Comparison of South African short-term and ceiling exposure limits with those of developed countries

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PREFACE

This mini-dissertation was presented in article format in accordance with the North-West University's' General Academic Rules 2015 (section 4.4.2.9). The Annals of Occupational Hygiene was chosen as the potential journal for the publication of the articles (i.e. Chapters 3 and 4) of this study; therefore, the articles were written as according to the guideline of The Annals of Occupational Hygiene. These guidelines, or "Authors instructions", can be found on the page prior to the two articles (i.e. pages 49-52). In order to achieve consistency, the reference style, Vancouver, was used as the style of reference throughout the whole mini-dissertation. English was chosen as the preferred language of correspondence for this mini-dissertation where proof reading and language editing was completed by a competent language editor (see Chapter 6).

AUTHOR'S CONTRIBUTION

In compiling this mini-dissertation and carrying out the study, a team of researchers were involved and individually contributed as is listed below:

NAME	CONTRIBUTIONS
Miss ER Maponya (Author)	✓ Planning and compiling of research proposal ✓ Collecting and organisation of data ✓ Accumulating and writing literature study ✓ Statistical analysis and results interpretation ✓ Writing of the mini-dissertation and articles
Prof FC Eloff (Supervisor)	✓ Assisted with the study concept and design ✓ Assisted with the planning and write up of mini-dissertation ✓ Assisted with data collection and organisation ✓ Assisted with the review of whole mini-dissertation
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The following statement hereby confirms and validates the abovementioned contributions of the relevant individuals:

I declare that I have approved the article and that my role in the study as indicated above is representative of my actual contribution and that I hereby give my consent that it may be published as part of Evelyn R Maponya's MSc (Occupational Hygiene) mini-dissertation.

_____	_____	_____
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“I shall not die, but live, and declare the works of the LORD”

Psalm 118:17

SUMMARY

Occupational exposure limits (OELs) are established with the purpose of regulating exposure to hazardous chemical substance (HCSs) in the workplace. However, the effectiveness of controlling such risks is largely dependent on scientifically up-to-date OELs. For many HCSs, peak levels that go transiently above the time-weighted average (TWA) are acceptable under condition that the exposure is truly for a short period of time. These concentration levels of short-term exposure limits (STELs), are defined as the maximum average concentration to which workers can be exposed for usually a short period of 15 minutes. A limit set for an even shorter period of time are the ceiling limits (CLs), which are intended to protect against high exposures resulting in acute effects.

In South Africa, there are two national departments governing occupational health and safety (OHS). The Department of Labour governs the publishing of two types of OELs including STELs, listed in the Regulations for Hazardous Chemical Substance (RHCS). The Department of Mineral Resources (DMR) publishes three types of OELs including STELs and CLs – published in the Mine Health and Safety Regulation (MHSR), the latter OEL exclusively listed by the DMR. Since the original publishing of the STEL and CLs listed in the RHCS (1993) and MHSR (1996) only a few known amendments have been made to the Regulations. This then deems South African STELs and CLs in the Regulations as out-dated. However, as stated earlier, the effectiveness of any type of OEL in controlling risk is largely dependent on scientifically up-to-date OELs. Therefore, the aim of this study was to determine the extent of effectiveness of South African STELs and CLs. This was achieved by comparing the South African STELs and CLs with those of a total of 12 developed countries/organisations based on coverage (frequency and selection) and level (concentration). These 12 countries/organisations included, Australia, Canada (British Columbia), European Union, Finland, Germany, Japan (CLs only), New Zealand, Sweden, United Kingdom and United States of America [NIOSH, OSHA (CLs only) and ACGIH].

Results indicated that there is significant disparity of STEL coverage between the RHCS and the ten selected developed countries/organisations, but in contrast significant similarities in CL coverage between the MHSR and the nine selected developed countries/organisations were observed. Regarding STEL coverage, the disparity was observed from the >5 countries/organisations that had a <50% overlap in HCSs, for both the RHCS and MHSR. Regarding CL coverage there were five developed countries/organisations that had a >50% overlap in HCSs with those of the MHSR. Concerning overall level comparison, there are significant disparities in STEL levels between the RHCS and MHSR, and the selected developed countries/organisations. There are also in contrast significant similarities in CL levels between the MHSR and the developed countries/organisations. The overall level comparison was analysed via the use of the geometric means (GMs) method and interval method. For STEL levels based on the GMs methods, nine and eight countries/organisations had more stringent STEL levels compared to those of the RHCS and MHSR respectively. The interval method results of STEL overall level supports the GMs method which also proved that there were disparities between South African STEL levels and those of developed countries/organisations, with the overall STEL levels of the developed countries/organisations being lower. While conclusions on the overall CL levels were contradictory between the GMs and interval methods, a conclusion was made that there are significant similarities between the MHSR and the developed countries/organisations. This conclusion was based on judgement from the thorough observation of the raw data and based on the literature which stated the lack of variation for most acute OELs over time.

Therefore, in conclusion, as concluded by Viljoen (2012) in a previous study comparing TWAs coverage and level, South African STELs are inadequate to regulate acute exposure from HCSs and thereby inadequate to minimising the potential risks of adverse health effects manifesting following short-term acute exposure to HCSs in the workplace. In contrast there are significant similarities in both coverage and level of CLs between South Africa and the selected developed countries/organisations. It may be concluded that South African CLs are adequate enough to regulate acute exposure from HCSs thereby minimising the potential risks of adverse health effects manifesting following very short-term exposure to HCSs in the workplace.

Key words: *Occupational exposure limits (OELs), comparison, South Africa, developed countries/organisations, hazardous chemical substances (HCSs), coverage, Geometric means (GMs) method, Interval method*

OPSOMMING

Beroepsblootstellingslimiete (BBL'e) is vasgestel met die doel om blootstelling aan gevaarlike chemiese stowwe (GCS'e) in die werkplek te reguleer. Effektiewe beheer van verwante risiko's is egter grootliks afhanklik van wetenskaplik-opgedateerde BBL'e. Spitsvlakke van baie GCS'e wat die tydbeswaarde gemiddelde (TBG) oorskry, is aanvaarbaar mits die blootstelling van korte duur is. Hierdie konsentrasievlakke van korttermyn-blootstellingslimiete (KTBL'e), word gedefinieer as die maksimum gemiddelde konsentrasies waaraan werkers vir 'n kort tydperk, gewoonlik 15 minute, blootgestel kan word. Plafonlimiete (PL'e) is perke wat vir selfs 'n korter tydperk vasgestel en bedoel is om beskerming te bied teen hoë blootstellings met akute nagevolge.

Daar is twee nasionale departemente in Suid-Afrika wat beroepsgesondheid en -veiligheid (BGV) bestuur. Die Departement van Arbeid bestuur die publisering van twee tipes BBL'e, insluitend KTBL'e, wat in die Regulasie vir Gevaarlike Chemiese Stowwe (RGCS) gelys is. Die Departement van Minerale Hulpbronne (DMH) publiseer drie tipes BBL'e, insluitend KTBL'e en PL'e, in die Regulasie op Gesondheid en Veiligheid in Myne (RGVM). PL'e word uitsluitlik deur die DMH gelys. Sedert die aanvanklike publisering van KTBL'e en PL'e wat in die RGVM (1993) gelys is, is slegs enkele wysigings aan die Regulasies gebring. Dus is die Suid-Afrikaanse KTBL'e en PL'e in die Regulasies verouderd. Soos voorheen genoem, is die effektiwiteit van enige BBL vir die beheer van risiko egter grootliks afhanklik van BBL'e wat wetenskaplik op datum is. Daarom was die doel van hierdie studie om die omvang van die effektiwiteit van Suid-Afrikaanse KTBL'e en PL'e te bepaal. Dit is bereik deur Suid-Afrikaanse KTBL'e en PL'e te vergelyk met dié van 12 ontwikkelde lande/organisasies, gebaseer op dekking (frekwensie en seleksie) en vlak (konsentrasie). Hierdie 12 lande/organisasies het die volgende ingesluit: Australië, Kanada (Brits-Kolombië), die Europese Unie, Finland, Duitsland, Japan (slegs PL'e), Nieu-Seeland, Swede, die Verenigde Koninkryk en die Verenigde State van Amerika [NIOSH, OSHA (slegs PL'e) en ACGIH].

Resultate het aangedui dat daar 'n beduidende verskil in die dekking van KTBL tussen die RGCS en tien van die gekose ontwikkelde lande/organisasies is, maar in teenstelling daarmee was daar betekenisvolle ooreenkomste in PL-dekking tussen

die RGVM en die nege geselecteerde ontwikkelde lande/organisasies. Daar is ook wesenlike ooreenkomste was tussen die >5 lande/organisasies wat ‘n <50% oorvleueling van GCS’e, vir beide die RGCS en RGVM getoon het. Aangaande PL-dekking, was daar vyf ontwikkelde lande/organisasies wat ‘n >50% oorvleueling van GSC’e met RGVM getoon het. Wat die algehele vergelyking van vlakke betref, was daar betekenisvolle verskille in KTBL-vlakke tussen die RGCS en RGVM en die gekose ontwikkelde lande/organisasies. Daar was ook, in kontras, wesenlike ooreenkomste in PL-vlakke tussen die RGVM en die ontwikkelde lande/organisasies. Die algehele vergelyking van vlakke is geanaliseer deur middel van die geometriese gemiddeldes (GG’s) metode en die intervalmetode. Gebaseer op die GG’s metode was KTBL-vlakke van nege en agt lande/organisasies strenger in vergelyking met dié van die RGCS en RGVM afsonderlik. Die resultate van die intervalmetode aangaande algehele KTBL-vlakke het dié van die GG’s metode ondersteun, wat ook getoon het dat daar verskille tussen Suid-Afrikaanse KTBL-vlakke en dié van ontwikkelde lande/organisasies was, met die algehele KTBL-vlakke van die ontwikkelde lange/organisasies wat laer was. Hoewel afleidings oor die algehele PL-vlakke van die GG’s- en intervalmetodes teenstrydig was, is daar beduidende ooreenkomste tussen die RGVM en ontwikkelde lande/organisasies. Hierdie afleiding is gemaak op grond van uitsprake oor die deeglike waarneming van die roudata en gebaseer op literatuur wat ‘n gebrek aan variasie vir die mees akute BBL’e oor tyd.

Daarom ten slotte, soos opgesom in ‘n vorige studie deur Viljoen (2012) wat die dekking en vlak van TBG’s vergelyk het, is Suid-Afrikaanse KTBL’e onvoldoende om akute blootstelling aan GCS’e te reguleer, waardeur die potensiële risiko’s van nadelige gesondheidsgevolge wat manifesteer na kort-termyn akute blootstelling aan GCS’e in die werkplek, nie voldende word. In teenstelling was daar beduidende ooreenkomste in beide die dekking en vlak van PL’e in Suid-Afrika en die gekose ontwikkelde lande/organisasies. Dus kan dit afgelei word dat Suid-Afrikaanse PL’e voldoende is om akute blootstelling aan GCS’e te reguleer, waardeur die potensiële risiko’s van nadelige gesondheidsgevolge wat manifesteer na kort-termyn blootstelling aan GCS’e in die werkplek, verminder word.

Sleutelwoorde: *Beroepsblootstelling limiete (BBL'e), vergelyking, Suid-Afrika, ontwikkelde lande/organisasies, gevaarlike chemiese stowwe (GCS'e), dekking, geometriese gemiddeldes (GG's) metode, intervalmetode*

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LIST OF ABBREVIATIONS

% - Percentage

ACGIH - American Conference of Governmental Industrial Hygienists, United States of America

AGS - Ausschuss für Gefahrstoffe, Germany

AGW - Arbeitsplatzgrenzwerte, Germany

BC - British Columbia, Canada

BOELV - Binding Occupational Exposure Limit Value

CAS - Chemical Abstracts Service

CDC - Centres for Disease Control and Prevention

CL - Ceiling Limit

CO - Carbon Monoxide

COSHH - Control of Substances Hazardous to Health Regulations, United States of America

DMR - Department of Mineral Resources

DoL - Department of Labour, South Africa

EC - European Commission

EU - European Union

GMs - Geometric means

HCS - Hazardous chemical substance

HSE - Health and Safety Executive

HTP - Haitalliseksi tunnetut pitoisuuder (HTP-values), Finland

IDLH - Immediately Dangerous to Life or Health

IOELV - Indicative Occupational Exposure Limit Value

JSOH - Japan Society of Occupational Health

kPa - kilopascal

MAC - Maximum Allowable Concentration

MAK - Maximum workplace concentrations

MBIE - Ministry of Business, Innovation and Employment

MEL - Maximum Exposure Limit

mg/m^3 - milligrams per cubic metre

MHSR - Mine Health and Safety Regulations, South Africa

NHMRC - National Health and Medical Research Council

NIOSH - National Institute for Occupational Safety and Health, United States of America

NOAEL - No Observed Adverse Effect Level

NOHSC - National Occupational Safety and Health Commission

ºC - Degrees Celsius

OD - Occupational disease

OEL - Occupational Exposure Limit

OEL-CL - Occupational Exposure Limit, Control Limit

OEL-RL - Occupational Exposure Limit, Recommended Limit

OES - Occupational Exposure Standards

OHS - Occupational Health and Safety

OHSA - Occupational Health and Safety Act, South Africa

OSHA - Occupational Health and Safety Administration, United States of America

PEL - Permissible Exposure Limit

ppm - parts per million

REL - Recommended exposure Limit

RHCS - Regulation for Hazardous Chemical Substances

SCOEL - Scientific Committee on Occupational Exposure Limits

STEL - Short Term Exposure Limit

SWA - Safe Work Australia

TLV - Threshold Limit Value

TRGS - Technical Guidance Concentrations

TRK - Technishe Richtkonzentrationen (Technically-feasible Guidance Concentrations), Germany

TWA - Time Weighted Average

UK - United Kingdom

UN - United Nations

USA - United States of America

WEL - Workplace Exposure Limit

WES - Workplace Exposure Standard

GLOSSARY OF KEY TERMINOLOGIES

Ceiling limit (CL) - A CL is the concentration maximum limit of a potentially harmful chemical; it is the upper concentration to which a worker may be exposed.

