Comparing South African occupational exposure limits for pesticides, metals, dusts and fibres with those of developed countries

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It all starts here ™

Preface

This mini-dissertation is presented for the partial fulfilment of the degree *Master of Science in Occupational Hygiene* at the North-West University. It was decided to use the article format for the purpose of this study. Throughout, references are for uniformity purposes presented according to the guidelines of an accredited journal, *Annals of Occupational Hygiene.* Chapter 1 includes a brief introduction to the importance of occupational exposure limits (OELs) as well as why these comparisons are necessary. Furthermore, it includes the problem statement, research aim and objectives and hypothesis. Chapter 2, the literature study, consists of an in-depth discussion of OELs, the type of OELs, the importance of the different categories, and a perspective on the process of setting an OEL. Chapter 3 is a manuscript (article). All tables and figures are included in Chapter 3, in the text, to present the findings of this study in a readable and understandable format. Chapter 4 includes a final summary, addressing of the hypothesis, results and conclusion, as well as recommendations for future studies.

"The first rule of Occupational Hygiene – Wing It." – CJ van der Merwe

Author's Contribution

This study was planned and executed by a team of researchers. The contribution of each researcher is listed in the table below.

Name	**Contribution**
Mr JP Viljoen (Student)	• Designing and planning of the study; • Literature study, execution of all data collection, interpretation of data and writing of the mini-dissertation.
Mr CJ van der Merwe (Supervisor)	• Assisted with approval of protocol, interpretation of results and documentation of the study.
Prof JL du Plessis (Co-supervisor)	• Assisted with designing and planning of the study, approval of protocol, interpretation of results and documentation of the study; and • Guidance with regards to scientific aspects of the study.

The following is a statement from the researchers confirming their role in this study:

I declare that I have approved the mini-dissertation and that my role in the study, as indicated above, is representative of my actual contribution. I hereby give my consent that it may be published as part of JP Viljoen's *Magister Scientiae in Occupational Hygiene* mini-dissertation.

Mr CJ Van der Merwe (Supervisor)	Prof JL Du Plessis (Co-supervisor)	Mr JP Viljoen (Student)

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List of Abbreviations

%	Percentage
<	Smaller than
ACGIH	American Conference of Governmental Industrial Hygienists, United States of America
ACTS	Advisory Committee on Toxic Substances, United Kingdom
CAS	Chemical Abstracts Service
CDC	Centres for Disease Control and Prevention, United States of America
C	Ceiling Limit
COPD	Chronic Obstructive Pulmonary Diseases
COSHH	The United Kingdom's Control of Substances Hazardous to Health Regulations
DDT	Dichlorodiphenyltrichloroethane
DFG	Deutsche Forschungsgemeinschaft, Germany
DNA	Deoxyribonucleic acid
EMP	Elongated Mineral Particulate
GCSR	Gevaarlike Chemiese Substanse Regulasies, Suid-Afrika
HCSR	Hazardous Chemical Substances Regulations, South Africa
HTP	Haitalliseksi tunnetut pitoisuuder (HTP-values), Finland
IARC	International Agency for Research on Cancer
ICMM	International Council on Mining & Metals

IDLH	Immediately Dangerous to Life or Health
ILO	International Labour Organisation
IOHA	International Occupational Hygiene Association
IUPAC	International Union of Pure and Applied Chemistry
JSOH	Japan Society of Occupational Health
LD_{50}	Lethal Dose, commonly refers to the dose in milligrams per kilograms of body weight (mg/kg body weight) causing death in 50% of the exposed experimental group
LOAEL	Lowest Observed Adverse Effects Level
MAC	Maximum Allowable Concentration
MEL	Maximum Exposure Limit, United Kingdom
mg/m^3	milligrams per cubic meter
MHSA	Mine Health and Safety Act, South Africa
MGVR	Myn Gesondheid en Veiligheids Regulasies, Suid-Afrika
MHSR	Mine Health and Safety Regulations, South Africa
NIOSH	National Institute for Occupational Safety and Health, United States of America
NOAEL	No Observable Adverse Effect Level
NTP	Normal Temperature and Pressure
OECD	The Organization for Economic Co-operation and Development
OELs	Occupational Exposure Limits, this commonly refers to an 8 – hour time-weighted average referred to by different countries. This is also a term used to broadly refer to a collection of TWA, STELs and C's

OEL-CL Occupational Exposure Limit, Control Limit

OEL-RL Occupational Exposure Limit, Recommended Limit

OES Occupational Exposure Standard, United Kingdom

OHS Occupational Health and Safety

OSHA Occupational Safety and Health Administration, United States of America

PCM Phase Contrast Microscopy

PNOC/R Particles Not Otherwise Classified or Regulated

ppm parts per million

ROS Reactive Oxygen Species

Sen Sensitisation notation

STEL Short Term Exposure Limit

STP Standard Temperature and Pressure

TLV Threshold Limit Value

TWA Time-weighted average

UK United Kingdom

USA United States of America

VSA Verenigde State van Amerika

µm Micrometers

WHO World Health Organisation

Abstract

The ever-changing industrial processes which are becoming more globalised as well as the merging of markets in different economies, led to an increased focus on the health and safety of workers in the industries and the mining sector over the past decades. Occupational exposure limits (OELs) have been used for more than half a century as a risk management tool for the prevention of work-related illnesses which may arise from the exposure to a wide variety of hazardous chemical substances in the working environment. **Aim**: The aim of this study is to analyse comparatively occupational exposure limits (OELs) of hazardous chemical substances from selected groups contained in the Hazardous Chemical Substance Regulations (HCSR) and the Mine Health and Safety Regulations (MHSR) with those of selected developed countries and organisations. **Method:** The two lists of OELs from South Africa – HCSR and MHSR – were compared with 11 different developed countries and/or organisations namely: Canada (British Colombia), United Kingdom (Health and Safety Executive, HSE), Australia (National Occupational Health and Safety Commission, NOHSC), New Zealand (Ministry of Business, Innovation and Employment), Japan (Japan Society for Occupational Health, JSOH), Finland (Ministry of Social Affairs and Health), Germany (Deutsche Forschungsgemeinschaft-DFG), Sweden (Swedish Work Environment Authority) and United States of America (American Conference of Governmental Industrial Hygienists, ACGIH, Occupational Safety and Health Administration, OSHA and National Institute for Occupational Safety and Health, NIOSH). The selection of these countries and organisations was done on the basis of their dominance in the literature as well as the availability of the lists containing OELs. The OELs from each country and/or organisation, depending on the nature and characteristics of the said element and/or compound, were categorised into one of four groups, namely: pesticides, metals, dusts and fibres. The geometric means of each country and/or organisation were calculated from the ratios of each list by using the HCSR and MHSR as the denominator respectively. **Results:** It became evident that South Africa performed poorly when compared to other countries and/or organisations, indicated in this study. OSHA overall had the highest set OELs, in five out of the six comparisons that could be made, thus being less stringent than South Africa's. Countries and organisations such as Sweden, Japan and Finland have the lowest overall set OELs for the different groups respectively. **Conclusion:** South African OELs legislated by both the HCSR and MHSR, are overall higher (less stringent) when compared to those of developed countries and/or organisations. The less stringent nature of South African OELs may be attributed to infrequent rate at which they are updated. The failure to incorporate recent scientific knowledge into OELs may impact on the health of workers. South Africa should follow international best practice and increase the frequency at which OELs are updated. **Recommendations:** The effectiveness of having two sets of OELs within a country; each applicable to its own industry should be investigated. Attention with regards to the groups lacking attention, i.e. fibres and pesticides should be given priority when revised. Although the other groups should not be disregarded. Duplicate OELs identified in the HCSR should be removed. To prevent duplicate OELs from being established it would be prudent to utilise CAS numbers when referring to substances in addition to their common and chemical names, thus this supports the recommendations made in an earlier study.

Key words: *Occupational exposure limits, pesticides, metals, dusts, fibres, South Africa, developed countries, organisations, hazardous chemical substances.*

Opsomming

Die vergelyking van Suid-Afrikaanse beroepsblootstellingsdrempels vir pestisiede, metale, stof en vesels met die van ontwikkelde lande

Die ewig-veranderende industriële prosesse wat steeds daagliks meer geglobaliseerd raak, sowel as die samesmelting van markte in die verskillende ekonomieë, het gelei tot 'n groter fokus op die gesondheid en veiligheid van die werkers in die nywerhede en die mynbou-sektor oor die afgelope dekades. Beroepsblootstellingdrempels (BBD) word al vir meer as ŉ halwe eeu gebruik as ŉ risiko bestuur hulpmiddel om werk-verwante siektes, wat veroorsaak word deur die blootstelling aan ŉ wye verskeidenheid gevaarlike chemiese substanse wat in die werksomgewing voorkom. **Doel:** Die doel van hierdie studie is om die BBD van gevaarlike chemiese substanse uit die geselekteerde groepe van Suid-Afrika se lyste met dié van ontwikkelde lande en organisasies vergelykend te analiseer. **Metode:** Die twee lyste van BBD van Suid-Afrika – Gevaarlike Chemiese Substanse Regulasies (GCSR) en die Myn Gesondheid en Veiligheid Regulasies (MGVR) – is vergelyk met 11 verskillende ontwikkelde lande en/of organisasies, naamlik: Kanada (Britse Colombia), Die Verenigde Koningryk (Health and Safety Executive, HSE), Australië (National Occupational Health and Safety Commission, NOHSC), Nieu-Seeland (Ministry of Business, Innovation and Employment), Japan (Society for Occupational Health, JSOH), Finland (Ministry of Social Affairs and Health), Duitsland (Deutsche Forschungsgemeinschaft-DFG), Swede (Swedish Work Environment Authority) en die VSA (American Conference of Governmental Industrial Hygienists, ACGIH, Occupational Safety and Health Administration, OSHA en National Institute for Occupational Safety and Health, NIOSH). Die keuse van hierdie lande en organisasies is op die basis van hul oorheersing in die literatuur sowel as die beskikbaarheid van die lyste gedoen. Die BBD van elke land en/of organisasie, afhangende van die aard en eienskappe van die element en/of stof, is verdeel in een van die vier groepe naamlik: pestisiede, metale, stof en vesels. Die rekeningkundige gemiddeld van elke land en/of organisasie is bereken vanaf die verhoudings van elke lys deur die HCSR en MHSR as die deler onderskeidelik te gebruik. **Resultate:** Daar is gevind dat Suid-Afrika 'n algehele hoër (minder streng) BBD vir al vier die groepe het. Dit is duidelik dat Suid-Afrika swak gevaar het in vergelyking met die ander lande en/of organisasies, soos dit aangedui is in hierdie studie. Die OSHA het oor die algemeen die hoogste BBD, vyf uit ses van die vergelykings wat gemaak kon word, was hul minder streng as Suid-Afrika. Lande en organisasies soos Swede, Japan en Finland het die laagste algehele BBD vir die verskillende groepe gehad, onderskeidelik. **Gevolgtrekking:** Suid-Afrikaanse BBD word wetlike uitgesit deur beide die GCSR en MGVR, en is oor die algemeen hoër (minder streng) in vergelyking met dié van ontwikkelde lande en/of organisasies. Die minder streng aard van die Suid-Afrikaanse BBD kan toegeskryf word aan ongereelde tempo waarteen hulle opgedateer word. Die versuim om nuwe wetenskaplike kennis te inkorporeer in BBD kan 'n invloed op die gesondheid van werkers hê. Suid-Afrika moet die internasionale voorlopers van BBD volg en die frekwensie verhoog waarteen hul BBD opdateer. **Aanbevelings:** Die doeltreffendheid van twee stelle BBD in 'n land, elk van toepassing op sy eie sektor, moet ondersoek word. Daar moet prioriteit gegee word aan die groepe wat aandag verg, naamlik: vesels en pestisiede, wanneer BBD hersien word, hoewel die ander groepe nie vergete gelaat moet word nie. Duplikaat BBD wat in die HCSR geïdentifiseer is moet verwyder word. Om die duplikaat BBD te voorkom, in die toekoms, moet daar gebruik gemaak word van CAS nommers wanneer daar na ŉ stof verwys word tesame met hul algemene sowel as hul chemiese name. Dus ondersteun dit die aanbevelings wat gemaak is in ŉ vorige studie.

Sleutelwoorde: *Beroepsblootstellingsdrempels, pestisiede, metale, stof, vesels, Suid Afrika, ontwikkelde lande, organisasies, gevaarlike chemiese substanse.*

Chapter 1

Introduction

1.1. Problem statement

The occupational health and safety of workers have received increased focus during the past few decades. Arguably, one of the most used “tools” for the management of occupational health is occupational exposure limits (OELs). OELs have been used for more than half a century by the occupational hygiene and toxicology community to prevent job-related illness that may be induced by exposure (McCluskey, 2003; Aneziris *et al.*, 2010). Since workers are exposed to a variety of hazardous chemical substances (HCS), these OELs are used as a risk management tool for achieving health protection of workers (Topping, 2001; Schenk *et al.*, 2008a; Ding *et al.*, 2011). An OEL may be defined as that concentration of a substance in the workplace to which workers may be exposed to without causing adverse health effects. Unfortunately OELs are only set for a single substance, yet exposure to mixtures containing various substances is more likely to occur in the working environment (Sterzl-Eckert and Greim, 1996).

South African legislation makes provision for two sets of OELs. One is provided for by the Hazardous Chemical Substance Regulations (HCSR) which is ascertained under the Occupational Health and Safety Act (85 of 1993) and which are applicable to general industries and the other is provided for by the Mine Health and Safety Act (MHSA) and its Regulations (29 of 1996) which apply to the mining industry.

