal threshold shift, is maintained, the threshold of hearing will not recover completely with time and permanent threshold shift will result. It seems that prolonged exposure to noise brings about metabolic changes in the auditory receptors cells and nerves that eventually lead to degenerative damage to the cell structure (Ychida *et al.,* 2005; and Syka & Popela, 2000). Damage to the organ of Corti is linked to the type of noise, its intensity and frequency distribution (Prince, 2007). With continued noise exposure or in cases of acoustic trauma, the damage to the cilia and the loss of hearing is permanent (Prasher, 1998).

The progression of permanent hearing loss is a slow process that can develop over a number of years and is often not perceived by the individual until the frequencies that are important for speech are impaired (Duan *et al.,* 2002; and Plinkert *et al.,* 1999). Individuals with NIHL often complain of ringing in the ears, a complication of noise exposure known as tinnitus (Heinrich *et al*., 2005; and Duncan & Saunders, 2000). The effect of noise on the auditory organ cannot be regarded in isolation and many other factors may contribute to the development of permanent threshold shift (Davidovits, 2008). These factors are known as nosocusis and sociocusis (Griest & Bishop, 1998). Thus, permanent threshold shift may cause permanent hearing loss or severe NIHL as the organ of Corti becomes damaged.

2.4.6 Acoustic Trauma

According to Martini (2006), acoustic trauma is injury to the hearing mechanisms within the inner ear, caused by excessive loud noise. Such damage usually results from a brief exposure to intense noise in particular those of high frequency. Acoustic trauma is a common cause of sensorineural hearing loss (Kopke *et al.,* 1999). Damage to the hearing mechanisms within the inner ear may result from an explosion near the ear, gunshots, or long exposure to loud noises (such as loud music or loud machinery) (Lee *et al*., 2005; Cole & Jahrsoerfer, 1998; and Sataloff, 1998). Hearing loss resulting from noise damage is dependent on a number of both intrinsic and extrinsic factors (Ahroon & Hamernik, 1999). Thus, acoustic trauma is an irreversible hearing loss (Martini, 2006). It is often observed in individuals involved in car accidents and in individuals who have brain damage (Lapointe *et al*., 2006(a); and Oosterveld *et al*., 2002).

2.4.7 Combined Effects of Noise and Vibration

Vibration coupled with noise can exacerbate the hearing loss caused by the noise (Chen *et al.,* 2005; Pourbakht & Yamasoba, 2003; and Schneider *et al.,* 2002). In humans, vibration causes a larger temporal threshold shift after noise exposure (Chen *et al.,* 2005; and Doswell, 1996). However, a permanent threshold shift does not occur, as is the case with animal studies (Rosen *et al*., 2001). In the construction, and manufacturing sectors, vibration induced diseases is well documented (Neitzel & Seixas, 2005; Rowlinson, 2004; and Zou *et al*., 2001).

Symptoms may include damage in the vascular and neurological systems, as well as muscular damage (Tomei *et* al. 2010; and Bies & Hansen, 2009).

2.5 Occupational Noise and Exposures in Industries

2.5.1 Introduction

Noise in agriculture, construction, engineering, foundries, musical industry and mines are usually above the noise rating limit (Rabinowitz, 2000). This includes shop tools, truck traffic, chainsaws, pneumatic drills, snowmobiles, sandblasting, loud rock concerts, auto horns, gun muzzle blasts, and jet engines (Landen *et al*., 2004; and Freeman *et al*., 1999). Between 68% and 80% of workers at the construction industries are exposed to noise levels of 85 dB(A) or more during a work shift. This is a significant risk for the development of NIHL (Miyakita & Ueda, 1997). The source of these high levels of noise stems primarily from foundry, agricultural and construction equipment, such as drills, shovels, crashers, which are inherently noisy (Department of Minerals and Energy Noise Control in Mines, Document number ZMR922UU, 1997). Most of the equipment and processes also require operator attendance, placing workers in close proximity of the sources of noise (Hermanus, 2007; OHS Act 85/93; and Department of Minerals and Energy Noise Control in Mines, Document number ZMR922UU, 1997).

2.5.2 Occupational Noise

Occupational NIHL is a common disease (NIOSH, 1998). Many workers are exposed to potential hazardous noise levels in the workplace. Various elements within a person's working environment can lead to predispose an individual to developing NIHL (Fletcher *et al*., 2002). Sound levels above 85 dB(A) can result in hearing loss, therefore noise exposure in the workplace should be limited to 8 hours per day at 85 dB(A), 4 hours per day at 95 dB(A) and two hours per day at 100 dB(A) (Chung *et al*., 2005; Camp *et al.,* 2004; Kopke *et al*., 2001; Kozak & Grundfast,1999; and Wolgemuth *et al*., 1995). The occupational health and safety association (OSHA) adopted a Permissive Exposure Level (PEL) in the hearing conservation amendments (46 Fed. reg. 4078, 1981). The type of sound/noise that has potential to cause hearing loss is discussed in section 2.2.3 of this study. This study measured continuous noise levels in selected sections of the Polokwane Smelter and results are discussed in Chapter 4.

It is clear that exposure to noise levels exceeding the noise rating limit can result in NIHL, at the human voice range, which will lead to social and occupational complications (Chen *et al*., 2005; and Emmerich *et al*., 2000). The degrees of hearing impairment caused by occupational noise vary and are associated with the degree of susceptibility of an individual to noise damage (Helfer *et al.,* 2010; Pourbakht & Yamasoba, 2003; and Chen, 2002). Prevention of damage in more susceptible individuals thus becomes critically important, because there is no cure for hearing loss once the structures in the cochlea has been permanently damaged by noise (Björk, 2002; and Clark & Bohne, 1999).

2.5.4 Prevalence Noise-Induced Hearing Loss in South African Mining Industry

In South Africa, mining is the largest industry, employing 5.1% of all workers in the non-agricultural, formal sector of the economy, a reported total of 458 600 employees in 2006 (SAMI 2006/2007). The processes associated with mining generate tremendous noise as a result of activities such as percussion drilling, blasting and crushing of ore, often exacerbated by confined and reflective spaces MHSC (2006). The results of a recent study, investigating the profiles of noise exposure in South African mines, indicate that the mean noise exposure levels in the South African mining industry range from 63.9 to 113.5 dB(A), and that approximately 73.2% of miners in the industry are exposed to noise levels above the legislated occupational exposure limit of 85 dB(A) (Edwards *et al.,* 2011).

NIHL is preventable and the South African government mandates hearing conservation programmes. Still, a high prevalence of NIHL is reported. An audit of the Department of Mineral Resources in South Africa reported 1 820 cases of NIHL in 2007 (PMHSA (2008). The Chamber of Mines reported a positive downward trend in the number of NIHL cases since the baseline in 2002/2003 (a rate of 15 per 1000 workers was reported then); the current rate of NIHL is 3.1 cases per 1 000 employees (Chamber of Mines Annual Report 2011). It is possible that reported NIHL cases could have been inflated soon after 2001 as baseline hearing testing was only mandated after 2001 when Circular Instruction 171 was issued under the Compensation for Occupational Injuries and Diseases Act (No. 130 of 1993) (COID, 1993).

Continued concerns about the high incidence of NIHL, and the costs to the South African mining industry, resulted in the setting of targets in 2003 by industry stakeholders to eliminate NIHL (DME, 2008). The targets are that:

- after December 2008, hearing conservation programmes must ensure that deteriorations in hearing are no greater than 10 per cent amongst occupationally exposed individuals; and
- by December 2013, the total noise emitted by all equipment installed in any workplace must not exceed a sound pressure level of 110 dB(A) at any location in that workplace.

In order to achieve the targets set by industry and to monitor the progress towards meeting them, the mining industry needed reliable, representative and current noise exposure data. Therefore, the South African Mine Health and Safety Council (MHSC: 2006) initiated a study to quantify the noise exposure levels in the mining industry. The MHSC (2006) study incorporated objectives relating to both noise and dust exposure and prevention of NIHL and silicosis (Dekker *et al.,* 2007).

In 2005, the Mine Health and Safety Council (MHSC), comprising representatives of state, labour and employers, signed an agreement with the mining industry. As a consequence, the MHSC (2006) recommended the calculation of reliable prevalence data on NIHL as a focus area within occupational health research. Apart from annual reports available from specific mining groups, the MHSC (2006) and the Chamber of Mines, limited data exist on the prevalence and incidence of NIHL in the mining industry against which the MHSC (2006) target to reduce NIHL can be measured. Only one paper relating to prevalence of NIHL in underground mining in Africa, published in 1987, describes the hearing thresholds of a group of white South African gold miners (Hessel & Sluis-Cremer, 1987).

2.6 Hearing Conservation Programs and Legislations

2.6.1 Introduction

Hearing conservation means the avoidance or reduction of NIHL by the control of noise through engineering methods and the execution of hearing conservation procedures (Bies & Hansen, 2009; and Melnick, 1994). Due to the impact of both the auditory and non-auditory effects of NIHL, it is important to prevent the development of NIHL. Worldwide, employers and governments have recognized the importance of preventing NIHL (NIOSH, 1998). Therefore, legally, it is the responsibility of the employer to provide safe working conditions and practices appropriate to the particular circumstances in each environment, including the prevention of noise hazards and NIHL (Bies & Hansen, 2009; and OHS Act 85/93).

2.6.2 Compliance to Legislation

Many workers are routinely exposed to noise levels greater than the legally recognized safety limit; therefore legislation has been put into place to ensure the protection of the worker from noise damage (Hermanus, 2007). The Machinery and Occupational Safety Act (Act 6 of 1983) established a maximum noise exposure of 90dB(A) over an 8 hour period compared which was replaced by the OHS Act (85/93) which requires an exposure limit is 85 dB(A). The noise exposure limit can be found in the Noise Induce Hearing Loss Regulations (2003). If noise increase by five decibels, the duration of exposure need to be decreased by half (Rosen *at al*., 2001). The OHS Act (85/93) and South African National Standards (SANS (10083:2004)) addressed the employees in commerce and citizens with regard to the effect of noise on public health and welfare.

2.6.3 Legislation Regarding Noise and Hearing Loss

The two main standard-setting agencies impacting on the development of legislative requirements in South Africa with regards to noise are International Organization of Standardization (ISO) and Standards South Africa that publish the South African National Standards (SANS). Both institutions specifies an occupational exposure limit of 8hr/day, 40hr/week, equivalent continuous noise level (Leq) of 85 dB(A) (ISO, 1990; SANS 10083, 2004). Legal requirements with respect to occupational noise exposure in South Africa are specified in the Noise-induced hearing loss (NIHL)

Regulations, promulgated under the Occupational Health and Safety Act of 1993. The Polokwane Smelter should further adhere to Mine Health and Safety Act No. 29 of 1996, (updated by the Mine Health and Safety Amendment Act, 1997) in addition to the Occupational Health and Safety Act of 1993.

The noise rating limit is set at a noise rating level of 85 dB(A) normalized to a nominal working day of 8 hours (NIHL regulation, 2003). The legislation requires the employer to implement a Hearing Conservation Programme (HCP) when workers are exposed to noise-rating levels at or above this limit (Mine Health and Safety Amendment Act, 1997). Regulation that aimed to control noise at the work place is Noise-induced hearing loss Regulation (2003).

- *Noise-induced hearing loss Regulation, 2003*
    - The regulation shall apply to an employer or self-employed person who, at any workplace under his or her control, carries out work that may expose any person at that workplace to noise at or above the noise-rating limit.

2.6.4 Hearing Conservation Programmes

In a study on the hearing conservation practice of ten foundries in industries with a high rate of compensation claims, it was found that workers continued to face a substantial risk of developing NIHL due to poor management and implementation of Hearing Conservation Programs. This is due to poor education of employees regarding NIHL and poor noise management on the part of the employer. These findings may be applicable in the South African context. Only if the employee and employer become part of the solute

on can a hearing conservation program begin to work (Doke, 1996).

Hearing loss entails substantial economic costs for industries (Hermanus, 2007). In addition to this, NIHL is associated with social handicap and the quality of the affected individual's life is greatly reduced (Heggins, 1998; and Job, 1996). This underlines the importance of having effective regulatory strategies for noise control and prevention in place (Kardous *et al*., 2005; and Prasher, 1998). With such high levels of noise present in construction industries and manufacturing South African

Hearing Conservation Programs have been in place since 1988 (Kardous *et al*., 2005; and Attais *et al.,* 1998). These programs follow strict guidelines, which both the employer and employee should abide by. These include risk assessment and management, noise monitoring, education, and medical surveillance as discussed earlier (SANS, 10083: 2004; and OHS (Act 85/93)). The program is discussed in detailed below.

The South African mining industry introduced Hearing Conservation Programs (HCP) in 1988 (COMRO User Guide No. 11). This was a voluntary and proactive initiative from the industry itself, through the Chamber of Mines, and it shows that as far back as 1988 the industry had already identified NIHL as a priority problem. The concern shown by the mining industry was due to recognition of the fact that labour-intensive methods, common to many mineral extraction and processing operations, were resulting in large numbers of people being routinely exposed to noise beyond the recognized safe limit (DME's Code of Practice, 2000).

As further proof of the mining industry's commitment to deal with the effects of noise hazard on their employees, MOHAC (which is a tripartite advisory body comprising employers' representatives, workers' representatives and government representatives) has adopted a set of milestones that are ultimately meant to eliminate NIHL in the workplace. After December 2008, the Hearing Conservation Programs implemented by industry must ensure that there is no deterioration in hearing greater than 10% amongst occupationally exposed individuals. By December 2013, the total noise emitted by all equipment installed in any workplace must not exceed a sound pressure level of 110 dB(A) at any location in that workplace. The milestones themselves are targeted at the various health and safety problems that are deemed to be a high priority by the industry (DME, 2008).

Therefore, they include the elimination of: Injuries & Fatalities, Silicosis and of course NIHL. Subsequent to the 1988 Chamber of Mines Guidelines, the HCP has been enforced by law through the Mine Health and Safety Act (1995 chapters 9 & 11). This law was further enforced through the DME's Hearing Conservation Guidelines (2000).

The programme should include risk assessment, followed by education and training of workers; control of the noise, including personal hearing protection equipment; as well as regular medical surveillance and audiometric tests (SANS, 10083, 2004; Clark & Borne, 1999; NIOSH, 1998; and OHS Act 85/93). Risk assessment entails identifying and measuring the noise source by an occupational hygienist (Bies & Hansen, 2009; and Giuld *et al.*, 2001). This assessment determines whether hazardous noise sources exist and whether further analysis of noise is required. Once the hazard has been located and analysed, the employer should try to eradicate or control the noise (OHS Act 85/93; and Begley, 2003). Table A below indicates level of noise exposure and the possible control measures to be implemented.

Table A: Exposure classification according to noise exposure levels

Exposure classification according to:		
TWA(dB)	OH Regs	Risk factor (n), with significance of risk & required action
<82	-	0: Insignificant risk of NIHL. No action required
83-85	C 1	1: Potential risk of NIHL. OH monitoring of exposure levels
86-90	B	2: Moderate risk of NIHL. OH monitoring of exposure levels
91-95	B	3: Significant risk. Priority intervention and re-evaluation of risk
96-105	B	4: Unacceptable risk. Immediate intervention and
>106	A	5: Extreme risk. Urgent intervention and ongoing

*Reproduced from SIMRAC (2001, pp199***)**

The application of these guidelines has been summarized by SIMRAC (2001) and simplified into six elements as follows:

- Risk assessment and Occupational Hygiene (OH) monitoring;
- Education, motivation and training;
- Noise control engineering;
- Administrative control measures;
- Personal protection; and
- Medical surveillance that includes audiometry.

- *Risk assessment and occupational hygiene*

Risk assessment and occupational hygiene monitoring for the noise hazard should follow a rational sampling strategy (Giuld *et al.*, 2001). There should be zoning of the work areas according their noise levels (SIMRAC, 2011). Noise levels are always expressed as a time-weighted average calculated over eight hours, which is the normal daily shift for workers (Chung *et al*., 2005; and Camp *et al.,* 2004).

- *Training and Awareness*

Education, motivation and training are the obligation of the employer if a significant risk exists (OHS Act (85/93)). This element is a fundamental aspect to the success of the HCP. There are two areas of focus that must be addressed in training. The first one is to instil awareness of the noise hazard. The second one is to inform workers about the noise-control measures and also give them a positive image of the measures that are in place, such as the use of HPE and the routine medical surveillance required by Mine Health and Safety Act No. 29 of 1996, (updated by the Mine Health and Safety Amendment Act, 1997). In this way, you also empower them to be vigilant and to recognize any risk that they could become exposed to during the course of their work. Therefore, the employer creates an additional but powerful policing mechanism of the Risk Management procedure. In practical terms, the training must start at induction and continue throughout the employee's stay in the company. It must also be targeted at all employees and at all levels; not just those who are routinely exposed to noise (DME guidelines, 2000).

- *Risk Control Measures*

Noise-risk control measures are engineering control measures, administrative measures and personal hearing protection equipment such as HPD. The DME guidelines (2000) instruct that this is the order in which they should be prioritized in the implementation of HCP. This is also the order according to the hierarchy of controls (Bohnker *et al*., 2002, Suter, 2002; and NIOSH 1998). The rationale is that in the first instance you must try to remove the source of noise, i.e., noisy machinery. If that fails, you then remove the worker from the noise using administrative controls. If that also fails, then you try to stop the hazard from reaching the worker by protecting him with Personal Protective Equipment (PPE) such as ear muffs, ear plugs, etc. (Suter, 2002; and NIOSH 1998). The use of HPD is the last method of control that should only be considered if all other methods are not feasible (Suter, 2002).

Noise-control engineering means that the employer must change his machinery to that which emits safe levels of noise, preferably below 85dB. The practical problem of this requirement is that replacing equipment before the end of its intended lifespan is often expensive and not a viable option. The other problem is that, even when some of the machines have reached the end of their lifespan, the new and quieter options of replacement machinery are still not quite enough to completely eliminate the risk (Suter, 2002).

- *Administrative controls*

Administrative controls refer to those measures that can be used to reduce the time that is spent by a given worker in the high noise areas. This could mean a carefully controlled rotation of the work schedules aimed at reducing the time that each worker spends in the high noise areas. In complex organizations that have big workforces arranging effective administrative controls impose an additional administrative burden, such as more paperwork and work scheduling exercises. It is common knowledge that engineering controls and administrative control are not often taken as priorities by most industries, such as the smelter. The additional resources required to implement these measures are seen as a burden. Therefore, PPE is the most widely used intervention (Suter, 2002; and NIOSH 1998).

According to the DME guidelines HPD should be regarded as a last resort that is available for use when engineering and administrative measures fail. Its intended role is to supplement the other risk-control elements rather than being used as the primary control measure. However, the ease with which this particular intervention can be implemented has made it the most widely used (NIOSH 1998).

- *Medical surveillance*

The last element of a HCP is medical surveillance and audiometry. Audiometry is the clinical measurement that is used to assess the impact of noise on the workers' hearing and therefore to evaluate the impact of all the measures aimed at controlling NIHL. Because it measures the outcome, i.e., the hearing ability of individual workers, it is, therefore, the key to the monitoring program since it is the ultimate indicator of HCP effectiveness.

Medical surveillance has a legal basis since MHSA and Occupational Hygiene Regulations contained in the DME guidelines (2003) oblige the employer to implement a mandatory code of practice and occupational hygiene monitoring. Section 13(1) of the MHSA requires the employer to establish and maintain an appropriate system of medical surveillance. According to the act, the medical surveillance programs should be designed to provide the employer with information that enables the elimination, control or minimization of the hazard and associated risk.

- *Engineering Control*

The most reasonable way to do this is to create less noise with better machinery and equipment design. Noise controlled through engineering is the preferred method, but it is very expensive and therefore not always possible (Bies & Hansen, 2009). Where the elimination or control of noise is not feasible, minimization of the noise is acceptable according to Mine Health and Safety Act No. 29 of 1996, and SANS 10083 (2004). Examples of this include insulation of the noise source, the use of acoustic insulation and the reduction of vibration (Chen *et al.,* 2005; and Pourbakht & Yamasoba, 2003).