Comparison – Comparison is the act of considering or analysing similarities and/or dissimilarities between two entities.

Developed country - A developed country, also known as an industrialised country is a dominant state that has a highly developed economy and advanced technological infrastructure when compared to other less industrialised nations.

Developing country - A developing country is a nation with an underdeveloped industrial base, and a low Human Development Index relative to other countries. It is a poor country that seeks to become more advanced economically and socially.

Hazardous chemical substance (HCS) – A HCS means any toxic, harmful, corrosive, irritant or asphyxiant substance, or a mixture of such substances for which:

(a) an occupational exposure limit is prescribed; or
(b) an occupational exposure limit is not prescribed, but which creates a hazard to health.

Immediately dangerous to life of health (IDLH) value – An IDLH is defined by the US National Institute for Occupational Safety and Health (NIOSH) as exposure to airborne contaminants that is likely to cause death or immediate or delayed permanent adverse health effects or prevent escape from such an environment.

Occupational disease (OD) - An OD is defined as any disease contracted primarily as a result of exposure to risk factors arising from work.

Occupational exposure limit (OEL) – A general term that refers to an occupational standard for an eight-hour time-weighted average (TWA) denoted to by various countries. It defines the airborne concentration of a chemical substance and represents conditions under which it is believed that nearly all workers may be

repeatedly exposed, day after day, over a working lifetime, without adverse health effects. The term is also used as a collection of TWAs, including STELs and CLs.

Occupational health and safety (OHS) – OHS relates to the health, safety and welfare issues in the workplace. Legislations, standards and programmes related to OHS aim to make the workplace better for workers, co-workers, family members, customers and other stakeholders.

Short-term exposure limit (STEL) – A STEL is the acceptable exposure limit to a toxic chemical or an irritant chemical over a short period of time, usually 15 minutes. It is the maximum concentration of a chemical to which workers may be exposed continuously for a short period of time without any danger to health.

Threshold Limit Value (TLV) – A TLV is a registered and reserved term of the American Conference of Governmental Industrial Hygienists (ACGIH). TLVs® refer to airborne concentrations of chemical substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed, day after day, over a working lifetime, without adverse health effects. It is the maximum average concentration of a hazardous material present in the workplace to which workers can be exposed during an eight-hour work day and 40-hour work week, over a working lifetime, without experiencing significant adverse health concerns.

Time-weighted average (TWA) - A TWA is the average exposure to any HCS in the workplace based on a reference period of eight hours per day or 40 hours per week of a work shift. TWA is generally expressed in units of parts per million (ppm) or mg/m^3.

CHAPTER 1
GENERAL INTRODUCTION

1.1 INTRODUCTION

In general, people are exposed to a variety of chemicals during their everyday living; however, the working environment continues to be the major contributor to such exposure (Schenk *et al*., 2008*a*). Exposure to such hazardous chemical substances (HCSs) is attributed to the wide chemical use in several working sectors including industrial, agricultural and medical sectors, to name a few (SGV, 2011). This occupational exposure to HCSs can potentially cause a variety of negative health effects; both short and long-term undesirable health effects such as poisoning of living cells, skin rashes and diseases of major organs (lungs, the liver or kidneys) (Ding *et al*., 2011; SGV, 2011).

In order to assist in the control of HCS exposure in the workplace and the conforming potential adverse effects, Occupational Exposure Limits (OELs) were established and are used as important regulatory instruments (Schenk *et al*., 2008*a*; Schenk and Palmen, 2012). There are four functional types of OELs, namely Time-Weighted Averages (TWAs), Short-Term Exposure Limits (STELs), Ceiling Limits (CLs) and also Immediately Dangerous to Life or Health (IDLH) limits (Howard, 2005). These standards are aimed at restricting exposure to HCSs (Schenk *et al*., 2008*b*). Each standard serves a unique function and is usually established based on effects that may be as a result of a specific exposure time (eight-hours, 15 minutes, 30 minutes, etc.) (EHS, 2012). A HCS is, therefore, assigned a relevant OEL or in some instances, two or three of these OELs, depending on the physiological action of the HCS in question. While for most HCSs, the assigning of only a TWA alone or with a STEL is relevant, CLs alone may be applicable for some HCSs (usually irritant gases) (ACGIH, 2015).

Over the past six decades, many organisations in numerous countries have proposed OELs for airborne HCSs (Paustenbach *et al*., 2011). However, these concrete approaches of control only became valid after the 20th century in most of the countries/organisations (Tadesse and Admassu, 2006). The limits that had been most widely accepted and adopted by many of these countries/organisations are the

Threshold Limit values (TLVs). These TLVs were established and trademarked by the American Conference of Governmental Industrial Hygienists (ACGIH) in the 1940s, and continue to be adopted by some countries/organisations based on their annual issuing of the TLVs (Nielson and Øvrebø, 2008; ACGIH, 2012). However, most countries/organisations are increasingly establishing their own OELs (Schenk *et al*., 2008*b*). However, while OELs have a long history and form the cornerstone of most occupational risk assessment and management plans, their effectiveness in protecting workers' health is increasingly being questioned (Howard, 2005; Lethbridge, 2008; ILO, 2013). This questioning is being further aggravated by the worldwide statistics of more than 2.3 million workers dying annually from accidents and occupational diseases (ODs) resulting from the handling of HCSs in the workplace, as according to the International Labour Organisation (ILO) (Gasiorowski, 2013).

The mechanics of establishing OELs varies between countries/organisations (Schenk *et al*., 2008*a*). However, in general OELs can be classified into two categories, namely health-based and pragmatic OELs; classified on the basis of the factors taken into account during their establishment. "Health-based" OELs include those that are established by having a professional committee review the existing published and peer-reviewed literature data and studies carried out on experimental animals (Topping, 2001; Ding, 2013). These health-based OELs are established when it is possible to identify a clear threshold dose below which exposure to a HCS in question is not expected to lead to adverse effects. This threshold is referred to as a no observed adverse effect level (NOAEL) (Ding, 2013). Therefore, health-based OELs are set only on the basis of medical and toxicological data, paying no consideration to factors such as technical and economic feasibility (Schenk, 2013).

"Pragmatic" OELs in contrast, are based on medical and toxicological knowledge as well as socio-economic factors (Remaeus, 2001; Schenk, 2013). Pragmatic OEL values may have to come with some form of residual risk as a form of trade-off with feasibility of compliance (Ding, 2013). However, health-based OELs also come with the risk of not protecting all workers including sensitive workers (Schenk, 2013). While a distinction between health-based and pragmatic OELs is not clear, in

practice, indicative or recommended (i.e. not legally binding) OELs are often health-based while legally binding OELs are pragmatic (Norseth, 2001; Ding *et al*., 2011).

In most developed countries/organisations, OELs have improved the field of occupational health and safety (OHS), as well as occupational medicine. However, there is still a long way ahead for such improvement in developing countries/organisations (Tadesse and Admassu, 2006). Although many developing countries/organisations have tried to improve their working conditions to high standards, the improvements still do not meet the minimum standards and guidelines set by international agencies (LaDou, 2003). OHS continues to remain neglected in developing countries/organisations (Nyuwayhid, 2004; Puplampu and Quartey, 2012).

While South Africa has become one of the major drivers of the global economy (Matola, 2014), it is still recognised and listed by the United Nations (UN) as a developing country (UN, 2014). This is due to the relatively low Human Development Index. Amongst various issues that contribute to a low Human Development Index in South Africa, one worth noting is the poor OHS standards. These poor OHS standards in turn not only decrease the life expectancy of most workers exposed to HCSs, but also contributes to the lowering of the world gross domestic product due to deaths as a result of ODs and occupational injuries (ILO, 2013).

South Africa has two main Acts that regulate OHS, the Occupational Health and Safety Act (No 85 of 1993) and the Mine Health and Safety Act (No. 29 of 1996). South Africa adopted its OELs, contained within the Regulations for Hazardous Chemical Substances (RHCS) of the OHSA, from the United Kingdom (UK) in 1995 and has since then only made a few amendments (TWA-OEL of crystalline silica) to the Regulation (PHSC, 2002). The Mine Health and Safety Regulation (MHSR) 22.9 of the MHSA was also last amended approximately a decade ago. This then raises the question of whether the South African OELs are adequate to protect workers from adverse health effects resulting from HCS exposure.

In addition to the out-dated OELs of the RHCS, other shortcomings worth noting are the difference in OEL definitions (i.e. for TWA and STEL), the assigning of the OELs (absence of CLs in the RHCS) and the usage of such OELs. One would assume that

because both Regulations restate a common ruling on OHS and strive for the same goal (preventing the contraction of ODs and occupational injury), that their legal structure would be similar if not the same. These differences then bring about room for criticism directed at South Africa's OHS legislation and overall OHS system and calls for a thorough review of these inconsistencies within the OHS legislation framework (Nuwayhid, 2004).

Forging a new pathway for occupational health research and improvement of the OHS will not be an easy task (Tadesse and Admassu, 2006). Nevertheless, attempts can be made as opposed to staying with the prevailing standard which further promotes continued deaths and injuries, ineffectiveness and professional unproductivity (Nuwayhid, 2004; IHRG, 2011).

One of the first steps that was taken towards determining the extent of South Africa's OHS inadequacy was by comparing South Africa's OELs for HCS with that of leading developed countries/organisations. However, it should be emphasised that the approaches followed in the developed countries/organisations will not essentially serve equivalently for South Africa and other developing countries/organisations, but will provide a good guideline (O'Neill, 2000; Nuwayhid, 2004). This restriction owing to legislative political mechanisms (a system that is able to mediate the translation of scientific findings into policies and regulations that are enforced by regulatory agencies) and risk assessment processes is being carried out differently in the developed and developing worlds (O'Neill, 2000). The other aspect is due to the industrial and agricultural development in South Africa as opposed to the stabilised growth in most developed countries (Rosenstock *et al*., 2006).

Viljoen's (2012) study compared South Africa's TWAs with that of some leading developed countries/organisations, including Sweden, United States of America (USA), Germany, etc. She concluded that there were large discrepancies in the selection of HCSs between South Africa and the selected developed countries/organisations. Furthermore, South Africa as a developing country has higher overall levels of TWAs than that of most of the developed countries/organisations [with the exception of Occupational Safety and Health Administration (OSHA), an OHS regulatory agency of the United States Department of Labour].

Having also compared South African TWAs of the RHCS with those of other developing countries, it was established that South Africa has an overall higher level of TWAs than the other developing countries/organisations, except for Brazil (Viljoen, 2012). The variation that exists between the developing countries/organisations may be explained by the time lags between updates (Schenk and Johanson, 2011), considering that South Africa has yet to make any noticeable reviews on its RHCS since establishment in the year 1995. Therefore, further comparison of South African OELs with those of other developing countries/organisations is not advised considering not only the time lags between OEL list updates, but also including the main reason that most of the developing countries/organisations still demonstrate challenges with their own OHS, just as in South Africa (Wang *et al*., 2011; Tevlin, 2012; Dudarev *et al*., 2013). The aforementioned exclusion of comparison shall also apply to least developing countries/organisations, specifically those within the African continent, who share a similar issue of neglecting their OHS system (Pulplampu and Quartey, 2012).

Therefore, the abovementioned conclusions made by Viljoen (2012) indicate inadequacy to control exposure and protect South African workers against adverse health effects consequent from HCSs (Viljoen, 2012). It is, therefore, deemed necessary that OEL comparisons be made between countries/organisations of poor OEL settings and those exhibiting adequate and on-going OEL settings, with the aim of improving the OHS system in the countries/organisations with poor OEL settings.