As the current HCSR was published in 1995, which themselves were based on even older legislation of the UK, there exists a perfect opportunity at the moment to establish updated South African OELs that is benchmarked against those of developed countries. Recent research has concluded that the HCSR has overall higher OELs for HCS when they were compared to those of developed countries and organisations, and this indicated that South African OELs in the HCSR are inadequate to some extent to protect the South African workforce from the adverse health effects resulting from HCSs exposure (Viljoen, 2012).

It was, therefore, decided that a unique contribution could be made through this study by identifying deficiencies in current legislation and by recommending changes that will enable government to benchmark the South African HCSR with those of developed countries. To that end it was decided to categorise HCS, depending on the characteristics and nature of the said element and/or compound, into one of the following groups: pesticides, metals, dusts and fibres. Although other criteria may exist to define groups, it was decided to use the above mentioned groups due to the following:

i. HCS can easily be defined as belonging to any of the above mentioned groups using existing definitions that are internationally accepted.
ii. The groups above can easily be aligned with economic sectors within a country e.g. metals with mining or manufacturing.
iii. To some extent the toxicological effects of the above mentioned groups tend to elicit a physiological response from specific organ systems e.g. fibres mainly elicit a response from the lungs.

The four groups will be compared with those of selected developed countries and organisations that are perceived to be dominant in the literature as this process will indicate to what extent South African OEL values should be set to be considered adequate to protect the workforce's health with the current body of knowledge and measurement techniques available from an international viewpoint (Schenk *et al.*, 2008a).

1.2. Overview

The American Conference of Governmental Industrial Hygienists (ACGIH) — which is perceived as the most influential organisation with regards to the setting of OELs — led to the establishment of the first OEL lists in 1942 according to Schenk *et al.* (2008b). In the late 1980's, early 1990's the United Kingdom's Control of Substances Hazardous to Health (COSHH) Regulations used two types of OELs namely: 1) the Occupational Exposure Standards (OESs); this standard is applicable to substances for which there is no significant risk to a person's health and when the OEL can be followed by the industry; and 2) Maximum Exposure Limits (MELs), this is applicable to substances which are not easily identifiable and have severe health implications on persons (Topping, 2001). South Africa adopted the above mentioned OELs and published them as the Hazardous Chemical Substances Regulations (HCSR) in 1995. For this reason, two types of OELs exists in the South African general industry, namely; 1) OEL-RL

(Occupational Exposure Limit – Recommended Limit) which is the same as COSHHs OES, and 2) OEL-CL (Occupational Exposure Limit-Control Limit) which is based on the MEL of the COSHH (South African Department of Labour, 1995). An OEL-CL is the maximum concentration of an airborne pollutant, averaged over a reference period, to which workers may be exposed to which has serious health implications, and should be controlled to levels as far as reasonably practicable below the OEL of the substance, although evidence exist that there is still a health risk at the set level. In contrast, an OEL-RL is the concentration of an airborne pollutant, averaged over a reference period at which, according to current knowledge, there is no evidence – such as toxicological data – that it may be deteriorating to a workers health if exposed to that concentration of the substance day after day (South African Department of Labour, 1995). Most of the set OELs are set as time weighted average exposure limits (TWA) which is defined as the concentration to which a worker may be exposed to for an 8-hour work day and a 40-hour work week (Viljoen, 2012).

Short term exposure limits (STEL) are set upon a substance that has recognised acute effects and is the maximum concentration to which a person may be exposed to, over a short period, usually 15 minutes (South African Department of Labour, 1995; McCluskey, 2003). TWA-Ceiling limit (C) this indicates a concentration that may not be exceeded during any part of the workday according to McCluskey, (2003).

Scientific evidence exists that the setting of an OEL to a substance lacks standardisation and is inconsistent between different countries and organisations (Nielsen and Steinar, 2008; Schenk, 2010). As stated by Liang *et al.* (2006), actual OELs set for substances differ significantly between different countries. This can be explained due to the data that is needed to set an OEL for a specific substance, such as toxicological data, and these values must be balanced by socio-economic and practical/technical feasibility. This determines to what extent it may be practicable/technically feasible to maintain exposure to a certain substance at a specific limit and if it is affordable to do so according to Klonne (2003).

1.3. Research aims and objectives

Aim of the study:

To analyse comparatively selected groups of HCS OELs from South Africa's lists, i.e. HCSR and MHSR, with those of developed countries.

The specific objective of this study was:

- To compare South African OELs for pesticides, metals, dusts, and fibres in the HCSR and MHSR with each other and to those of Canada (British Colombia), USA (OSHA, ACGIH and NIOSH), UK, Japan, New Zealand, Australia, Sweden, Finland and Germany by means of the geometric mean method.

1.4. Hypothesis

The level at which South African OELs are set for pesticides, metals, dusts and fibres as groups of HCS are higher than the OELs set by the other countries and organisations included in this study.

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Chapter 2

Literature study

Introduction

An occupational exposure limit (OEL) is defined as that concentration of a substance in a workplace to which a worker may be exposed to without causing adverse health effects (South African Department of Labour, 1995). The American Conference of Governmental Industrial Hygienists (ACGIH) was the first to attempt formalisation of exposure controls in 1946 by adopting 148 exposure limits for substances, and today there is a huge variety of OELs when assessing various exposures to different chemicals as well as physical factors (McCluskey, 2003). In the legislation there are many references towards certain substances i.e. DDT (dichlorodiphenyltrichloroethane), lead, mercury, silica and asbestos to mention a few. These substances that are mentioned in the legislation have had a huge impact on society due to excessive use and/or exposure to them. Thus in this chapter the purpose behind OEL establishment and the different types of OELs will be discussed. The importance of the different groups of hazardous chemical substances i.e. pesticides, metals, dust and fibres will be explained from an occupational hygiene point of view, because of their significance in the industry and exposure thereto. The different steps in establishing an OEL will also be discussed as well as the different countries and organisations relating to this study.

2.1 Occupational exposure limits

OELs may be established by three different types of organisations according to Still *et al.* (2008).

1) Private industry where there may exist a unique chemical for which they develop an OEL applicable to their workforce.

2) Regulatory agencies who develop an OEL, which is based on exposure- and risk assessments, and who uses scientific knowledge obtained from studies conducted as a basis. These agencies may or may not be governmental agencies for example the Occupational Safety and Health Administration (OSHA) and the National Institute for Occupational Safety and Health (NIOSH). OSHA is the only regulatory agency in the USA, and legally enforces the OELs set out by them.

3) Consensus organisations are groups that use knowledge and results from scientific studies to determine an OEL for a substance that is safe for a worker, for example the ACGIH.

2.1.1 The purpose behind OEL establishment

According to the International Occupational Hygiene Association (IOHA) (2013), OELs have been constituted for airborne contaminants in the workplace by a number of authorities and organisations such as the American Conference of Governmental Industrial Hygienists (ACGIH) over the past few decades. These OELs needs to be adapted due to the ever changing industrial processes as well as in reaction to globalisation and the inclusion of emerging markets in established economies. Takala *et al.* (2014) reported that the World Health Organisation (WHO) and the International Labour Organisation (ILO) estimated that 5-7% of all fatalities in industrial countries can be assigned to occupational-related injuries and illnesses. In the past OELs were only used to establish levels of exposure that were presumed to be safe in a working environment, yet in some instances they were used to establish an acceptable level of exposure (Paustenbach *et al.*, 2011). Thus it is important for the establishment of OELs to substance to which persons may be exposed to in a working environment, to protect the workforce from adverse health effects that may arise from exposure to hazardous chemical substances. These adverse health effects may include cancer, silicosis, irritation and sensitisation, just to mention a few.

2.2 Types of OELs

OELs that are commonly used during exposure evaluation to airborne pollutants consist of three types namely Time-Weighted Average Occupational Exposure Limits (TWA-OEL), Short-term Exposure Limits (STELs) and Ceiling Limits (C). A substance for which TWA exists usually implies that the substance may have chronic toxicity effects when a worker is exposed above the OEL. Alternatively if the substance has a STEL and/or C set for it, it may have acute health effects when a worker is exposed above the OEL (South African Department of Labour, 1995; Viljoen, 2012).

1) Time-weighted average exposure limits (TWA), this is defined as the maximum allowable concentration of an airborne pollutant to which a person may exposed for an 8-hour work day and a 40-hour work week, without adverse health effects (McCluskey, 2003; Paustenbach *et al*., 2011; Viljoen, 2012).

2) Short term exposure limits (STELs). These are defined as the maximum concentration to which a person may be exposed to for a short term interval, which usually consist of 15 minutes, and this limit is set upon a substance that has recognised acute effects. With substances which also have a TWA, the STEL restricts the magnitude of excursion above the average concentration during longer exposures (South African Department of Labour, 1995).

3) Ceiling limits (C) are commonly set for a substance that is considered to be Immediate Dangerous to Life or Health (IDLH), such as asphyxiants, where exposure at or above the C for the reference period can cause death or extreme health effects in a worker. The C, therefore, indicates a concentration that may not be exceeded during any part of the workday (McCluskey, 2003).

In the South African context two distinct types of TWA-OELs exist which were originally adopted from the UK's Control of Substances Hazardous to Health Regulations (COSHH) in the early 1990's:

1) An OEL-RL (recommended limit) which will only be set to a substance if no evidence exists that it will be injurious to a workers health when inhaled day after day at a specific concentration.

An OEL-RL can be assigned to a substance if all three of the following criteria are met:

- Criterion 1: There is significant scientific evidence that suggests when a person is exposed to a substance, at a certain concentration over a reference period, it will have no indication of health implications to workers when prolonged inhaled,
- Criterion 2: If a worker is exposed above the limits, derived under criterion 1, which may occur in practise, where it is unlikely to produce serious short/long-term health implications over a time period that may be necessary to identify and cure the cause of the excessive exposure, and

- Criterion 3: Compliance, under criterion 1, is reasonably practicable (South African Department of Labour, 1995).

When a substance does not comply with the aforementioned criterion it can be assigned the following:

2) OEL-CL (control limit) is set upon a substance where significant scientific data exists about a substance that when a worker is exposed to it, it may have adverse health effects and exposure should be controlled to levels, as far as reasonably practicable below the OEL.

An OEL-CL must comply with the following criteria:

- Criteria 1: Criterion 1 and/or 2 for an OEL-RL is not complied with, due to evidence that suggests that when exposed, it has or may have serious health effects, and
- Criterion 2: Socio-economic factors indicate that more stringent OELs for the substance are required for it to be reasonably practicable, although it complies with criterion 1 and 2 (South African Department of Labour, 1995).

2.3 Overview of selected groups of OELs

In this section an overview of the various groups of HCS included in this study will be provided.

2.3.1 Pesticides

According to Costa (2008) pesticides can be defined as any substance or a mixture of different substances which are intended for the destruction, repulsion, prevention, or extenuating of pests. Pesticides are usually classified based on the target organism it destroys or injures. For example herbicides target plants by either killing or injuring them, thus plant specific. Fungicides usually target basic cellular functions of the organism, whereas insecticides is not species-selective regarding target toxicity (Costa, 2008; Casida, 2009).

Pesticides play a major role in the control of vector-borne diseases such as the use of DDT (dichlorodiphenyltrichloroethane) on mosquitos during the prevention of the spread of malaria, but it was found that DDT bio-accumulates in the environment, interfering with the reproduction of bird species (Costa, 2008). Occupational exposure to pesticides may occur amongst others in the agricultural domain, where the worker mixes and applies these chemicals to structures, such as buildings or plants (Wagner, 2003).

According to Costa (2008), pesticides are not always selective to their target species, which may lead to adverse health implications in non-target species such as during the accidental exposure of humans. These effects are dose-dependent, with regards to duration of exposure, frequency of exposure and dosage. Toxic effects may be described as chronic or acute or a combination of both (Hathaway and Proctor, 2004). Most pesticides affect the nervous system leading to tremors, paralysis and convulsions. In other instances, certain herbicides such as paraquat and 2,4,5-T (2,4,5-trichlorophenoxyacetic acid) which are used for soil fumigation, have nephrotoxic potential, thus they inhibit the elimination mechanisms of the proximal tube and thus inhibit the excretion of organic ions (Greim, 2009). According to Stenersen (2004) and Casida (2009), pesticides causes death to an organism by acting on one of the following seven routes:

1. Disturbance of the chemical signal systems of the organism.
2. Degradation of pH gradients across membranes.
3. Inhibition of normal enzyme functioning.
4. Generation of reactive molecules that destroy cellular components.
5. Disturbance of either the electrolytic, osmotic, or pH balances.
6. Destruction of DNA proteins and / or tissues through the action of strong acids, alkalis or oxidants.
7. Interruption of the physical state of membranes.

As stated by Hook *et al.* (2008) more industrialised, developed countries have become more aware when handling pesticides. This can be ascribed to technological advances, increasing awareness regarding the use of pesticides, and training of workers mixing and applying pesticides. In contrast, developing countries have more occurrences of poisoning relative to developed countries. Thus with the major agricultural domain that resides within South Africa, it is understandable that pesticides will be used to prevent the destruction of crops and other fauna and flora, and exposure to pesticides is inevitable.

2.3.2 Metals

Metals are among the oldest poisons known to human kind, for example, the effects of lead poisoning has been known for more than 2000 years (Summer *et al.*, 2009). From a general viewpoint a metal is usually defined by the physical properties of the element in its solid state. The properties include: mechanical pliability and strength, high thermal and electrical conductivity, and high reflectivity (Hook *et al.*, 2008). However, from an occupational health perspective, the definition of a metal is not that precise as there are many exceptions to the definition (Liu *et al.*, 2008).