- *Personal Hearing Protective Devices*

The HPD should provide sufficient reduction of noise in order to reduce the noise that affects the hearing of the worker. Various types of HPDs are available and the type chosen is dependent on the magnitude n of the noise and environmental conditions (Berger & Kieper, 2000). In the construction, foundry, and mining sector, both earplugs and earmuffs can be used. In order to effectively implement the use of the HPDs, the program requires an educational component (OHS Act 85/93). This is the responsibility of the employer and is, unfortunately, frequently neglected (Katz, 1994).

- *Training*

According to Abdulla (1998), the educational component should cover the effect of noise on hearing, the purpose of noise surveillance and proper use and fitment of the HPDs. Correct use of HPDs is important, since NIHL will continue to develop if the HPDs are incorrectly inserted, use inconsistently or provide inadequate reduction in noise.

Hearing conservation programmes are implemented in an attempt to detect, manage and primarily to prevent NIHL. This is important, as there is no medical cure once the auditory system is severely damaged (Attias *et al.,* 1998). If the damaging influences cannot be avoided, the secondary prevention or early identification becomes important (Probst *et al.,* 1993). Screening forms part of the medical surveillance of the hearing conservation programme. Should screening indicate a possible HL, further testing and diagnosis are specified. Screening is not the same as diagnosis and should rather be viewed as a selection procedure for diagnostic testing.

Within a hearing conservation programme, both the employer and the employee have responsibilities in fulfilling certain obligations with regard to noise (Lusk, 2004; William, 2000; and Doke, 1996). Traditionally, industrial hearing conservation programmes have sought to preserve the hearing of workers already exposed to noise (Nash 2000; and Probst *et al.,* 1993). Since then programmes have additionally emphasized the importance of the prevention of NIHL (William, 2000).

The South African employer is obliged to implement a mandatory code of practice and occupational hygiene monitoring when employees are subjected to noise levels exceeding 85 dB(A) (Bies & Hansen, 2009). According to these acts, a hearing conservation program is necessary where workers are exposed to high levels of noise on a daily basis. In addition, (Cesar & Pedrero, 2006; Bohnker *et al.,* 2002; Nash, 2000; and NIOSH, 1998) the establishment of hearing conservation programmes for workers is recommended where noise exposure is equal to or exceeds 85 dB(A). This study examines if the smelter has a Hearing Conservation Program and its effectiveness and compliance to legislation such as the use of PPE and noise demarcation areas.

2.6.5 Programs for Prevention Hearing Loss in the Mining Industry

NIHL is a worldwide problem and has been recognized as such by the World Health Organization (WHO, 2004). As a result of this concern, WHO (2002) has adopted the ‘Program for Prevention of Deafness and Hearing Impairment (PDH). One of the resolutions that were passed by WHO-PDH acknowledged the worldwide estimated prevalence of disabling hearing difficulty to be around 120 million. In that resolution, WHO has urged member states to set up National Programs for prevention of deafness. Each National Program must set an integrated strategy using the WHO guidelines but taking into consideration the local objective conditions (WHO, 2002).

NIHL is the most prevalent irreversible industrial disease and the biggest compensable occupational disease (Begley, 2003; and Royster et al., 1982). The significance of NIHL in the South African mining industry can be demonstrated by Harmony (2004) and De Beers (2002), who reported that NIHL was the biggest occupational disease in their workforce. A such, the government has accordingly put legislative controls (DME, 2001). The study aimed to assess noise levels and legislative controls at various areas in which the Polokwane Smelter has implemented.

2.6 Non-Occupational Noise

Many individuals are exposed to damaging noise during leisure time and recreational activities including noise from traffic, music, machinery and guns (Catalano & Levin, 2003; and Aono, 2000). Non-occupational noise includes hobbies such as motorcar racing, motorbikes, listening to loud music, hunting and target shooting (Chung *et al*., 2005; Catalano *et al*., 2003; Nondahl *et al*., 2000; Narawiwat & Thai, 2001; and Napoli, 1999). Several studies have reported an increasing trend in the development of NIHL among adolescents and young adults (Katbamna *et al.,* 2008; Meyer-Birch, 1996; and Johnson & Zylen, 1ref995). This is associated with recreational or leisure time activities including noisy toys, music and recreational vehicles that produce sound greater than 85dB(A) (Opperman *et al*., 2006; Chung *et al*., 2005; and Lukes & Johnson, 1999). Some recreational noises are more damaging than occupational noise (Ahmed & Dennis, 2001; Chung *et al*., 2005; Nondahl *et al*., 2000; and Dalton *et al*., 1998).

2.9 Conclusion

Exposure to noise occurs in many industries but particularly within the manufacturing, construction and farming industries (Aybek *et al.,* 2010; Neitzel & Seixas, 2005; and Seixas, 2004). Occupations that carry a high risk of hearing loss include tunnelling, quarrying and operation of textile machines (Hermanus, 2007; Ersen *et al.,* 1998).

It is clear that industrial noise does not only affect hearing, it also has a psychological effect on workers. Researchers such as Ohlemiller (2004) proved that hearing might interfere with speech and communication. When people have problems with hearing and communicating, it may lead to misunderstanding, which results in waste and inefficiency. This is associated with poor performance and injuries while at work (Heggins, 1998). The main social consequence of hearing impairment is an inability to understand speech in daily living conditions, which is considered as a severe social handicap. Even small values of hearing impairment (10 dB(A) averaged over 2 000 and 4 000 Hz, and over both ears) may have an effect on the understanding of speech. When the hearing impairment exceeds 30 dB(A) (again averaged over 2 000 and 4 000 Hz and both ears), a social hearing handicap is noticeable (Berglund & Lindvall, 1995; and Katz, 1994).

Occupational noise in smelters is created throughout the smelting process, but especially at the Flash Dryer and in the Furnace (Anglo Platinum, 2003). Since workers do not have set workstations (Henderson *et al.,* 2001), it is difficult to assess the average exposure through static sampling.

CHAPTER 3
METHODS AND MATERIAL

This chapter discusses the methodology and procedures utilized to investigate the aims of the study.

3.1 Design

The aim of this study was to determine if noise levels areas are above REL of 85 dB(A) at specific areas of the Polokwane Platinum Smelter, in the Limpopo Province as certain workers may spend time periods of eight hours or more in these areas, thus resulting in excessive exposure to noise. Fieldwork included taking noise measurements, noise surveys and monitoring. It was conducted from March 2005 to September 2006. The study was designed as a cross-sectional study with seventeen utility workers from the Polokwane Platinum Smelter forming the experimental group, and second year students registered for the BSc Physiology programme at the University of Limpopo as the control group. Some of the students were used to match the older subjects in the experimental group.

The population was only utility workers. All work areas have been measured to have a time weighted average as discussed in Tables 4.1 to 4.9. These measurements were not based on the classification of 'high' and 'low' risk areas as provided by the smelter Occupational Hygienist. Measurements are carried out in accordance with the criteria laid out by the Department of Mineral and Energy Guidelines (2003) and SANS 10083 (2004).

3.2 Selection of Subjects

3.2.1 Number of Subjects

At the Polokwane Platinum Smelter, a group of seventeen males forms a utility team responsible for general maintenance of the entire smelter. These subjects perform general duties around the plant. They worked four hours to 12 hours a shift, during which they move among the ore, concentrate, as well as in the Coal Off-loading areas, Flash Dryer, Furnace Building, Matte and Storage Silos. Since these workers are not designated to work at a specific part of the smelter, but rather do maintenance wherever it is necessary, the management of the smelter was worried about the extent of noise exposure and therefore possible hearing loss in this group. The entire group therefore formed the experimental group in this study.

The control group was randomly selected (but a convenient sample) to match the experimental group for age, gender, geographical region and education (possession of a matriculation certificate). In this study, 20 second year and 10 third year male students from the School of Molecular and Life Sciences at the University of Limpopo (Turfloop Campus) were selected as a representative but convenient sample to form the control group. In addition, 9 honours students in Physiology were used to match the older subjects in the experimental group.

3.2.2 Age Ranges

The ages of the experimental group were between 21 and 48 years. Subjects for the control group were chosen to match the ages of the subjects from the experimental group as best as possible. The ages of the subjects in the control group ranged between 19 and 29 years.

3.2.3 Exclusion Criteria

All subjects in the experimental group had an education level of at least Grade 12 (Matric) and basic safety training and came from the Capricorn District in the Limpopo Province. The control group was selected to match the experimental group as closely as possible; therefore, the following subjects were excluded from the control group:

- Females;
- Subjects younger than 19 years;
- Subjects without a valid matriculation certificate; and
- Subjects who did not come from the Capricorn District.

3.3 Ethical Considerations

The study was approved by the Ethics Committee of the University of Limpopo. Subjects signed an informed Consent Form (Appendix A) giving the researchers permission to use the results from the hearing tests and the information on the questionnaires in a research project. Each subject received a subject number and no names were recorded to ensure confidentiality.

3.4 Organisational Procedures

The researcher contacted the management at the Polokwane Platinum Smelter regarding the possibility to do a research project. The management gave permission to conduct such a research project and indicated that there was a need to determine possible hearing loss in a group of 17 utility workers. A research proposal was written and approved by the management of the Polokwane Platinum Smelter, as well as by the relevant managers at the Head Office and by the University of Limpopo. A group of 39 subjects were selected from the undergraduate and B.Sc. Honours students. The researcher explained the procedures and the purpose of the study to the experimental and control groups on separate occasions, after which all subjects signed informed Consent Forms.

The researcher did a walkthrough survey under the supervision of the Occupational Hygienist employed by the Polokwane Platinum Smelter, at the locations where the subjects in the experimental group perform their duties. Based on the Polokwane Platinum Smelter risk profile, the study focuses on areas denoted as noise zones and utility workers that worked within the designated areas. The study took into account that a part of the group was utility workers whose work was not necessarily based in those areas, such as employees working as cleaners at the offices and kitchens. Such workers were excluded. During this survey, noisy areas were identified and surveyed to confirm previous survey conducted. This information was used to determine the locations where noise measurements should be taken and the amount of measurements at each location.

At a time during normal production that was convenient for the Polokwane Platinum Smelter, the researcher took the required noise measurements using a sound level meter Type 1 as required by SANS 10083 (2004). A type 1 sound level meter was selected as it is considered to be sufficiently accurate and can integrate time and sound pressure level. The use of Type 2 sound level meters are acceptable according to the legal method, however the sound level meter together with Type 3 instruments have limited application (SANS 10083, 2004).

As the smelter is considered to be an industrial environment, background noise should be a consideration. The level of background noise, in proportion to the sound that is being measured, has an influence on the accuracy of noise measurements so that certain adjustments are necessary (Martini, 2006). The noise level being measured must be at least 3 dB(A) higher than the background noise. If the noise level to be measured is 10 dB(A) higher than the background noise, no adjustment is necessary (Michael & Byrne, 2000). However, background noise could not be measured during this study as it requires the total shut down of the smelter which was not possible due to financial reasons.

The researcher interviewed all the subjects on an individual basis to complete a questionnaire (Appendix B). The questionnaire provided personal, medical and demographic information of the subjects.

3.5 Procedures

3.5.1 Walkthrough Survey

Since the main aim of this study was to determine noise levels areas that are at or above the noise rating limit of 85 dBA at the Polokwane Platinum Smelter, it was important to identify areas that have possible high levels of noise amongst the locations where the subjects perform their duties. The qualified Occupational Hygienist employed by the Polokwane Platinum Smelter assisted in identifying areas within the Polokwane Platinum Smelter where noise has a potential to cause hearing loss and areas that are demarcated as noise zones. The survey was done under his supervision and professional guidance. The areas that were identified as noise hazards were the Flash Dryer, Furnace and the Crusher. All these areas where the survey was conducted were clearly demarcated as noise zones.

The information gathered during the walkthrough survey was used to determine where noise measurements should be taken, and how many noise measurements should be taken. During the walkthrough survey, environmental noise such as noise from machines, maintenance activities and other sources of noise were observed and recorded in each section of the Polokwane Platinum Smelter. All noise measurements were taken during a smelter full operational period.

3.5.2 Noise Measurements

The study was carried out at the Polokwane Platinum Smelter located on the road to Burgersfort, about 10km South of the Polokwane city centre. The experimental study was conducted from September 2005 to September 2006.

The Type 1 precision integrating sound level meter (*1900 Casella Cel: 450*, serial number *074225)* with a ½" microphone (serial number *5825)* was used to measure the noise levels. The sound level meter was calibrated (SANS 10083: 2004; SANS 656:2008) before and after each set of measurements, with a *Cel 110/1* acoustical calibrator (serial number *074460)*. De Beers Calibration Services calibrated the sound level meter and calibrator on 31 August 2005 (certificate number 2005-598*).* The sound level meter was used from September 2005 to May 2006 whilst the instrument was within the validity period.

The sound level meter was set on the "A" weighted scale, which has a similar response to the human ear. The integrating sound level meter was also set on "I" for measuring of impulse noise response. The noise survey was performed in accordance with the legislated method for evaluating the workforce for hearing conservation purposes as prescribed in the SANS (10083:2004) "The Measurement and Assessment of Occupational Noise for Hearing Conservation Purposes". An initial sound pressure (SPL) survey was performed, and noise measurements in each area did not differ from each other.

In each zoned area, at least three (3) representative points were selected, representing a good average and exposure spread in that area. The instrument was set up with the microphone ± 1.5m from the floor level and at least 1.2m from reflecting surfaces. Each of the measured parameters was taken for a period of five minutes. Care was taken to take enough measurements, where workers were working to evaluate the noise levels as near as possible to representative exposure levels.

An acoustical dust shield was used to reduce interference from air movement (wind) and dust and also to ensure that humidity, air temperature, atmospheric pressure, as well as electrical and acoustical interference were within the specifications/limitations of the sound level meter. Both the air movement (wind) and dust changes did not pose any significant accuracy risks during this survey.

Observations were made regarding the current engineering and administrative controls, as well as HPDs' use by the workers.

3.5.3 Questionnaire

The researcher interviewed all subjects in the study (experimental and control subjects) individually to complete an extensive questionnaire. The questionnaire was aimed to investigate subjects' demographic information, medical and hearing history, lifestyle (exercise, smoking habits and use of alcohol) and family history of hearing loss. The ISO 9612:1997 Standard describe a model for the prediction of hearing loss. The questionnaire aimed to evaluate whether, for example, age, noise exposure time, years of exposure and daily noise exposure can contribute to hearing loss. It also contained detailed questions concerning occupational and non-occupational noise exposure histories. Although the items included in the questionnaire fall outside the scope of this study, they were included to explain possible impaired hearing.

The occupational history included;

- the duration that employees worked in noisy environment;
- tasks and activities that were undertaken;
- tools or equipment previously used, and;
- use of hearing protection (ear muff, and earplug) during their previous employment.

Information relating to non-occupational noise exposure that has a potential to exceed the noise exposure limit was also collected through the interview and questionnaire survey. The occupational history data were used informally and for statistical analysis of the results, to try and explain possible hearing problems or risk for the development of impaired hearing in any of the experimental or control subjects.

3.6 Statistical Analysis

During the analysis of the data collected for this study, the researcher employed descriptive statistics. Results are presented in the form of graphs and tables, accompanied by a discussion expanding and clarifying on what they represent. Questionnaire data were captured using Microsoft Excel. After capturing, the data were analysed using Statistical Package for the Social Sciences (SPSS) for statistical analyses. SPSS was also used to create graphs and tables.

3.6.1 Comparing Readings

The measurements obtained were evaluated against the statutory requirements as set out in the following:

- Occupational Health and Safety Act, (Act 85 of 1993);
- Noise Induce Hearing Loss Regulations of the Occupational Health and Safety Act 85 of 1993 as amended;
- Mine Health and Safety Act, Act 29 of 1996 and its Regulations; and
- SANS code of practice, SANS 10083 - 2004: "The measurement and assessment of occupational noise for hearing conservation purposes".

In general, the above-mentioned regulations and standards could be summarized as follows:

- No employer shall require or permit an employee to work in a workplace where he/she is exposed to an equivalent noise level equal to or exceeding 85 dB(A) (time weighted average) over an 8 hours per day. The employer shall measure the noise levels according to the applicable SANS (10083:2004). Noise measured for the purpose of the study was continuous noise;
- where the noise levels reach or exceeds 85 dB(A), the employer shall institute engineering noise controls. Where this is not practical, the

employer shall train employees in the usage of hearing protectors, demarcate said areas as noise zones, limit their time of exposure;

- if engineering controls are not practical in the area the employer shall conduct regular audiometric testing. However, if the noise levels are reduced to below 85 dB(A), audiometric testing will be voluntary; and
- implement a comprehensive hearing conservation programme.

3.7 Summary

The experimental group consisted of Platinum Smelter workers and the control group was a randomly selected (but convenient) sample, selected from undergraduates and B.Sc. Honours students at the University of Limpopo (Turfloop Campus). Subjects completed questionnaires and underwent audiometric testing. Static sampling was done to determine noise levels were done. The data were computerised and submitted to the University Research Statistics Department and analysed utilizing statistical procedures.

CHAPTER 4
RESULTS AND DISCUSSION

The purpose of this chapter is to present all the results obtained from the experimental phase of the research conducted.

4.1 Introduction

The aim of the study was to determine which areas where the experimental group are required to work have noise levels above legal limits that can result in NIHL or potential HL; to determine if all such areas with high noise levels are demarcated as noise zones; and to further evaluate existing control measures such as engineering, administrative controls and PPE.

The results presented below consist of data collected through interviews, observations and noise measurements. During the analysis of the data collected for this study, descriptive statistics were employed. Results are presented in the form of graphs, figures and tables accompanied by a discussion expanding and clarifying on what they represent.

The results compare sources of noise in different areas of the Polokwane Platinum Smelter during normal shifts and during maintenance periods or during boiler making activities with statutory requirements.

The current study further focused on the compliance monitoring of HPD and the use thereof. Assessment of whether employees were wearing their HPDs during working hours was conducted during plant inspections and walkabouts by the Smelter Hygienist and research team during the period of the study. The study observed legal compliance, for example, the wearing of HPDs by employees working or entering in noise-zoned areas, including adherence to safety signs displayed in various work areas at the smelter. These actions were also considered as part of the basic smelter safety requirements.

Mining remains an important industrial sector in many parts of the world. Although substantial progress has been made in the control of occupational health hazards found in this sector, there remains a room for further risk reduction (Donoghue, 2013; and Hermanus, 2007). This applies particularly to traumatic injuries, ergonomic hazards and noise (Donoghue, 2013). The study investigates noise levels in specific areas and verifies the existing control at the Polokwane Smelter.

4.2 Descriptive Analysis of Noise Levels at Various Areas

In this section, the results presented in tables indicate the measured and recorded occupational noise at the Polokwane Platinum Smelter. Each of the measured parameters was taken for a period of five minutes. These results represented in eight tables that indicate measured levels of noise (Time Weighted Average); main sources of noise, and a location where measurements were taken. Furthermore, there are six figures in this paper that indicate the average noise levels as recorded in different areas within the Polokwane Platinum Smelter. The red lines on the figures represent the noise rating limit of 85dB(A) as required by OHS Act (85/93).

If the graph exceeds this red line, it indicates that the noise levels in the specific areas are equal or above 85dB(A) which shows the areas should be demarcated as noise zones. Workers should wear hearing protective device such as earmuff or earplugs when entering such areas. Employees were not encouraged to work for the entire shift without necessary hearing protective aid as excessive noise may cause hearing shift/loss.

The noise measurements presented in this section were only those that the experimental group (workers in the Polokwane Platinum Smelter) were exposed to. Noise was only measured in all areas that the experimental group was working.