It was recommended by Viljoen (2012) that a similar study be conducted on STELs, which when compared to that of the TWA-OEL values, may yield a more representative assessment of the levels of OELs set by different countries/organisations. Therefore, as part of this study, comparison of HCSs STEL and CL values between the South African legislation (i.e. RHCS and the MHSR) and leading developed countries/organisations was carried out. This helped uncover the extent of South African STEL and CL inadequacy, considering that the TWA-OELs in the RHCS have already been concluded as inadequate by Viljoen (2012).

1.2 AIMS AND OBJECTIVES

1.2.1 General aim:

- To compare the STELs of the South African Regulation for Hazardous Chemical Substance (RHCS) with that of the Mine Health and Safety Regulation (MHSR) and then their STELs and CLs to that of 12 leading developed countries/organisations* based on the variables of (i) coverage (frequency and selection) of individual HCSs and (ii) level (concentration) of STELs and CLs set for different HCSs.

*Australia; Canada (British Columbia); European Union; Finland; Germany; Japan; New Zealand; Sweden; United Kingdom; United States of America [Occupational Safety and Health Administration (OSHA), National Institute for Occupational Safety and Health (NIOSH) and American Conference of Governmental Industrial Hygienists (ACGIH)]

1.2.2 Specific objectives:

- To compare the coverage and levels of STELs between the two major South African Regulations, the RHCS and MHSR.
- To compare the coverage and levels of STELs between South African RHCS and MHSR to the ten leading developed countries/organisation.
- To compare the coverage and levels of CLs between South African MHSR and the nine leading developed countries/organisations.

1.3 HYPOTHESES

Viljoen (2012) stated that only 7% of the HCSs (76 out of 1110 HCSs) were listed by all of the 11 considered developed countries/organisations, thus highlighting considerable disparities in TWA coverage between South Africa and the considered developed countries/organisations. Viljoen (2012) also stated that all the geometric means (GMs) of ratios were below the value of one (with the exception of one organisation, OSHA of the USA); thereby stipulating that all the other developed countries/organisations had lower overall TWA levels than that of South Africa's RHCS. Therefore, the following two hypotheses were postulated.

Hypothesis 1:

There is significant disparity of STEL coverage and level between the RHCS/MHSR, and the ten developed countries/organisations, where ≥5 of the developed countries/organisations have a <50% overlap with RHCS/MHSR HCSs and the STEL levels are lower (<1 GMs ratio and/or <95% interval of a compared HCSs level) than that of South Africa's STELs.

Hypothesis 2:

There are significant disparities in CL coverage and level between the MHSR and the nine developed countries/organisations, where ≥5 of the developed countries/organisations have a <50% overlap with the MHSR HCSs and CL levels are lower (<1 GMs ratio and/or <95% interval of a compared HCSs level) than that of South Africa's CLs.

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CHAPTER 2
LITERATURE STUDY

Issues relating to occupational health date as far back as the 15th century and yet to this day OHS still remain to be a tremendous challenge in both the developing and developed countries (Schenk, 2011). In this chapter, light will be shed on the history and origin of OELs, their purpose and intended use and how they are differently set and used in different countries/organisations, both developing and developed.

2.1 OCCUPATIONAL EXPOSURE LIMITS (OELs)

2.1.1 The history of occupational hygiene

Dating as far back as the 15th century, a number of diseases have been related to the occurrence of HCSs in the occupational environment (Schenk, 2011). As time progressed numerous attempts were made to try to quantitatively evaluate the hazards within the workplace, though lack of resources did not allow for much progress (Paustenbach *et al*., 2011). Nevertheless, the occurrences of countless deaths and diseases experienced by workers were enough proof that there were indeed hazards within the work environment. Therefore, it then became necessary that standards be determined in order to establish safe exposure (Paustenbach, 2000; Paustenbach *et al*., 2011).

The earliest effort to set a standard for safe exposure was directed at carbon monoxide, a toxic gas that rates the highest exposure within the work environment (Paustenbach *et al*., 2011). Max Gruber was the one to identify a probable NOAEL of carbon monoxide within the range of 200-500 parts per million (ppm) in 1883 (Figure 2.1). This identification continues to be commonly known as the first occupational exposure limit (OEL). This first OEL was described according to Duckering as follows (Piney, 1998):

“ the most scientific way of regulating a dusty trade would be to impose a limit on the amount of dust which may be allowed to contaminate the air breathed by the work people and to leave the manufacturer a completely free choice of methods by which this result may be attained”.

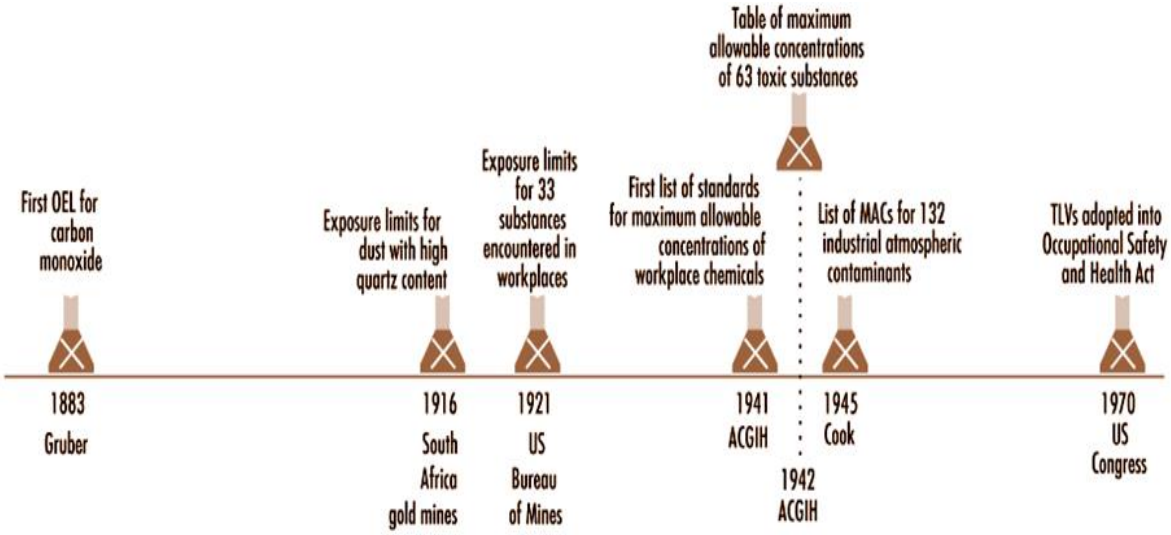

Figure 2.1: The chronology of occupational exposure limits (OELs) (Paustenbach, 2012).

While the first OEL was established in 1883, what was considered to be the most substantial progress in the field of occupational hygiene and toxicology was the identification of the effects of fibres, asbestos, quarts and other dusts during the 20th century (Figure 2.1) (Nielsen and Øvrebø, 2008). Figure 2.1 further depicts a chronology of all the substantial developments of OELs from the onset till the 1970s.

2.1.2 ACGIH, Threshold limit values (TLVs) as a starting point

Although the American Conference of Governmental Industrial Hygienists (ACGIH) was not the one to publish the first list of OELs (Fairhurst, 1995), the history of systemic setting of OELs is often said to have begun with the Threshold Limit Values (TLVs) which were published in the 1940s (Topping, 2001). During the period of publishing in 1947, these TLVs (formerly MACs) were defined as (Piney, 2001):

“Health-based OELs which not only protect exposed individuals’ health now, but also offer protection after many years of exposure”.

The ACGIH, formerly known as the National Conference of Governmental Industrial Hygienists, soon became one of the most influential organisation worldwide regarding occupational health regulations (Hansson, 1997; Piney, 1998). During the 1950s and 1960s, many countries/organisations adopted the TLVs and ever since

then, the concept of OELs became the most extensively used tool of managing HCSs in an occupational setting (Schenk, 2011).

Currently as per definition, TLVs refer to airborne concentrations of chemical substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed to, day after day, over a working lifetime, without adverse health effects. These TLVs are recommended exposure limits (instead of mandatory exposure limits) based on the belief that there are thresholds of response to chemicals (McDermott, 2004). This means that they do not point out the exact point at which impairment of health will occur nor represent a fine line between a healthy and unhealthy work environment (ACGIH, 2015).

The TLVs were derived from the assessment of scientific information based on experimental animals and on studies of exposed humans. They were set based on health effects data only rather than approaching them holistically by considering economic or technical feasibility (ILO, 2013; ILPI, 2015). Therefore, unlike ambient air standards, which are used to protect the general population, TLVs will not necessarily prevent discomfort or injury for everyone (i.e. women and children, hypersensitive individuals) who are exposed (ICMM, 2010; Paustenbach *et al*., 2011).

These TLVs were established at a standard temperature and pressure of 25 ºC and 760 torr and are, therefore, mainly expressed in terms of mass of the chemical substance in air by volume. Three categories of TLVs exist, namely TLV-TWA, TLV-STEL and TLV-C, which shall be discussed in section 2.1.3 of this study (ACGIH, 2015).

2.1.3 Common types of OELs

The term OEL is a generic term that refers to an occupational standard for a concentration of a substance in workplace air. However, these OELs may be defined in various ways, including according to their meaning or time limit reference. OELs are set at an exposure level at which no adverse health effects can be expected, for both short term and/or a standardised working lifetime. To this end OELs may be set for both short term exposures and long term exposures (ICMM, 2010). For airborne exposure there are three common and mainly used OELs, namely time-weighted

averages (TWAs), short-term exposure limits (STELs) and ceiling limits (CLs). An additional fourth OEL was later introduced, the Immediately Dangerous to Life and Health (IDLHs) limits, which are gradually beginning to receive recognition as OELs (Howard, 2005; EHS, 2012).

2.1.3.1 Time-weighted average (TWA) - OELs

Time-weighted averages (TWAs) are the most common type of OELs used for airborne hazardous chemicals. They represent the average measured chemical exposure based on the interval of time during which the exposure occurred as is depicted in Figure 2.2. They represent the maximum average concentration of airborne chemicals for a normal eight-hour working day and 40-hour week (an average work shift) (ILO, 2011). However, there are exceptions which take into account deviations in work conditions and work shifts, including the four hour TWA for asbestos (DoL, 1993; ACGIH, 2015). TWAs were designed with the aim of assisting in the control of adverse health effects on workers arising from exposure to hazardous chemical agents over a working lifetime – stretching out to approximately 30 to 40 years (Howard, 2005). Therefore, TWAs are ideal for use in protection against chronic health effects.

2.1.3.2 Short-term exposure limits (STELs)

For many HCSs, peak levels that go transiently above the TWA are permissible provided that the exposure is indeed for a short period of time (Figure 2.2). However, within certain countries/organisations, a condition that states no more than four excursions above the TWA is allowed a day with at least 60 minutes intervals between the exposure periods, is applicable (EHS, 2012). These concentration levels are defined as short-term exposure limits (STELs). STELs are the maximum average concentration to which workers can be exposed to for usually 15 minutes (Howard, 2005; ILO, 2011). Within this short period of time, workers may be exposed to these permissible higher levels provided they do not suffer irritation, chronic and irreversible tissue damage. This OEL is, therefore, ideal for HCSs that result in acute health effects.