Within the context of occupational health, a metal may refer to the metal in its elemental state, as a compound with another chemical or even as a vapour or fume. The importance of OELs for metals cannot be understated due to the amount of exposure that exists worldwide. Metals naturally occur in the earth's crust and are introduced into the environment by means of biological, geological and anthropological pathways, such as excavation by the mining industry, and thus metals are omnipresent in the human environment (Liu *et al.*, 2008; Summer *et al.*, 2009). Thus no matter how safely metals are used in industrial and consumer processes, human exposure is unavoidable. Metals differ in toxicity from other substances, because they are neither destroyed nor created by human activities, thus they are only concentrated by humans in the environment (Liu *et al.*, 2008). Some metals are crucial to certain biological processes in the body, thus differentiating them into essential and non-essential metals (Liu *et al.*, 2008). Non-essential metals have no physiological function in the body and are, therefore, sometimes called toxic metals. In contrast, essential metals or trace metals have important physiological roles to play with regards to normal cell metabolism. Iron, for instance, is essential for erythropoiesis (red blood cell production) and a crucial element of myoglobin, mitochondrial enzymes, heme enzymes, and haemoglobin (Liu *et al.*, 2008; Summer *et al.*, 2009).

Most metals, especially the heavy metals, are carcinogenic to humans such as arsenic which has been recognised as a human carcinogen for more than 110 years (Liu *et al.*, 2008). Carcinogens such as arsenic, chromium and beryllium produce new neoplastic growths in an organ/tissue or they increase the incidences of spontaneous neoplastic growths in the target organ/tissue (Klaunig and Kamendulis, 2008). Thus with the omnipresence of metals, such as arsenic in ground water, diseases such as cancer may be inevitable. Due to the major mining and refining activities of metals that occurs in South Africa, it is inevitable that exposure to all kinds of metals as well as mixtures of different metals will occur. Although certain metals are carcinogenic, other health effects are also of concern for example lead can cause lead-induced hypertension or haematological effects such as anaemia (Liu *et al.*, 2008).

Metals in their ionic state are reactive and interact with a variety of biological ways (Liu *et al.*, 2008). According to Leonard *et al.* (2004), the most common mechanism for metal-induced toxicity is the generation of reactive oxygen species (ROS) which affects the cell's signalling capability and if the body cells are unable to maintain the proper redox balance, a chronic inflammatory state results where the end result damage can be metal-induced diseases and cancer. The following are a few of the mechanisims through which toxcicity are induced according to Chen *et al.* (2008):

1. Oxidative stress and DNA damage
2. Enzyme inhibition
3. Direct irritation of tissues
4. Sequestration

2.3.3 Dusts

Dusts can be defined as small solid particulates with a diameter ranging between 1-100 µm, which can become airborne depending on its physical characteristics, origin and atmospheric conditions (World Health Organisation (WHO), 1999). The most common sources of airborne dust in the industrial and mining industry may include: sweeping, grinding, milling, blasting, drilling, ore tipping and transport, crushing, movements of workers, blast and drilling hole cleaning (Stanton *et al.*, 2006).

The term nuisance dust was given in the early 1990's to dusts, where studies concluded that exposure to dust with an OEL less than 15 mg/m^3, and also with a low crystalline content, had no indication of the development of lung diseases. The term "nuisance dust" was inaccurate due to the fact that no dust could be classified as being a "nuisance" without having health effects, so the terminology of particles not otherwise classified or regulated (PNOC/R) was used to refer to all dusts, except those with already established exposure limits (Hearl, 1998). Thus particulates, having its own OELs assigned to, are listed as that specific substance in the list of OELs, i.e. silica, grain dust, and wood dust. Other particulates such as "general dust" are still contained under the term PNOC/R.

Particulate matter, such as dust, is deposited in the human respiratory tract at different anatomical sites dependent on the physical size of particles. These mechanisms of deposition of particles inside the lung tissue are dependent on the aerodynamic diameters of the particles which are then defined as three different fractions:

- Inhalable fraction includes particles with a 50% cut-off point of 100 µm, where the inhaled airborne material can be deposited anywhere in the respiratory tract.
- The thoracic fraction on its part includes particles with a 50% cut-off point of 10 µm that passes through the larynx.
- Respirable fraction which includes particles with a 50% cut-off point of 4 µm and can penetrate the gas exchange regions of the lungs (EUR, 2002; Möller, 2004; Greenberg *et al.*, 2007).

With the deposition of the particles in the different areas of the lungs, particle clearance will be different for these regions of deposition (Greenberg *et al.*, 2007). Maintenance of homeostasis in the lungs is done by covering the airways with a mucus layer, which captures pollutants and cell debris, and ciliary movement rapidly transport deposited particles in the thoracic region outwards where the air velocity is high, this is known as the mucociliary escalator (Möller, 2004; Witschi *et al.*, 2008). Respirable particulates, which are confined to the alveolar region, are removed by three mechanisms:

1) physical process by means of the mucociliary escalator,
2) phagocytosis of foreign bodies by the alveolar macrophage, particles that possess low solubility properties are retained for longer periods in lungs, and
3) removal via the lymphatic system of the body (Möller, 2004; Lehman-McKeeman, 2008).

When these elimination mechanisms are overburdened or the lungs are impaired due to diseases such as *Tuberculosis* or lifestyle factors such as smoking, the removal of captured particles and debris are inefficient and lead to excessive burden on the lung (Lehman-McKeeman, 2008).

In industries, workers are exposed to a number of dusts, inhalable and respirable, and when the worker is exposed for years it can cause lung diseases. As an example, exposure - both chronic and acute - to grain dust may have health implications such as a decrease in lung function. This is due to the complex composition of grain dust which is mainly a mixture of organic and inorganic materials that may also contain fungal and bacterial contamination, insects, mites and crystalline silica (Spankie and Cherrie, 2012). Other health effects of dust exposure, such as sinonasal and nasal cancers, can also be due to prolonged exposure to wood dusts. The International Agency for Research in Cancer (IARC) in 1995 classified wood dust, such as those from beech and oak trees, as a group 1 human carcinogen, due to the health effects that were observed from workers that were exposed to hardwood dust (Barcenas *et al.*, 2005; Kauppinen *et al.*, 2006).

Silicon, which primarily exists in its dioxide state (silica), has a crystalline form and three isomers, namely: quartz, cristobalite and tridymite. Crystalline silica is one of the major components of which the earth's crust is comprised of, and quartz is found basically in all types of sands, rocks and gravels, hence the relevance to the mining industry

(International Council on Mining & Metals (ICMM), 2007; Witschi *et al.*, 2008). When inhaling silica, it causes a characteristic lung disease known as silicosis. It may present as acute or chronic silicosis, each manifesting differently in the affected person. Acute silicosis occurs when a person is exposed for a short time period at levels high above the OEL. The persons usually have symptoms such as weight loss, fever, cough and worsening dyspnoea which normally results in death of the person, generally within two years, due to respiratory failure. Chronic silicosis, which is the most common form, typically has a long latent period (between 10-20 years). Symptoms of chronic or classic silicosis includes: shortness of breath, poor gas exchange, fatigue and fibrotic nodules in the lungs, which generally manifests into lung cancer or fibrosis (Greenberg *et al.*, 2007; Witschi *et al.*, 2008).

2.3.4 Fibres

According to the Centres for Disease Control and Prevention (CDC) (2011) the terminology for defining fibres is: An acicular single crystal or similarly elongated polycrystalline aggregate particle, which presides over macroscopic properties such as axial lineation, flexibility, silky luster and a high aspect ratio. When they are evaluated microscopically only particles that have an aspect ratio of 3:1 or greater are defined as a fibre.

Most of the fibres that workers are exposed to in the working environment are mainly ceramic fibres, rock wool, glass wool, and asbestos and its analogues. These types of fibres have a wide variety of application in the industry. For example ceramic fibres are used in the automotive and aerospace industries, glass wool is a great insulator for pipes in air-conditioning heating and cooling systems and asbestos was previously used in the production of brake linings of brake pads as well as for the strengthening of road surfaces (Matos *et al.*, 2012).

The most fibre related studies were conducted on the exposure of asbestos and asbestos related fibres. As described in the underlying text, asbestos as well as other fibre forms may have health implications in humans.

Some fibres can form with the same structure as that of asbestos, without any health threats. Particulates with the same structure as asbestos can be formed during milling, crushing or grinding and may produce structures known as cleavage fragments. Cleavage fragments are defined as a particle created by breakage along specific crystallographic planes from a mineral that did not originally grow along its long axis with a fibrous habit (Ilgren, 2004; Aust *et al.,* 2011). Exposure to cleavage fragments should not be exempt from similar controls to the asbestos industries, if elongated particles meeting the phase contrast microscopy (PCM) definition (with aspect ratio criteria of 3:1) of fibres pose qualitatively and quantitatively the same levels of health risk as its asbestiform counterparts. Population studies done on the health effects of exposure to non-asbestiform elongated mineral particulates (EMPs) have not yielded any answers regarding these EMPs toxicity (CDC, 2011). Although the significant hazards of exposure to inhaled airborne asbestos fibres is well known, an on-going debate exists whether thoracic-sized EMPs exposure from non-asbestiform analogue minerals may also be hazardous (CDC, 2011).

Health experts have come to an agreement that thin, long fibres pose more of a health risk than moderate to low doses of short, wide fibres (Lee *et al.*, 2008). However, if fibres pose no or a lesser risk than the asbestos minerals, they should be regulated accordingly (Gamble and Gibbs, 2008). Different types of asbestos fibres are associated with significant differences in the risk of contracting mesothelioma (Gibbs and Berry, 2008). The exposure to asbestos and asbestos like fibres can cause a number of diseases, like asbestosis, mesothelioma, lung cancer, benign pleural effusion, pleural thickening and bronchiectasis amongst others (Manning *et al.*, 2002).

2.4 The steps in establishing an OEL

The process for establishing an OEL, will differ between different organisations and countries, thus different organisations have their own procedure for the setting of an OEL for a substance and the process they use may be similar to some extent (Schenk and Johanson, 2010; Schenk and Johanson, 2011).

According to Still *et al.* (2008), the overall OEL setting process for a substance requires 1) the collection of a full data set for the substance in question, 2) identification of the critical endpoints, as well as documentation of physio-chemical properties, animal studies, nomenclature, human use and experience data as well as the rationale that is used to develop an OEL, and 3) evaluation of published animal and human studies for the substance of interest.

The above mentioned three requirements may be met when the following eight components that form the outline for the development of an OEL for a substance are addressed.

2.4.1 Chemical identification and properties

Identification of the substance in question, by means of its IUPAC name or CAS number, and by obtaining data with regards to the physical and chemical properties of the substance, may assist in understanding the health-based effects it may pose when humans are exposed to the said substance. Knowing the physical and chemical properties of the substance such as its stability, boiling and melting point, physical appearance under normal temperature and pressure (NTP) or standard temperature and pressure (STP) can provide important information on how the said substance will react in certain situations (Klonne, 2003; Still *et al.*, 2008). Certain metals exist in different forms such as mercury which has elemental, organic and ionic forms with each having its own unique toxicity characteristics. Other metals, like cadmium seem to have similar toxicological effects regardless of its form (Merrill *et al.*, 2001).

2.4.2 Animal toxicity data

The understanding of the use of animals for the testing of toxicological effects is not complete because a wide variety exists of species to choose from. Animals such as mice and rats are extensively used in laboratory testing whose biological characteristics have been widely explored in the past (White, 2001). With descriptive animal toxicity testing, two main principles form the basis of all the descriptive testing: 1) all the effects that are produced by a substance on animals in a laboratory are applicable to humans, because with the dose per body surface unit humans will have the same toxic effect in the same range as the experimental animals, and 2) high dose exposure in experimental animals is of vital importance to establish possible hazards in humans, this is based on the quantal dose-response concept that the relative incidence of an effect in a population is greater as the exposure increases (Eaton and Gilbert, 2008). With testing done on experimental animals, required data is obtained to determine the toxic effect that it possibly may have on humans. The types of tests that were done included the oral LD_{50} in rats or mice, eye and dermal irritation in rabbits, and dermal sensitisation in guinea pigs (Still *et al.*, 2008). The fundamental endpoints in non-human studies are sensitisation, irritancy, reduced growth and reproduction, changes in behaviour and death. These changes are all connected, just to mention a few (Stenersen, 2004).

The usage of animals for toxicological testing should not be taken for granted, thus responsible animal usage has stimulated the interests in the scientific community to use *in vitro* modelling and computer-simulated models, but these systems need to be extensively validated by accepted regulatory bodies to serve as substitutes for animals used in toxicological testing (White, 2001; Garber and Luttrell, 2008).

2.4.3 Chronic and acute toxicity

A very important toxic evaluation that forms part of the OEL setting process is the consideration of chronic and acute toxicity, where the fundamental estimation of toxicity is obtained from acute toxicity data (DiNardi, 2003; Klonne, 2003; Schenk and Johanson, 2011). The toxicity data are extrapolated from experiments conducted on laboratory animals, which were exposed to a single dose of a substance and where after the effects of the said substance were monitored over a period of 14 days. This usually is expressed as an estimated lethal dose (LD_{50}) (Eaton and Gilbert, 2008). The LD_{50} is the dose in milligrams per kilograms body weight where 50% of the test animals have died.

Chronic toxicity is where extended exposure to a substance manifests into negative health implications. Chronic toxicity estimation is also done on laboratory animals over an extended time period to determine the effects of repeated exposure. The common goal of these tests is usually to establish a lowest observed adverse effects level (LOAEL) or a no observable adverse effects level (NOAEL) for a substance (Eaton and Gilbert, 2008). Death is the first endpoint in acute toxicity testing. A substance that produces major health effects after exposure over a short time period, poses a potential risk associated with acute toxicity and will possess a lower OEL than other substances (Klonne, 2003).