An Occupational Noise Survey (ONS) was conducted on the Plant Cooling and Ventilation Fans of the Polokwane Platinum Smelter in order to measure and assess the noise levels. There were three measurements taken in each area, with the exception of the Compressor House Cooling Fans where four measurements were taken as reflected in Table 4.1. Four measurements in the Compressor House

Cooling Fans were taken because the area had more sources of noise compared to the other areas.

The Plant Cooling and Ventilation Fans area includes the Compressor House Cooling Fans, Intake Manifolds, Furnace Ventilation Intake Fans, Water Reticulation Cooling Fans and Furnace Water Cooling Fans.

The results presented in Table 4.1 indicate that the Compressor House Cooling Fans noise levels were below the statutory limit of 85 dB(A), with an average noise level of 82.3 dB(A) in the area. The highest noise level was 84.2 dB(A) whilst the lowest noise level was 80.3 dB(A). Employees working in this area are unlikely to developing hearing loss, however, they are encouraged to wear HPD when working in this area.

In the Compressor House Intake Manifolds, one measurement exceeded the occupational noise exposure limit 85 dB(A) while the second measurement was equal to the statutory limit and the third measurement was below the statutory limit 84.9 dB(A). However, the average noise level in the area was 85.5 dB(A). The area should therefore be demarcated as a noise zone

In the Furnace Ventilation Intake Fans, two measurements were below the statutory limit while one noise measurement exceeded the statutory limit by recording at 86.9 dB(A). In the Furnace Water-Cooling Fans, all three measurements were below the statutory limit. The highest noise level was 84.3 dB(A) whilst the lowest noise level was 80.5 dB(A). The average noise level in the area was 84.5.

In the Water Reticulation Cooling Fans, all three noise measurements were below the statutory limit of 85 dB(A) as the machines present produced less significant noise. The highest noise level was 84.7 dB(A) and the lowest noise level was 82.5 dB(A). The average noise levels in the area was 83.9 dB(A) which conformed to the noise exposure limit.

The results in Table 4.1 indicate that noise levels were largely within the required occupational exposure limits of 85 dB(A). The high levels of noise, above 85 dB(A), were at the Compressor House air Intake Manifolds and Furnace Ventilation Intake fans. As a result, the Compressor House Air Intake Manifolds and Furnace Ventilation Intake Fans were the two highest risk areas in terms of noise levels. This means that, should utility workers be required to work normal shift hours of eight hours or more at the Compressor House Intake Flow Manifold and Furnace Ventilation Intake Fans locations, a worker can potential develop hearing loss if exposed to the high noise level of above 85dB(A) in these areas.

Table 4.1: Noise levels and sources of noise for Plant Cooling and Ventilation Fans of the Polokwane Platinum Smelter in, South Africa.

Sample	**Noise level** (with impulse weighing) ($L_{Aieq,T}$)	**Noise source**
Compressor House Cooling Fans.		
1	84.2 dB(A)	Motors; cranes; overhead; pumps; sirens; transformer fans; bobcats.
2	81.5 dB(A)	
3	80.3 dB(A)	
4	82.3 dB(A)	
Compressor House Intake Manifolds.		
1	85.0 dB(A)	Motors; pumps; mud gun firing; overhead cranes; sirens; transformer fans.
2	86.4 dB(A)	
3	84.9 dB(A)	
Furnace Ventilation Intake Fans.		
1	80.8 dB(A)	Motors; pumps; mud gun firing; cranes; bobcats, transformer fans sirens.
2	86.9 dB(A)	
3	83.8 dB(A)	
Furnace Water Cooling Fans.		
1	84.3 dB(A)	Motors; pumps; mud gun firing; cranes; bobcats, transformer fans, sirens.
2	82.7 dB(A)	
3	80.5 dB(A)	
Water Reticulation Cooling Fans.		
1	84.2 dB(A)	Motors; pumps; mud gun cranes; bobcats, sirens; transformer fans
2	84.7 dB(A)	
3	82.5 dB(A)	

During this study, utility workers were not working at the Furnace Water-Cooling section and Furnace Ventilation Intake Fans section the entire shift. Additionally, by wearing HPD by employees when entering Furnace Water-Cooling section, Furnace building, and Ventilation Intake Fans area the noise levels that the employee may be exposed to are reduced. This includes those employees working within the vicinity of the Compressor House. Other areas where noise levels were measured, i.e., at the Cooling, and other fans on the plant, were not in excess of the statutory limit for noise, even though there was a need for careful monitoring of any changes.

Noise sources and other environmental noise at the Compressor House Cooling Fans do not produce noise above the statutory level that can potentially lead to employees developing NIHL during normal or extended working shifts. The average noise level at the Compressor House (Plant Cooling and Ventilation Fans) was above than 85 dB(A), which means that employees working in this area are subjected to any known potential risk of hearing loss as a result of noise.

In this section, the study reports the results from the Casting Platform area within the Polokwane Platinum Smelter. An occupational noise survey was conducted on the Casting Platform area and in the area under the Casting Platform of the Polokwane Platinum Smelter in order to assess noise levels. Table 4.2 indicates that there were three measures taken at the casting area platform, while four measurements were taken from the area under the Casting Platform.

Table 4.2: Noise levels and sources of noise on the Casting Platform and in the Area under the Casting Platform of the Polokwane Platinum Smelter, South Africa

Sample	**Noise level** (with impulse weighing) ($L_{Aieq,T}$)	**Noise source**
Casting Platform.		
1	80.6 dB(A)	Drive motors ; boiler making activities; repair operation.
2	81.5 dB(A)	
3	82.3 dB(A)	
Area under-Casting Platform.		
1	82.0 dB(A)	Drive motors ; boiler making activities; repair operation.
2	84.1 dB(A)	
3	84.7 dB(A)	
4	78.5 dB(A)	

The results in Table 4.2 shows that in the Casting Platform, recorded noise levels were 80.6 dB(A), 81.6 dB(A), and 82.3 dB(A), which was below the noise exposure limit of 85.0 dB(A). The average noise level of 81.5 dB(A) is also below the noise exposure limit which is considered the limit beyond which health problems associated with noise can be experienced.

A noise level in the Area Under- Casting Platform was 84.7 dB(A), which was higher than the noise levels at the Casting Platform and the Area Under Casting Platform). The lowest noise level was 78.5 dB(A) recorded under the Casting Platform. A fourth measurement was collected because the second and third measurements were closer to the statutory limit. When comparing the average noise levels recorded in the two areas, the readings showed that the Casting Platform area noise levels were lower when compared to those taken in the area under the Casting Platform. Both were under the noise exposure limit.

Boiler-making activities at this section of the plant do not last for an entire shift but are only conducted during maintenance and minor repairs. Most of the operation produced acceptable noise levels at the Area Under - Casting Platform.

The results in Table 4.3 indicate that in the Furnace Roof the highest measured noise level was 86.6 dB(A), which is above the statutory limit. In the same area, the lowest noise level was 82.7 dB(A). However, the average noise level in the area was below the noise rating limit at 84. 3 dB(A).

In the Matte Tapping Floor area, the highest measured level of noise was 88.3 dB(A) and 78.0 dB(A) the lowest. The area that had the highest level of noise was the Slag-Tapping Floor. The highest noise level in the Slag-Tapping Floor was 92.9 dB(A), and the lowest noise level was 86.3 dB(A) with an average of 90.3 dB(A). These high noise levels above the statutory level of 85.0 dB(A) could potentially lead to hearing loss, therefore, it is considered as a human health risk.

Table 4.3: Noise levels and sources of noise in the Furnace Roof, Matte Tapping Floor, Slag Tapping Floor, Paste Floor and Slow Cooling Area of the Polokwane Platinum Smelter, South Africa

Sample	Noise level (with impulse weighing) ($L_{Aieq,T}$)	Noise source
Furnace Roof.		
1	84.3 dB(A)	Drive motors; fans; air movement through piping; water flow through piping; Furnace "hum"; boiler making activities; compressed air release; mud gun alarm.
2	86.6 dB(A)	
3	83.8 dB(A)	
4	84.3 dB(A)	
5	85.2 dB(A)	
6	82.8 dB(A)	
7	82.7 dB(A)	
8	82.8 dB(A)	
Matte Tapping Floor.		
1	78.0 dB(A)	Drive motors; water flow through piping; Furnace "hum"; Boiler making activities; diesel generator; ladle trolley cranes; mud gun alarm.
2	80.4 dB(A)	
3	88.3 dB(A)	
4	79.8 dB(A)	
5	80.5 dB(A)	
6	85.7 dB(A)	
Slag Tapping Floor.		
1	87.5 dB(A)	Air movement through piping; water pumps; drive motors; Furnace "hum"; boiler making activities; compressed air release; mud gun operation. alarms; Tapping activities.
2	86.3 dB(A)	
3	89.3 dB(A)	
4	90.0 dB(A)	
5	92.3 dB(A)	
6	92.9 dB(A)	
Paste Floor.		
1	88.4 dB(A)	Drive; fans. Transformers, air movement through piping; diesel generator; vacuuming of Paste Floor. Boiler making activities; boiler making activities.
2	85.2 dB(A)	
3	84.3 dB(A)	
4	92.6 dB(A)	
5	83.2 dB(A)	
Slip Floor.		
1	91.9 dB(A)	Drive motors; fans; air movement through piping; Furnace off-gas; boiler making activities; compressed air release; pingon operation.
2	82.2 dB(A)	
3	80.1 dB(A)	
4	84.5 dB(A)	
5	89.0 dB(A)	
Slow Cool Area.		
1	101.8 dB(A)	Compressor; drive; motor; blow-off exhausts; Cranes; Motors; WCM breaking;. Intermittent boost release from air vents on roof; cooling fans.
2	104.8 dB(A)	
3	101.8 dB(A)	
4	107.8 dB(A)	
5	108.3 dB(A)	
6	95.8 dB(A)	

Results reported in Table 4.3 indicate that the noise levels were controllable to below the statutory requirement according to OHS Act (85/93) except in the four areas, the Slag Tapping Floor, Paste Floor, Slip Floor, and Slow Cool Area. Therefore, the employees working in the areas where the noise level was under the statutory level were not likely to develop NIHL. Employees working in areas where noise levels could not be controlled to within legal limits, can only be allowed to work in these areas if they are wearing hearing protection devices. As long as effective hearing protection devices are worn by workers chances of employees losing hearing lost are significantly reduced. Wearing of hearing protection devices is known to be one of administrative controls aim to reduced high noise level that has potential to damage hearing capabilities.

In addition, the noise values in the Slow Cooling Area, as indicate in Table 4.3 were above the occupational exposure limit of 85.0 dB(A). This suggests that precautionary measures should be taken to ensure that workers in this area are not exposed to these noise levels that can be a threat to their health. In the Slow Cool Area, the noise levels were also above the statutory occupational exposure limit, the highest level was 105.1 dB(A) at the Slow Cooling Area as indicated in Table 4.3. Employees in this area are not allowed to work more than 15 minutes during normal operation at the smelter. Employees are required to wear double ear protection when working at Slow Cooling Area as noise levels are above legal limits.

On the Paste Floor, the highest measured noise level of 92.6 dB(A) was recorded, while the lowest was 83.2 dB(A). Three of the five measurements in this area were above the statutory limit. In the Slip Floor area, only two of the five measurements were above the statutory limit with the highest noise level being 91.9 dB(A) and the lowest of 80.1 dB(A).

Noise levels normally increase when the Furnace starts due to rattling, grinding, whining or other noise that accelerates as the fan picks-up speed. The bearings in the fan blades or motor also contribute to the noise. Noise levels during Furnace start-up is regulated by the Department of Labour. The employer, Polokwane Platinum Smelter, has taken reasonable care by ensuring that a guideline document is available to all on request at the office of occupational hygienist and employees' are aware of the working document. In addition to the mentioned communication strategies, the Polokwane Platinum Smelter Management uses work team sessions to discuss technical aspect of the Furnace start-up. On-site notice boards, electronic display, display boards at security entrance and community radio station are used to communicate to visitor and communities. During Furnace start-up, no employee is allowed to work near the Furnace up until the Furnace is fully running. A siren will indicate that employees need to evacuate from the plant prior to start up. The results above were taken during normal running of the Furnace. Noise sources were from crushing and grinding operations from Furnace activities and machineries.

The results indicated in Figure 1 (Furnace) also show that two-thirds of the average noise levels were below noise rating limit. Only one-third of the Furnace area indicated noise levels which may contribute to the development of NIHL if they are overexposed to these noise levels for the entire shift. However, the utility workers who formed the experimental group of this study worked in some part of the Furnace for a few minutes only. Thus, due to the short exposure to noise at the Furnace section of the Polokwane Platinum Smelter, they are not likely to develop NIHL unless the employee is exposed to noise during Furnace start-up which is strictly controlled. Since most activities at the Furnace are not manually operated, utility workers were not working in this area for long periods and the time of noise exposure was limited. Continued monitoring was conducted as a part of the control measures of the Polokwane Platinum Smelter.

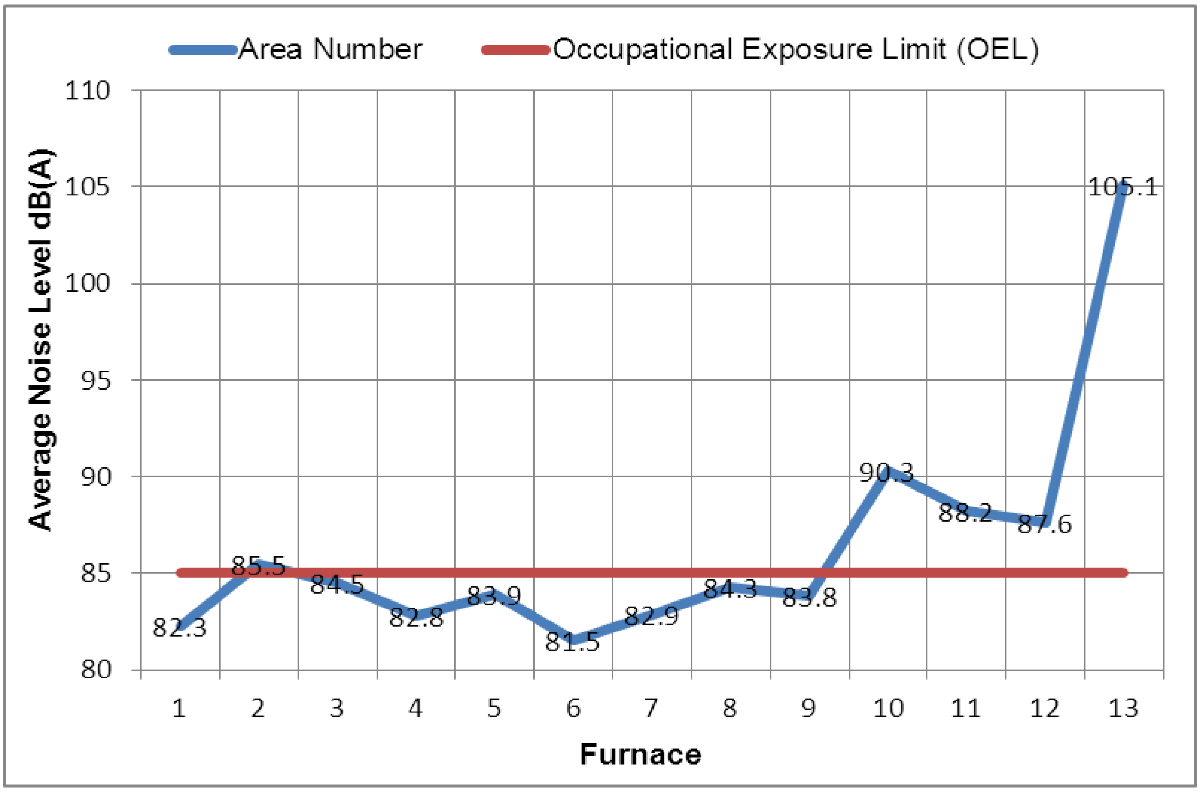


Figure 1: Average noise level at the different areas of the Furnace.

Area Number: 1= Compressor House Cooling Fans; 2 = Compressor House Intake Manifold; 3 = Furnace Ventilation Intake Fans; 4 = Furnace Water Cooling Fans; 5 = Water Reticulation Cooling Fans; 6 = Casting Platform; 7 = Area under-Casting Platform; 8 = Furnace Roof; 9 = Matte Tapping Floor; 10 = Slag Tapping Floor; 11 = Paste Floor; 12 = Slip Floor; 13 =Slow Cool Area.

The results in Figure 1 indicate that a total of thirteen areas were measured in the Furnace. The results further indicate that the average noise levels of five areas at the Furnace were above the statutory occupational exposure limit of 85.0 dB(A). Therefore, the average noise levels at the Furnace, especially the Slow Cooling Area, was higher than the statutory limit, and this indicates that the employees were at risk, even though the area was demarcated as a noise zone.

Employees working within or at the vicinity of Furnace are required to wear necessary HPD to reduce the effects of noise that may impair their hearing. The employees of the Polokwane Platinum Smelter are not working in the same area for the 12 hour shift. Employees are unlikely to be overexposed to a high level of noise. However, they were required to use HPDs to prevent possible excessive noise exposure and development of NIHL.

Based on the results indicated in Tables 4.1 to 4.3 and Figure 1, the study can therefore conclude that several areas at the Furnace produce high noise levels above the statutory limit. Noise levels are especially high at the Slow Cool Area as an average noise level over 105.1dB(A) was recorded in this area. No employee is allowed to work for more than 15 minutes in Slow Cool Area to prevent them from suffering from heat stress due to the excessive heat produced by the Furnace as per the Polokwane Platinum Smelter safety operation procedures. According to Chen *et al.,* (2004) heat and high noise level may stress the auditory system and reduce hearing abilities. High levels of noise above the statutory limit at the Slow Cool Area were due to air vents and Cooling Fans. Employees working in these areas supposed to wear necessary HPD.

According to the Compressor House noise level results in Table 4.3, the Furnace Roof and the Slow Cooling Area (Figure 1) were high-risk areas to employees for the development of NIHL. The results clearly indicate that the area has excessive high noise levels and if employees work in such areas they can develop NHL (Cruickshanks *et al.,* 2010). This risk could be severe when workers are allocated overtime hours as this will mean workers have to spend more time in this areas with a high level of noise. In a case where employees are working extended hours or overtime, noise exposure should be managed. Rotational system should be implement as part of the control measure. This will allow minimum noise exposure to areas with high noise levels. Continuous survey needs to be conducted to ensure that workers are aware of noise levels and will be able to implement correct control measures where required. Employees working within that vicinity were required to wear HPD such as earplugs or earmuffs and to work in the area for a maximum time of 15 minutes. These areas were regarded as a priority area for noise measurement in this study.

Table 4.4: Noise levels and sources of noise in the Compressor House area of the Polokwane Platinum Smelter, South Africa

Sample	**Noise level** (with impulse weighing) ($L_{Aieq,T}$)	**Noise source**
Compressor House area.		
1	85.9 dB(A)	Compressor; motors; compressor pumps; intermittent boost release from air vents on roof; cooling fans.
2	86.7 dB(A)	
3	87.4 dB(A)	
4	86.2 dB(A)	
5	86.5 dB(A)	
6	87.2 dB(A)	
7	87.0 dB(A)	
Areas immediately surrounding the Compressor House.		
1	72.1 dB(A)	Compressor; drive motors; compressed air release; constant air release; intermittent boost release from air vents on roof; cooling fans; constant air release through vents; rear fans of Compressor House.
2	71.9 dB(A)	
3	70.7 dB(A)	
4	70.2 dB(A)	
5	70.6 dB(A)	
6	74.9 dB(A)	
7	76.3 dB(A)	
8	76.7 dB(A)	
9	78.5 dB(A)	
10	87.5 dB(A)	
11	80.7 dB(A)	
12	97.5 dB(A)	
Main Control Room adjacent to the Compressor House.		
1	70.0 dB(A)	Compressor drives; motors; compressed air release; air conditioning; intermittent boost release from air vents on roof; Cooling fans, and motors.
2	82.9 dB(A)	
3	80.3 dB(A)	
Cooling Plant adjacent to the Compressor House.		
1	78.8 dB(A)	Compressed air release; cooling fans; motors; intermittent boost release from air vents on roof; constant air release through vents rear of Compressor House.
2	79.9 dB(A)	
3	81.9 dB(A)	
4	80.2 dB(A)	
5	79.5 dB(A)	
6	82.1 dB(A)	

An occupational noise survey was also conducted on the Compressor House of the Polokwane Platinum Smelter in order to assess noise levels as indicated in Table 4.4. The areas where noise was measured were the Compressor House Area, the area immediately surrounding the Compressor House, Main Control Room adjacent to the Compressor House and the Cooling Plant adjacent to the Compressor House.