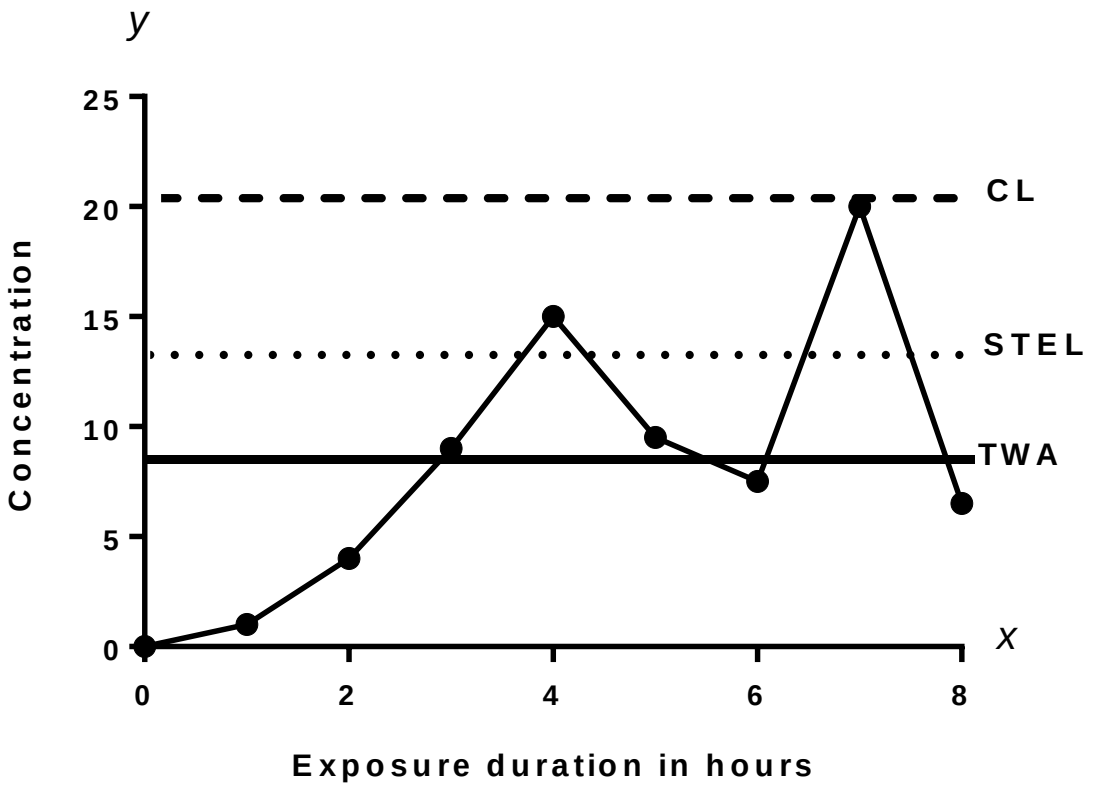

Figure 2.2: The three commonly used exposure limits for airborne hazardous chemical substances (HCSs), namely the ceiling limit (CL), short-term exposure limit (STEL) and time-weighted average (TWA). The curve represents the fluctuating concentration of the airborne hazardous chemicals. The *y*-axis represents the concentration of hazardous chemical and the *x*-axis represents the duration of exposure in hours.

*The figure is not a true representation of any particular chemical or true situation, but rather based on a hypothetical situation just to aid in depicting the relationship between the three common exposure limits.

2.1.3.3 Ceiling limits (CLs)

Ceiling limits (CLs) are concentrations above which a worker should never be exposed (EHS, 2012). They are concentrations of a HCS that should never be exceeded at any time during the workday (Howard, 2005). While TWA and STEL exposure limits permit limited excursions above their limit (i.e. under certain circumstances), a ceiling value should never be exceeded at any time (Figure 2.2). Therefore, CLs are ideal for fast acting HCSs.

2.1.3.4 Immediately Dangerous to Life or Health (IDLH) limits

Immediately Dangerous to Life or Health (IDLH) are a form of emergency chemical exposure limits to which nobody should be exposed to under any circumstances (Howard, 2005; EHS, 2012). They are values, set by the National Institute for Occupational Safety and Health (NIOSH). NIOSH defines an IDLH condition as a situation that poses a threat of exposure to airborne HCSs of which such exposure is likely to cause death or immediate, or delayed permanent adverse effects which may then prevent escape from such an environment (EHS, 2012). Therefore, an IDLH limit serves the purpose of enabling a worker to escape such a hazardous environment without injury and irreversible health effects in event of failure of the workers' respiratory protective equipment (Howard, 2005).

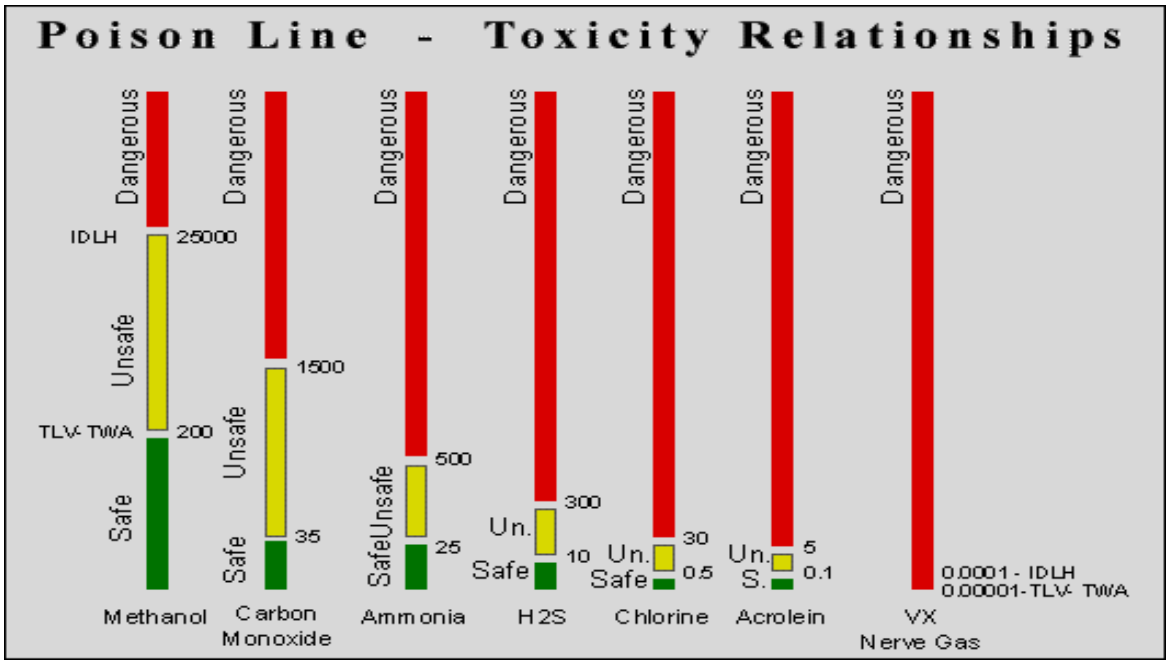

Figure 2.3: Toxicity relationships of chemicals listed in reference to their IDLH value and TWA limits. IDLH limits depicted in descending order from left to right, with all concentrations given in parts per million (ppm) (Callan, 2001).

*H_2S - Hydrogen sulfide

In determining the IDLH values, effects that are likely to occur as consequence of a period of 30 minutes exposure were considered (EHS, 2012). While a TWA limit is set at a level considered as a cut-off point between safe and unsafe for a particular chemical, the IDLH limit is set at a level which is considered to be the cut-off point between unsafe and dangerous (Figure 2.3).

2.2 THE PURPUSOE OF OELs

It is believed that if exposure to a hazardous chemical substance (HCS) is sufficiently low and small, that some negative effects will manifest. The dose-response relationship does, however, differ from one HCS to another (Schenk, 2011). Thus, the objective in establishing OELs is to control occupational illness and disease of workers, both locally and systemically, by setting the highest possible OEL at which no adverse health effects can be anticipated in workers (ICMM, 2010).

It cannot be stressed enough that these OELs are a means to an end and not the actual end to such adverse health effects. Nevertheless, OELs were established with the aim to (Howard, 2005):

- Convey information to both the employer and workers on the occupational health risks of occupational exposure.
- Provide guidance to OHS professionals.
- Aid in the determination of which control measures (including respirators) are to be selected to aid in the protection against chemical exposure and hazard.
- Serve as legally enforceable requirements under the OHS legislation

Since the inception and use of OELs in the abovementioned manner, the usefulness of OEL establishment for potentially harmful chemicals in the workplace has been demonstrated. It has been claimed that when these OELs are implemented in a work environment, that no workers would sustain serious adverse effects on their health. This, therefore, implies that there is a direct correlation between the proper use of OELs and avoided serious health effects (Paustenbach *et al*., 2011). While OELs are of great importance and serve adequately when properly implemented, their improper use may result in unfavourable concerns in the field of OHS (Jansen, 2003).

2.2.1 A vulnerable worker

The OHS plays a crucial role in the protecting of workers against occupational diseases (ODs) and occupational injuries (Tshoose, 2011). While OHS awareness is the main itinerary to aid in the prevention and reduction of occupational diseases and

injuries respectively, its awareness remains insufficient (Leman and Nor, 2013). According to the World Health Organization (WHO), an unnecessary number of workers die globally owing to ODs (2 022 000) and occupational injuries (318 000) annually (Takala *et al*., 2014).

The list of ODs usually encountered at work as a result of HCSs may be classified into three categories based on their causative agents. Firstly, they are ODs that are caused by agents, namely chemical, physical and biological agents. According to the International Labour Organisation (ILO), there are approximately 40 agents capable of eliciting an OD including isocyanates, lead, carbon disulfide, etc. Secondly, there are ODs that specifically target organ systems, usually targeting the organs related to routes of entry for hazard exposure, namely the skin and respiratory tract (ILO, 2010). The last category is that of occupational cancers, with the three common cancers being, lung cancer, leukaemia and mesothelioma (Discroll *et al*., 2005; ILO, 2010).

While it is common knowledge that most ODs are a result of occurrences experienced within the workplace, this is not true for South Africa. In South Africa the development of ODs have stepped out of the isolation of contributory risk factors stemming from only occupational settings, but rather stepped into the realm of both environmental and public health concerns (Nuwayhid, 2004). Examples of such noteworthy environmental risk factors include, tobacco smoking (including 2nd hand smoking), poor water sanitation, malnutrition and alcohol and drug use, all of which are common in most developing countries (Lim *et al*., 2012). The major public health concern in South Africa is the human immunodeficiency virus infection and acquired immune deficiency syndrome (HIV/AIDS) and tuberculosis (TB). This damage brought on by the HIV/AIDS epidemic is endured mostly in the South African mining sector where HIV infected workers have increased susceptibility to TB, and TB in turn increases and contributes to the development of ODs, specifically occupational respiratory diseases, with silicosis in the forefront (Hermanus, 2007; Naidoo, 2013). However, when a disease has multiple causes (usually from workplaces and the environment), such diseases are rather referred to as work-related diseases. This in turn contributes to the large statistic of deaths and injuries, where in fact most of the fatalities correspond to work-related diseases (Gasiorowski, 2013; ILO, 2013).

Therefore in general, ODs do not only lead to deaths and immeasurable human suffering but also impact negatively on the productivity and economy of the company and ultimately on the entire society (i.e. approximately 4% loss in global gross domestic product (ILO, 2013).

2.3 THE SETTING OF OELs

2.3.1 Deriving OELs

A system for setting OELs was first developed by the ACGIH during the 20th century. They soon thereafter published a list of OELs (TLVs) in the 1940s (Ding *et al*., 2011), and went on to become the most influential OHS regulatory agency worldwide. This led to the use of TLVs as benchmark for setting OELs for most OHS regulatory bodies within various countries/organisations (Schenk *et al*., 2008*b*; Ding *et al*., 2011). However, as time went on, an increasing number of countries began to produce their own OELs (Schenk *et al*., 2008*b*; Schenk, 2011).

Setting an appropriate OEL is a complex process (Schenk, 2011). Several OEL-setting organisations use the process of seeking a consensus before establishing a standard; this involves going through the step of consequence analysis as depicted in Figure 2.4. This consensus process usually involves canvassing information concerning economic and/or technical feasibility before accepting an OEL value (Howard, 2005; Schenk, 2011). The prioritisation and selection of HCSs to be evaluated and assigned an OEL value, and also the regulatory enforcement and practical use of such OEL values usually varies between countries. Therefore, the outcome of the OEL setting process tends to differ considerably from country to country (Schenk *et al*., 2008*b*; Schenk, 2010). However, a general OEL setting process exists that is used as guideline by most countries/organisations (Figure 2.4).