With these and other data obtained from animal testing, an OEL can be set for a substance; also it may assist in the type of OEL that should be set to a substance i.e. STEL or C (Klonne, 2003; Paustenbach *et al.*, 2011).

2.4.4 Human use and experience data

When a person is exposed to a chemical their health effects can be directly observed and there is no need for animal exposure data for the determination of the possible effects on the said person (Stenersen, 2004). Epidemiological data is needed which arises from research done and observations on a specific substance, data obtained from human exposure is the most valuable when an OEL needs to be set for a substance, and this data may give the best information for the setting an OEL to a substance which possesses potential chronic health effects. Thus quality human data is preferred instead of animal test data (ICMM, 2007; Schenk and Johanson, 2011). It’s hard to establish data for chronic exposure to a substance, volunteer studies mainly focus on acute effects due to exposure, this can be useful when a substances’ key health effects have already been identified (ICMM, 2007).

2.4.5 Toxicokinetic modelling

This is very useful during the evaluation of toxicity, because it provides viable information on the duration of exposure, route of exposure, distribution, inter-individual variability, risk of cancer, and target organ sensitivity (Merrill *et al.*, 2001). Toxicokinetics testing's goals are to establish safe exposure levels to a certain substance and it's also critical to determine where the said substance is localised in the body (Garber and Luttrell, 2008).

2.4.6 Sensitisers and irritants

Substances which possess the ability to cause sensitisation, usually by inhalation, are noted with a sensitisation notation (Sen) in most of the countries' table of OELs, so that employers as well as employees can take note that sensitisation to the said substance can occur when exposed (Eaton and Gilbert, 2008). The Organisation for Economic Co-operation and Development (OECD) has developed two tests to determine if a substance has the potential to cause sensitisation, but neither of these two tests are capable to test sensitisation caused by particulate or gaseous materials (ICMM, 2007)

Numerous airborne substances have the ability to produce irritation in the eyes, nasal, and trachea-bronchiolar regions when a person is exposed at certain concentrations. It is not always irritation that a person may experience, because in some instances it is hard to differentiate between displeasing odours, such as that of ammonia, and irritation of the nasal passage (ICMM, 2007).

2.4.7 Genotoxicity, reproductive toxicity, and cancer

The most obvious health effects from exposure to certain substances are genotoxicity, reproductive toxicity and cancer (ICMM, 2007). According to Stenersen (2004), obtaining endpoints in human data is much more advanced than in animals, where cancer is seen as the most feared effect of exposure to chemicals. Takala *et al.* (2014) reported that of the 2.3 million work-related deaths in the world, an estimate of 32% can be prescribed to work-related cancers. The most relevant information needed to set an OEL to a substance is obtained from 28-90 day inhalation studies conducted on experimental animals. The OECD has developed a manual with tests for the testing of a substances toxicity, which can be used in different laboratories across the world, which will produce the same experimental data and will also be accepted by the different regulatory bodies (ICMM, 2007).

Some metals have positive results in a genotoxicity test; these metals will typically be classified as carcinogens if there is no identifiable limit that can be regarded as adequate to protect the health of a person. On the other hand metals can produce gene mutations via mechanisms such as production of ROS and DNA damage repair mechanism inhibition (Costa, 2008).

Reproductive toxicity testing should be done via the oral route, but for certain substances inhalation would be more appropriate, whatever exposure route is chosen for testing, dosing should occur daily at precisely the same time (ICMM, 2007). As Costa (2008) stated that the use of certain pesticides has documented reproductive effects in birds and other animals due to the bioaccumulation of these substances in the ecosystems.

2.4.8 Socio-economic factors

As ICMM (2007) stated, the American Conference of Governmental Industrial Hygiene (ACGIH) Threshold Limit Values (TLVs) are the most adopted OELs by countries and organisations across the world, but these OELs are only health based and do not consider aspects such as economic impact, technical feasibility, and risk management when OELs are being developed for substances.

Determining maximum levels of exposure to a substance, weighing health-based limits with economic impact or technical feasibility are just some of the different risk management approaches used by the different countries and/or organisations (Haber and Maier, 2002). Other factors that may have an impact on the difference between OELs of countries and organisations may be due to: the gender and predominant age profile of workers, economic considerations, and work-week length (Paustenbach, 2000). Another factor that may lead to differences in OEL is the legal environment in which a specific country functions. The legal system may either aid or hamper the setting and revision of OELs. It should be kept in mind that OEL lists without a legal mandate will not be more than a list of recommended OELs which will lessen the power it may have to protect the health of workers in the respective countries and/or organisations (Paustenbach *et al.*, 2011). Each authority that has set an OEL for a substance has documentation, but these documentations are not always accessible, that assisted them in the setting of an OEL to a substance, and contain information about the data that were used during the setting process. When setting an OEL to a substance practical and technical feasibility must also be taken into account (Liang *et al.*, 2006; Ding *et al.*, 2011; Schenk and Johanson, 2011). Thus is it economically viable to maintain an exposure limit far below the already established limit.

With the assessment of socio-economic factors, a cost-benefit analysis/assessment is used, this is just an instrument to quantify as many benefits and costs of a proposal as possible, and will include factors such as health status. Quantification of the so called benefit of an OEL can be difficult, because it is generally based on how far the OEL will reduce a certain risk by using dose-effective information. When this dose-effective information is unobtainable, like in the case of certain carcinogens having no thresholds, which can be debateable, other methods have been developed to determine the gains of an OEL, such as improved workers retention and recruitment (ICMM, 2007).

2.5 The different developed countries and organisations

There are very few organisations in the world that independently set OELs, most countries and/or organisations follow guidelines from the HSE, ACGIH or the German-Deutsche Forschungsgemeinschaft (DFG) (ICMM, 2007).

The different countries and/or organisations that are reviewed in this study are: Australia, Canada (British Colombia), Finland, Germany, Japan, New Zealand, Sweden, United Kingdom (UK) and the United States of America (ACGIH, OSHA and NIOSH).

2.5.1 Australia

In 1985 the National Occupational Safety and Health Commission, which is a national corporation in Australia, was established by the National Occupational Health and Safety (OHS) Commission Act of 1985. The National Occupational Safety and Health Commission sets the OHS standards for HCS in Australia and each state or area legally bounds these standards when they are adopted as regulations by the said state or area. Before 1985 separate states of Australia had their own regulations that were applicable to the said state or area, and each state or area are also responsible for the enforcement of their health and safety (Brandys and Brandys, 2008).

2.5.2 Canada (British Colombia)

Canada has a total of 13 provinces, with each having their own health and safety regulations. The province of British Colombia is controlled by the Industrial Health and Safety Division of the Workers' Compensation Board, which sets out the legal requirements that are necessary to comply with by the general industry within this district. British Colombia, in 1995, adopted the ACGIH TLV's and is thus strongly influenced by them (Brandys and Brandys, 2008; Paustenbach, 2011).

2.5.3 Finland

The Ministry of Social Affairs and Health regulates all occupational safety and health in Finland. Finland's Department of Occupational Safety and Health is responsible for all the aspects regarding OELs, such as: monitoring, legislation and research. Finland adopted their first OELs from the ACGIH TLV's in 1960, and since then the Advisory Committee on Chemicals, which resides within the aforementioned department, developed their own two types of OELs namely: "Haitalliseksi tunnetut pitoisuudet" (HTPs) and "Sitovat Raja" (Maximum Allowable Concentration [MACs]) (Brandys and Brandys, 2008; Viljoen, 2012).

2.5.4 Germany

Germany's first OEL values were published in 1886 and in 1958 the first MAC list was published, and these values were mainly based on the ACGIH TLV's. Lately Germany publishes their OELs independently from those of the ACGIH. Germany also implements scientific based criteria when developing OELs rather than economical and technical feasibility, for health protection of their workforce. Legal enforcement of the OELs set out is done by The Federal Ministry of Labour and Social Affairs (Brandys and Brandys, 2008; Paustenbach, 2011).

2.5.5 Japan

In Japan, occupational exposure to chemicals is the responsibility of the Department of Environmental Health. The Japan Society for Occupational Health (JSOH) has an OEL committee which recommends the OELs as reference values to the aforementioned department. The OELs set out by the JSOH are made legally binding by the Department of Environmental Health (Brandys and Brandys, 2008; Viljoen, 2012).

2.5.6 New Zealand

The Department of Labour institutes and enforces, by law, the OELs for exposure in the working environment. When these limits are being developed, the department's goal is to ensure that there are no adverse health effects, but they also state that it does not guarantee protection when complied with these limits (Brandys and Brandys, 2008).

2.5.7 Sweden

The authority to establish OELs in Sweden is given by the Swedish Work Environment Authority. The Work Environment Regulation enforces the OELs legally and the employer is compelled to keep exposure as far below the OEL as possible. Sweden reviews research data, such as toxicological and scientific literature, when establishing a list of OELs (Brandys and Brandys, 2008).

2.5.8 United Kingdom

The OELs set out in the UK, which are health based, function under the Control of Substances Hazardous to Health Regulations (COSHH). The Health and Safety Commission's Advisory Committee on Toxic Substance (ACTS) is responsible for the revision of the current OELs or recommends new OELs. After approval of the new or revised OELs by the ACTS, then they are sanctioned by the Health and Safety Commission (HSC) (ICMM, 2007; Brandys and Brandys, 2008; Ding *et al.*, 2011).

2.5.9 The United States of America (USA)

The organisation responsible for the health and safety regulations in the USA is the Occupational Safety and Health Administration (OSHA) which were established in 1970 with the first OHS Act. This led to the establishment of the National Institute for Occupational Safety and Health (NIOSH) (Brandys and Brandys, 2008).

OSHA

OSHA is the USA's regulatory body, due to the legal enforcement of the OELs set out by them. These OELs also referred to as Permissible Exposure Limits (PELs) and were also originally based on the ACGIH TLV's in the late 1960's (ICMM, 2007; Brandys and Brandys, 2008).

NIOSH

This organisation in the USA usually develops new exposure limits, standards and recommends these findings to OSHA. However NIOSH have no legal obligation as the OELs set out by the OSHA (ICMM, 2007; Brandys and Brandys, 2008). All recommendations to OSHA or other institutes are made through the criteria documents set out by NIOSH (ICMM, 2007).

ACGIH

Established in the 1940's, this non-profit organisation which represents a wide variety of occupational hygiene expertise and opinions is the most used or adopted OELs in the world, yet they have no legal obligation in the USA. The ACGIH TLV's are exclusively health-based and does not take factors such as practical/technical feasibility and socio-economic factors in account when establishing an OEL for a substance (ICMM, 2007; Brandys and Brandys, 2008).

2.6 Previous comparative studies on OELs

Schenk *et al.* (2008a) compared the OELs from fifteen different countries or territories, some of which include: ACGIH, Japan, OSHA, France, California, Canada (Alberta) and Poland, using a standard comparison list. The standard comparison list was comprised out of the ACGIH first list of TLVs and the European Union (EU) OELs. The reason for this combined list is that it contained substances that are likely to be present in the rest of the countries' lists, which were used for their study. The geometric means method were used rather than the arithmetic means because when using the latter, the list that is used as the denominator will have a lower value, thus each OEL participating in the analysis will carry the same weight. When a geometric value of < 1 is obtained, it will indicate that the list that is being compared will have overall lower OELs and *vice versa*. The study concluded that the geometric mean values of all the countries and/or organisations used in that study ranged between 0.28 and 0.41, thus below one, which could be expected due to the fact that most of the OELs that were used in the comparison list were derived from the ACGIH first list. The study also concluded that OELs differ between different countries based on the comparison conducted in that study. Yet they found no descriptive evidence which may explain this anomaly such as legal status or differences in the risk analysis to establish an OEL.

On the other hand Viljoen (2012) comprised its own list of OELs for her study, thus mostly representing the HCS that was common throughout the countries' lists that were used. The study compared the OELs from the list created - by Viljoen (2012) - to the OELs of different developed as well as developing countries used in the study. The study concluded that although South Africa was more stringent with regards to OELs when compared to developing countries, the OELs set out in the HCSR were very outdated when compared to those of developed countries and that the OELs from the HCSR are inadequate to control exposure and thus protect the workforce from adverse health effects.

This concludes the literature study on the different types of OELs which exist, the different countries and organisations used in this study and an overview on the different selected groups used as well as the steps deemed necessary for the establishment of an OEL.

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Chapter 3

Article

Guidelines to Authors

This article will be submitted to the *Annals of Occupational Hygiene*. The author's instructions are as follows:

- *Structure of paper.* Paper should generally conform to the pattern: Introduction, Methods, Results, Discussion and Conclusions – consult a recent issue for style of headings. A paper must be prefaced by an abstract of the argument and findings, which may be arranged under the headings: Objectives, Methods, Results, and Conclusions. Keywords should be given after the list of authors.

- *Brevity.* The necessary length of a paper depends on the subject, but any submission must be as brief as possible consistent with clarity. The number of words, excluding the abstract, references, tables and Figures, must be stated as a message to the Editor at the time of submission. If this length is more than 5000 words, a statement must be included justifying the extra length, and papers without this information may be returned unread.

- *Units and symbols.* SI units should be used, though their equivalent in other systems may be given as well.

- *Figures.* Good quality low resolution electronic copies of figures, which include photographs, diagrams and charts, should be sent with the first submission. It is helpful to reviewers to incorporate them in the word-processor text or at the end. The revised version, after review, should be accompanied by high resolution electronic copies in a form and of a quality suitable for reproduction. They should be about the size they are to be reproduced in, with font size at least 6 point, using the standard Adobe set of fonts.