In total, seven measurements were taken in the main Compressor House and the Slow Cool Area. In addition, twelve measurements were taken in the area immediately surrounding the Compressor House and three measurements at the Main Control Room adjacent to the Compressor House. Lastly, six measurements were taken in a Cooling Plant adjacent to the Compressor House.

The results in Table 4.4 (Compressor House Area) indicate that the Compressor House noise levels were above the statutory limit as all seven measurements were above 85 dB(A). The lowest noise level was 85.9 dB(A) while the highest noise level was 87.4 dB(A). The average of the noise levels recorded in the Compressor House is 86.7 dB(A) which exceeds the noise exposure limit.

In the areas immediately surrounding the Compressor House the lowest recorded noise level was 72.2 dB(A) while the highest recorded noise level was 97.5 dB(A). Only two of the twelve recorded noise levels were above the statutory limit of 85 dB(A). However, the average noise level of 87.4 dBA exceeded the 85 dBA noise exposure limit.

All the recorded noise levels in the Main Control Room adjacent to the Compressor House, as well as the Cooling Plant adjacent to the Compressor House, were below the statutory limit. The highest recorded noise level Main Control Room adjacent to the Compressor House in the was 82.9 dB(A) and the lowest noise level was 70.0 dB(A). In addition, the highest recorded noise level in Cooling Plant adjacent to the Compressor House was 82.1 dB(A) while the lowest noise level was 78.8 dB(A). The average noise levels in the Main Control Room adjacent to the Compressor House and the Cooling Plant adjacent to the Compressor House were 80.2 dBA and 80.6 dBA respectively.

From the Compressor House (Figure 2), it can be noted that there were four areas where noise was measured at the Compressor House. The results indicated that the average noise levels at the Main Control Room adjacent to the Compressor House 80.2 dB(A) and Cooling Plant at the Compressor House 80.6 dB(A) were below the statutory limit. The average noise levels at the Compressor House were below the statutory. The average noise level, ranges from a minimum of 70.2 dB(A) to a maximum of 97.5 dB(A).

Noise levels at the Compressor House and Area immediately surrounding the Compressor House need not to be monitored continuously as two of the four Areas were below the statutory level and, where there is a need, this should be reduced by introducing machines that produce less noise. Employees are not at risk to develop NIHL because they do not work the entire length of a shift at Compressor House.

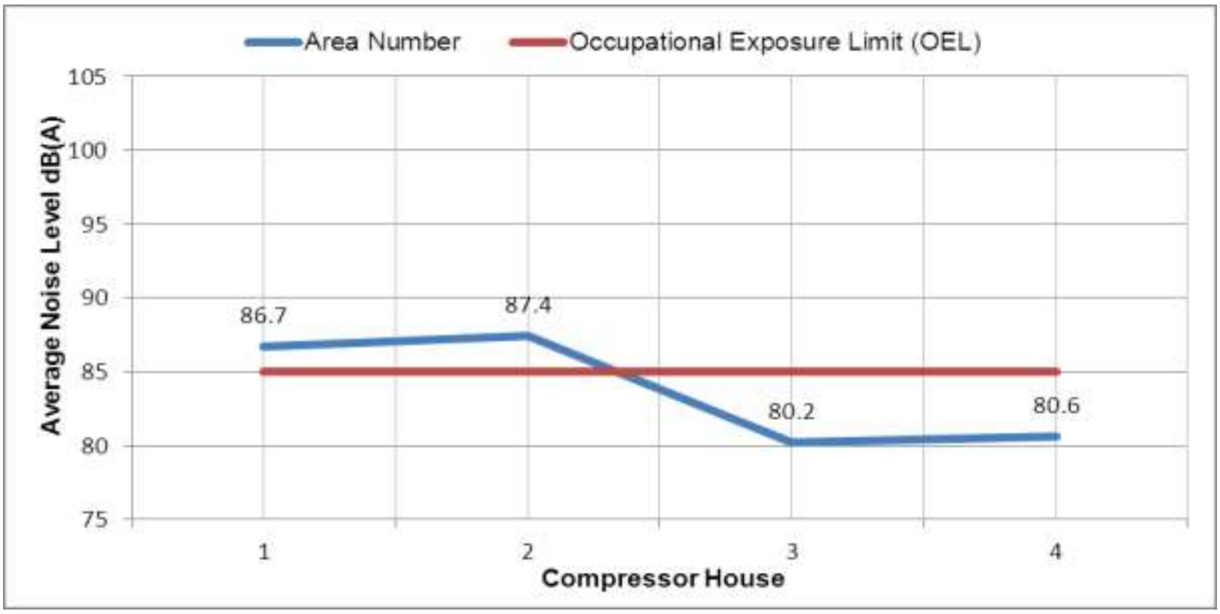


Figure 2: Average noise level at the four areas at the Compressor House.

Area Number: 1 = Compressor House; 2 = Area immediately surrounding the Compressor House; 3 = Main Control Room adjacent to the Compressor House.; 4 = Cooling Plant at the Compressor House

An Occupational Noise survey was conducted at the Compressor House of the Polokwane Platinum Smelter in order to assess noise levels. There were four areas where noise was measured. These were Larox Filter Press (Ground and First Floor); Dry Concentrate Storage, and Coal Storage Silo. There were three recorded noise measurements in the Larox Filter Press and in the Coal Storage Silo, whereas four measurements were taken in the Dry Concentrate storage.

Table 4.5: Noise levels and sources of noise for the Larox Filter Press and Storage Silo (Dry Concentrate Storage and Coal Storage Silo) of the Polokwane Platinum Smelter, South Africa

Sample	Noise level (with impulse weighing)($L_{Aieq,T}$)	Noise source
Larox Filter Press.		
Ground Floor.		
1	80.6 dB(A)	Motors; pumps; boiler making activities during plant maintenance; and repairs operation.
2	80.5 dB(A)	
3	82.3 dB(A)	
First Floor		
1	82.0 dB(A)	Motors; pumps boiler making activities during maintenance and repairs operation.
2	84.1 dB(A)	
3	84.7 dB(A)	
Storage Silo		
Dry Concentrate Storage Silo Ground Floor		
1	89.8 dB(A)	Drive; pumps; motors; boiler making activities during routine maintenance; and pingon operation.
2	94.5 dB(A)	
3	88.9 dB(A)	
4	89.8 dB(A)	
Coal Storage Silo Ground Floor		
1	87.7 dB(A)	Drive motors; boiler making; and maintenance activities, pingon
2	89.8 dB(A)	
3	88.2 dB(A)	

The results shown in Table 4.5 indicate that noise levels on the Ground Floor and First Floor of the Larox Filter Press were below the statutory limit. The highest recorded noise level at Ground Floor was 82.3 dB(A) while the lowest was 80.5 dB(A). These two levels were all below the statutory level and not considered risky. On the First Floor, the highest noise level was 84.7 dB(A) while the lowest recorded noise level was 82.0 dB(A). The average noise levels on the Ground Floor and First Floor of the Larox Filter Press are 81.2 dBA and 83.7 dBA respectively.

All recorded noise levels in the Dry Concentrate storage Silo and the Coal Storage Silo were above the statutory limit, and considered a risk to hearing. The highest noise level in the Dry Concentrate Silo was 94.5 dB(A) while the lowest noise level was 88.9 dB(A). The average noise level in this area is 91.4 dBA. The highest noise level in the Coal Storage Silo was 89.9 dB(A) while the lowest recorded noise level was 88.2 dB(A). The average noise level is 88.7 dB(A). Drive motors from air fans produce significant noise. The results indicated 88.7 dB(A) which is above noise rating limit. Smelter ensures that continuous survey is conducted and employees working at Coal Storage Silo Ground Floor wear earmuffs when entering the area to prevent being over exposed to noise hearing levels.

The results in Table 4.5, indicate that more than half of the measurements were above required limit of 85 dB(A). Pingon activities affect the noise levels in this area of the Polokwane Platinum Smelter. Pingon activities includes, running machines, fans and noise producing equipment. An increase in noise is evident during Concentrate Transfer due to machine activities. Based on the results indicated in Table 4.5, (Storage Silo) NIHL may develop over time should an employee work in this area without wearing HPD. Due to the high levels of noise at Storage Sile, overexposure on noise while working the entire shift in this section of the Smelter may contribute to the development of NIHL.

The results in Figure 3 (Larox Filter Press and Coal Storage) indicate that there were four areas were noise was measured, two of the areas were at the Larox Filter Press and two at the Storage Silo. The results shown in Figure 3 (Larox Filter Press and Coal storage Area) indicate that the average noise at the Larox Filter Press Ground and First level were below the statutory limit of 85.0 dB(A). The figure indicate that the average noise at the Ground Floor was 81.2 dB(A) and First Floor 83.7 dB(A).
In addition, the average noise level indicate that the Dry Concentrate Storage was above the statutory occupational exposure limit 91.4 dB(A), while the Coal Storage Silo was 88.7 dB(A), indicated that the results was above the statutory level as indicated in figure 3 (Larox Filter Press and Coal Storage). An increase in noise levels in this Area Storage Silo was probably due to the pingon activities during the Storage Silo (Dry Concentrate Storage Silo and Coal Storage Silo Ground Floor) 91.4 dB(A), and 88.7 dB(A) respectively.

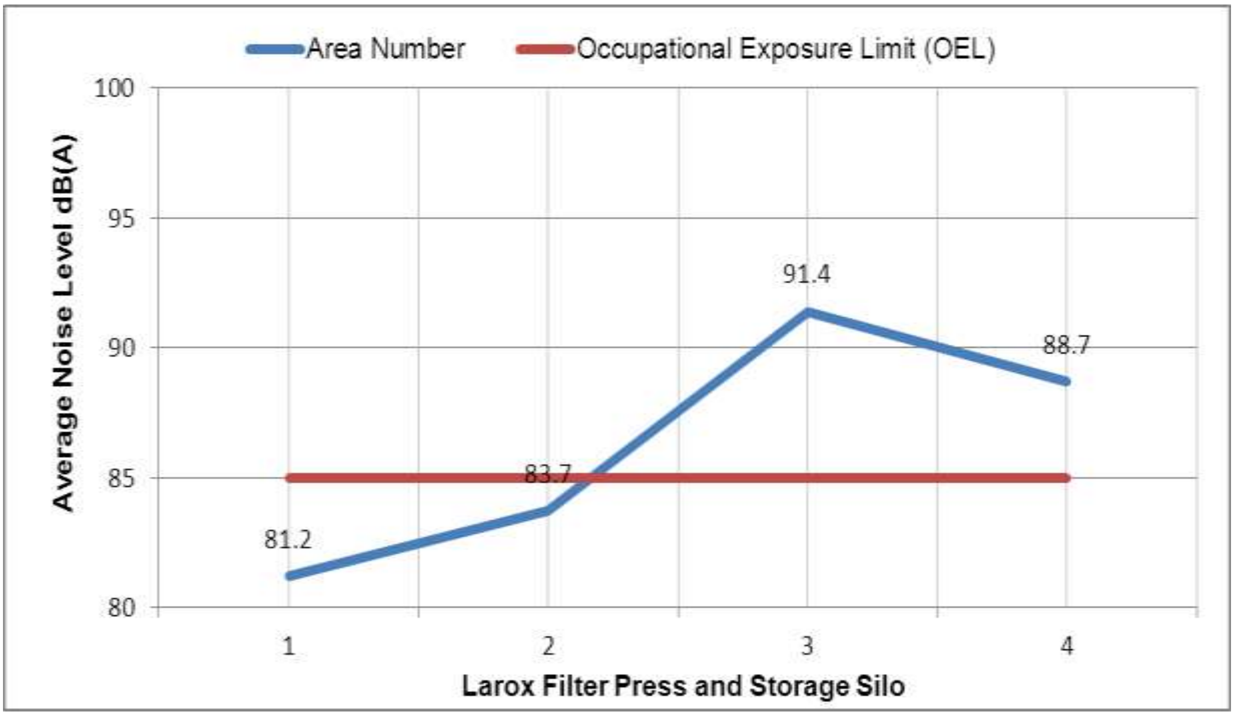


Figure 3: Average noise levels at the Larox Filter Press and Coal Storage

Area Number: 1 = Larox Filter Press Ground Floor; 2 = Larox Filter Press First Floor; 3 = Dry Concentrate Storage Silo; 4 = Coal Storage Silo Ground Floor

Average noise levels at the Coal Storage Silo and Dry Concentration Storage Silo area need to be continuously monitored and reduced. One can conclude that employees may be at risk for the development of NIHL if working in the Compressor House for an extended period of time even though the area is demarcated as a noise zone. It should be mandatory that employees entering or working in the vicinity of the Dry Concentrate and Coal Storage Silo should always have their correct HPD (earmuffs) while working or entering storage areas where results of this study indicated noise levels are above the legal limit. No engineering control can be implemented currently at the smelter in this areas as the existing machines and equipment used and installed are of modern technology. Current existing control measures and conservation hearing programme have proven to be effective. Chances of employees developing hearing loss has been minimized by the employees as they have introduced stringent control measure such as surveillance cameras to monitor employees that follow good practices like wearing hearing devices in noise-zoned areas. This assists the smelter to effectively monitor compliance with safety standards in various areas as required by the NIHL, 2003.

An occupational noise survey was also conducted on the Process Laboratory of the Polokwane Platinum Smelter in order to assess noise levels as indicated in Table 4.6. Noise levels were measured in seven areas, these were, namely, the Slag Room (2 measurements), Matte Room (2 measurements), Concentrate Area (2 measurements), Storage Room (2 measurements), Office X-Ray Fluorescence Room (2 measurements) and the Area in front of the Process Laboratory (3 measurements).

Table 4.6: Noise levels and source of noise for the Process Laboratory of a Platinum Smelter in Polokwane, South Africa

Sample	**Noise level** (With impulse weighing) ($L_{Aieq,T}$)	**Noise source**
Slag Room.		
1	89.2 dB(A)	Boiler making activities; pumps; fans, pingon; and constant air release through vents rear of Compressor House.
2	75.0 dB(A)	
3	102.0 dB(A)	
Matte Room.		
1	90.9 dB(A)	Boiler making activities; and pumps, fans.
2	80.9 dB(A)	
Concentrate Area.		
1	77.3 dB(A)	Boiler making activities; and pumps fans.
2	86.3 dB(A)	
Storage Room.		
1	63.8 dB(A)	Boiler making activities; pumps; and fans
2	73.2 dB(A)	
Office Room.		
1	59.6 dB(A)	Boiler making activities; pumps fans
2	65.2 dB(A)	
X-Ray Fluorescence Room.		
1	61.5 dB(A)	Boiler making activities; pumps, and fans.
2	63.5 dB(A)	
Area in front of building Process Laboratory.		
1	81.2 dB(A)	Cooling fans; motors; air release through vents rear of Compressor House; and boiler making activities.
2	89.5 dB(A)	
3	83.7 dB(A)	

The results in Table 4.6 indicate that average noise levels in three of the seven measured areas at the Process Laboratory were above the OEL of 85dB(A). Two of the three noise measurements at the Slag Room were above 85 dB(A). The highest noise level at the Slag Room was 102.0 dB(A) while the lowest measured noise level was 75.0 dB(A). The average noise level in this area is 97.5 db(A), which is above the noise exposure limit of 85 dB(A).

In the Matte Room, one of the two noise measurements were above 85 dB(A). The highest recorded noise level was 90.9 dB(A) while the lowest noise level was 80.9 dB(A). The average noise level of 88.3 dB(A) exceeded the noise exposure limit.

One of the two noise measurements in the Concentrate area was above 85 dB(A). The highest noise level in the Concentrate area was 86.3 dB(A) while the lowest recorded value was 77.3 dB(A). The average noise level was 83.8 dBA, which was below the noise exposure limit.

All the measured noise levels at the Storage Room, X-Ray Fluorescence Room and Office Room were below the 85 dB(A). The average noise levels in the three areas were 70.7 dB(A), 63.2 dB(A) and 62.6 dB(A), which all fell below 85 dB(A).

One of the three measurements taken in the area in front of the Process Laboratory was 89.5 dB(A) when compared to occupational exposure limit of 85 dB(A). The average noise level also exceeded the noise exposure limit, which means that if employees stay in the area for extended periods of time, such as an eight hour shift, there will be a risk of NIHL.

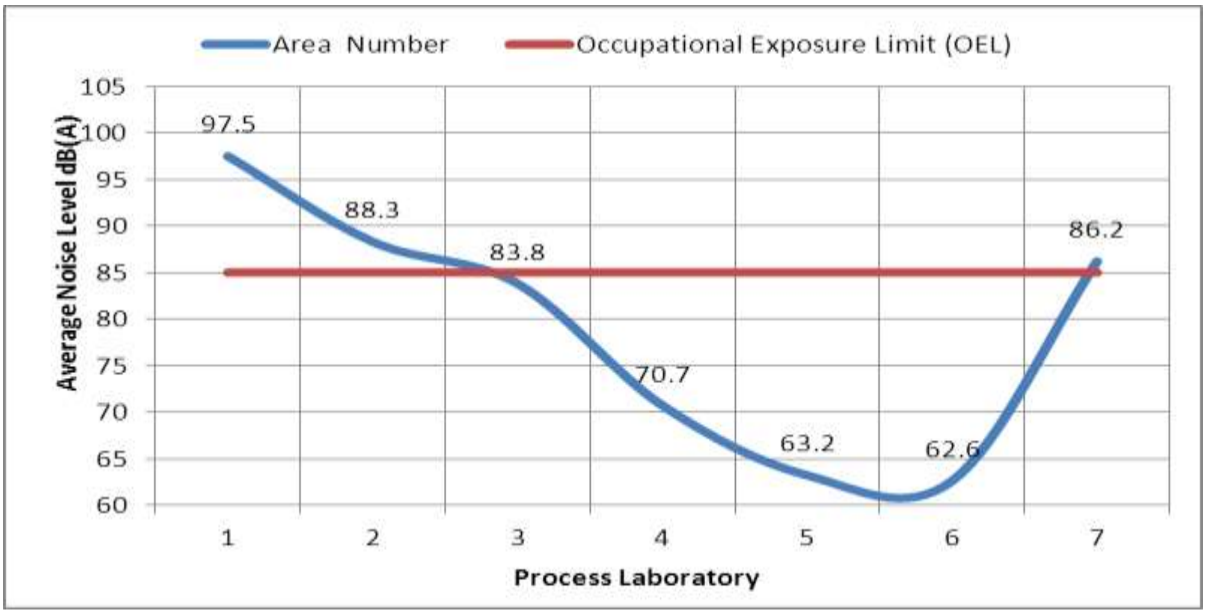


Figure 4: Average noise level in the different areas of the Process Laboratory

Area Number: 1 = Slag Room; 2 = Matte Room; 3 = Concentrate Area; 4 = Storage Room; 5 = Office Room; 6= X-Ray Fluorescence Room; 7 = Area in front of building Process Laboratory

As the results indicated, special care and monitoring need to be done to employees working fulltime in the Matte Room and Slag Room to avoid any employee developing NIHL in the future. The results indicate excessive noise in these two areas. In a case where employees work 8 hours a day, such an employee is likely to develop NIHL.