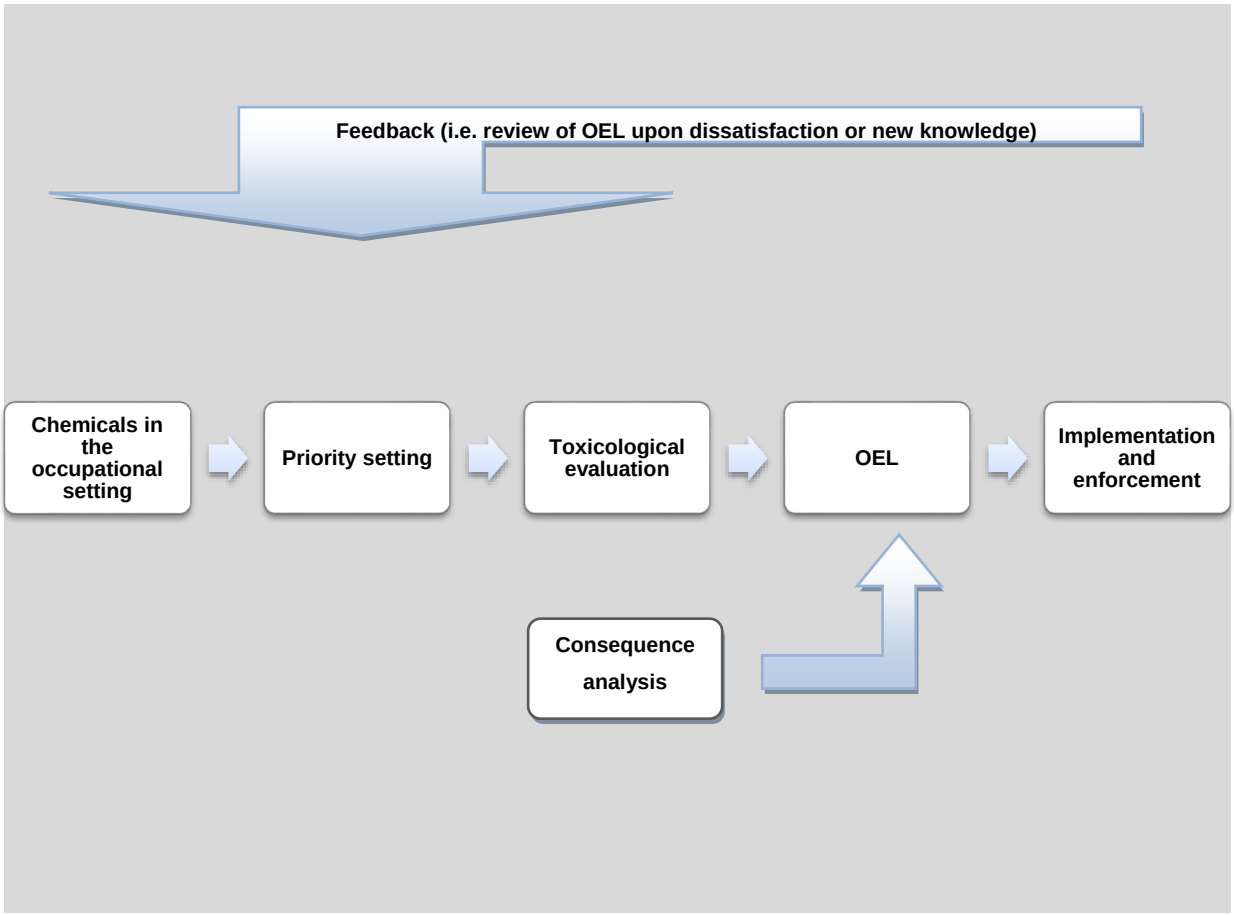

Figure 2.4: The general process of setting OELs (Schenk, 2011).

2.3.2 Heath-based or pragmatic OELs

OELs may be classified into two categories, based on how they are established. OELs may be either health-based or pragmatic (Ding, 2013).

2.3.2.1 Health-based OELs

Health-based OELs differ from pragmatic OELs in that they are set taking into account only medical and toxicological data (Schenk, 2013). These health-based OELs are set based on a totally available scientific data base that leads to the conclusion that it is possible to identify a clear threshold dose below which exposure to the chemical in question is unlikely to lead to adverse health effects (Topping, 2001; Ding, 2013). Health-based OELs do not protect the whole population, including the sensitive and the ill-health population (Schenk, 2013).

2.3.2.2 Pragmatic OELs

Pragmatic OELs are usually assigned to HCS where it is not possible to define a threshold level, from present knowledge (including studies and data), and therefore, any level of exposure to such a HCS presents a risk to health (Topping, 2001; Ding, 2013). Pragmatic OELs, in addition to medical and toxicological knowledge, also take into account socio-economic factors namely (i.e. how the economic activity affects and is shaped by social processes) (Remaeus, 2001; Ding, 2013). These OELs may therefore, for the aforementioned reason, also not fully protect the health of workers (Ding, 2013).

Generally, HCS that are classified into the health-based OELs category are usually not legally binding (i.e. recommended) while chemicals that are classified into the pragmatic OELs are legally binding (i.e. mandatory) (Norseth, 2001; Ding *et al*. 2011). Even with the option of being able to set your own OELs, most countries, specifically developing countries/organisations, opt to rather adopt their OELs from other countries' while the opposite is true for most leading developed countries/organisations (Howard, 2005).

2.4 OCCUPATIONAL EXPOSURE LIMITS BY COUNTRY

Currently, risk assessment and chemical management in the workplace varies considerably from country to country (Schenk, 2011). This leads to there being different OEL levels set for the same hazardous chemical, posing the same adverse effects (Hansson, 1997; Hansson and Rudén, 2006). However, this may be explained by the fact that most countries define special arrangements for their OELs based on their individual social factors (Schenk *et al*., 2008*a*). Nevertheless, as better information on adverse effects becomes available and with the protection of workers' health being given increased priority, several countries seem to share a common goal of having to identify a numerical value for as many HCSs as possible and to make sure that the OEL value is achieved at a concentration where the risk to most workers is reduced to a level of little concern (Ding, 2013). Hence, in various countries there is an observed trend of having an increased number of HCSs assigned exposure standards and a gradual decrease of the standard levels upon review (Schenk *et al*., 2008*a*).

2.4.1 OELs in leading developed countries

2.4.1.1 Australia

There are six states and several territories in Australia, all which collaborate through the Safe Work Australia (SWA) to develop a common set of OELs and model of occupational laws and regulations to adopt (ChemDAQ, 2013). These OELs are referred to as “exposure standards” (IFA, 2012). The exposure standards represent airborne concentrations of particular substances (or mixtures) that must not be exceeded. They are airborne concentrations of a particular chemical or substance in the workers’ breathing zone that should not cause adverse health effects or cause undue discomfort to nearly all workers (IFA, 2012; SWA, 2013). Exposure standards can be of three forms, namely:

2.4.1.1.1 8-hour Time Weighted Average (TWA)

Eight-hour TWA means the maximum average airborne concentration of a substance when calculated over an eight-hour working day, for a five-day working week (SWA, 2013).

2.4.1.1.2 Peak limitation

Peak limitations represent the maximum or peak airborne concentrations of a substance determined over the shortest analytically practicable period of time which does not exceed 15 minutes (SWA, 2013).

2.4.1.1.3 Short term exposure limit (STELs)

Short-term exposure limits (STELs) refer to the time-weighted average maximum airborne concentration of a substance calculated over a 15 minute period (SWA, 2013).

The National Health and Medical Research Council (NHMRC) originally adopted a revised edition of the ACGIH TLVs in 1992 (Paustenbach *et al*., 2011). Their OELs are currently established by the National Occupational Safety and Health Commission (NOHSC) as exposure standards for HCSs which are considered a common hazard for many industries and workplaces across Australia. However, these standards do not become law until they are adopted as regulations by an

individual state or territory (Brandys and Brandys, 2008). Therefore, exposure standards are legal concentration limits that are adhered to only by the states and territories that adopted them (IFA, 2012).

The official latest uprated list of OELs is obtainable under Appendix A of the Work Health and Safety Act (SWA, 2013). The exposure standards are meant to be updated every two years (Brandys and Brandys, 2008).

2.4.1.2 Canada (British Columbia)

While there are 13 provinces in Canada, OELs in Canada are regulated within each province (ILO, 2011). In the province of the British Columbia (BC), the WorkSafeBC (the Workers Compensation Board) publishes legal requirements and the OEL list in accordance with its mandate under the Workers Compensation Act, with which most of the BC must comply (Paustenbach *et al*, 2011). These OELs are referred to as "exposure limits" in Canada and are listed under the OHS Regulation section 5.48 under the Workers Compensations Act. The table of exposure limits for chemical substances includes two column entries, namely:

2.4.1.2.1 TWA column

Comprising of TWA limits which are defined as time weighted average (TWA) concentration of a substance in air which may not be exceeded over a normal 8 hour work period (OHSR, 2015).

2.4.1.2.2 STEL/Ceiling column

Comprises of either a STEL or a ceiling limit (latter indicated by a 'C' notation) value per chemical. STELs are, as according to Canada, defined as the TWA concentration of a substance in air which may not be exceeded over any 15 minute period, limited to no more than four such periods in an eight hour work shift with at least one hour between any two successive 15 minute excursion periods. Ceiling limits rather represent the concentration of a substance in air which may not be exceeded at any time during the work period.

The exposure limits were established based on the 1994-95 ACGIH TLVs (Brandys and Brandys, 2008), however, the exposure limits are revised and updated by the WorkSafeBC board annually when necessary (ILO, 2011). The latest update was done during the beginning of the year 2015.

2.4.1.3 European Union (EU)

The evolution of OELs in the EU started in 1978 with the announcement of its first Action Programme on OHS. An informal advisory board gave a recommendation to the European Commission (EC) from 1990 (Paustenbach *et al*., 2011) and then the Scientific Committee on Occupational Exposure Limits (SCOEL) began recommending OELs to the EC in 1995 (Schenk *et al*., 2008*b*). The SCOEL recommends health-based OELs to the EC when the EC finds it impossible to identify threshold doses below which no harm to human health can be guaranteed (Schenk *et al*., 2008*b*; Tynkkynen *et al*., 2015). The feasibility of the OELs recommended by the SCOEL is then evaluated by the Advisory Committee for Safety, Hygiene and Health at Work. The SCOEL recommends two main types of chemical limit values, namely:

2.4.1.3.1 Indicative Occupational Exposure Limit Values (IOELVs)

IOELVs are established by the EC when it is concluded that there is a clear threshold dose below which there are no adverse effects on human health after short term or daily exposure over a working lifetime (SCOEL, 2009). These indicative exposure limits are to be taken into consideration by each Member State, but the national OEL is allowed to be higher or lower than the EC indicative OEL (Schenk *et al*., 2008*b*). For any chemical agent for which an IOELV or Binding occupational exposure limit values (BOELV) value is established at European Union (EU) level, Member States must establish a national exposure limit value, taking into account the Community indicative limit value, determining its nature in accordance with national legislation and practice. IOELVs are adopted through Commission Directives (ILO, 2011).

2.4.1.3.2 Binding Occupational Exposure Limit Values (BOELVs)

Binding OELs are mandatory and each Member State must either implement the limit set by the EC or a lower limit (Feron, 2003). These BOELVs are not only health-based, but also take into account the socio-economic and other aspects (Tynkkynen *et al*., 2015). The BOELVs are adopted through Council and European Parliament Directives (ILO, 2011).

In total, the EU has five OEL publications, two which list BOELVs and three which list IOELVs. In this study, only the three IOELV lists were used. The first two lists were

published in the years 2000 and 2006. The third and latest published list of IOELVs was available as from 2009, however, both list one and two of the IOELVs are still relevant, unless otherwise due to an amendment. Both the IOELVs and BOELVs are reviewed under relevant circumstances, such as that of recent scientific data and per recommendation (EU, 2009). The EU is not a pioneering agency concerning coverage of chemicals or level of OELs, but rather sets exposure limits for substances that are already regulated by several European countries (Schenk *et al*., 2008*b*).

2.4.1.4 Finland

The Ministry of Social Affairs and Health is responsible for the enforcement and development of OHS and for the preparation of related legislation in Finland. The Ministry confirms a list of the Finnish OELs which are defined as concentrations of impurities in workplace air known to be hazardous. These OELs are referred to as “Haitallisiksi tunnetut pitoisuudet (HTP) values”; however these HTP values are not a specific legal requirement (Tynkkynen *et al*., 2015). The HTP values include both eight hours and 15 minutes exposure values.

In establishment of the HTP values, the possible effects to susceptible subgroups (such as people with chronic diseases, atopic people, people with allergies, etc.) have not been taken into account, nor are those exposures where the possibility of deleterious effects are probable (Paustenbach *et al*., 2011). In contrast to the ACGIH, the view point in Finland is that where exposure is above the limiting value, deleterious effects on health may occur (Paustenbach *et al*., 2011). While the first list of OELs in Finland were based on that of the ACGIH during the 1960s (Brandys and Brandys, 2008), its latest published HTP values are of the year 2014 and they intend to review their HTP value every other year (STM, 2014).

2.4.1.5 Germany

The German Committee on Hazardous Substances (Ausschuss für Gefahrstoffe – AGS) is an advisory body of the Federal Ministry of Labour and Social Affairs, concerned with occupational safety and health measures. The AGS is assisted by three subcommittees in recommending “occupational limit values (Arbeitsplatzgrenzwerte – AGW)”. According to the German Hazardous Substances Ordinance (Gefahrstoffverordnung), an AGW is defined as a TWA concentration in

the workplace air, referring to a given period of time. The AGWs are set at a concentration below which acute or chronic adverse health effects are generally not expected (IFA, 2010).

Germany is considered the country that has the most advanced system for developing OELs (Ripple, 2010; Ding *et al*., 2011), due to their AGWs being based exclusively on available occupational medical experience and toxicological findings (Paustenbach *et al*., 2011). The German AGWs are listed in Technical Rule for Hazardous Substances (TRGS) No. 900. These AGWs were introduced on the 1st of January 2005 as the new version of the Hazardous Substances Ordinance (GefStoffV). They replace the TLV and the Technical Guidance Concentration (TRK). However, until the AGWs are fully incorporated into the technical regulations for all chemicals, the previous MAK (maximum workplace concentrations) values and TRK values for assessing the risk at workplace are still to be used (Herbert and Philip, 2007).