- *Tables.* Tables should be numbered consecutively and given a suitable caption, and each table typed on a separate page. Footnotes to tables should be typed below the table and should be referred to by superscript lowercase letters.

- *References.* References should only be included if essential to the development of an argument or hypothesis, or which describe methods for which the original account is too long to be reproduced, only publications which can be obtained by the reader should be referenced. References in the text should be in the form Jones (1995), or Jones and Brown (1995), or Jones *et al.* (1995) if there are more than two authors. For example: Jones and Brown (1995) observed total breakdown control… or Total breakdown of control has sometimes been observed (Jones and Brown, 1995).

- At the end of the paper, references should be listed in alphabetical order by name of first author, using the Vancouver Style of abbreviation and punctuation. Examples are given below. ISBNs should be given for books and other publications where appropriate. Material unobtainable by readers should not be cited. Personal Communications, if essential, should be cited in the text in the form (Professor S.M. Rappaport, University of California). References will not be checked editorially, and their accuracy is the responsibility of authors.

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Comparing South African occupational exposure limits for pesticides, metals, dusts and fibres with those of developed countries

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Abstract

Objective: To analyse comparatively selected groups i.e. pesticides, metals, dusts and fibres of Hazardous Chemical Substances' (HCS) occupational exposure limits (OELs) from South Africa with those of developed countries. **Method:** OELs legislated by the two relevant regulatory bodies in South Africa through the Hazardous Chemical Substances Regulations (HCSR) of the Occupational Health and Safety Act and Regulations of 1993, and the Mine Health and Safety Regulations (MHSR) of the Mine Health and Safety Act of 1996 were compared with 11 different developed countries and/or organisations. The OELs from each country and/or organisation were categorised into one of the four groups, depending on the characteristics and nature of the said element and/or compound and compared with both of South Africa's lists of OELs. The selection of the countries and organisations were done on the basis of their dominance in the literature as well as the availability of their OEL lists. The geometric means of each country and/or organisation were calculated from the ratios of each list by respectively using the HCSR and the MHSR as the denominator. Furthermore, a regression analysis was conducted on the results to investigate the trends of OELs over time. **Results:** It was found that South African OELs from all four groups are overall set at a higher level when compared to the other countries and/or organisations. On average OELs of Sweden, Japan and Finland are set at the lowest level. It became evident, as indicated in this study, that South Africa performed poorly when compared to other countries and/or organisations. OELs decrease over time, although some decreased more than other. **Conclusion:** South African OELs legislated by both the HCSR and MHSR, are overall higher (less stringent) when compared to those of developed countries and/or organisations. The less stringent nature of South African OELs may be attributed to infrequent rate at which they are updated. The failure to incorporate recent scientific knowledge into OELs may impact on the health of workers. South Africa should follow international best practice and increase the frequency at which OELs are updated; furthermore, current OELs should be updated to bring them in line with international OELs.

Key words: *Occupational exposure limits, pesticides, metals, dusts, fibres, South Africa, developed countries, organisations, hazardous chemical substances.*

3.1 Introduction

Occupational hygiene may be defined as the art and science of the control and prevention of hazards in the work environment which may result in the injury, illness or impaired well-being of workers (South African Department of Minerals and Resource, 1996). To this end, occupational exposure limits (OELs) have been used for more than half a century by the occupational hygiene and toxicology community for the prevention of work-related illness that may be induced by exposure to hazardous chemical substances (McCluskey, 2003; Aneziris *et al.*, 2010). Since workers are exposed to a variety of chemicals these OELs are used as a risk management tool for achieving health protection of workers (Topping, 2001; Schenk *et al.*, 2008a; Ding *et al.*, 2011). An OEL may be defined as that concentration of a substance in the workplace to which workers may be exposed to without causing adverse health effects (South African Department of Labour, 1995). Unfortunately OELs are only set for a single substance, yet exposure to mixtures containing a specific substance can occur in the working environment (Sterzl-Eckert and Greim, 1996).

South African legislation makes provision for two sets of OELs, one is provided for by the Hazardous Chemical Substance Regulation (HCSR) which is applicable to general industries and the other is provided for by the Mine Health and Safety Act (MHSA), Section 22.9 of the Regulations which applies to the mining industry in South Africa (South African Department of Labour, 1995; South African Department of Minerals and Resource, 1996). During previous research, it became apparent that OELs as contained in the HCSR have overall higher limits (less stringent) when compared to developed countries and organisations. It was, furthermore, ascertained that while some developed countries have set OELs for both parent compounds and their unique isomers, South African mainly regulates the parent compounds (Viljoen, 2012). Both these aspects indicate that South African OELs in the HCSR are inadequate to some extent to control exposure and protecting the South African workforce from adverse health effects resulting from hazardous chemical substances (HCSs) exposure (Viljoen, 2012).

In the early 1990's the United Kingdom's Control of Substances Hazardous to Health (COSHH) Regulations used two types of OELs namely: 1) the occupational exposure standards (OESs); this standard is applicable to substances for which there is no significant risk to a person's health and when the OEL can be adhered to by the industry, and 2) maximum exposure limits (MELs), this is applicable to substances which are not easily identifiable and have severe health implications on persons (Topping, 2001). In the HCSR, published in 1995, there are two types of OELs, namely; 1) OEL-RL (Occupational Exposure Limits-Recommended Limits) that is the same as COSHHs OES, and 2) OEL-CL (Occupational Exposure Limits-Control Limits) which is based on the MEL of the COSHH (South African Department of Labour, 1995; Topping, 2001). An OEL-RL is the concentration of an airborne pollutant, averaged over a reference period, which according to current knowledge, there is no evidence — such as toxicological data — that it may be detrimental to a workers health if exposed to that substance day after day. For an OEL-CL to be assigned to a substance serious implications to the health of workers should exist and exposure should be controlled to levels below the OEL, as far as it is reasonably practicable (South African Department of Labour, 1995). Historically, OEL-CLs have been assigned to carcinogens and other substances to which no threshold of effect can be identified and where there is little doubt about the seriousness of their health effects on workers after exposure (South African Department of Labour, 1995).

Most of the set OELs are set as time weighted average exposure limits (TWA) which is defined as the concentration at which a worker may be exposed to for an 8 hour working day and a 40 hour work week, but scientific evidence exists that the setting of an OEL to a substance lacks standardisation and is inconsistent between different countries and organisations (Nielsen and Steinar, 2008; Schenk, 2010). As stated by Liang *et al.* (2006) actual OELs set for substances differ significantly between different countries. This can be explained due to the data that is needed to set an OEL for a specific substance, such as toxicological data, and that these values must be balanced by socio-economic and practical feasibility.

Short term exposure limits (STEL) is set upon a substance that has recognised acute effects and is the maximum concentration to which a person may be exposed to, over a short period, usually 15 minutes (South African Department of Labour, 1995;

McCluskey, 2003). TWA-Ceiling limit (C) indicates a concentration that may not be exceeded during any part of the workday according to McCluskey (2003).

During 2013 it was made known that the Department of Labour of South Africa is in the process of reviewing the HCSR. As the current HCSR was published in 1995, which themselves were based on even older legislation of the UK, it is clear that the HCSR legislation needs to be benchmarked with those of developed countries in order to establish a level of best practice for South Africa with regards to its HCSR as a third revision may be years away. It was, therefore, decided that a unique contribution could be made through this study by identifying deficiencies in current legislation and by recommending changes that will enable government to benchmark the South African HCSR with international best practise.

Previous research concluded that South African OELs are less stringent when compared to those of developed countries, and that OELs also differ considerably between countries (Schenk *et al.*, 2008a; Viljoen, 2012). Viljoen's (2012) study was based on the comparison of all the HCS OELs present in the HCSR with those of developed countries, and concluded that the HCSR are outdated. During this study the HCS' were divided into one of four groups i.e. pesticides, metals, dusts and fibres in order to obtain more information with regards to which specific group or sector of OELs need more attention. Thus by categorising the HCS, depending on the nature and characteristic of the said element and/or compound, into one of the four groups, it will provide insight into where South African legislation lacks standardisation in order to establish a level of best practise. In the context of the above, the aim of this study is to compare South African OELs for pesticides, metals, dusts and fibres in the HCSR and MHSR with each other and to those of developed countries and/or organisations.

3.2 Methods

3.2.1 Lists of OELs:

The most recent, published lists of OELs were obtained from different countries and/or organisations. The selection of countries and/or organisations for comparison was done on the basis of their dominance in the literature as well as the availability of their OEL lists. The lists that were obtained include: Canada (British Colombia), United Kingdom (Health and Safety Executive, HSE), Australia (National Occupational Health and Safety Commission, NOHSC), New Zealand (Ministry of Business, Innovation and Employment), Japan (Japan Society for Occupational Health, JSOH), Finland (Ministry of Social Affairs and Health), Germany (Deutsche Forschungsgemeinschaft-DFG), Sweden (Swedish Work Environment Authority), USA (American Conference of Governmental Industrial Hygienists, ACGIH, Occupational Safety and Health Administration, OSHA and National Institute for Occupational Safety and Health, NIOSH), and South Africa (Hazardous Chemical Substance Regulations, HCSR and Mine Health and Safety Regulations, MHSR) for the comparison.

The substances from each country and organisations were categorised into one of the four groups, depending on their nature and characteristics, namely: pesticides, metals, dusts, and fibres. It was decided to categorise hazardous chemical substances into the previously mentioned groups and to compare them with those of developed countries and organisations as this process will indicate to what extent South African OEL values should be set to be considered appropriate from an international viewpoint for these groups of HCS. It should be kept in mind that although asbestos and lead has its own regulations, within South African legislation, they were included in this study.

3.2.2 Database establishment:

All the substances from the different countries and organisations' 8-hour TWA were documented for each of the different groups. The TWAs were thereafter systematically entered into a database in such a way that a comparison between the OELs of the HCSR and the MHSR as well as the OELs of the other countries was possible.

The final database used in this study contained OELs for each of the different groups collected from 13 countries and/or organisations.

The OELs in the database are listed in both parts per million (ppm) and milligrams per cubic meter (mg/m^3). The unit used for the comparisons were mg/m^3, because it was the unit for which the least amount of conversions were necessary, also it occurred the most in the different lists. If it was necessary to convert an OEL of a substance to mg/m^3 from ppm, it was done by the calculation as given by Schenk *et al.* (2008a).

$$\mathbf{Concentration\ (mg/m^3)} = \frac{(\mathbf{Concentration\ in\ ppm})\ (\mathbf{Molecular\ weight})}{\mathbf{24.45}}$$

This conversion equation was used at conditions of standard temperature of 25^{o}C and atmospheric pressure of 1 atmosphere (101.325 kPa) for all the substances. In instances where substances had only a STEL assigned to it, the STEL was adjusted by conversion factors as recommended by the ACGIH provided for in (Table 1) (Schenk *et al.*, 2008a).

Table 1: Factors for calculating an 8-hour TWA average from a STEL value (As first suggested by ACGIH in 1963) (Schenk *et al.*, 2008a).

TWA (ppm or mg/m^3)	C factor
X ≤ 1	3
1 < X ≤ 10	2
10 < X ≤ 100	1.5
100 < X ≤ 1000	1.25
1000 < X	1

If a substance had more than one OEL, for example inhalable and respirable fractions or different compounds, then all of the OELs were included in the database. Substances that had a Ceiling limit were excluded from the database because the HCSR had no ceiling limits thus substances that had a C could not be included in this study.

3.2.3 Statistical analysis by means of the geometric means method:

The OELs in the different groups were statistically compared by means of the geometric means method, which was first used by Hanson (1997). For these comparisons between the different countries and/or organisations, only the substances of the four groups that are listed by the 13 countries and/or organisations were included for comparison. For the comparison between two countries and/or organisations, only the substances that had OELs on both of the lists that were compared were included for example MHSR versus Canada (British Colombia).

The geometric means method was chosen rather than arithmetic means or median method; because when using the arithmetic means or median values, obtained from the list will have a higher value depending which list was used as the denominator. This is illustrated in the following example:

List A and B for instance both had OELs assigned for three substance in a specific category. List A has allocated the following:

- Substance I : 20 ppm
- Substance II: 15 ppm
- Substance III: 10 ppm

List B allocated the following OELs for the same substances:

- Substance I: 200 ppm
- Substance II: 15 ppm
- Substance III: 1 ppm

The arithmetic means of the ratios of A/B = 3.7, which indicates that that A has a higher value, on the other hand the arithmetic means of the ratios of B/A also equals 3.7 indicating that B has higher values. In contrast both have a geometric means equalling 1, suggesting that the averages of both lists do not deviate from each other (Schenk *et al.*, 2008a; Schenk *et al.*, 2008b). A geometric mean with a value lower than 1 will indicate that the list that is being compared have overall lower OELs, in contrast to a geometric mean value of more than 1 which will indicate overall higher OELs. An "average" geometric mean were calculated as depicted in the results. This value includes all the countries and/or organisations geometric means, excluding the comparisons made between both of South Africa's OEL lists respectively. Thus for example the average geometric mean of the HCSR for a certain group, will indicate if closer to 1 than the average geometric mean of the MHSR comparisons, that the HCSR has more stringent OELs set than those set by the MHSR for the said group and *visa versa.*

A repetitive approach where each country and/or organisation's OEL was compared to only the HCSR or the MHSR OEL, one at a time was used. This process was repeated for each of the four groups. All of the results obtained were thereafter presented in bar charts. The results were, furthermore, used to perform a regression analysis in GraphPad Prism (2006) in order to investigate trends over time.