The results in Figure 4 (Process Laboratory) indicate that there were seven areas where noise was measured. The areas where the average noise measurements were above the noise rating limit were, namely, the Slag Room 97.5dB(A), Area in front of building Process Laboratory 86.2dB(A) and Matte Room 88.3dB(A). The average noise level ranged from a minimum of 59.2 dB(A) to a maximum of 102.0 dB(A). The average noise measurements in the remaining four areas were below the statutory occupational exposure limit of 85.0 dB(A) and the lowest that was recorded was at office room.

Therefore, the average noise level at the Slag Room Area in front of building Process Laboratory and Matte Room should be continuously monitored and if possible it should be reduced to the averages below the statutory occupational limit. Despite the fact that employees are exposed to a high level of noise and are at the risk of developing NIHL even though the area is also denoted as a noise zone, HPDs should be worn. Experimental group did not spend a full eight hours or a full 12 hour shift and as such that reduced chances of them developing NIHL.

An occupational noise survey was also conducted at Flash Dryer 1 of the Polokwane Platinum Smelter in order to assess noise levels around this area as indicated in Table 4.7 (Flash Dryer 1) and there were six areas where noise levels were measured at the Flash Dryer 1. These were, namely, the Bag House, Ground Floor, Hot Gas Generator, First level, second level and third level. There were two noise measurements taken at each of the second and third levels, while three noise measurements were taken at the Hot Gas Generator and First level. Lastly, four measurements were taken at the Ground Floor and the Bag House respectively.

The results in Table 4.6 and Figure 4 clearly indicate the variation of noise levels within the Process Laboratory. An employee working fulltime in the office at the process lab will not require HPDs, however, an employee working at the Slag Room for an extended period of time will require to wear HPD. Occupational noise exposure in this work area requires that constant supervision be enforced. Workers that are exposed to high levels of noise above the occupational exposure limit during their 12 hour working shift should be rotated to areas where noise levels is lower than 85 dB(A) to avoid continued exposure to high noise levels. Studies have shown that excessive noise has an effect on both work performance and the quality of work as discussed earlier (Seixas *et al*., 2005; and Lusk *et al*., 1998). The results indicate that the high level of noise can have negative impact on employees working fulltime at the Process Laboratory as compared to utility workers.

The results in Table 4.7 (Flash Dryer 1) indicate that at the Bag House, only one recorded noise measurement was above the statutory limit while the other three measurements were below the statutory limit. The highest recorded noise level was at Flash Dryer 1 Bag House 87.6 dB(A) while the lowest recorded noise level was 80.3 dB(A). This resulted in an average noise level that was below the 85 dBA standard.

Table 4.7: Noise levels and sources of noise for Flash Dryer 1 of the Polokwane Platinum Smelter, South Africa

Sample	**Noise level** (With impulse weighing) ($L_{Aieq,T}$)	**Noise source**
Flash Dryer 1 – Bag House.		
1	87.6 dB(A)	Motors; sirens; air sucking fans; boiler making activities during maintenance; routine; pingon operation; and maintenance activities.
2	80.3 dB(A)	
3	81.1 dB(A)	
4	84.7 dB(A)	
Flash Dryer 1 - Ground Floor.		
1	85.6 dB(A)	Motors, sirens; air sucking fans; boiler making
2	88.8 dB(A)	

3	88.1 dB(A)	activities during maintenance; and pingon operation
4	87.9 dB(A)	
Flash Dryer 1- Hot Gas Generator.		
1	85.9 dB(A)	Motors; sirens; air sucking fans; boiler making activities during maintenance; and pingon operation.
2	87.2 dB(A)	
3	97.2 dB(A)	
Flash Dryer 1 – First Level.		
1	86.6 dB(A)	Motors; sirens; and fans; boiler making activities during maintenance; and pingon operation.
2	89.8 dB(A)	
3	86.4 dB(A)	
Flash Dryer 1 – Second Level.		
1	86.0 dB(A)	Motors; sirens; and boiler making activities during maintenance.
2	86.7 dB(A)	
Flash Dryer 1 – Third Level.		
1	87.5 dB(A)	Motors; sirens; fans; and boiler making activities during maintenance.
2	82.9 dB(A)	

The highest noise level at Flash Dryer 1 Ground Floor was 88.8 dB(A) and the lowest noise level was 85.6 dB(A). The highest recorded noise level at the Hot Gas Generator was 97.2 dB(A) while the lowest noise level was 85.9 dB(A). The highest noise level at the First level at Flash Dryer 1 was 89.8 dB(A), while the lowest noise level was 86.4 dB(A). The highest noise level at second and Third levels were 86.7 dB(A) and 87.5 dB(A), respectively, while the lowest noise levels were 86.0 dB(A) at the Second Level and 82.9 dB(A) at the Third Level. The results indicated one of the two measurement was 87.5 dB(A) and was above OEL of 85dB(A).

The results further indicated that the average noise levels measured at the Ground Floor, Hot Gas Generator, as well as the First, Second and Third levels of Flash Dryer 1 were all above 85.0 dB(A). NIHL will occur if employees work for extended periods of time in these areas. The Flash Dryer area has generators motors and sirens that, even under normal operations, produce high noise levels.

The results in Figure 5 (Flash Dryer 1) indicate that the average noise levels measured at Flash Dryer 1 were above the statutory limit of 85.0 dB(A) in five of the six areas. Average noise levels measured at the Bag House 84.4 dB(A) and was below 85.0 dB(A). Therefore, the average noise levels at the entire Flash Dryer should be continuously monitored and reduced where possible to be below the statutory limit. With regard to these five areas, employees could be at risk of developing NIHL should the precautionary measures of wearing HPD's not be considered when working in this area, including the Bag House.

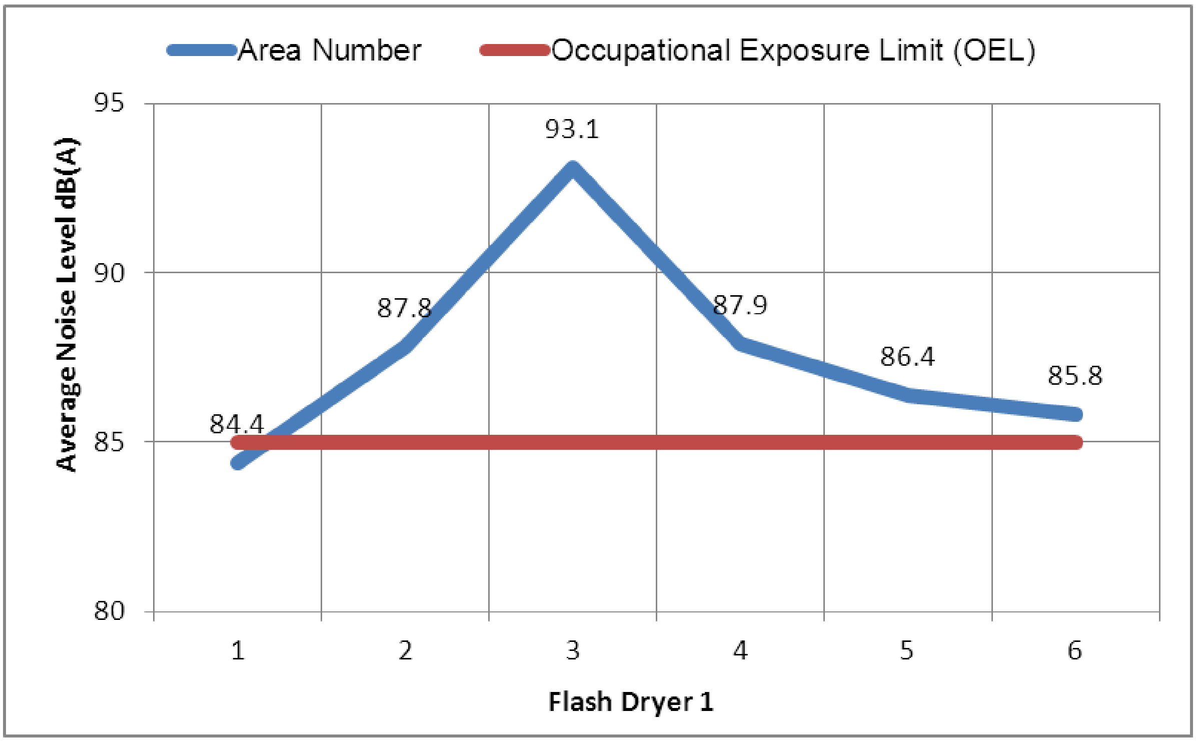


Figure 5: Average noise level of different areas Flash Dryer 1.

Area Number: 1 = Flash Dryer 1- Bag House; 2 = Flash Dryer 1- Ground Floor; 3 = Flash Dryer 1- Hot Gas Generator; 4 = Flash Dryer 1- First Level; 5 = Flash Dryer 1- Second Level; 6 = Flash Dryer 1- Third Level

Noise levels were not within the required occupational exposure limit in the Flash Dryer 1 as indicated in Figure 5. One area in the Flash Dryer 1 was below the occupational exposure limit. Based on this study, the Flash Dryer 1 is one of the areas at the Polokwane Platinum Smelter wherein employees are at a high-risk of developing NIHL due to high level of noise areas that exceeded the statutory occupational exposure limit. In the majority of the areas where noise was measured, average noise level measured exceeded the statutory limit. In spite of the fact that there was an area with noise level below the statutory level, all these areas require frequent monitoring to ensure that noise is within the required level and employees are not exposed to health-threatening situations of high noise.

An occupational noise survey was also conducted on Flash Dryer 2 of the Polokwane Platinum Smelter in order to assess noise levels. There were six areas where the noise levels were measured in the Flash Dryer 2. These areas were the Bag House, Ground Floor, Hot Gas Generator, First Level, Second Level, and Third Level. There were two noise measurements that were taken at Second and Third Levels and three noise measurements at the Hot Gas Generator and First Level while four measurements were taken at the Ground Floor and the Bag House respectively. The results in Table 4.8 indicate that all areas at Flash Dryer 2 had noise levels that were above the occupational exposure limit of 85.0 dB(A).

The highest recorded noise level at the Bag House was 87.4 dB(A) while the lowest recorded noise level was 85.3 dB(A). The highest noise level at Ground Floor was 91.9 dB(A) while the lowest noise level was 88.1dB(A). If these high noise levels cannot be controlled or lowered down to below statutory level, then the employees that perform routine duties in these areas can be at risk of impaired hearing. Alternatively, employees can wear HPD's at all times to minimize the amount of noise entering the inner ears. In addition, there should be enforcement laws or security at the gates that enter within this section or area of work to compel employees to wear HPD's. The Polokwane Smelter as a company can potentially get into a financial loss for employee's injury on duty, which generally cost companies a lot of money.

Table 4.8: Noise levels and sources of noise for Flash Dryer 2 - of the Polokwane Platinum Smelter, South Africa

Sample	**Noise level** (With impulse weighing)($L_{Aieq,T}$)	**Noise source**
Flash Dryer 2 – Bag House.		
1	85.5 dB(A)	Motors; sirens; air sucking fans; Boiler making activities and pingon operation.
2	86.6 dB(A)	
3	86.4 dB(A)	
4	85.3 dB(A)	
Flash Dryer 2 - Ground Floor.		
1	88.1 dB(A)	Motors; sirens; air sucking fans; boiler making activities; and pingon operation.
2	90.0 dB(A)	
3	90.0 dB(A)	
4	91.9 dB(A)	
Flash Dryer 2- Hot Gas Generator		
1	94.4 dB(A)	Motors; sirens and air sucking;

2	85.2 dB(A)	fans; and boiler making activities.
3	85.4 dB(A)	
Flash Dryer 2 – First Level.		
1	88.2 dB(A)	Motors; sirens; air sucking fans, and boiler making activities
2	90.0 dB(A)	
3	88.7 dB(A)	
Flash Dryer 2 – Second Level.		
1	85.8 dB(A)	Motors, sirens and fans, Boiler making activities,
2	86.2 dB(A)	
Flash Dryer 2 – Third Level.		
1	86.0 dB(A)	Motors; sirens; air sucking fans; and boiler making activities,
2	95.9 dB(A)	

The lowest noise level recorded at the Hot Gas Generator was 85.2 dB(A), while the highest noise level was 94.4 dB(A). The highest noise level recorded at the First Level was 90.0 dB(A) and all noise levels in the area were exceeding 85.0 dB(A). The highest noise levels at the second and third levels were 86.2 dB(A) and 95.9 dB(A) respectively, and the lowest noise levels reported were 85.8 dB(A) and 86.0B (A) at the Second and Third level respectively. The results in Table 4.7 and Table 4.8 indicate that noise levels at the Bag House in Flash Dryer 1 were lower compared to the Bag House in Flash Dryer 2. Employees need to continue wearing earmuff and are at risk of developing NIHL despite that the area is demarcated as noise zone.

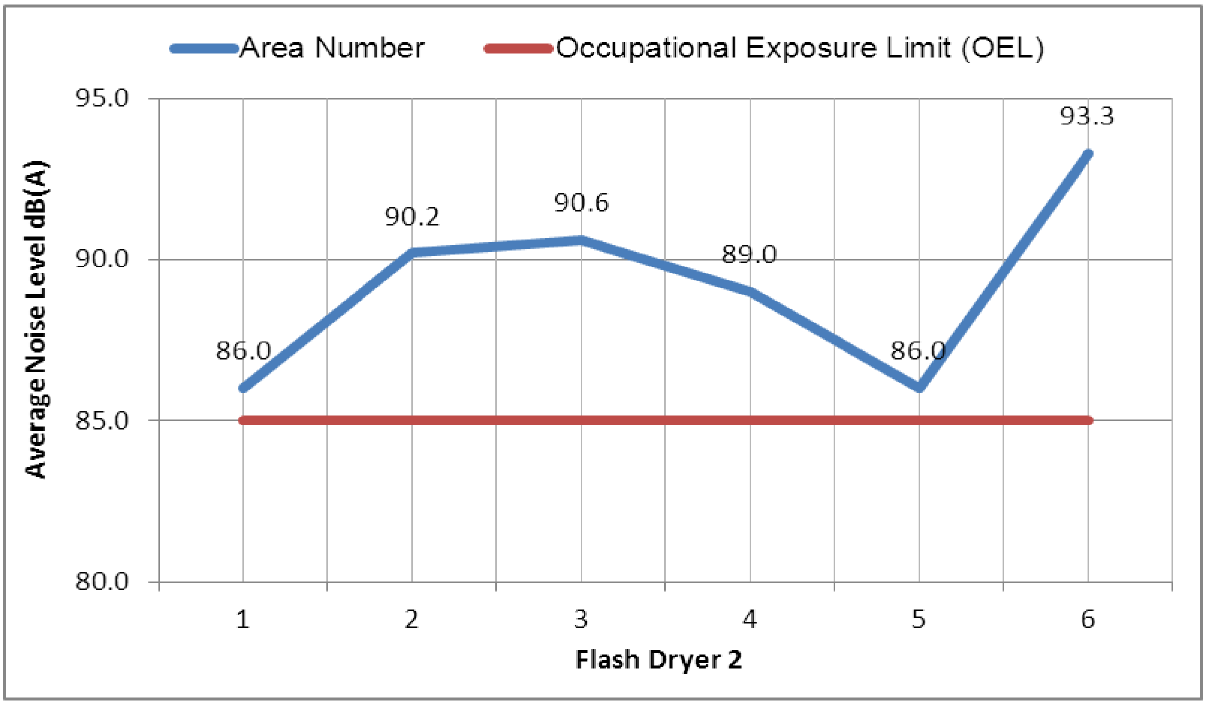


Figure 6: Average noise level of different areas at Flash Dryer 2.

Area Number: 1 = Flash Dryer 2- Bag House; 2 = Flash Dryer 2- Ground Floor; 3 = Flash Dryer 2- Hot Gas Generator; 4 = Flash Dryer 2- level 1; 5 = Flash Dryer 2- level 2; 6 = Flash Dryer 2- level 3

The results in Figure 6 (Flash Dryer 2) indicate that the all average noise levels measured in all areas in Flash Dryer 2 were above the statutory limit of 85.0 dB(A). Possible noise sources that contribute to high level of noise are sirens, pigeon and noise from operation activities. Thus it can be said the Flash Dryer 2 is a high-risk area for as employees may be exposed to excessive noise that cause hearing loss and as such, it must be regarded a priority area as the lowest average was 86.0dB(A). Although the entire Flash Dryer 2 was demarcated as noise zone, the average noise levels in this area should be reduced to acceptable levels below the statutory limit to ensure that employees are not at risk to develop NIHL.

Based on the discussed averages noise levels, it is clear that there is a possibility of employees developing NIHL over time if workers are in the Flash Dryer 2 area for eight hours or more. In the literature, it is clear that NIHL may be detrimental to employees' hearing ability and may hamper communication as well (Nandi & Dhatrak, 2008; and Saunders *et al.,* 2000). Based on the results of this study, continuous risk assessment and noise monitoring needs to be conducted at the Polokwane Platinum Smelter, especially when new equipment are installed or when the smelter equipment is upgraded after schedule maintenance.

Polokwane Platinum Smelter should consider implementing engineering controls to ensure that noise levels are within accepted levels for the benefit of employees. Engineering control may include methods such as using noise dampening technology to reduce noise levels; enclosing a process in a Plexiglas "glove box"; using mechanical lifting devices; or using local exhaust ventilation that captures and carries away noise before employees are exposed to excessive noise levels. A positive aspect is that no employees are working for 12 hours per day within the Flash Dryer area. Employees at the Polokwane Platinum Smelter are working a 12 hour shift but do not spend the entire shift in one area. If there were employees who were spending a 12 hour shift in one of the high-noise areas, there could be risks of developing NIHL in future. The monitoring should specifically include the medical assessment all employees working in the vicinity of the Flash Dryer. This practice will allow early detection of any hearing shift to its employees.

The results of this study suggest that employees in certain areas workers were over exposed to noise and were at risk to develop NIHL, if noise levels are not monitored on regular bases. Noise levels at areas such as the Slow Cooling Area which fall under the Furnace suggest that if employees were to work a normal shift, then there was likelihood that development of NIHL could be experienced. The average noise level at the Slow Cooling Area was 105.1dB(A) and exceeded the acceptable noise level 85 dB(A). However, where noise levels exceeded the occupational legal limit, such areas at the Polokwane Platinum Smelter are clearly marked as noise zones.

Employees working in such areas were given hearing protective equipment to ensure their safety. In these areas, noise monitoring should be done at regular intervals, even though such areas are demarcated that does not mean that employees are not at risk of developing noise induce hearing loss.

The Polokwane Platinum Smelter further requires employees to wear their HPD when entering demarcated noise areas. One of the good safety practices was that, there were shift rotations among employees in different sections during their various shifts. In noise zones such as the Furnace and the Flash Dryers where they may be exposed to potential damaging noise while the plant was operating, employees did not work a full 12 hour-shift. This ensured that workers were not continuously exposed to high-risk noise in one area for a long time. In addition, the presence of the occupational hygienist and the supervisors to monitor noise levels, as required by the OHS Act (85/93), also ensured that the Polokwane Platinum Smelter adhered to the requirements as stipulated in the act.

In a case where average noise level increase to 110 dB(A) at the Polokwane Platinum Smelter, this could affect human organ balances. In the Polokwane Platinum Smelter, vibration sources include fans, loading tracks, and drills machines that may also play a role in increasing of noise levels. This may cause dizziness, communication, nausea, and loss of balance during working hours.