The eight hour OELs (five days a week during a lifetime), short term exposure peaks - STELs and Ceiling limts are included in the TRGS 900 (BAuA, 2015).

2.4.1.5.1 Eight Hour exposure limit

The eight hour exposure limit states the concentration of a substance below which acute or chronic adverse health effects are not generally expected. The risks refer to a working lifetime of 40 years and continuous exposure every working day (IFA, 2010).

2.4.1.5.2 Short-term exposure limits/Ceiling limits

Germany uses a peak exposure factor to address STELs and CLs. This factor ranges between one and ten times the AGW TWA value. In addition, for each factor, the maximum frequency per shift and time between two events are also limited (Brandys and Brandys, 2008).

While the first German occupational limit values were published based on the ACGIH TLV list (Brandys and Brandys, 2008), the TRGS 900 list was amended and supplemented in early 2015 (BAuA, 2015)

2.4.1.6 Japan

The Japan Society for Occupational Health (JSOH) recommends the OELs in Japan. The Society defines their OEL as the concentration of a chemical substance in air which will be inhaled by a worker during a job without the use of protective respiratory equipment (Takahashi and Higashi, 2006; JSOH, 2014). There are two types of OELs that govern chemical exposure which are included in the Japan OEL list, namely:

2.4.1.6.1 Occupational Exposure Limit-Mean (OEL-M)

OEL-Ms are defined as the mean exposure concentrations at or below which adverse health effects caused by substances do not appear in most workers working for eight hours a day, 40 hours a week under a moderate workload (JSOH, 2014).

2.4.1.6.2 Occupational Exposure Limit-Ceiling (OEL-C)

OEL-Cs are defined as the reference values to the momentary maximal exposure concentrations of substances during a working day, at or below which adverse health effects do not appear in most workers. These OEL-C are represented by an asterisk (*) following a value under the OEL column. While STELs are not included in the Japan OEL list, short-term measurement lasting for 5 minutes or less at the time when the highest exposure concentration is expected may at times be used as a substitute for the measurement of maximal exposure concentration (JSOH, 2014).

The OELs set by the JSOH are recommended OELs which have no legal binding power (Takahashi and Higashi, 2006). The OELs are updated and published annually in the Japanese Journal of Industrial Health (Brandys and Brandys, 2008). The lasted publication by JSOH of the recommended OELs is of the year 2014 (JSOH, 2014).

2.4.1.7 New Zealand

In New Zealand, the OELs are called “Workplace Exposure Standards (WESs)”. The exposure limits are prepared by an expert committee, consisting of representatives of the Occupational Safety and Health Service of the Department of Labour, toxicologists, and medical or scientific experts as required. The committee considers

documentations from the ACGIH (USA), the Health and Safety Executive (HSE) (UK), the National Occupational Health and Safety Commission (NOHSC) (Australia), and MAK (Germany) (PHSC, 2009). These WESs are defined as values that refer to airborne concentration of substances at which it is believed that nearly all workers can be repeatedly exposed to day after day without harm. The values are usually calculated on the basis of an "assumed" work pattern of an eight hour working day and a 40 hour work week. In some cases, a correction is needed to take other work patterns into account (MBIE, 2013).

The WESs publication includes TWAs, STELs and CLs as standards for chemical exposure.

2.4.1.7.1 Time-Weighted Average (WES-TWA)

A WES-TWA is defined as an eight-hour TWA, representing a work shift of eight hours over one day. This means that the value assigned for a WES-TWA should not be exceeded over the period of 8 hours during a working shift (MBIE, 2013).

2.4.1.7.2 Short-Term Exposure Limit (WES-STEL)

The WES-STEL applies to any 15 minute period in the working day and is designed to protect the worker against adverse effects of irritation, chronic or irreversible tissue change, or narcosis that may increase the likelihood of accidents. The WES-STEL is not an alternative to the WES-TWA; both the short-term and TWA exposures apply (MBIE, 2013).

2.4.1.7.3 Ceiling (WES-Ceiling)

A WES-Ceiling value is a concentration that should not be exceeded for any time during any part of the working day (MBIE, 2013).

The WESs list is published by the Ministry of Business, Innovation and Employment (MBIE). The MBIE was formed on the 1st of July 2012 and forms part of the New Zealand Department of Labour. These WESs are intended to be used as guidelines for those involved in occupational health when applying the hierarchy of control set out, as required by the Code of Practice for the Management of Substances Hazardous to Health and obliged under Health and Safety in Employment Act (PHSC, 2009). The Workplace Exposure Standards are meant to be reviewed

annually (Brandys and Brandys, 2008). The latest Workplace Exposure Standards and Biological Exposure Indices publication dates the year 2013 (MBIE, 2013).

2.4.1.8 Sweden

The authority to establish OELs is given by the Swedish Work Environment Authority (Arbetsmiljöverket). The OEL values, as listed in the AFS 2011:18, are pursuant to section 18 of the Work Environment Ordinance (Arbetsmiljöförordningen) SFS 1977:1166 (SWEA, 2011). These standards are mandatory as according to the national regulations (Brandys and Brandys, 2008; Ding *et al*., 2011). Sweden has three OEL standards which are defined as:

2.4.1.8.1 Level limit value

An OEL value for exposure during a working day, normally 8 hours (SWEA, 2011).

2.4.1.8.2 Short term value

A recommended highest value for exposure calculated as TWA over a reference period of 15 minutes. Short term values in Sweden are rather recommended (not mandatory) values. They serve as a guideline in the protection of workers and are used in the assessment of exposure conditions (SWEA, 2011).

2.4.1.8.3 Ceiling limit value

An OEL value for exposure during a reference period of 15 minutes. For ammonium, monoisocyanates and diisocyanates a 5 minute reference period applies (SWEA, 2011). However, the latter CL values with a 5 minutes reference period will not be considered in this study.

These Swedish OELs are pragmatic in nature (i.e. comprised from health-based, technical constraints and socio-economic factors) (Schenk, 2013). The most recent limits were published in 2011 (SWEA, 2011)

2.4.1.9 United Kingdom (UK)

The OELs in the UK are known as “Workplace Exposure limits (WELs)”. These WELs are defined as the maximum concentration of airborne substances, averaged over a reference period, of eight hours (TWA) or 15 minutes (STEL) (IFA, 2013*a*).

The WELs function under the Control of Substances Hazardous to Health Regulation (COSHH) (Brandys and Brandys, 2008). These WELs replaced the maximum exposure limits (MELs) and occupational exposure standards (OESs) (Paustenbach *et al*., 2011). A majority of the WELs are derived from limits set by the EC under the Chemical Agents Directive (98/24/EC). However, the WELs can also be set on a national basis for substances with particular concern for UK workplaces, given it is not possible to obtain a limit through the EU process within the required timescale.

The numerical values of the WELs are listed in Table 1 of the guidance document EH40/2005 Workplace exposure limits (IFA, 2013*a*). However, the UK OEL list does not include the OELs of some HCSs that have their own specific legislation, including lead and asbestos (Brandys and Brandys, 2008). There is no fixed timetable for the revision of the WELs publication, however, the latest edition was published in the year 2011 (HSE, 2013).

2.4.1.10 United States of America (USA)

The OHS systems of the USA vary from one state to another. However, there are three major providers of OELs in the USA, namely the American Conference of Governmental industrial Hygienists (ACGIH), the Occupational Safety and Health Administration (OSHA) and the National Institute for Occupational Safety and Health (NIOSH) (PHSC, 2009).

2.4.1.10.1 ACGIH

ACGIH is a private, not-for-profit, nongovernmental corporation, The ACGIH is not a standards setting body, but is rather a scientific association that develops recommendations or guidelines to assist in the control of occupational health hazards. The ACGIH functions as an independent authority in the USA that sets trademarked OELs known as “TLVs®” (Brandys and Brandys, 2008). These TLVs are the new name for the formerly known maximum allowable concentration (MAC) (PHSC, 2009). TLVs refer to airborne concentrations of chemical substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed, day after day, over a working lifetime, without adverse health effects. Four categories of TLVs are specified:

2.4.1.10.1.1 Threshold Limit Value - Time Weighted Average (TLV–TWA)

The TLV-TWA concentration is for a conventional eight-hour workday and a 40-hour work week (ACGIH, 2015).

2.4.1.10.1.2 Threshold Limit Value - Short-Term Exposure Limit (TLV–STEL)

A 15-minute TLV-STEL is an exposure that should not be exceeded at any time during a workday, even if the eight-hour TWA exposure is within the TLV–TWA. The TLV–STEL is the concentration to which it is believed that workers can be exposed continuously for a short period of time without suffering from 1) irritation, 2) chronic or irreversible tissue damage, 3) dose-rate-dependent toxic effects, or 4) narcosis of sufficient degree to increase the likelihood of accidental injury, impaired self-rescue, or materially reduced work efficiency. Exposures above the TLV–TWA up to the TLV–STEL should be less than 15 minutes, should occur less than four times per day, and there should be at least 60 minutes between successive exposures in this range (ACGIH, 2015).

2.4.1.10.1.3 Threshold Limit Value - Ceiling (TLV–C)

The TLV-C represents a concentration that should not be exceeded during any part of the working exposure (ACGIH, 2015).

2.4.1.10.1.4 Excursion Limits

For many substances with a TLV–TWA, there is no TLV–STEL. Nevertheless, excursions above the TLV–TWA should be controlled, even where the eight-hour TLV–TWA is within recommended limits. Excursion limits apply to those TLV–TWAs that do not have TLV–STELs (ACGIH, 2015).

In contrast to the OSHA which sets regulatory exposure limits, TLVs are a scientific opinion, based solely on health factors (no consideration given to economic or technical feasibility) and, therefore, do not carry the force of law, they are only recommendations (ILPI, 2015). These health factors are determined by the ACGIH from a review of existing peer-reviewed scientific literature by committees of experts in public health and related sciences. TLVs are not consensus standards (i.e. formulated by a broad-based committee across a particular industry), but based on ACGIH opinion. Nevertheless, ACGIH-TLVs and their criteria documents are a very

common bases for setting OELs in the USA and in many other countries (PHSC, 2009). The latest list of TLVs is available as in the year 2015 from the ACGIH publication (ACGIH, 2015).

2.4.1.10.2 OSHA

The OSHA of the USA Department of Labour publishes the regulatory limits, “Permissible Exposure Limits (PELs)”. PELs are regulatory limits on the concentrations of substances in the air. OSHA PELs are based on an eight-hour TWA exposure. OSHA recognises that many of its PELs are out-dated and inadequate for ensuring protection of workers’ health (IFA, 2008). Most of OSHAs PELs were issued shortly after adoption of the OSH Act in 1970, and have not been updated since that time. Most of the PELs contained in the Z-Tables of 29 CFR 1910.1000 were adopted from the Walsh-Healy Public Contracts Act as existing Federal standards for the general industry. These in turn had been adopted from the 1968 TLVs of the ACGIH. Some consensus standards from the American Standards Association were also adopted at that time (PHSC, 2009; OSHA, 2015).

Originally, NIOSH was responsible for developing new exposure limits and recommending them to OSHA. However, NIOSH became part of the Centres for Disease Control and Prevention (CDC) and, therefore, could not be further funded by the federal USA government to develop and recommend OELs to OHSA. The OSHA OELs are out-dated as far as two decades (Brandys and Brandys, 2008; OSHA, 2015). Therefore, to provide employers, workers, and other interested parties with a list of alternate OELs that may serve to protect workers better, OSHA has annotated the existing Z-Tables with other selected OELs, including the PELs of the California Division of Occupational Safety and Health, the Recommended Exposure Limits (RELs) of NIOSH and the ACGIH TLVs (OSHA, 2015). However, OSHAs mandatory PELs in the Z-Tables remain in effect (Brandys and Brandys, 2008; OSHA, 2015). There are two types of OELs that are found in the OSHA regulation, namely the eight-hour PEL (PEL-TWA) and the CL, both of which are used and defined in a similar way as that of the ACGIH (PHSC, 2009).

2.4.1.10.3 NIOSH

NIOSH is a federal agency that has a statutory responsibility for conducting research and making recommendations for exposure levels that are protective to workers

(PHSC, 2009; IFA 2013*b*). NIOSH is part of the CDC in the US governments Department of Health and Human Services. Acting under the authority of the Occupational Safety and Health Act of 1970 (29 USC Chapter 15) and the Federal Mine Safety and Health Act of 1977 (30 USC Chapter 22), NIOSH develops and periodically revises RELs for hazardous substances. RELs are recommendations based on a critical review of the scientific and technical information available on a given hazard and the adequacy of methods to identify and control the hazard (CDC, 2015). They are developed based on risk evaluations using human or animal health effects data, and on an assessment of what levels can be feasibly achieved by engineering controls and measured by analytical techniques. Therefore, RELs project not only a no-effect exposure, but also exposure levels at which there may be residual risks (IFA, 2013*b*). For NIOSH RELs, the following definitions apply:

2.4.1.10.3.1 Time-weighted average – Recommended exposure limit (TWA-REL)

TWA-REL indicates a time-weighted average concentration for up to a 10-hour workday during a 40-hour work week (CDC, 2015).