3.3 Results

3.3.1 Pesticides

Evident from Figure 1(A), all of the geometric means of OELs for pesticides, that appear on the OEL lists of the selected countries and/or organisations, were lower (more stringent) that those of the HCSR. Of note are OELs for pesticides from Sweden and Japan whose geometric means, 0.451 and 0.473 respectively proved to be the most stringent as well as the ACGIH which, in relation to the USA's other organisations, NIOSH and OSHA, have overall lower OELs for pesticides than the two aforementioned organisations. The lower geometric mean value of Sweden and Japan may have been influenced by the limited number of comparisons that could be made in relation to the other countries and/or organisations due to their low number of OELs.

From Figure 1(B) it is apparent that when the OEL lists of the selected countries and/or organisations are compared to the MHSR, that only OELs as provided for by the OSHA are less stringent than those of the MHSR. Figure 1 (B) also indicates that South Africa's HCSR, when compared to the MHSR, has higher OELs for pesticides as indicated by the geometric mean of 1.046.

The MHSR, on average, have lower set OELs for pesticides than those set out by the HCSR as seen from Figure 1 (A and B) with average geometric mean values of 0.684 and 0.782 respectively. Thus it is evident that the closer the geometric mean value to 1 the more stringent the OELs, hence the OELs for pesticides is set lower by the MHSR.

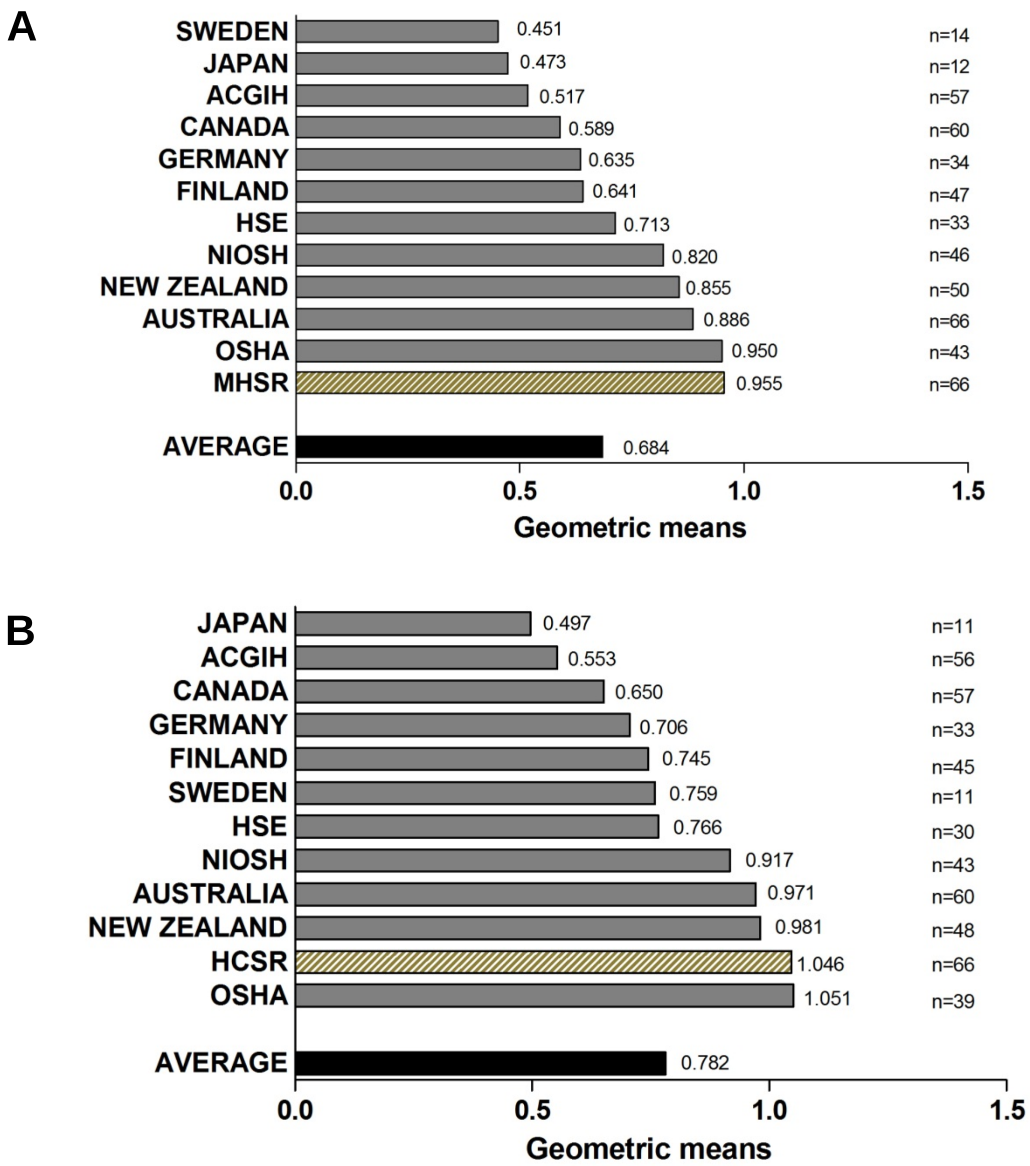


Figure 1: Pesticides (A) Comparing developed countries and/or organisations' geometric mean of ratios by using the HCSR as the denominator. **(B)** Comparing developed countries and/or organisations' geometric mean of ratios by using the MHSR as the denominator. n = Number of substances which had OELs assigned to them on both lists. "Average" refers to the average of the different countries and/or organisations excluding the HCSR and the MHSR.

3.3.2 Metals

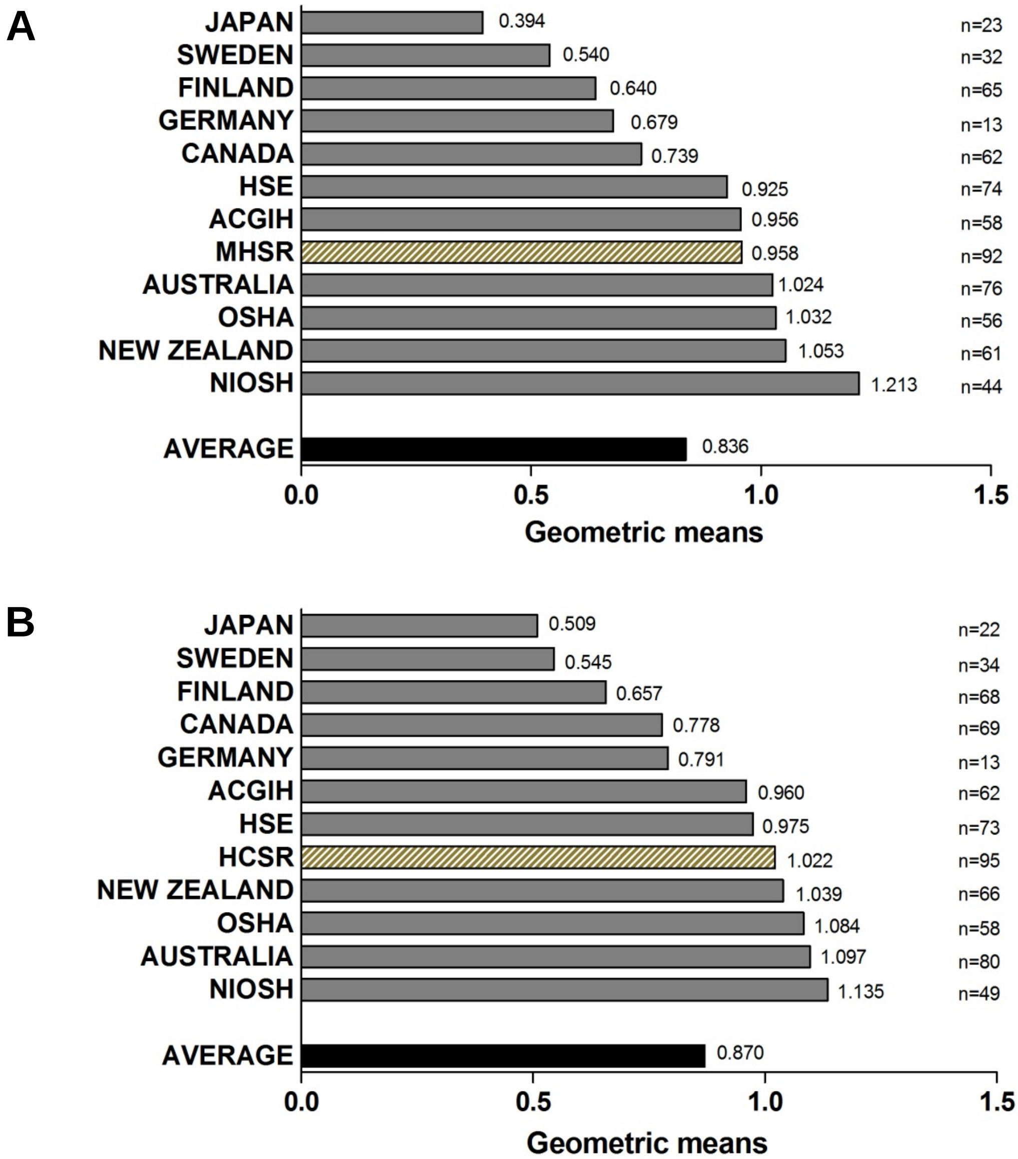


Figure 2: Metals (A) Comparing developed countries and/or organisations' geometric mean of ratios by using the HCSR as the denominator. **(B)** Comparing developed countries and/or organisations' geometric mean ratios by using the MHSR as the denominator. n = Number of substances which had OELs assigned to them on both lists. "Average" refers to the average of the different countries and/or organisations excluding the HCSR and the MHSR.

In Figure 2 (A) an (B), it is illustrated that the geometric means of OELs for metals that were present in lists of OELs from Australia, New Zealand, NIOSH and OSHA were overall higher (less stringent) than those of the HCSR and the MHSR respectively. In contrast Sweden and Japan had the most stringent OELs according to the geometric means values. From Figure 2 (A) it is also evident that the geometric mean values, when the OELs of the HCSR are compared to those of the MHSR, are in close agreement.

On average, both the HCSR and the MHSR, set their OELs for metals alike as is evident from the average geometric mean values of 0.836 and 0.870 respectively.

3.3.3 Dusts

Figure 3 (A) indicates that the overall OELs from the different countries and/or organisations have more stringent levels for dusts, except for OSHA who has the highest set OELs, with geometric mean value greater than 1, in relation to those set by the HCSR. Figure 3 (B) indicates that OSHA has an almost two times higher geometric mean for dust in relation to the MHSR's. The HSE, Australia, New Zealand, NIOSH and Germany also have higher OELs for dusts as indicated by their geometric means of 1.024, 1.122, 1.090, 1.116 and 1.135 respectively. The OELs legislated by the MHSR are in close agreement to those set out by developed countries as seen from the average geometric mean value of 0.998. The few comparisons that could be made with regards to Japan and Sweden could have had an influence on the low geometric mean value obtained for each of them. The same could be the case with the relatively high geometric mean value obtained for Germany.

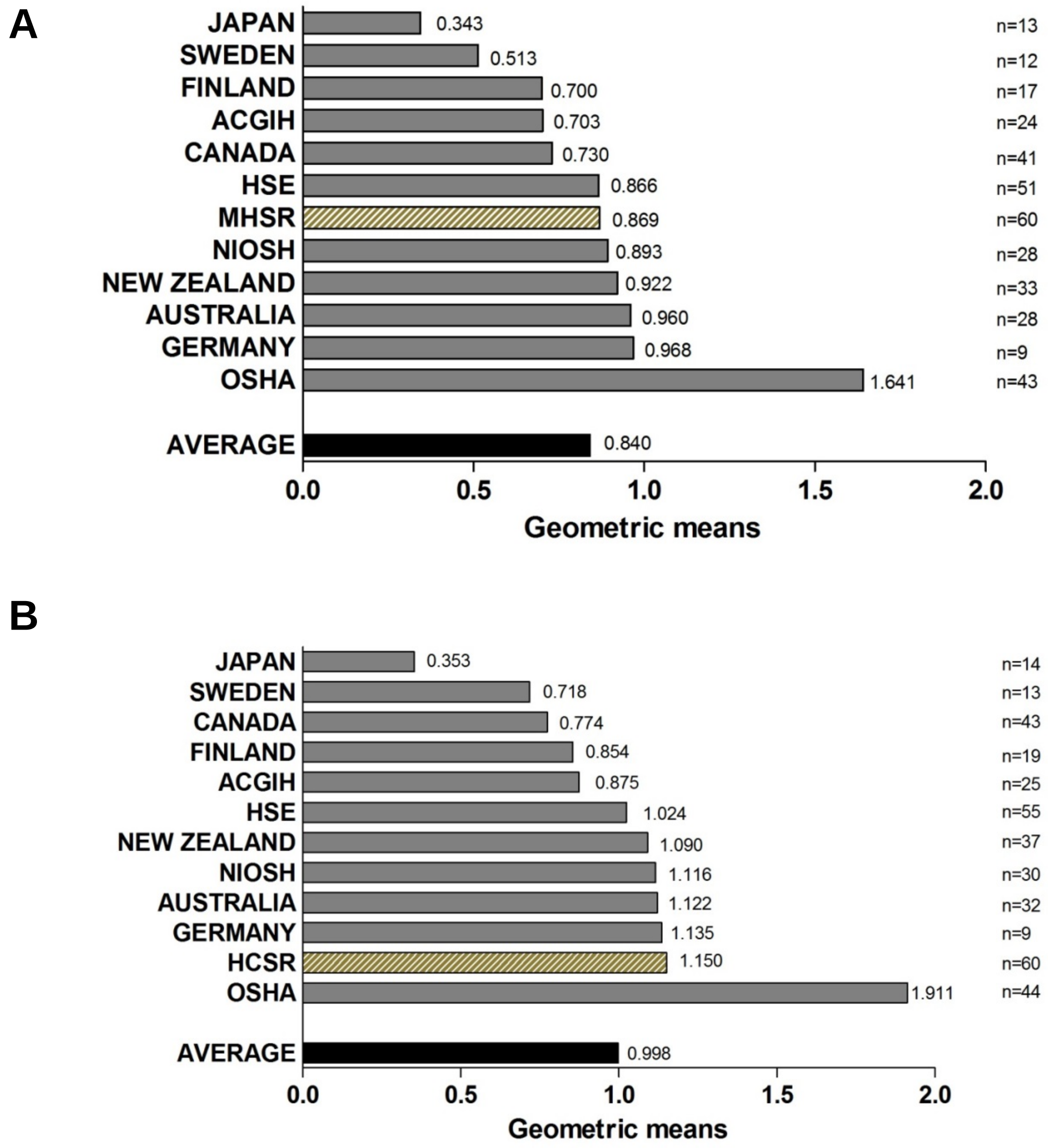


Figure 3: Dusts (A) Comparing developed countries and/or organisations' geometric mean of ratios by using the HCSR as the denominator. **(B)** Comparing developed countries and/or organisations' geometric mean of ratios by using the MHSR as the denominator. n = Number of substances which had OELs assigned to them on both lists. "Average" refers to the average of the different countries and/or organisations excluding the HCSR and the MHSR.