An average intense noise between 100dB(A) and 130dB(A) has negative effects on the eyes including a slower speed of focusing, changed colour vision and nystagmus (Sasaki *et al.,* 2006; Prince *et al.,* 2003). Rotational interventions ensured that hearing of employees is able to recover and chances of developing hearing loss are reduced. This minimizes the damage to ear function (Chen & Henderson, 2009). Special care should be given to areas which indicated high level of noise such as Furnace, Flash Dryer's, Storage Silo as the average noise was above 90dB(A). The results show that employees working in these six areas are likely to develop NIHL, if they do not take necessary safety precautions.

In this study, the results indicated that there were areas where average noise levels were higher than occupational exposure limit of 85dB(A) and that may affect the middle ear as is evident in the study performed by Merchant *et al.,* (2005).

4.3 Types of Noise and Its Effect

The Polokwane Platinum Smelter contains different types of noise such as fluctuation, continuous and intermittent noise. Noise sources such as noise released from compressed air (impulsive noise), the use of angle grinders (intermittent noise) may have impact on hearing loss if not effectively control or managed by the smelter. During route plant maintenance and normal operations, noise surveys are conducted by the Smelter Hygienist to ensure that compliance is not compromised. The study discusses the effect of noise, socio and the physiological effect of noise.

The use of advance pumps and electrical motors contribute to the increase of noise exposure and this type of noise can be referred to as continuous noise. During the survey, the researcher noticed that such equipment play a role in the increased level of noise within the entire Polokwane Platinum Smelter.

Occupational noise exposure statutory limit of 85 dB(A) was exceeded during the normal processes at the Polokwane Platinum Smelter, due to equipment fans and pumps in some areas such as Flash Dryer 1, Storage Silo, and Flash Dryer 2.

During mud guns operation, noise level increased and it was concluded that mud guns play a role in the increase of noise levels at the Polokwane Platinum Smelter. Based on the observations, mud guns were a major source of noise during normal operations at the Polokwane Platinum Smelter. The noise was monitored during noise survey.

Study results indicate that the average noise levels were high in the following areas, Coal Storage Silo, Flash Dryers, Furnace, and Storage Silo (Dry Concentrate Silo and Coal Storage Silo). During the occupational noise survey the Polokwane Platinum Smelter operations continued as usual and no equipment were switched off during noise monitoring. Identified noise sources included the mud guns, pingon, compressed air release, alarms, and boiler making activities. This types of noise sources may be a combination of Intermittent, fluctuating, continuous or impulsive noise. The study propose that future studies be conducted to assess impact of noise sources on hearing loss and increase in noise levels. The current study aimed to assess noise level in certain areas of the smelter and not to deal effectively with sources of noise and its effects. Acoustic reports and engineer were not available to be examined during the period of the study.

During observation the pingon in the casting bays was used to break up the caste Matte and during that process the noise level increased and was above the statutory occupational exposure limit. The study concluded that pingon, and mud gun contribute to excessive noise at Flash Dryer 1 and other areas as discussed above. Occupational noise controls were discussed daily with employees during toolbox talk prior to the start of each shift.

During the noise survey, which was before the noise measurements were taken, it was observed that the noise exceed the noise rating limit in areas such as the Flash Dyer, Furnace, Matte Casting and Dry Concentrate Storage, during normal activities. The results confirmed these observations; in addition, impulsive noise caused by compressed air being released caused excessive noise levels.

Overhead crane and diesel forklifts (intermittent noise) were also used on a regular basis in the loading activities that occur on a daily basis. Contractors doing boiler-making work were using a diesel generator. These activities were other potential sources of excessive noise. Pumps and fans equipment also produced excess noise. Based on the observation of NIHL at the Polokwane Platinum Smelter can result from activities other than normal activities and operational related equipment, generators can cause hearing damage as well. There are noise sources that were usually operated independently of each other, but do contribute to an increase in noise levels. The study indicated that different areas of the Polokwane Platinum Smelter produced different types of noise. Occupational noise measured depended on the type of activity that is performed.

Most studies of noise-induced hearing loss in humans and animals involved continuous noise exposure. Intermittent noise is reported to cause TTS and less hair cell damage compared to continuous noise (Martini, 2006; and Patuzzi, 1998). Employees at the Polokwane Platinum Smelter were exposed to continuous noise. Instruments and equipment that produce intense sound that clearly deserves special attention by reducing noise using engineering control aids.

According to the observation and survey of this study, there is evidence that the Polokwane Platinum Smelter produces intermittent, impulsive, continuous and fluctuating noise in the Flash Dryer area. Intermittent noise exposures produce less TTS and PTS and less cochlear damage than continuous exposure (Kardous *et al.,* 2005). In the present study, the experimental group was not at risk to developing PTS as they were not exposed to excessive potential hearing damage noise for an entire shift. Employees could develop temporary deafness for minutes (Botteldooren *et al.,* 2006; and Patuzzi, 1998). Auditory damage can be explained by the fact that the auditory system has time to recover between noise phases (Starck *et al.,* 2003).

Previous studies showed that the degree of protection from noise damage afforded by periodic interruption of exposure depends both on the noise and rest parameters (Opperman *et al.,* 2006; and Kardous *et al.,* 2003). Those reports suggested that if the rest of the period between exposures is too short and/or the intensity of exposure too strong, intermittency will not result in a decrease in cochlear damage (Starck *et al.,* 2003). Auditory system is able to recover from any potential damaging noise. This is because employees were not permitted to work for more than 15 minutes in noise-zones, especially the Furnace during normal activities for a specific day. Results indicated that noise increased above the occupational exposure limit and as such physiological effects in the auditory system can exist and cause NIHL among employees.

4.4 Control Measures

4.4.1 Existing Control Measures

In considering the auditory and non-auditory effects of NIHL, the Polokwane Platinum Smelter took important action to lower noise levels prior to operation by using most recent Safeguarding Technology (i.e., noise dampening technology to reduce noise levels). However, Polokwane Platinum Smelter's average noise level in certain areas was above 85 dB(A), all areas where noise exceeded 85 dB(A) were demarcated noise areas with adequate warnings. Employees working or entering such area must wear ear protection. It is a responsibility of the employer to provide proper HPD (earmuff or earplugs) according to OHS Act (85/93) and to make employees aware of related risk. Hence the Polokwane Platinum Smelter put warning signs and denoted such areas as noise zone. The OHS Act (85/93), further states that employees have the responsibility to inform the employer of new risks and should wear the HPD as provided by the employer. Legal compliance is both for the employer and the employee.

4.4.1 Engineering methods

In this study, the results indicated that average noise levels did exceed the statutory limit in certain areas of the Polokwane Platinum Smelter such as the Furnace. To control notorious high noise in the Polokwane Platinum Smelter facilities, engineering controls are implemented as a first safety management priority as required by the law.

Engineering controls include proper sound absorptive treatment in the Furnace and other parts of the Polokwane Platinum Smelter (e.g. for ceiling, floor, walls, and doors). Sound absorption material in the area of the Furnace at the time of the survey were installed. However, noise levels at the denoted areas may still exceed the statutory limit because of the activities in this area.

In addition, the classical commercial machines were designed so that the volume and equalizer can only be set or adjusted by the technician and engineers as they were the only personnel trained and allowed to adjust equalizers. In other words, other employees including utility workers that were employed to work in demarcated noise zone were not allowed to adjust noise levels by themselves. For this reason many employees who were working at the denoted noise zones do not generally ask for adjustment.

4.2.2 Administrative Controls

- *Demarcation of noise zones*

All areas with high noise levels were demarcated as noise zones, i.e. areas with noise levels that equal or exceed 85dB(A) during normal working hours. Polokwane Platinum Smelter has also ensured that all areas where high noise is evident such areas are clearly identifiable with safety mandatory signs and notices at the Smelter. Administrative controls at the Smelter involved changes in workplace policies and procedures. This included the following:

- Warning alarms;
- Labelling systems;
- Reducing the time workers are exposed to a hazard; and
- *Training*

For example, workers be rotated in and out of a hot area rather than having to spend eight hours per day. Back-up alarms for example of effective warning systems. However, warning signs used instead of correcting a hazard that can and should be corrected are not acceptable forms of noise control. High noise areas are zoned and clearly demarcated. Employees are aware of the Hearing Conservation program introduced by the Smelter.

- *Communication and training*

Results of the conducted surveys are posted on safety notice boards and further discussed during Smelter start-up meeting and management meetings on weekly bases. Display and communication of survey results are encouraged by NIHL, 2003. This may be regarded as a best practice by the Smelter as required and is in line with the Mine Health and Safety Act (MHSA) (29 of 1996) of South Africa. Current control measures entail strict measures such as use of HPD, clearly demarcated noise zone areas. Employees participate during meetings and give inputs on hearing conservation program during department meetings including the utility employees.

4.2.3 Personal Protective Equipment

Results indicated that certain areas (i.e., Storage Silo and Flash Dryers), employees where exposure to high noise levels that can lead to loss of hearing over time. Polokwane Smelter, through its internal procedure aims to reduce the noise level emitted by all noisy equipment to below 110 dB(A). Level of noise currently attenuated through the use of hearing protection devices (HPDs) to below the targeted level of 85dBA in those areas where noise level was above 85 dB(A). There were no cases of NHL identified since the start of operation of the Smelter. The Polokwane Smelter ensures noise reduction target are met and are in line with the South African Mine Health and Safety Council targets through:

- baseline assessments of all work areas to identify noise reduction needs;
- the silencing of noisy equipment; and
- mandatory wearing of HPDs in areas where noise levels exceed 85dB(A).

In addition to the engineering methods that the Polokwane Platinum Smelter applied, employees were given earplug and earmuff. HPD do not keep out noise entirely. Employees were expected to wear HPD in areas that were identified as noise zones, and again employees were trained to use and fit HPD such as ear muffs and ear plugs properly.

Hearing Protective Devices (HPDs) should be used during the operation of the mud gun and pingon in Matte casting to prevent exposure, as such operations can increase noise levels as it was observed during the study.

Thus damage to hearing is greatly reduced when employees are wearing HPD, but some damage to hearing may still occur. All employers and visitors are required to wear basic protective clothing such as safety boots, earmuffs, or ear protective equipment before entering the Polokwane Platinum Smelter.

The Polokwane Platinum Smelter further has put notices in most areas to show what type of safety or protective gear is needed. A supervisor is available to ensure that visitors and workers adhere to the safety regulations and safety requirements. Though noise levels cannot be blocked 100% by HPD's, it is reduced significantly when wearing the correct HPD in the correct way.

In the questionnaire employees were questioned about their use of HPD's and the training on how to use these devices. Cross Tabs and Pearson chi-square analysis were used to compare the use of HPD, training on the use of HPD, and the fitting of the HPD for the experimental group. Control group never used HPD so the significant differences in this regard were expected and are meaningless, except to indicate that there are successful training and use of HPD at the Polokwane Platinum Smelter. More than 90 % of workers used HPD including earmuffs. All experimental subjects were trained and knew how to fit the HPD. Control group never used HPD's and as a result, such employees were excluded from this part of the report.

Frequencies of the use of HPD, training on the use of HPD, and the fitting of the HPD for both the control and the experimental group based on the questionnaire participation are discussed and the results indicate that employees that wear their HPD during the course of the study was 94.2%, even though the expected number of employees compliance should be 100%. This is a positive indication that there was awareness of NIHL amongst employees. This can be attributed to the fact that management was committed in ensuring that no employee is harmed or affected by occupation noise, and indicated compliance to NIHL Regulations, 2003.

More walkthrough survey and enforcement need to be done especially for workers based at noise zones to ensure that they are not over-exposed to noise. Employees may be over exposed while wearing HPD's as prescribed due to the fact that employees were not properly trained and do not know on how to fit hearing protective aid/device properly. During the study less than 10% of employees indicated that they forgot to wear their HPD especially earplugs although they were provided with them.

Thus, the study indicated that because of the possible average noise increase during normal operation times, when the Polokwane Platinum Smelter switched of fans or were on standby and when minor repairs work are in progress, employees were provided with HPD and warning signals. Warning safety signs indicate the type of HPD that needs to be used and indicate whether it is a noise zoned area or not. However, the high level of occupational noise at the Polokwane Platinum Smelter may have a serious negative health effect on employees. If employees do not wear HPD in demarcated noise areas their hearing can be affected.

This study further, concludes that the present control measures play a pivotal role to reduce noise levels and noise exposure and that the experimental group of utility workers were not at high risk for the development of NIHL as long as precautionary measures of wearing their HPD's as prescribed in all noise zones.

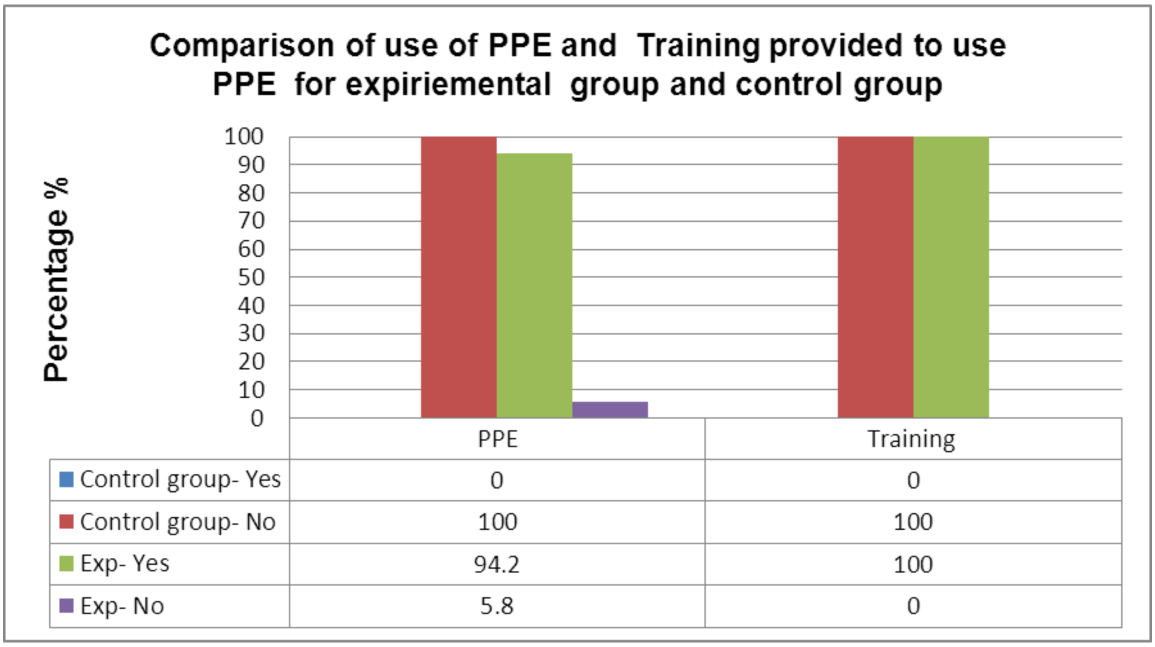


Figure 7: Indicate that the control group did not use or fit PPE aimed for hearing loss prevention compared to the experimental group that confirmed the use, training and proper fitting of ear protection

The present study expected that the control group indicated that 100% of the group did not wear HPD nor trained to use HPD. The accurate of this section of the result is as a results of the control group do not need HPD while performing their daily activities whilst compared workers at the Polokwane Platinum Smelter.

The results of this study confirmed that Polokwane Platinum Smelter and its employee's use of HPD as required by the job specification. The study further confirmed that the Polokwane Platinum Smelter provides training on the use of HPD and demonstrations on how to fit HPDs. Failure to use earmuffs as discussed can lead to possible loss of hearing in members of the experimental group of this study.

4.4.4 Hearing Conservation Program

Researchers investigated the hearing protective conservation practices of the ten foundries in industries with high compensation claims (Danielle *et al.,* 2002). Kim and colleagues (2010) suggested that workers continue to face a substantial risk of developing NIHL due to poor management and implementation of hearing conservation programme. This was due to both poor education of employees regarding NIHL and poor noise management on the part of the employer.

These findings were possible in the South African context. Whatever the area of failure may be, only once both employee and employer became part of the solution can hearing conservation really begin to work (Doke, 1996). In this study as the Polokwane Platinum Smelter is still new, compensation claims, poor management and a lack of proper education were not identified. According to the current practice the Polokwane Platinum Smelter has a properly identified conservation programme that may reduce such problems.

More than a decade ago, NIHL and exposure of employees to occupational noise were evident in general in South Africa; hence industries are now required by the Department of Labour to report these incidents on annual basis. Anglo Ashanti embarked on occupational hygiene programs, which included monitoring noise on a regular basis and option of replacing existing machines with less noise producing machines as part of engineering controls. The programme for continuous monitoring, medical surveillance and a summary of the plan to reduce noise levels, was sited at safety and health performance in 2008. All employees at Anglo underwent regular audiometric tests (Anglo Platinum, 2007). The good practice was adopted by the majority within the mining sector, agriculture and construction industries as it was evident during inspection and during the period of the study.

Early identification of NIHL in susceptible individuals will enable appropriate intervention to be implemented and reduce the risk of further impairment. Therefore, as the results indicated that average noise level in all areas at the Polokwane Platinum Smelter exceeded the occupational exposure limit, assessment of personal exposure to employees remains important to assess whether employees have not developed hearing loss. Experimental group employees were involved in various work methods. Noise exposure differs from employee to employee; wearing of HPD's may attenuate the effect of noise on hearing. Employees may differ in terms of noise sensitivity and as such, development of hearing loss may differ.

In addition, employees could be involved in habits during their private time that may potentially expose such employees to different levels of noise. These employees use different modes of transport giving rise to different levels of external environmental noise. Again, some employees worked in other industries that might have had potential damaging noise that may cause slow progression of NIHL. Audiometric tests were used to determine the effects of possible over exposure to noise and can be regarded as an indicator of damage due to noise exposure in employees at the Polokwane Platinum Smelter.

A hearing conservation programme was implemented at the Polokwane Platinum Smelter. Hearing conservation was introduced with the aim to increase awareness and educate employees about NIHL and its implications. The Polokwane Platinum Smelter used the program to ensure that its employees were aware of the risks within the Polokwane Platinum Smelter that were likely to affect and reduce their hearing capabilities. According to Kim and colleagues (2010), who studied the behaviour of workers using hearing protection, some employees adhered to wearing of hearing protection and others not. The present study indicated that 5.8% of the employees were found not wearing their proper HPD.

4.5 Questionnaire Analysis

The results below indicate the analysis of the questionnaire. Results were analysed using an SPSS Programme facilitated by the University of Limpopo Research Office.

4.5.1 The Effect of Age

The study conducted by Nandi and Dhatrak (2008), indicated that aging might be one of the factors that may contribute to the hearing loss, though in the present study the individuals who participated in this study were below the age of 55 years which is determined as a susceptible age to develop NIHL. Hearing abilities reduce as you get older and the Cochlear ability to function is reduced (Nandi & Dhatrak, 2008; and Riva *et al.,* 2007).

In the present study, subjects between the ages of 16 and 48 years were included. The average age of the experimental group was between 29.8 (±6.2) years and that of the control group was 24.0 (±3.4) years. Thus, the average age of the experimental group was higher than the control group although every effort was made to ensure that the control group match the experimental group. The independent samples t-test was used to compare the mean ages of both control and the experimental group. The experimental group was significantly older than the control group ($p = 0.003$).

In this study age did not seem to contribute to the development of HL, because of the relatively young age of the subjects. There were no cases of HL reported during this study as age seems not to be the factor as subject were young. The effect of aging on hearing thresholds is gradual (Pichora-Fuller and MacDonald, 2009; and Celik *et al.,* 1998). There is no precisely defined onset of this process. Nevertheless, there are some reports which use a limit of 55 years for an onset of a detectable age-induced hearing loss (Pouyatos *et al.,* 2005; and Chen *et al.*, 2007). All subjects who participated in the present study were younger than 55 years.

Therefore, it would be reasonable to state that in the present study, the age difference between the control and experimental groups had no significant effect. The occurrence of auditory damage (if present) would probably not be due to age. However, various factors such as non-occupational noise exposure contribute to hearing loss.