2.4.1.10.3.2 Short-term exposure – Recommended exposure limit (STEL-REL)

A STEL-REL is a 15-minute TWA exposure that should not be exceeded at any time during a workday (CDC, 2015).

2.4.1.10.3.3 Ceiling REL

A ceiling value should not be exceeded at any time (CDC, 2015).

These limits have no legal authority (PHSC, 2009). NIOSH RELs can be found in the NIOSH Pocket Guide to Chemical Hazards (IFA, 2013*b*). The latest NIOSH Pocket Guide was published in the year 2007 (CDC, 2015).

2.4.2 South Africa as a developing country

The OELs in South Africa are issued by two governmental departments, namely the Department of Labour (DoL) and the Department of Mineral Resources (DMR). The DoL publishes its OELs for airborne pollutants in the Regulations for Hazardous

Chemical Substance (RHCS) and the DMR in the Mine Health and Safety Regulation (MHSR) (Brandys and Brandys, 2008; PHSC, 2009).

2.4.2.1 Regulations for Hazardous Chemical Substance (RHCS)

The DoL published its first OELs, authorised by the Occupational Health and Safety Act (No. 85 of 1993) in the year 1995 (Brandys and Brandys, 2008). These OELs as listed in Annexure 1 of the RHCS of 1995 are based on the OELs of the UK. The OELs assigned for airborne HCSs are divided into OEL-CL (control limits) and OEL-RL (recommended limits) (PHSC, 2009). Both limits are listed for reference periods of eight hours (TWA) and 15 minutes (STEL). These limits are listed in Table 1 and Table 2 respectively of Annexure 1 of the RHCS (DoL, 1993).

2.4.2.1.1 Occupational exposure limits – Recommended limits (OEL-RL)

An OEL-RL is defined as the concentration of an airborne substance, averaged over a reference period, at which, according to current knowledge, there is no evidence that it is likely to be injurious to employees if they are exposed by inhalation, day after day, to that concentration. The OEL-RL is set at a level at which there is no indication of a risk to health (DoL, 1993).

2.4.2.1.2 Occupational exposure limits – Control limit (OEL-CL)

An OEL-CL is defined as the maximum concentration of an airborne substance, averaged over a reference period, to which employees may be exposed by inhalation under any circumstances, and is specified together with the appropriate reference period in Table 1 of Annexure 1. However, a residual risk may exist and the level set takes into account socio-economic factors (DoL, 1993).

Since establishment, only a few amendments have been made to the OELs in the RHSC (PHSC, 2009). One of the amendments includes review of silica's OEL in the year 2008 by the Minister of Labour. According to an announcement made in the Government Notice No. R 683, the OEL-CL for silica in Table 1 of the RHCS was changed from 0.4 mg/m^3 to 0.1 mg/m^3 (SAFLII, 2014). However, the rest of the OELs in the RHCS remain out-dated.

2.4.2.2 Mine Health and Safety Regulation (MHSR)

The OELs as listed in the Mine Health and Safety Regulation (MHSR) 22.9 are under the authority of the Mine Health and Safety Act (No. 29 of 1996). The MHSR lists three types of OELs, including (DMR, 1996):

2.4.2.2.1 Occupational exposure limit (OEL)

OEL means the TWA concentration for an eight hour work day and a 40 hour work week to which nearly all workers may be repeatedly exposed without adverse health effects.

2.4.2.2.2 Occupational exposure limit – Short term exposure limit (OEL-STEL)

An OEL-STEL means a 15-minute TWA exposure which should not be exceeded at any time during a workday even if the eight-hour TWA exposure is within the OEL-TWA. Exposures above the OEL-TWA up to the STEL should not be longer than 15 minutes and should not occur more than four times per day. There should also be at least 60 minutes between successive exposures in this range.

2.4.2.2.3 Occupational exposure limit – Ceiling limit (OEL-C)

OEL - C means an instantaneous value which must never be exceeded during any part of the working exposure.

The OELs in the MHSR were last updated in the year 2006 (Viljoen, 2012).

2.4.2.3 South Africa's OHS system

Apart from the out-dated OELs, South Africa's OHS framework is deficient in numerous other ways (Puplampu and Quartey, 2012). While both the DoL and DME share the principle responsibility of governing OHS, the activities of these departments are guided by separate policies, each involving their own approach and own priorities (Hermanus, 1999). The most part of such differences can be highlighted by the non-equivalence in the Acts (and respective regulations) that govern health and safety. Even with both the RHCS and MHSR serving a common goal of striving to prevent the contraction of disease and injuries of workers, there are some interesting key differences between them. These differences are listed in Table 2.1.

Table 2.1: Key differences between the two regulations that govern South Africa's Occupational health, the RHCS and MHSR (DMR, 1996; DoL, 1993)

	RHCS	MHSR
Responsible institution	DoL	DMR
Scope of Act	Persons at work (general industry workers, exclusive of miners)	Employees and other persons at mines
Types of OELs	TWA STEL	TWA STEL CL
Same OEL definition and use	No	No
CAS system	No	Yes
Date of last revision	1995*	2006
Main source of influence	UK	Unknown

DoL = Department of Labour; DMR = Department of Mineral Resources; UK = United Kingdom

*With only a few amendments, including that of respirable crystalline silica OEL-CL

Generally, the MHSA (including the regulation) specifies occupational health requirements in greater detail compared to the OHSA. However, the latter Act is responsible for the health and safety of approximately 95% of South Africa's population (Hermanus, 2007; SSA, 2013). Another difference worth noting is the difference in OEL levels in the two Regulations. However, this can be justified by the difference in date of review of the individual regulations. Nevertheless, this further highlights the difference in approach and priorities by the two departments. These differences then raise the ultimate question of whether both groups of workers (i.e. the general industry workers versus miners) are being protected impartially and adequately against diseases and injuries within the workplace.

2.5 CONCLUSION

OELs were established with the aim to restrict the allowable concentration of hazardous substances in the workplace air averaged over a period of time. While the ACGIH historically influenced many countries/organisations on OEL setting, most countries/organisations increasingly produced their own OEL lists (Schenk, 2011). However, today various countries tend to set their OELs based on their countries individual socio-economic feasibility, thus resulting to the same HCS having different OELs throughout the world. This makes the harmonisation of OEL levels throughout the world almost impossible to achieve. This also implies that there are disparities in the protection of workers from one country to another (Howard, 2005).

In South Africa marginal efforts have been taken by the DoL to update the now two decades old OELs in the RHCS (with the only known amendment being silica) (SAFLII, 2014). This is also true for the nine years old out-dated OELs in the MHSR. However, the controlling of exposure of workers to HCS exposure is largely dependent on scientifically up-to-date OELs (Howard, 2005). Therefore, before any further action can be invested towards the managing of HCS exposure in South Africa as a developing country, OEL comparison has to be done alongside those of developed countries whom are known to have the adequate resources and technical expertise to further develop and update their OELs (Schenk *et al*., 2008*a*; Schenk, 2011).

Therefore, the next two chapters will consist of articles that will compare the STELs (Article 1) and CLs (Article 2) listed in the South Africa's Regulations, with the STELs and CLs of various leading developed countries/organisations.

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Comparison of South African short-term exposure limits with those of developed countries

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Abstract

Introduction: The purpose of occupational exposure limits (OELs) is to regulate exposure to hazardous chemical substances (HCSs) in the workplace thereby minimising the risks of adverse health effects resulting from such exposure. However, the effectiveness of controlling such risks is largely dependent on scientifically up-to-date OELs. Therefore, the aim of this study was to determine the extent of effectiveness of South African short-term exposure limits (STELs) by comparing them with those of leading developed countries/organisations based on the coverage and level of STELs.

Methods: The study was performed by reviewing and comparing the latest published lists of STELs of ten developed countries/organisations with two of the main South African STEL lists as listed in the Regulations for Hazardous Chemicals Substances (RHCS) and the Mine Health and Safety Regulations (MHSR). These ten countries/organisations include, Australia, Canada (British Columbia), European Union, Finland, Germany, New Zealand, Sweden, United Kingdom and United States of America (NIOSH, and ACGIH). Coverage comparison was achieved by categorising the HCSs as either, unique to the RHCS (or MHSR), or overlapping with the other country/organisation. The overall STEL level comparison was achieved by use of the geometric means (GMs) method and interval method.

Results and Discussion: There is significant disparity of STEL coverage between the RHCS and the ten selected developed countries/organisations, where seven of the countries/organisations had a <50% overlap in HCSs with the RHCS. This is also true for comparison with the MHSR, where also seven countries/organisations had a significantly low number of overlapping HCSs with the MHSR; that is a <50% overlap. There are also significant disparities in STEL levels based on the GMs methods, where nine and eight countries/organisations had lower STEL levels when compared to the RHCS and MHSR respectively. The interval method results of STEL overall level supports the GMs method which both proved that there were disparities between South African STEL levels and those of developed countries/organisations, with the overall STEL levels of the developed countries/organisations being lower.

Conclusion: There are disparities in both coverage and level of STELs between South Africa and the selected developed countries/organisations. This conclusion corresponds with that made by a previous study comparing time-weighted averages (TWA-OELs) coverage and level. This thereby corroborates the conclusion that South African STELs are inadequate to regulate acute exposure from HCSs and thereby minimising the potential risks of adverse health effects manifesting following short-term acute exposure to HCSs in the workplace.

Key words: Occupational exposure limits (OELs), comparison, South Africa, developing countries/organisations, hazardous chemical substances (HCSs), STEL coverage, geometric means (GMs) method, interval method

1. Introduction

Hazardous chemical substances (HCSs) in the occupational industry are infamously known to pose a wide variety of health risks to workers (dating as far back as the 15th century). As an important tool for managing these HCS exposures and risks, amongst other precautions, occupational exposure limits (OELs) were established and implemented (Paustenbach *et al*., 2011). The purpose of the OELs is to control exposure to HCSs and thereby minimise the risk of health effects developing due to HCSs in the workplace. Three categories of OELs are specified: a time-weighted average (TWA) for an eight-hour and 40-hour work week; a short-term exposure limit (STEL) value set for 15 minutes for HCSs with irritating or narcotic effects; and a ceiling limit (CL) which should never be exceeded even for very short exposure periods (Nielsen and Øvrebø, 2008; ACGIH, 2015). For most HCSs, a TWA alone or with a STEL is relevant. However, for some HCSs, usually irritant gases, only a CL is applicable (ACGIH, 2015).

Although the first list of OELs was not published by the American Conference of Governmental Industrial Hygienists (ACGIH), the history of systemic setting of OELs is said to have begun with the first list of threshold limit value (TLVs) published in the 1940s by the ACGIH (Topping, 2001). During the 1950-60s, many countries/organisations adopted the ACGIH TLVs, as their concept of OELs had become the most extensive management tool of HCSs within the workplace (Schenk, 2011). Currently, different countries/organisations have taken up the responsibility of setting and updating their own OELs. This is, however, mainly true for most developed countries (Tynkkynen *et al*., 2015). With most developing countries, because of lack of resources and technical expertise, OELs are usually adopted from other OEL-setting organisations (Howard, 2005; Paustenbach *et al*., 2011).

In South Africa, a developing country, two governmental departments govern OEL-setting, implementation and enforcement, namely the Department of Labour (DoL) and the Department of Mineral Resources (DMR) (Brandys and Brandys, 2008). Both departments are not OEL-setting entities, but rather OEL-adopting entities. The DoL which is responsible for publishing the OELs listed in Annexure 1 of the Regulations for Hazardous Chemical Substances (RHCS) of 1995, under the

Occupational Health and Safety Act (No. 85 of 1993) (DoL, 1993), adopted its OELs from the then published OELs of the United Kingdom (UK). This adoption occurred in 1995 and since then negligible action has been taken by the DoL to update the now two decades old OELs (DoL, 1993). The DoL is known to only have updated one OEL; the OEL for crystalline silica (South Africa, 2010). The DMR, authorised by the Mine Health and Safety Act (No. 29 of 1996), in the Mine Health and Safety Regulation (MHSR) 22.9 (DMR, 1996), also share the same concern as that with the DoL of harbouring out-dated OELs which were last updated ten years ago (DMR, 1996; Howard, 2005). This slow pace of adopting or revising the OELs in South Africa then raises a question of whether the OELs are effective enough at protecting workers from the exposure and corresponding adverse health effects that result from HCS exposure.