3.3.4 Fibres

As illustrated in Figure 4 (A) the majority of the OELs are more stringent for fibres when compared to those of the HCSR. In contrast, when the MHSR were compared to the HCSR, the MHSR had a geometric mean of 1.00, indicating that the OELs from the MHSR for fibres are exactly the same as those from the HCSR. Figure 4 (B) indicates that when comparing the geometric means of fibres to those of different countries and/or organisations, the MHSR have an average geometric mean value of 0.554 in relation to the HCSR's average geometric mean value of 0.535 when compared to the different countries and/or organisations. This indicates that the MHSR in relation to the HCSR has more stringent OELs for fibres than those set out by the HCSR. It should be noted that Germany and the OSHA were not included in this comparison due to the fact that they had only TWA_8-OELs whereas the rest of the countries and/or organisations had TWA_4-OEL. Again, the small number of OELs from Finland could have affected the results obtained from the comparison with regards to Finland.

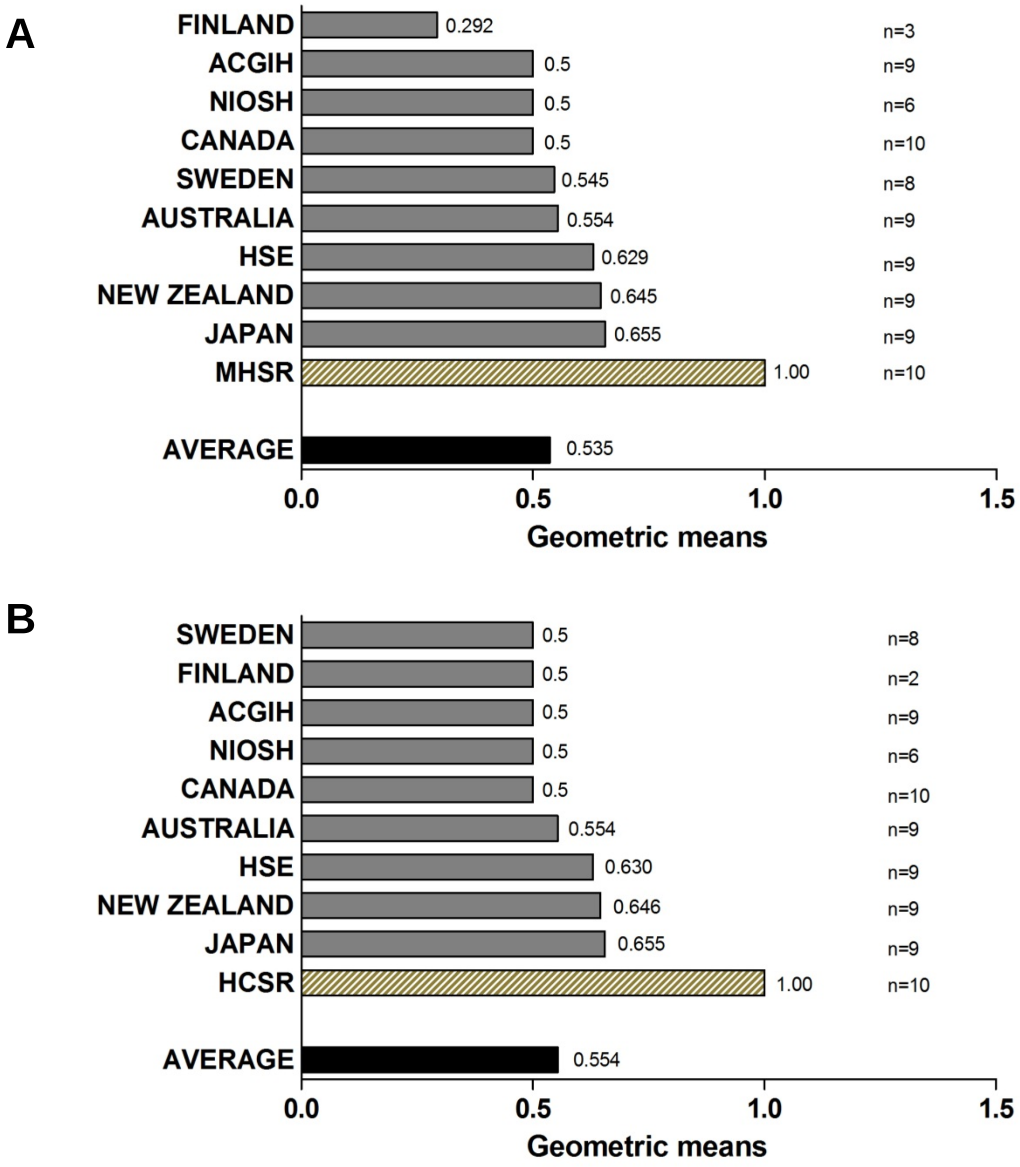
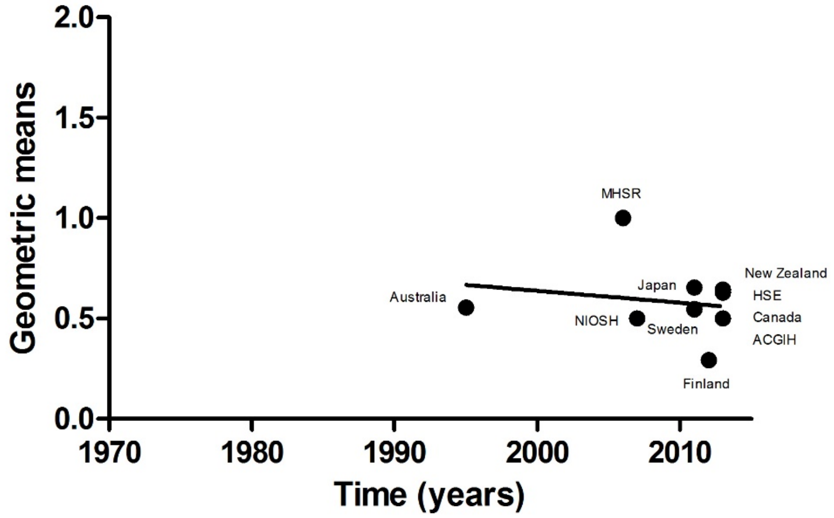


Figure 4: Fibres (A) Comparing developed countries and/or organisations' geometric mean of ratios by using the HCSR as the denominator. **(B)** Comparing developed countries and/or organisations' geometric mean of ratios by using the MHSR as the denominator. n = Number of substances which had OELs assigned to them on both lists. "Average" refers to the average of the different countries and/or organisations excluding the HCSR and the MHSR.

A



B

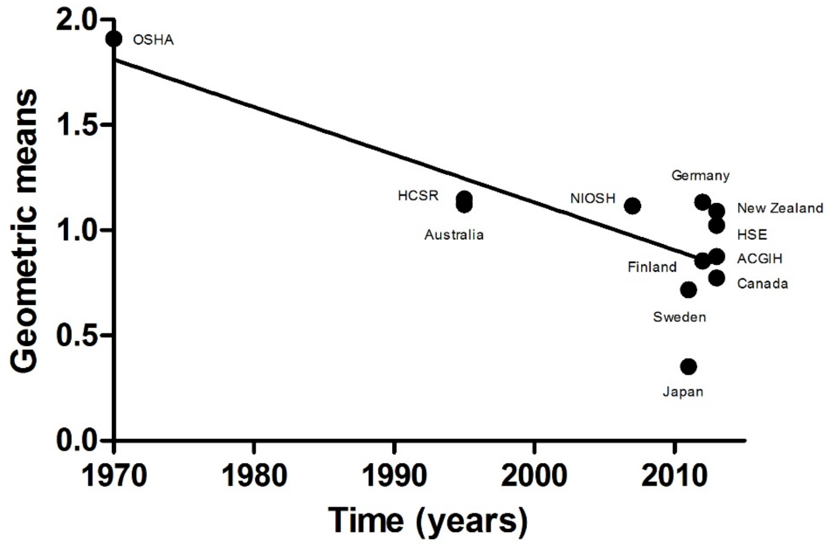


Figure 5: (A) The geometric means of ratios for fibres when compared to the HCSR of the different countries and/or organisations in relation to time. **(B)** The geometric means of ratios for dusts when compared to the MHSR of the different countries and/or organisations in relation to time**.**

Regression analyses were conducted on the results. This was done to represent the trend of OELs decreasing over time. Figure 5 (A and B) seems to confirm the claim by Schenk *et al.* (2008a) that OELs gradually decrease over time, although it should be noted that certain substances decreased more than others. While it seems that they do decrease, one should consider each country and/or organisation first to their most recent lists of OELs to obtain a true reflection of the decreasing of OELs over time.

The above Figures illustrate the trends for those OELs that decreased at a higher rate as well as those OELs that decreased at a lower rate.

The comparison of the geometric means for the 4 groups between the HCSR and the MHSR, with a paired t-test, revealed no significant difference ($p = 0.092$).

3.4 Discussion

The OELs as provided for in South Africa's HCSR and MHSR were categorised into 4 groups and compared to each other and to those of the various developed countries and/or organisations. South Africa's HCSR and MHSR were respectively used as the basis or denominator in each case.

The MHSR generally regulates pesticides more stringently than the HCSR, because they have lower OELs set out for pesticides than the HCSR. Based on the assumption that the HCSR would tend to regulate the use of pesticides to a larger extent than the MHSR. This is due to the nature of the chemicals used in the work environment, i.e. agricultural industry vs mining industry, one would have expected the OELs as legislated by the HCSR to be both more encompassing, i.e. more OELs for more pesticides and more stringent. From the results this was found, however, not to be the case since the MHSR legislated the OELs for pesticides more stringent. One could argue that this could be attributed to a lack of regulation by the HCSR or that the MHSR could find it elementary to regulate the use of a substance which they, in general, do not use in their industry. Another possible reason for the higher OELs set out by the HCSR can be due to the fact that they were last revised in 1995 while those of the MHSR were revised in 2006. The control of pesticides by well developed countries such as Sweden, Finland and Japan can be due to their economic status. For instance DDT is still being used as an insecticide in rural parts of South Africa as well as in certain parts of South-East Africa and central Africa (Roll Back Malaria, 2014), where in contrast, the use of DDT has long been banned and or substituted with a less lethal or a more efficacious pesticide in developed countries. Developed countries, furthermore, increasingly rely on organic farming which negates the use of pesticides (Costa, 2008). The overall lower OELs for pesticides by the different countries and organisations may also be attributed to the fact that the more industrialised and developed countries became acutely aware of the health and safety risks when handling and applying pesticides (Hook *et al.*, 2008) and incorporated this knowledge during the setting of OELs.

When comparing South African OELs of the HCSR and MHSR for metals with those of developed countries and/or organisations, South African OELs have the same geometric mean value irrespective of the legislative body concerned, indicating that the OELs that are set for metals are more or less equal as illustrated in Figure 2 (A and B). Despite the aforementioned, some substances are regulated to a larger extent by the MHSR than the HCSR which may be due to differences in the industries to which each applies. Due to the mining industry playing a very prominent role in South Africa this could be expected. It is also expected that the HCSR and the MHSR should have the same OELs for metals, because the mining industry exploits and concentrates the metals for the use in the general industry. Finland on the other hand does have a lower set OEL for metals and, therefore, the lower geometric mean in relation to South Africa, this can be due to more recent updated OELs. In general, with regard to the regulation of OELs set for metals, South Africa is in close agreement with those set out by the developed countries and organisations. With revision, in the near future, it may be possible and sensible to set OELs for metals that are on par with those of developed countries.