4.5.2 Non-Occupational Noise

In this study, the results indicated that experimental group were exposed to possible damaging noise during their leisure activities. Recently, there was more concern about self-reported leisure (non-occupational) noise than before, although most research was concentrated on occupational hearing loss (Berger & Kieper, 2000; and Casali *et al.,* 2000). This studies evaluated leisure noise. This includes exposure to music (Aono, 2000); live disco (Phillips & Owens 2004; and Betz, 2000), classical or jazz concert (festival) noise, (Opperman *et al.,* 2006; and Bogoch *et al.,* 2005), exposures from walkman-type personal listening devices (Charles, 1997), noise around home, noise from sports-related activities such as hunting and gambling-related entertainment noise (Aono *et al.,* 2000).

According to Opperman *et al., (*2006) and Bogoch *et al.* (2005), it is evident that exposure to non-workplace noise is potentially dangerous. In addition, it is clear that self-reported leisure or non-occupational activities may cause hearing loss. The control group, their nature of activities including doing practicals and attending classes, in that study environment there were no equipment that produced noise according to self-reported and observation. Therefore, there was no exposure to occupational noise.

The analysis of a questionnaire indicates that there were various factors in the occupational and leisure time environment that may contribute to the development of NIHL. The results suggest that before an employee is diagnosed with a hearing disability, the employer should identify other possible sources of noise that the employee may be exposed to before concluding that it may be occupational noise levels. Self-reported leisure activities and non-occupational noise that exposes individuals to high levels of noise may contribute to the development of hearing deficiency in employees at the Polokwane Platinum Smelter as duration of noise is not monitored and the intensity of noise is not measured. Studies as indicated in the literature indicate that leisure activities contribute in the development HL (Casali *et al.,* 2000). It is important to note that NIHL are caused by both non-occupational and occupational activities.

Table 4.9: Results indicating the percentages of subjects in the experimental and control groups exposed to noise during leisure activities

Leisure activities						
Variables	Grinding	Hammeri ng	Noisy machine	Welding	Radio	Other
Experimental group	0.00 %	12.1%	0.00%	0.00%	93.8 %	6.3%
Control group	2.6%	7.7%	2.6%	2.60%	61.4 %	10.3 %

The results in Table 4.9 indicate that 93.8% of the experimental group listened to loud music when compared to 61.4% of the control group during self-reported leisure activities. The results further indicated in the control group that 2.6% of the subjects participate in grinding activities, 7.7% hammers, 2.6% work with noisy machines, and 2.6% welds. In the experimental group, 12.1% does hammering work. None of the subjects in the experimental group participated in grinding activities, used noisy machines, or welded in their leisure time.

As it is also found in some of the non-workplace noise evaluation studies, levels of non-occupational noise may be, in some cases, significantly higher than those measured at their workplace (Yearout & Brown, 1991). In this present study, non-occupational noise may accelerate potential NIHL. Individuals in both the control and experimental groups reported that they participated in activities that produced excessive noise such as those in Table 4.9. In this study, it can be concluded that the study group may be exposed to various noise sources outside the working environment. As such, when exposed to high level of noise such as loud music and noisy machines their hearing ability may be reduced.

The study further indicates that employees and control group listen to radio while travelling to work and during leisure time respectively. Employees were exposed to car radios and it was evident from the questionnaire response. Thus, employees should be educated about the effects of noise during leisure activities.

4.5.3 Occupational History

Occupational history may also contribute to hearing loss more especially when an employee's previous work experience include working in an area producing loud noise. Exposure to high level of noise within the mining, construction, farming and other industries are common (Aybek *et al.,* 2010; Burns & Robinson, 2009; Abdulla, 1998).

Table 4.10: Results indicating the % of individuals in both the control and experimental groups that reported exposure to noise during occupational history

Occupational history						
	Farming	Construction	Transport	Mining	Workshop	Factory
Experimental group	6.7%	25.0%	6.30%	43.0%	26.7%	40.0%
Control group	0.00%	5.1%	0.00%	0.00%	2.6%	5.00%

Research has shown that employees working in manufacturing, construction, and transport were prone to NIHL (Lusk, 2004). According to Table 4.10 (Occupational History), many individuals in the experimental group previously did work in which they were exposed to loud noise. The control group 5.1% was previously employed in the construction industry, and workshop (performing grinding, workshop and boiler-making activities) (2.6% and 5% respectively) and factory work.

According to Table 4.10 (Occupational History), there was evidence that a large percentage of the experimental group was exposed to noisy occupational environments before joining the Polokwane Platinum Smelter. In contrast, only a small percentage of the control group were previously exposed to high levels of occupational noise.

All workers at the Polokwane Platinum Smelter had baseline audiograms performed before starting with work. Thus it is unlikely that any HL in the control group was caused by previous occupational exposure. In the case of the experimental group, any previous development of HL could be easily detected during the baseline measurements.

In the present study, employees who worked in other industries that generated excessive noise such as construction, foundries, mines, and agriculture had a high risk of developing hearing loss. There were no employees that developed hearing loss from the previous noise exposure. However, some of the experimental groups were exposed to power drills and chain saws that had a potential to produce noise level of up to 100 decibels (Lusk *et al.,* 1998) in their previous work. For this reason, the experimental group was at a risk of developing HL.

The results further indicate a significant difference between the control and experimental groups in relation to previous employment specifically with regard to the mining and construction sector. 43% of experimental group has previously worked in mining environment and none of the control group. A quarter of the experimental group has previously worked at construction industry compared to 5.1% of the control group. The difference is expected as there is no risk of occupational noise at the university, the control group level of exposure and risk to noise is negligible as compared to the significant exposure of the experimental group. Control group did not indicate any signs of NIHL as they are currently studying towards potential employment and only few students indicated that were previously employed. Thus, the average work history of the experimental group was higher than that for the control group although every effort was made to ensure that the control group match the experimental group. The independent samples t-test was used to compare the occupational history of both control and the experimental group. The occupational history for the experimental was group significantly higher than the control group ($p= 0.001$).

4.5.4 Exposure to Chemicals

The Polokwane Platinum Smelter produces various occupational and environmental hazards, for example heat (from exhaust system, machines and fans) and chemicals (nitrogen oxide, sulphuric oxide, carbon dioxide and nitrate oxide) in small quantities.

Each employee at the smelter had been be conscious of their health in their work environment by formal and informal training including staff engagement session. This include recording or reporting any pain, discomfort, injury or illness that they believe is work-related or caused by Environmental Hazards. Such information shall be reported to supervisors and appropriate corrective action to reduce the risk to health and safety shall be taken by the employer (Smelter Representative).

The risk associated with each environmental hazard can be **controlled** by implementing the following hierarchy of controls:

- **eliminating** the risk from the workplace, e.g., by removing hazardous that have a potential to cause excessive noise such as machine that require maintenance.;
- **substituting** a material in the workplace environment with a less hazardous one, e.g. purchasing non-hazardous equipment, or using lead free paints;
- **redesigning** the workplace layout to reduce risks, e.g., rearranging furniture to allow easy access to materials and equipment;
- **isolating**, closing off or guarding a particular hazard in the work environment, e.g., keeping machines and equipment isolated;
- **administration**- adjusting the time and conditions of an individual's exposure to the noise and areas that is poorly ventilated, e.g., rotating tasks so that employees do not spend too long in noisy conditions, or too long performing a task next to exhaust or uncontrollable fumes.
- providing **Personal Protective Equipment** as a last resort, when higher-order controls are not practicable, e.g., providing hearing protection equipment, and respirators to prevent potential fumes.

Table 4.11: Results indicating the percentage of individuals in both the control and experimental groups that reported chemical exposures exposed to during a working shift

Exposures					
Variables	Paint	Electro-chemical	Gases exposure	Lead	Other
Experimental group	13.3%	12.5%	93.30%	12.5%	12.5%
Control group	0.00%	0.00%	12.50%	0.00%	5.1%

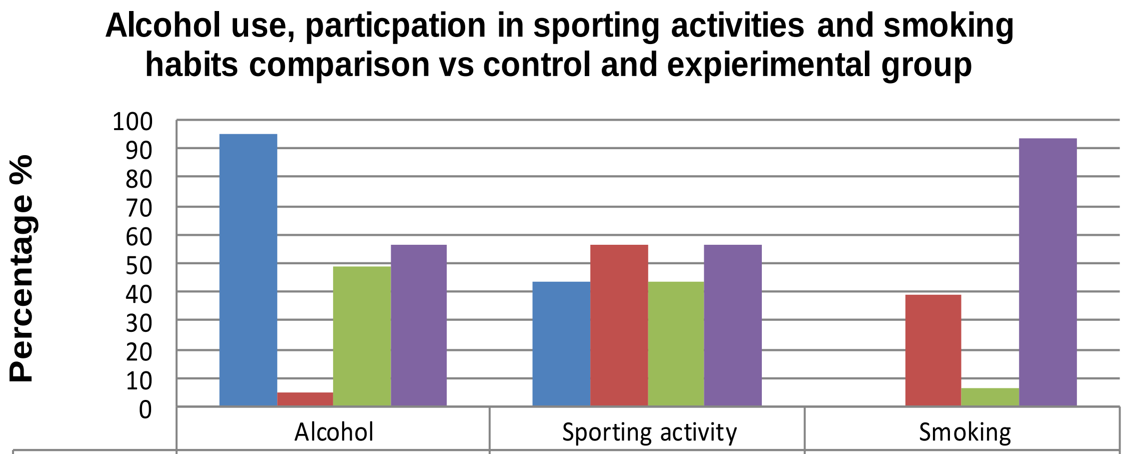
According to Table 4.11, the experimental group are much more exposed to chemicals that may potentially damage hearing as opposed to the control group. Since the control group was a group of students who should not be exposed to chemicals this is to be expected. Based on the Table 4.11 (% of individuals in both the control and experimental groups that reported chemical exposures exposed to during a working shift), it is necessary to understand the correlation of noise and other work related activities (painting, gas exposure, exposure to lead) that may influence development of NIHL.

Combination of noise and chemicals may have effects on hearing loss. Excessive exposure to chemical may reduce the oxygen supply and put employees at a risk of developing HL (Chen and Fechter, 1999; and Morata *et al.*, 1999). However, in the study there were no cases reported yet where hearing loss developed because of exposure to chemicals that the Polokwane Platinum Smelter produces. Chemicals may cause insufficient oxygen supply and exposure to CO may cause development of hearing loss (Morata *et al.*, 1999). However, the Polokwane Platinum Smelter is well ventilated, sucking fans are being used; occupational and environmental hazards are eliminated.

4.5.6 Medical History

In the present study, medical history was studied and the results indicated that none of the subjects were at risk to develop NIHL due to their genetic or medical histories based on the questionnaire responses. However, this does not mean that employees do not have the potential to develop NIHL. The study did not investigate genetics as it was not part of the scope of the study. However, this does not rule out the possibility of the study group and experimental group developing hearing loss as the questionnaire did not provide clinical evidence.

4.5.7 Smoking, Alcohol and Exercise



	Alcohol	Sporting activity	Smoking
Control-Yes	94.9	43.6	0
Control- No	5.1	56.4	39
Exp- Yes	48.8	43.8	6.2
Exp- No	56.3	56.2	93.8

Figure 8: Indicates smoking habits, use of alcohol and physical activities by both the control and the experimental group based on the questionnaire participation

Exp= experimental group and control refers to the control group.

- *Smoking*

Hearing thresholds of smokers are reported to be consistently poorer than their non-smoking counterparts (Ecob *et al*., 2008; Ross & Murray, 2004). Smoking is reported to be associated with increased risk of developing high-frequency hearing loss when exposed to occupational noise, while these synergistic interactions with smoking associated with low frequency hearing loss could not be found (Mizoue *et al.,* 2003; Toppila *et al.,* 2001). Construction, woodworking, metal and foundry workers are therefore at the risk of the development of NIHL through lifestyle factors. The study concluded that even if there are smokers among the utility workers, there was no correlation that smoking can cause hearing loss as no clinical evaluation was conducted. Currently, smoking may not be a concern but because of the known effects of smoking, employees may be at risk in the near future. Based on the results, the experimental group smoked significantly more than the control group ($p \leq 0.115$).

- *Alcohol*

Alcohol use was reported to influence the development of HL, especially in the low frequencies (Brachtesende, 2006). The impact of this lifestyle factor on the development of NIHL was possible in the control group as they are not exposed to occupational noise. A significantly higher alcohol intake (p= 0.000)was when comparing the two groups. Lifestyle factors for this study did not indicate that HL can be caused by alcohol consumption. Some of the utility workers are occasional drinkers. Based on the questionnaire the study cannot conclude whether alcohol can cause permanent hearing loss. Polokwane Platinum Smelter management should educate its employees on HL and the effects of alcohol.

- *Exercise*

Dynamic physical exercise showed to accelerate the development of the TTS and HL (Chen *et al.,* 2007; Henderson *et al.,* 2006). Construction, foundries and metal steel is an arduous occupation that involves hard physical labour and a great deal of exercise while simultaneously being exposed to high levels of noise that can contribute to HL. The results show no sign of dynamic physical exercise and all workers that indicated regular exercise did not indicate any sign of hearing loss. The study can conclude that exercise did not have the impact on HL.

Cross Tabs and Pearson chi-square analysis was used to compare lifestyle and family history variables between the two groups. Based on the results there was a significant difference in the reported use of alcohol with only subjects in the experimental group using alcohol. Under reporting may be due to the fact that subjects in the control group did not want the researcher to know that they either smoked or consumed alcohol. The study concluded that smoking, alcohol use and exercise may not contribute to the development of HL.

Conclusion

The results of this study showed that noise level in various areas of the Polokwane Platinum Smelter are too high and above noise rating limit. Those areas with high level of noise are denoted as noise areas. effective control and measure are in place by the smelter and workers adhered to the warning signs displayed in the entrance of this areas. Low noise levels reduces impact of employees developing HL.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

This chapter discusses the main conclusion derived from the research as well as the limitations and recommendations of the study and future research that is needed.

5.1 Conclusion

In conclusion NIHL is a disease that continues to affect millions of people and costs companies a huge amount of money in a form of compensation and in loss of expertise (Landon *et al*., 2005; and Rabinowitz, 2000). NIHL develop gradually, and the full effects are generally only realized after 10 to 15 years of chronic exposure to noise (Cruickshanks *et al.,* 2010; and Rosen *et al.,* 2001). Development of NIHL is dependent on the characteristics of the noise, including its temporal pattern and spectral distribution, the overall sound level of the noise and the duration of the noise exposure (i.e., in hours, weeks and years). There are various factors involved in the development of this condition as discussed by (Kardous & Willson, 2004; and Katz, 1994).

In this study the experimental group who were exposed to the occupational noise was compared to the control group in the following aspect occupational history, medical history and lifestyle activities etc. The study groups had similarities such as age, gender and non-occupational activities. Non-occupational, lifestyle and occupational history activities may contribute in the developmental on HL. The study concluded that as there were areas within the Polokwane Platinum Smelter where noise levels exceeded the occupational exposure limit of 85 dB(A) required by the OHS Act (85/93) and related regulations. It was further concluded that during the period of the study, the experimental group at the Polokwane Platinum Smelter adhered to safety requirements and legislation that relate to noise management and other government legislations that are aimed to regulate excessive noise in the workplace and control occupational noise exposure. Management seems to be committed to their hearing conservation programme and all areas where the noise was above the occupational exposure limit were demarcated as noise zones. Thus, the possibility of employees developing NIHL with these controls was reduced.

According to Heggins (1998), workers under the age of 35 years do not generally take safety precautions due to behaviour and attitude of personnel as they do not want to make use of safety gear such as HPD (i.e., earmuffs/earplugs). As a result, they are exposed to various risks in workplaces and further exposed to high levels of noise resulting in early hearing shifts at high frequencies. In the present study, it was observed that 94.2 % employees in of the experimental group took safety precautions by wearing HPD (i.e., earmuff and earplugs) during the occupational noise surveys and HPD compliance monitoring. The study can conclude that general safety precautions with regard to areas with high levels of noise were followed by utility workers, as all employees wear their HPD on regular basis. Polokwane Platinum Smelter ensures that safety precautions are followed and adhered to by all employees including the experimental group. The study confirmed that employees were committed to HCP program for example attending training.

Polokwane Platinum Smelter management introduced a hearing conservation programme as a best practice to prioritize reduction of potential damaging excessive noise that may cause development of NIHL amongst employees at the Polokwane Platinum Smelter during normal plant operation. The conservation program included continuous noise monitoring plan, audiometric assessment and an awareness programme. This is in line with government measures to prevent NIHL among employees. A lot of literature about noise-induced hearing loss and noise conservation programmes are available and the subject is well researched as indicated in the literature. However, it remains important to ensure that employees continue to be educated on the effects of noise on hearing and the importance of using hearing protective devices.

In this study there was no case of hearing loss was reported. Employees were not at risk of developing hearing loss even though the Smelter has areas that are identified as noise zones areas as employees their HPD when working or entering in these identified areas. Areas such as Furnace and Flash Dryer's areas produced excessive noise levels that were higher than the occupational exposure limit since the start of operation at the Polokwane Platinum Smelter. This is an indication that the hearing conservation programme at the Polokwane Platinum Smelter is successful.

Therefore, the results indicate that the current control measure as implement by the smelter such as engineering and administrative controls, demarcation of noise zones are effective. Commitment by management was displayed by efforts of implementing hearing conservation program and various controls to prevent employees being over exposed to high noise levels.

The study further considered age as a factor that may contributes to hearing damage and eventually causes hearing loss. Hearing loss does not only affect the elderly, but also the youth of our society. Hearing abilities reduce as you get older and the Cochlear ability to function is reduced (Nandi & Dhatrak, 2008). However, the study group was below the age of 55 years and no cases of HL were reported by subject during the questionnaire survey. The study concludes that age did not contribute to the development of hearing loss.

It is a common practise that employees uses the protectors adequately as required. Therefore, an effort to establish the behaviour of employees at the Polokwane Platinum Smelter is necessary.

Audiometry for utility workers was not effectively accessed due to confidentiality agreement between the Polokwane Platinum Smelter and the University of Limpopo. The agreement was reached with the participants prior to the commencement of the study on ethical grounds. Future research also needs to focus on audiometric assessment of employees to assess personal hearing abilities.

As discussed earlier, current controls employed by the smelter are enough to arrest the development of HL among employees. However, it remain crucial that employees continue to wear their HPD and survey be conduct more frequent to minimize any unidentified noise levels that has a potential to damage hearing of employees. This must be seen against the background the smelter is fairly new and use modern technology. Modern technology for example extracting fans, motors and equipment's are designed in such way that it produces low noise levels when in operation and engineering controls are prioritized during design stage. Hearing Conservation Programs ensure that noise levels remain within acceptable legal limits by continuous monitoring done by the Smelter Occupational Hygienist.

Workshops and other areas at the Polokwane Platinum Smelter should be added in future studies. More information and data could contribute to the knowledge of how occupational noise at the smelter could have the potential to affect employees' hearing abilities. Smelter should ensure that personal noise monitoring program is fully implemented, this will assist in ensuring that personal noise levels which employees may be exposed to; is known and correct corrective action may be implemented. Environmental and non-occupational noise can be a difficult task to measure, because noise sources are readily found outside the working environment. Keeping that in mind, it may be difficult for the employer to prove that NIHL developed as a result of activities 'outside the work environment', or the result of leisure activities. However, it is also hard to argue that noise sources, outside the industrial environment, are powerful enough to result adequate exposure levels to result in hearing loss.

Most research that have been conducted in this area are occupational; relatively little has been done in the area of non-occupational hearing loss (Opperman *et al.,* 2006; Bogoch *et al.,* 2005). Hearing loss is a serious disability that needs to be addressed from all areas. Currently, there have been very few guidelines available for non-occupational noise exposure limits (DME, 2002). Since noise cannot be eliminated completely, it is important to develop legislative options that would encourage the prevention of non-occupational related hearing loss focusing on but not limited to those in their teenage years (control group). The study concludes that both the experimental and control groups may develop NIHL in the future due to non-occupational noise exposure.