Considering results depicted in Figure 3 (A and B), it may be deduced that both the HCSR and the MHSR regulates dusts at a more or less equal level than developed countries, due to a due to both bodies having an average geometric mean value close to 1. This may, however, be a false assumption when considering that OSHA has the highest geometric mean for OELs for dusts namely 1.641 and 1.911 respectively. In other words, the high geometric mean values of the OSHA may provide a false sense of regulation. Should one exclude OSHA values from the calculation an average geometric mean of 0.760 for the comparison with the HCSR and 0.906 for the MHSR were calculated. Since the OSHA OELs have last been revised in the 1970's, before the health implications caused by dust exposure were fully understood, this could prove to be the prudent route of action (Schenk *et al.*, 2008a) especially considering the amount of mining activity in South Africa and the number of people exposed. In August 2013 OSHA announced that they are in the process of lowering the TWA_8-OEL for respirable crystalline silica to 0.05 mg/m^3 and that the OEL would be legally enforceable (Occupational Health & Safety, 2014). The ACGIH has an OEL for silica set at 0.025 mg/m^3, both regulatory bodies in South Africa has set the OEL for silica at 0.1 mg/m^3, which is four times higher than that of the ACGIH. Yet, research has shown that silicosis has been reported at levels of exposure lower than that of the 0.1 mg/m^3

exposure limit (South African Department of Minerals and Resource, 1993; ACGIH, 2010). Like the ACGIH, the UK had already lowered their OELs for certain dusts over the past few years to what they considered to be acceptable levels. OELs gradually decrease, over time, as they are being revised as illustrated by Figure 5. The OEL for silica has last been revised in 2008 by the HCSR, which could explain the overall higher OEL for silica than that set by other countries and organisations such as ACGIH and UK (Schenk *et al.*, 2008a).

The comparison of South African OELs for fibres with those of the other countries and organisations revealed that both the OELs legislated by the HCSR and the MHSR compare poorly with those of the developed countries and/or organisations. This is evident from Figure 4 (A and B) which indicates an average geometric mean value of 0.535 and 0.554 for the HCSR and the MHSR respectively. This states that both of South Africa's regulatory bodies have OELs set for fibres at twice as high than those of the different countries and/or organisations. The geometric mean for the comparison between the HCSR and the MHSR revealed that the OELs of the MHSR were exactly the same as those of the HCSR. It should be kept in mind that with the comparisons with regards to pesticides, metals and dusts, those OELs legislated by the OSHA were included, and had the unwanted effect of skewing the geometric mean in South Africa's favour. With regards to fibres, no comparison could be performed with OSHA and Germany as they had TWA_8-OELs for asbestos fibres in contrast with the other countries and organisations which had 4-hour TWA-OELs. The OSHA as well as Germany, furthermore, had no OELs for any fibres other than those of asbestos. The standard of 4-hour sampling time for asbestos is adapted from the HSE's method MDHS 39/4 for the sampling of asbestos fibres in air; this is done to obtain samples with adequate fibre densities for analyses by means of phase contrast microscopy (PCM) (Health and Safety Executive (HSE), 1995). Recently the HSE replaced the MDHS 39/4 with method HSG 248: Asbestos: The analysts' guide for sampling, analysis and clearance procedure (HSE, 2006). This new method allows for higher sampling flow rates and shorter sampling duration, this can be due to the decrease and/or total ban placed on asbestos use, thus making sampling faster and more convenient. Finland also had TWA_8-OELs for asbestos, but their list of OELs contained OELs for other fibres that could be compared with those of both the HCSR and the MHSR. Some countries had no OELs set for asbestos, this can be due that there is no asbestos present in these countries, or the use of asbestos has long been ceased thus it may not be necessary to have an OEL for asbestos. The number of comparisons that could be made with regards to fibres was lower in relation to the other three groups. This may lead to a geometric mean value that is not a true reflection of reality.

From the results, South Africa's OELs, when compared to developed countries and organisations, were overall higher or in other words less stringent. One exception to this was with regards to the OELs set by OSHA. In five of the six comparisons that could be made, OSHA's OELs proved to be less stringent than South Africa's. This phenomenon has previously been pointed out by Schenk *et al.* (2008a) and may be attributed to the fact that the OSHA OELs has last been updated in the 1970s.

The three organisations of the USA – ACGIH, NIOSH and OSHA – where ACGIH is the most influential organisation and also has the lowest overall set OEL between the three organisations. This trend setting of lower OELs by the ACGIH can be due to that they incorporate recent results of studies conducted that could indicate that certain substance' OELs should be lowered due to conclusive results that they may have health implications. On the other hand OSHA lacks these incorporations into their OELs. Also OSHA is the only regulatory body in the USA which enforces the OELs by law. This can make it difficult to adapt OELs as research may indicate it. OELs of the ACGIH is the most adopted by different countries and organisations world-wide according to ICMM (2007), thus explaining the general lower set OELs. Canada, Japan, Finland, Sweden, Germany and ACGIH have the overall lowest set OELs in relation to the other countries and organisations when compared to the HCSR and MHSR respectively. It also came to light in this study that Finland regulates their substance more uniquely, because they include different isomers of a single substance in their OEL list (Viljoen, 2012).

The generally higher OELs set by both of South Africa's regulations, can also be ascribed to socio-economic factors, such as technical feasibility and cost benefit analysis as well as the fact that the first OELs were established 19 years ago. In contrast more developed countries and organisations such as Finland, Japan, Sweden and ACGIH have OELs that are only health based, thus they have the power and authority to set an OEL much lower in relation to less developed countries and can maintain that OEL in their industries (ICMM, 2007; Schenk *et al.*, 2008a; Viljoen, 2012). Developed countries and/or organisations which revise their OELs more readily will lead to a gradual decrease in the set OELs.

As concluded by Schenk *et al.* (2008a) from their results, the ACGIH had a geometric mean value of 0.347 in their combined comparison list, which contained substances that could be found in most of the countries' list of OELs that they used in their study, whereas Viljoen (2012) found that they had a geometric mean value of 0.591 based on the complete comparison list, which contained all the OELs that are present in the different countries and/or organisations' lists used in the study. Thus this study's results show the ACGIH had geometric mean values, for the four groups i.e. pesticides, metals, dusts and fibres, of 0.517, 0.956, 0.703 and 0.500 respectively when compared to the HCSR. From this study it is thus evident that when comparing the different groups of HCS with those of developed countries and/or organisations, both South Africa's legislative entities the HCSR and the MHSR, compared in close agreement, the best with dusts and metals and with fibres being the less regulated of the four groups of HCS. The fact that both the HCSR and the MHSR are almost similar mirrors national similarity.

After having ranked the results it became evident that South Africa performed poorly when compared to other countries and/or organisations, indicated in this study, as it had the less stringent OELs for pesticides and fibres. With regards to metals, South African OELs came 9th and 8th respectively with the HCSR and the MHSR. Interestingly South African OELs fared the second worst with regards to dusts when using the HCSR but the best (6th) when using the MHSR. Another factor that should not be overlooked is the fact that although the OELs provided by OSHA is seen as stemming from a developed country, those OELs are outdated and may have cast South African OELs in a positive light.

3.5 Conclusion

When considering the regulation of exposure to hazardous chemicals, one should be familiar with two concepts, the one being the number of OELs set, in total or for a group of substances, and the other the level at which OELs are set. Based on this study, the number of OELs set was on par with those of developed countries as well as with those of the ACGIH. This may indicate that South African legislation is familiar with most substances and, therefore, makes provision for a variety of substances. It should be noted that South African legislation had more OELs to compare with other countries and/or organisations than with Germany, Finland, Sweden and Japan.

It was, furthermore, also evident that the HCSR and the MHSR were closely aligned with regards to OELs for pesticides, metals and fibres whereas it differed the most with regards to dusts.

Taking the abovementioned into account it should be evident that South African OELs are currently not set at a level which is on par with developed countries and/or organisations which are perceived to be dominant in the field of occupational health. It should also be clear that this situation will put employees at risk from a health perspective as the risk associated with exposure to substances is downplayed. A case in point would be with regards to the OEL for asbestos. Despite the fact that asbestos has been banned, the South African OEL still exceeds Japan's which are the lowest set at 0.03 f/cc (fibres per cubic centimetre), than all of the countries and/or organisations used in this study.

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Chapter 4

Concluding Chapter

4.1 Conclusion

The aim of this study was to analyse comparatively selected groups of Hazardous Chemical Substances' (HCS) occupational exposure limits (OELs) from South Africa with those of developed countries and/or organisations. This was done by comparing South African OELs for selected groups of HCS from the Hazardous Chemical Substances Regulations (HCSR) and the Mine Health and Safety Regulations (MHSR) with each other and with other developed countries and/or organisations. This study confirmed the findings of Viljoen (2012) in the sense that when comparing the HCSR and the MHSR it was evident that both had almost similar OELs, echoed by their national origin. An exception to the aforementioned was the lower OELs for metals and dusts constituted by the MHSR, this may be explained by the expansive mining industry present in South Africa and the fact that the OELs in the MHSR was updated in 2006, more than a decade later than those in the HCSR (South African Department of Labour, 1995; South African Department of Minerals and Resources, 1996).

At the onset of this study, it was hypothesised, that the level at which South African OELs are set, are higher or less stringent, than those of the selected developed countries with regards to both OELs as provided for by the HCSR and the MHSR. In general, the comparison of South African OELs – both those from the HCSR and the MHSR – with those of the selected developed countries, indicated that the OELs stipulated in both, are set at an overall higher level when they were compared with those of the different developed countries and/or organisations. An exception to this was those OELs provided for by the Occupational Safety and Health Administration (OSHA). OELs of OSHA had overall higher levels than those set out by both the HCSR and the MHSR. The fact that South African OELs are set at a geometric mean level that is more stringent than those of OSHA could provide one with a false sense of superiority. It should, however, be kept in mind that most of the OELs that appear in the lists of OSHA were established in 1978, and are thus outdated. A more realistic view would be to assess South African OELs in an American context which includes OELs as set by the ACGIH. Surprisingly, the OELs for dust and metals from developed countries – represented by the National Institute for Occupational Safety and Health (NIOSH), New Zealand and Australia – in this instance, proved to be higher (less stringent) than those of the MHSR.

The American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLVs) is the most adopted OELs by countries and organisations world-wide, thus making them the most influential organisation in the world according to ICMM (2007) and Schenk *et al.* (2008b). Despite the aforementioned, it should be remembered that the OELs set out by the ACGIH are health based with no regard to socio-economic factors. In contrast, South Africa's HCSR are enforced by law and do take factors such as technical feasibility and socio-economic factors into account when revising or setting an OEL for a substance. As stated by Ding *et al.* (2011), each country's regulatory agency or organisation, which is responsible for health and safety, produces their own list of OELs that reflects the mandate of the respective agency or organisation.

The findings of this study correspond with those of Schenk *et al.* (2008a) who reported that OELs gradually decrease over time. As can be gathered from Figure 5 (A and B), it was, however, noted that some OELs decreased at a lower rate than others.

In light of the above, the hypothesis of this study may, therefore, be partially accepted, due to OSHA being the exception, in the sense that it was found that South African OELs, for all 4 the groups – from both the HCSR and the MHSR – are set at geometric mean values which are higher (less stringent) than those of selected developed countries. The HCSR lacks standardisation of its OELs, when compared to developed countries and/or organisations, since its OELs are based on outdated toxicological data from the 1990s and still relates to obsolete industrial processes. From an occupational health point of view it may, therefore, be argued that both legislator texts of South Africa, with regards to the level at which OELs are set, should prioritise on the groups lacking attention, i.e. fibres and pesticides, but not to disregard the other two groups, metals and dusts. Thus South Africa is in dire need of revision should one want to achieve the goals and objectives of the International Labour Organisation (ILO) such as the creation of decent working conditions that may not be deteriorating to a workers health (ILO, 1996).

4.2 Recommendations

Based upon the findings of this study, the following recommendations are suggested:

- South African OELs should be periodically revised at least once every two-three years. For example the ACGIH TLVs are annually reviewed.
- Attention with regards to the groups lacking attention, i.e. fibres and pesticides should be given priority when revised although the other groups should not be disregarded.
- Duplicate OELs identified in the HCSR should be removed. To prevent duplicate OELs from being established it would be prudent to utilise CAS numbers when referring to substances in addition to their common and chemical names. This supports the recommendation made by Viljoen (2012).
- The effectiveness of having two sets of OELs within a country; each applicable to its own industry should be investigated whilst being cognisant of the fact that worker health should be protected irrelevant of where the worker is employed. Thus one set of OELs should not protect a worker in the mining industry more than those in the general industry and *vice versa*.
- Not only listing a substance but also the various compounds containing that substance and the various isomers thereof. For example: Not only Chromium and its compounds but Chromium (III) and (VI) compounds, Cadmium oxide, Cadmium sulphide and sulphide pigments for example and not just Cadmium and its compounds.

4.3 Limitations of the study

During the execution of this study, some limitations were identified which future researchers should be cognisant of. They are listed below.

- When comparing local OEL lists with those of other countries, cognisance should be taken of the fact that many OEL lists are not available in English. This fact complicates the establishment of a master list and sufficient time and resources should be planned for this phase of a study.

- CAS numbers were absent in the HCSR making comparison of certain substances difficult.
- Not all OELs lists are readily available.

4.4 Future studies

During this study, gaps in the current body of knowledge with regards to OELs were identified. It may be worth the while to study some of these aspects of OELs. The more prominent gaps are listed below.

- OEL lists of South Africa do not classify substances according to their carcinogenicity despite international practice to do so. It would be interesting to investigate the OELs assigned to substances in South African OEL lists which have a carcinogenic classification assigned to it by the IARC and to compare them with substances that does not carry a carcinogenic classification.
- Future studies could include a fifth category in addition to the four included in this study (pesticides, metals, dusts and fibres) namely solvents. Substances such as toluene, benzene and propanol were not included in this study as they do not belong to any of the four earlier mentioned groups, and it is difficult to classify all the solvents in an OEL list. Yet the impact that they have in industry is unquestioned.
- The trend of OELs decreasing over time should be investigate more thoroughly.

4.5 References

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Chapter 5

Appendix

ENGLISH LANGUAGE EDITING CERTIFICATION

This is to certify that the English language editing of this dissertation by Mr J Viljoen was done by Prof L A Greyvenstein.

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