The International Organization for Standardization standard ISO 1999:1990 Acoustics Determination of occupational noise exposure and estimation of noise-induced hearing impairment recommends the use of the equal energy principle (3 dB exchange rate) in calculating the time-weighted average for a work shift. The noise exposure limit for a 12-hour shift, based on the equal energy rule, is 88.2 dB(A). In other words, if the noise level is kept below 88 dB(A) then, according to equal energy concept, the maximum permissible limit is not exceeded. The study took account of the duration and maximum exposure levels that an utility employee per shift and concluded that 12 hours shift may not have an impact employees hearing capabilities. Employees where not working on one area.

South African industries such as construction, manufacturing, foundries and transport have not yet developed their own guidelines on non-occupational noise that can be regarded as best practise. Reliable noise abatement regulations based on further large scaled non-occupational noise research are also warranted. More stringent regulations/guidelines are suggested to be imposed for non-occupational noise exposure limits for effective hearing conservation programme purposes (Royster *et al.,* 1982).

The results of this study indicated that, the experimental group participate in non-occupational activities that can generate loud noise, or noise above statuary exposure limit for about an hour to two per day. Non-occupational noise exposure is not regulated and such noise levels need to be self-regulated as it is difficult to monitor such activities non occupational activities. Non-occupational activities include attending a concert, soccer at the stadium and activities that may produce excessive noise, which, if not monitored by employees may have an effect on their hearing ability.

Smoking, regular consumption of alcohol and exposure to industrial chemicals may contribute to the development of NIHL over time according to (Boggia *et al.,* 2008). Individuals who smoke may have a problem with supply of oxygen to the cochlea and this may lead to hearing loss (Riva *et al.,* 2007). The study concluded that smoking habits and exposure to chemicals needs to be invested in future research. There were no previous scientific records available where chemicals or the effect of smoking were investigated at the Polokwane Platinum Smelter. The study relied on self-reported information from the questionnaire; hence only limited scientific conclusions can be drawn on the subject.

The findings of the study show that Polokwane Platinum Smelter management should be encouraged to focus on the prevention of non-work related hearing loss. Regardless of the preferred policy choice, it is important to keep in mind that the issue is not just going to disappear. Serious action is necessary in order to prevent future increase in health care cost and continual decline in the overall health and wellness.

Polokwane Platinum Smelter management needs to continually encourage employees to protect their hearing and to further strive towards ensuring that employees participate actively in training programme and hearing conservation plans put in place by the Polokwane Platinum Smelter. Monitoring of training programme increases knowledge on NIHL amongst employees. Education and awareness is an important tool that can be used towards meeting the goals of zero NIHL case at the Polokwane Platinum Smelter.

Lastly, based on the aforementioned results and discussion, the study indicated that NIHL may be prevalent at certain areas at the Polokwane Platinum Smelter which produces occupational noise which ranges between 62.6 dB(A) to 105 dB(A) and certain areas exceeded the occupational exposure limit during normal operation. According to noise exposure, noise levels for the Smelter was between 62.6 dB(A) to 105 dB(A) average noise level. All this work areas are noise-risk zoned areas. Demarcation of noise work areas is in line with legal requirement. Access to these areas is well controlled. Employees are trained to properly use HPD. Use of HPD minimizes the risk of employees developing NIHL. However, there are numerous factors that need to be considered before an employee is diagnosed with NIHL as a result of noise exposure time, age, and occupational history, etc. Based on the results, study concluded that occupational, non-occupational, and other factors such as age may contribute to the development of HL as discussed in Chapters 2 and 4.

The aim of this study was report any deviation to the statutory requirement such as (NIHL, 2003) and Polokwane Platinum Smelter Hearing Conservation Program to management. The study investigated possible areas with excessive high noise levels and noise control measures that exist.

The study concluded that:

- The experimental group at the Polokwane Platinum Smelter was at risk of developing NIHL as a result of excessive noise exposure levels as noise levels above the noise rating limit were produced in certain areas. Occupational noise levels at the Polokwane Platinum Smelter in certain areas were above the occupational exposure limit and such areas need to be monitored regularly.
- The study confirms that line managers are committed to ensure that the workplace is free from all hearing damaging noise and by the proven commitment cases of NIHL have remained low since the Smelter became operational by introducing engineering controls (modern technology) that release less noise and administrative control such as rotation of employees and use of HPD in areas identified as noise areas (demarcated areas).
- Noise exposure levels at the Polokwane Platinum Smelter comply with the minimum required levels according to the OHS Act (85/93), in areas, where noise is higher than the occupational exposure limit 85dB(A), were demarcated as noise zones.
- Existing noise control measures, regular monitoring and prevention of noise hazards were sufficiently managed and can further be improved by Polokwane Platinum Smelter Management.
- Noise monitoring conducted by the occupational hygienist is consistence with the legal requirements. Duties of the employees, such as training and informing workers of potential risks, are well managed by the smelter, though a detailed Hearing Conservation program.
- There are no major changes recommended for the control and prevention of noise hazard; future research needs to be conducted into the purchase of equipment that produce less noise during operation, as well as other measures or controls to reduce noise levels to which employees are exposed.

- The study recommend that in areas such as Flash Dryer and Storage Silo because of high level of noise levels, the smelter needs to consider that in this areas employees wears a double hearing protection equipment(s). HPD may be not sufficient enough, if an employees did not wear his HPD correctly as required.

This was the first consistent study of its kind that was conducted to detect noise challenges in the Polokwane Platinum Smelter. Therefore, the study recommends that supplementary research be done, especially in the field of Occupational Health and Hygiene.

5.2 Limitations of the Study

The limitations of the study were that:

- Previous medical history from the Polokwane Platinum Smelter restricted the conclusions which can be drawn from the data. No research was done previously at the Polokwane Platinum Smelter and was still relatively new at the time of this study and that they therefore had only a very short medical history of each subject. This could not be made available to the researcher due to confidentiality issues;
- The study concentrated on noise measurements taken at the Polokwane Platinum Smelter. The study was unable to compare the study findings with previous research to assess whether safety standards have decreased or increased. The study was unable to compare its findings with other smelters in South Africa as there were no published reports available to the public;
- The study was unable to compare its length of employment and previous occupational history as more the 80% of the experimental group was their first formal employment at the Smelter;
- NIHL can also be caused by noise exposure experienced during non-occupational activities. Non-occupational exposure in private time has only been self-reported (using a questionnaire) as precaution to ensure that any possible NIHL experienced by experimental or control subjects is indeed due to noise exposure at work. Future research should sample

some of the subjects to effectively assess non-occupational noise' contribution to NIHL;

- Personal noise monitoring was not done as the study focused on noise levels in various areas at the smelter. Future studies should also focus on personal noise monitoring.

5.3 Recommendations

Based on the study results and findings the following recommendations are made:

- Future research is necessary in the area of occupational hearing loss and among employers within the Anglo American group in particular;
  - . As a short term solution to the problem, more research needs to be conducted in areas of HPD and education pertaining to NIHL, use of HPD and technique of fitting ear protection including resources to allow accurate noise monitoring and efficient hearing conservation programme;
  - . As a long-term solution, a great deal of research needs to be done in the area of designing the machines to be quieter, though this may not currently be feasible in South Africa and developing countries (Nandi & Dhatrak, 2008);

- Administratively, rotating workers into quieter areas during their shifts will reduce overall noise exposure of an employee as workers deployed to work in various areas per shift. However, this type of intervention depends on the workplace environment, though this method is not always feasible depending on the job description of workers, during routine maintenance this may not be possible;
- Occupational and environmental settings including the type of activity can influence noise level. Therefore, environmental factors need to be carefully monitored as they may have a negative influence with regard to noise level;
- Polokwane Platinum Smelter produces chemicals and utilises vibrating instruments that may contribute to hearing loss when combined with noise. It was concluded that more research need to be done to cover these aspects on the development of NIHL;

- Polokwane Platinum Smelter should, where possible, develop strategies to assess the combined effects of environmental hazards, chemicals, vibration and chemicals that may cause the development of HL when combined with excessive noise. Studies need to be done that will seek to relate non-occupational noise and occupational noise in the future;
- Polokwane Platinum Smelter Management, where possible, should educate employees about the effects of non-occupational noise that may have an effect on the development of NIHL. Where possible, the management should further develop guidelines that will assist employees not to be exposed to recreational noise;
- In this study, cochlear damage due to high level of noise exposure was not adequately covered. Hair cell loss eventually causes NIHL and this should be studied in the near future. The other aspect that is necessary to study is the resting time to allow the auditory system to recover after excessive noise exposure. This was outside the scope of the current study;
- The study propose that future studies be conducted to assess impact of noise sources on hearing loss and increase in noise levels. As the current study aimed to assess noise level in certain areas of the smelter and to not dealt effectively with sources of noise and its effects. Acoustic reports and engineer where not available to be examined during the period of the study.
- The immediate application and incorporation of an approved occupational noise plan will bring the organization into compliance with safe work standards and significantly contribute to the goal of a healthy and safe workplace;
    i. employees will benefit from a safer work environment and practice since reducing noise exposure decreases chances of the health hazards commonly associated with NIHL;
    ii. ensures that compensation cost and insurance rate remain at zero;
    iii. ensure that more quieter machines and other advance technological machines are being used where possible, to ensure noise levels remain below 85dB(A), as certain areas has high level of noise as the results indicate and;

iv. workshops and other areas should be added in future noise studies conducted at the Polokwane Smelter.

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APPENDIX A: INFORMATION FOR PARTICIPANTS

INFORMATION FOR PARTICIPANTS

You are invited to participate in the following research project:

PROJECT TITLE:

Assessments of occupational noise-induced hearing loss amongst the workers at the Polokwane Platinum Smelter.

RESEARCHERS:

Mr. Mdaka T.C., Dr van Staden, M. & Prof Mulder, P.F.S.

Participation in the project is completely voluntary and you are free to withdraw from the project/experiment (without providing any reasons) at any time. You are, however, requested not to withdraw without careful consideration since such action might negatively affect the research project.

It is possible that you might not personally experience any advantages during the research project, although the knowledge that may be accumulated through the research project might prove advantageous to others.

You are encouraged to ask any questions that you might have in connection with this research project at any stage. The project leader and her/his staff will gladly answer your questions. They will also discuss the project/experiment in detail with you.

Your involvement in the research project

This project aims to verify if any of the experimental subjects are suffering from Noise-induced hearing loss at the Polokwane Platinum Smelter. This will help to find out if you are at risk or already have a problem with your hearing caused by your working environment. The research project will also determine whether the levels of noise in your workplace comply with the legal requirements. The researcher will make necessary recommendations on any measures that may be inappropriate.

You will be provided with a questionnaire that has questions regarding noise in your workplace, and demographical information. You need to complete the questionnaire and give it back to the researcher. You may be asked other questions verbally. The researcher will be available to assist you in completing the questionnaire.

Measurements of noise will be made in your workplace. A Sound Level Meter will be used to measure noise. The Sound Level Meter is not a speech-recording device; therefore it will not record what you say. Workers will be required to wear a sound meter level at their neckline area during a working shift. It is a small device that is attached to your clothing. It will not be uncomfortable to wear. Care will be taken to ensure that the equipment do not interfere with your normal duties; hence you should continue to work as you normally do. You are requested not to remove the Sound Meter Level from its place unless absolutely necessary and do not cover the microphone as this will interfere with the measurements.

The information that you provide us will be treated as confidential, to ensure that, a unique identification subject number will be entered on the questionnaire. Your identity and the information that you give us will only be made available to the research team.

APPENDIX B: CONSENT FORM

University of Limpopo
Turfloop Campus

PROJECT TITLE:
Assessments of occupational noise-induced hearing loss amongst workers at the Polokwane Platinum Smelter.

RESEARCHERS:
Mr. Mdaka T.C., Dr van Staden, M. & Prof Mulder, P.F.S.

CONSENT FORM

I____ hereby voluntarily consent to participate in the following project: *Assessments of occupational noise-induced hearing loss amongst workers at the Polokwane Platinum Smelter.*

I realize the following:

- The study deals with **Assessments of occupational noise-induced hearing loss amongst workers at the Polokwane Platinum Smelter.**
- The procedure or treatment envisaged may hold some risk for me that cannot be foreseen at this stage;
- The experimental protocol for example; the extent, aims and methods of the research, has been explained to me;
- The protocol sets out the risks that can be reasonably expected as well as possible discomfort for persons participating in the research, an explanation of the anticipated advantages for myself or others that are reasonably expected from the research and alternative procedures that may be to my advantage;
- I will be informed of any new information that may become available during the research that may influence my willingness to continue my participation;
- Any medical records/test or personal and Anglo Platinum information will not be available for public viewing, and the research report shall detained by the University for the period of five years before it is published.
- Access to the records that pertain to my participation in the study will be restricted to persons directly involved in the research;
- Any questions that I may have regarding the research, or related matters, will be answered by the researcher;
- If I have any questions about, or problems regarding the study, or experience any undesirable effects, I may contact a member of the research team;
- Participation in this research is voluntary and I can withdraw my participation at any stage;
- If any medical problem is identified at any stage during the research, or when I am vetted for participation, such condition will be discussed with me in confidence by a qualified person and/or I will be referred to my doctor.

I hereby give consent to utilization of lung function test and previous audiometric data from my medical tests as I voluntarily participate in the study, if necessary
I do this with understanding that my medical data with be treated with complete confidentiality.

I indemnify the University of the Limpopo and all persons involved with the above project from any legal or liability that may arise from my participation in the above project or that may be related to it, for whatever reasons, including negligence on the part of the mentioned persons.

(Employee)__________________Date:______________ Signature: _______________

Signature of witness: ____________________________Date__________________

Signature of (Researcher/University Representative)

_________________________________Date:____________________________

(Anglo Platinum/ Representative)

Signature: __________________________________Date: ______________________

APPENDIX C: QUESTIONNAIRE

University of Limpopo
Turfloop Campus

School of Molecular and life Sciences (Department of Physiology & Environmental Health)

HEALTH EVALUATION

COMPLETE IN BLOCK LETTERS

Company Name University of Limpopo ☐ Anglo Platinum (Polokwane Platinum Smelter) ☐	**Contact** Company address Telephone Number
Name:	**Job description:**
Risk exposure:	**Categorized:**

Information regarding medical examination

This form will be used for medical examination and tests with the consent of the Employee/ volunteer for the following reasons:

- To obtain information regarding previous occupational, personal and family history.
- To determine the health status of the said employee/volunteer, subject to an agreement between the surveyor (Anglo Platinum / University of Limpopo) and the employee/volunteer.

The employee/volunteer is expected to complete the questionnaire and submit himself/herself (where appropriate and possible) to a medical examination by the doctor appointed by the surveyor or the company.

Medical data will be available to the employee/ surveyor only. The employer/surveyor undertakes to treat all information as confidential, forwarded all reports to your doctor if requested, inform you of abnormal findings if requested and not to perform any test prior to your approval.

The employee/volunteer should not withhold information (previous medical information) concerning their health.

Name……………………Signed…………………………Date………………………

OCCUPATIONAL HEALTH SURVEY FORM

Please provide with the best answer suited on the space provided.

Mark with X or □ in the numbered box that reflects your situation.

Subject number

Section A: Personal information

Age (Years)

How long have you been working at Polokwane Platinum Smelter? Years.

Gender

Male	1	Female	2

How do you travel to work?

On foot	1	By bus	2	Car	3	Taxi	4	Bicycle	5

Lifestyle

Do you drink alcohol?	Yes	No	Quantity
Do you partake in sports?	Yes	No	Specify: hour(s)/day:_____hour(s)/day____:hour(s)/month___
Do you smoke	Yes	No	
Did you ever smoke before?			

Section B: Family History

Do any of your relatives have problem with hearing?

Relative	Yes	No	Age	Cause
Father	Yes	No		
Mother	Yes	No		
Brother	Yes	No		
Sister	Yes	No		
If other specify				

Section C: Occupational History

Have you worked in any of the types of occupations before?

	Yes	No	Specify: Period (years)
Farming	Yes	No	
Mining	Yes	No	
Construction	Yes	No	
Transport (truck driver, ship, airplane etc.)	Yes	No	
Factory	Yes	No	
Police & gun training	Yes	No	
Workshop: Grinding, hammering, sawing	Yes	No	
Music industry	Yes	No	
Welding	Yes	No	
Train station	Yes	No	
Street vending in town/city	Yes	No	
If other specify?			

If yes, explain in detail your former job tile and brief description of duties.

In which section of the Polokwane Platinum Smelter did you work before?

Section	Duty	Specify: Period (years)

In which section of the Polokwane Platinum Smelter are you currently working?

Section	Duty	Specify: Period (years)

Processes involved in your current job (Tick below)

Are you currently exposed to?

Painting	Lead exposure	Dust exposure	Chemical exposure
Noise exposure	electroplating	Other	

Please give details

____

____

Have you been counselled as to sick leave abuse or absenteeism?	Yes	No	If yes, specify
Have you been off-duty due to illness for a period more than two week?	Yes	No	
Been treated for any occupational disorder(s)?	Yes	No	
Been found medical unfit to perform any duties?	Yes	No	

Section D: Medical History (General)

Disease of the heart (e.g., heart attack, chest pains, hypertension etc.)	Yes	No	If yes specify
Disease of the lungs and respiratory diseases (e.g., asthma, TB, Sinuses, shortness of breath etc.)	Yes	No	
Disease of the musculo-skeletal system (e.g., back pain, arthritis, broken bones, gout etc.)	Yes	No	
Disease of the central nervous system (e.g., stroke, dizziness, head injury, loss of vision, epilepsy etc.)	Yes	No	
Mental disorders (e.g., depression, stress, anxiety, attempted suicide, drug or alcohol deficiency etc.)			
Cancer or trauma	Yes	No	
Are currently using any medication?	Yes	No	
Other disorder if not listed specify?			

Have you been hospitalized, had x-rays, or special investigations over the past 5 years (if not already stated)?

Date	Investigation/operation
Name of the family doctor(s)	Contact: Address & telephone number

Section E: Leisure Activities

On your spare time at home do you do any of the following?

Grinding	Yes	No	If yes, specify
Soldering	Yes	No	
Hammering	Yes	No	
Using Trackers	Yes	No	
Noisy machines	Yes	No	
Hunting with a firearm	Yes	No	
Motorbike	Yes	No	
Welding	Yes	No	
Listening to radio	Yes	No	
Other (Specify)	Yes	No	

If yes, specify the duration and the type of activities in details

____

____

Section F: General conditions in your workplace

Noise exposure		
Does the noise bother you?	Yes	No
Are you exposed to loud noise during working hours?	Yes	No
Are you experiencing hearing problems?	Yes	No
Are you experiencing communication problem after noise exposure?	Yes	No
For how long are you exposed to noise?	Hours/ shift:	
Other exposure		
Are you exposed to gases or chemicals?	Yes	No
Which type of gases or chemicals are you exposed to?		
For how long are you exposed to chemicals or gases?	Hours/ shift:	
Are you exposed to dust?	Yes	No
Personal Protective Equipment (PPE)		
Are you provided with PPE at work?	Yes	No
Are you trained to use PPE?	Yes	No
Are you comfortable working while wearing the PPE?	Yes	No
Does the PPE fit you well?	Yes	No
For how long do you use PPE?	Hours/ shift:	
What type of PPE are you using?		

Section G: Declaration

I………………………………………. hereby declare that the above information is truly correct and I further grant my permission to the examining officer/ doctor to obtain my relevant information from any medical practitioner whom I consulted previously including audiometric results (excluding any information pertaining to HIV tests performed).

Signed………………………………. Date……………………………..

Witness (examining practitioner)………………………………………

Thank you for your co-operation.