The effectiveness of assessing and controlling exposure to HCSs is largely dependent on having scientifically up-to-date OELs (Howard, 2005). It has also been stated by Schenk *et al*. (2008*a*) that OELs tend to decrease gradually in level (i.e. concentration) over time as they are revised. This is substantiated by the noticeable decrease of OEL levels of Swedish OELs from 1969 to 1994 and that of the ACGIH TLVs from 1946 to 1996 (Hansson, 1997).

While the establishment of individual OELs in South Africa may not seem feasible currently, due to lack of resources, poor occupational health and safety (OHS) awareness and various other reasons, attempts can however be made to improve OHS in South Africa. It is without doubt that OHS in South Africa receives very little attention, shown by the countless health and safety hazards, occupational diseases (ODs) and mortalities (Puplampu and Quartey, 2012; Naidoo, 2013). Therefore, before any attempts can be made to try and improve the OHS system in South Africa, by trying to manage the HCSs, it is deemed necessary that South Africa's OELs be compared with those established by various OEL-setting entities and of countries/organisation that regularly update or revise their OELs. This comparison will allow for the observing of disparities in HCSs level, which are meant to be of harmonised level worldwide due to them being assigned to the same HCS which exhibit the same hazardous effects worldwide. Noticeable differences in OEL levels amongst countries/organisations suggest that there are disparities in the protection

of workers from one country to another. Therefore, there is a possibility that some workers are protected while others are left vulnerable (Lethbridge, 2008). Once the extent of disparities, if any, has been uncovered, then attempts can be made to update the South African lists.

Therefore, the aim of this study entails the comparison of South African STELs with that of selected developed countries/organisations based on the variables of coverage (frequency and selection) of individual HCSs and level (concentration) of STELs set for different HCSs.

2. Methods

2.1 Database of STELs

The South African Regulations, RHCS and MHSR, are contained in the OHS Act and MHS Act respectively. The RHCS exposure limits are divided in OEL-RLs (recommended limits) and OEL-CLs (control limits). The OEL-RL is set at a level at which there is no indication of risk to the workers' health, whereas the OEL-CL is assigned to HCSs that may elicit residual risk at the set level, usually HCSs such as carcinogens. Both exposure limits relate to personal exposure to airborne HCSs within an eight-hour reference period. These OEL-CL and OEL-RL are listed in Table 1 and Table 2 of Annexure 1 respectively. The OELs in the RHCS do not apply to the exposure of HCSs that are hazardous to the health of workers in mines. The MHSR contains OEL values that regulate mine work environments only. Both regulations have TWA and STEL values, but only the STEL values were considered for comparison between the two (i.e. the South African Regulations) and to that of the developed countries for this study.

In both the South African lists there were duplicates of HCSs, therefore, all the synonyms were removed and noted (Supplementary material) before the commencement of the study. In the study by Viljoen (2012), the synonyms were identified and listed; therefore, that list was used as a guide for the removal of the duplicate HCS for the STEL list compilation. Another issue that was experienced during the study was of the use or non-use of a CAS (Chemical Abstracts Service) number. A CAS number is a unique numeral combination that identifies a HCS (Ding *et al*., 2011). While the CAS system is convenient in the minimising of confusion

during chemical naming, it has yet to be adopted by the RHCS list and, therefore, the STEL database used for this study had to include lists and individual HCSs that were not specified with CAS numbers (Supplementary material).

For the developed countries' lists, the most recent published lists of OELs were collected in published form, via websites or through personal communication with the relevant regulatory organisations or representatives. The selection and number of developed countries included in this study were based on the availability of data and dominance in literature. Some countries only publish their documents, including OEL lists, in their native languages (language other than English), thus language was taken into consideration during this selection process. Ten countries/organisations were considered for this study.

Spread sheets were used to compile the STEL values of all the different countries/organisations systematically. The final databases contained 12 sets of STEL values. The HCSs were listed based on their chemical names and CAS number in order to enable correct parallel pairing of HCSs with those of the countries to be compared. Most of the STELs in the RHCS and MHSR are listed in both ppm (parts per million) and mg/m^3 (milligrams per cubic metre). However, the units of mg/m^3 were used in this study. This being due to the reason that most HCSs on the RHCS, MHSR and most developed countries lists have assigned mg/m^3 units to their STEL values. Where necessary conversions were made from ppm to mg/m^3 by the following calculation as previously used to compare OELs by Schenk *et al*. (2008*a*), Ding *et al*. (2011) and Viljoen (2012):

$$\text{Concentration (mg/m}^3\text{)} = \text{(Concentration ppm) x (Molecular weight) / 24.45*}$$

*24.45 being the molar volume of air at 25 ºC and 101.325 kPa (AFS, 2005)

As part of the limitations in the previous study conducted by Viljoen (2012), conversions for a few HCSs could not be achieved due to the inability to calculate the exact molecular weights of those particular HCSs. This problem was encountered when dealing with aliphatic hydrocarbons. Therefore, those particular HCS were excluded from the database, but their removal was noted (Supplementary material). For HCSs that had isomers or fractions (respirable and inhalable) that were also designated STEL values, all the values were added to the lists.

2.2 Coverage of substances

The comparison of the STELs was done between the RHCS and the MHSR, followed by the individual comparison of both South African lists with that of the other ten countries. For the comparison between either one of the South African lists with that of a developed country/organisation, analysis was made to determine the number of overlapping HCSs (i.e. substances that appeared on both lists). All the other HCSs that appeared in only one of the lists to be compared were not included during the analysis and were, therefore, considered as unique HCS for that particular country/organisation. This shed light on the HCSs that are a common hazard and prevalent in most countries/organisations while also highlighting those HCSs that are solely regulated by certain countries/organisations.

2.3 Level of STELs

A comparison between the overall levels of STELs from different countries/organisations was made by making use of the geometric means (GMs) method. In addition to making use of the GMs method, another method was utilised for further comparison between the level differences, taking into consideration values in close proximity to one another which were considered as “different” during GMs analysis. The method was recently implemented by Tynkkynen *et al*. (2015) for establishing the differences in EU and Finnish OEL levels. The method involved using a 95-105% interval to determine disparity and similarity between levels of TWAs and STELs HCSs. This method was further referred to as the Interval Method.

2.3.1 Geometric means method

For each HCS, the measure between its values on the two lists was considered as the best indicator of their difference. These differences in STEL values on the two lists were compared statistically by use of the GMs method as used by Hansson (1997), Schenk *et al*. (2008*a*); Ding *et al*. (2011) and Viljoen (2012). It was important to make use of GMs as a statistical variable rather than arithmetic mean or median because the values on the list, when determined with arithmetic mean, was perceived as having a higher value, depending on which list is used as a denominator. To illustrate this, consider the following example: List A and B both assigns OELs for three HCSs. List A allocates 20 ppm to substance I, 15 ppm to substance II and 10 ppm to substance III. On the other hand List B has set the OELs

for the same HCSs at 200 ppm for substance I, 15 ppm for substance II and 1 ppm for substance III. The arithmetic means of ratios for B/A or A/B both equal 3.7 giving the impression that either A or B have set higher OELs. In both these instances the GMs of ratios equal 1, indicating that the overall level of the two lists does not differ (Schenk *et al*., 2008*a*; Ding *et al*., 2011). A GM less than 1 indicated that the list being compared had a lower overall STEL level, whereas a GM value of greater 1 indicated a higher overall STEL level. By using the GMs method, the ratios were more representative irrespective of their denominator.

For comparison between two lists, comparison was made only between HCSs that appeared on both lists. These overlapping HCSs, for STEL values, yielded a complete and comprehensive database that was used for comparison. This way, the absence of the unique HCS (i.e. HCS that only appear on one of the lists and not both), did not influence the average level of similarity or disparity of the overlapping HCS concentrations. The GMs method was used to compare the overall levels of STELs from the different countries relative to the RHCS and MHSR.

2.3.2 Interval method

This method involved the use of a 95-105% interval to determine disparities and similarities between levels of HCSs. Situations presented themselves where some HCSs STEL values on two lists were close in proximity to one another in value (see substance 1 in Table 1), as opposed to being identical (see substance 2 in Table 1). However, this difference in HCS values came about during the conversion of units from ppm to mg/m^3, suggesting that the slight difference in values was most likely meant to be identical. According to the Interval method, such HCSs having a value difference within the 95-105% interval (i.e. a unit difference within 5% above or below the compared STEL value) were considered as identical. Some HCSs on the other hand had STEL values that were outside of the 95-105% interval, either greater than 105% or less than 95%, these HCSs were considered as significantly higher (see substance 4 in Table 1) or significantly lower (see substance 3 in Table 1), respectively. Therefore comparison between the HCS STEL of two lists (e.g. comparison between the RHCS list and a developed country list) was categorised as, (i) identical to, (ii) significantly higher than or (iii) significantly lower than. This

comparison method served a purpose of giving a true reflection of the substance level disparities and similarities.

Table 1: Interval method categories description. Comparison between two HCS STEL values of two STEL lists, where comparison is done in relation to list A.

No.	Substance	CAS	List A	List B	Category
1	Methyl acetate	79-20-9	760	757	STEL identical to RHCS STEL
2	NN-Dimethylaniline	121-69-7	50	50	
3	n-Propyl acetate	109-60-4	1050	950	STEL significantly lower than RHCS STEL
4	1,1,2-Trichloro-1,2,2-triflouroethane	76-13-1	9500	9990	STEL significantly higher than RHCS STEL

3. Results

3.1 STEL coverage

The coverage of STELs, of all the selected developed countries/organisations, including South Africa's very own MHSR, compared to that of the RHCS are shown in Figure 1. The coverage was classified as overlapping or unique, with unique being either unique to the RHCS (or MHSR) or unique to the developed country/organisation. The highest overlapping is between the two South African lists, with 292 HCSs (86.6%) overlapping. The two countries/organisations that had the lowest overlap are the NIOSH and EU with a 68 and 46 HCS overlap, respectively. While Finland's list had one of the highest overlap of 227 HCS with the RHCS, it also had the highest number of 249 unique HCSs.

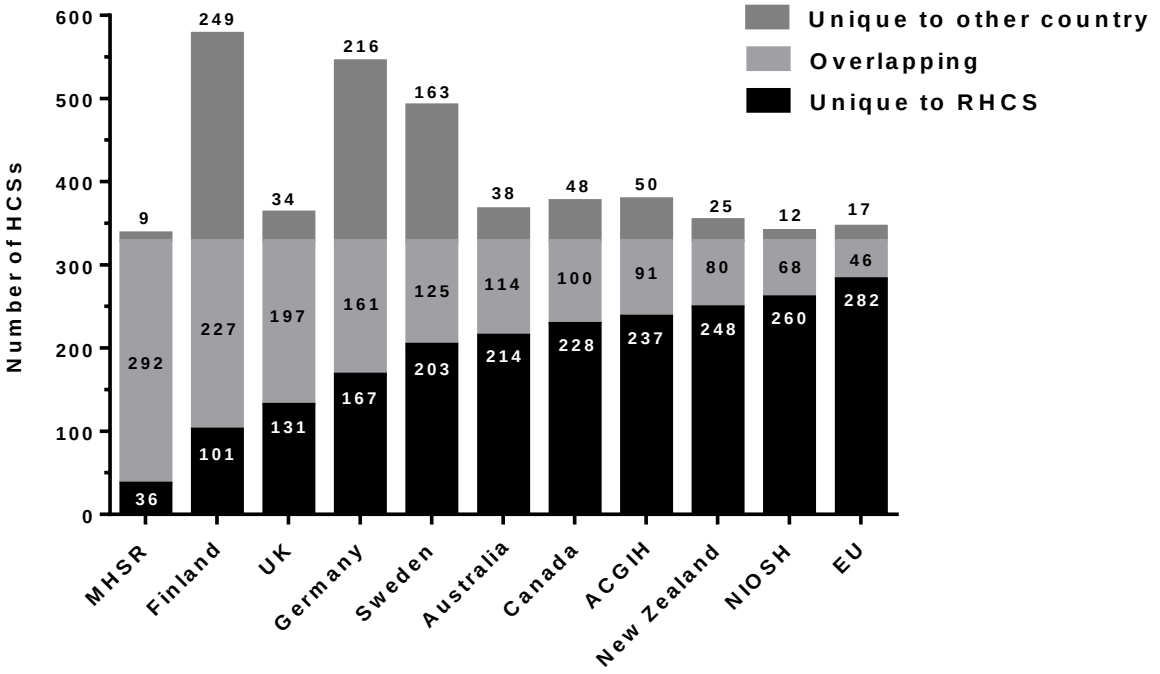

Figure 1: Disparities and similarities of the HCSs STEL coverage between the RHCS and the MHSR and ten developed selected countries/organisations. The overlapping numbers of HCSs are depicted in descending order from left to right.

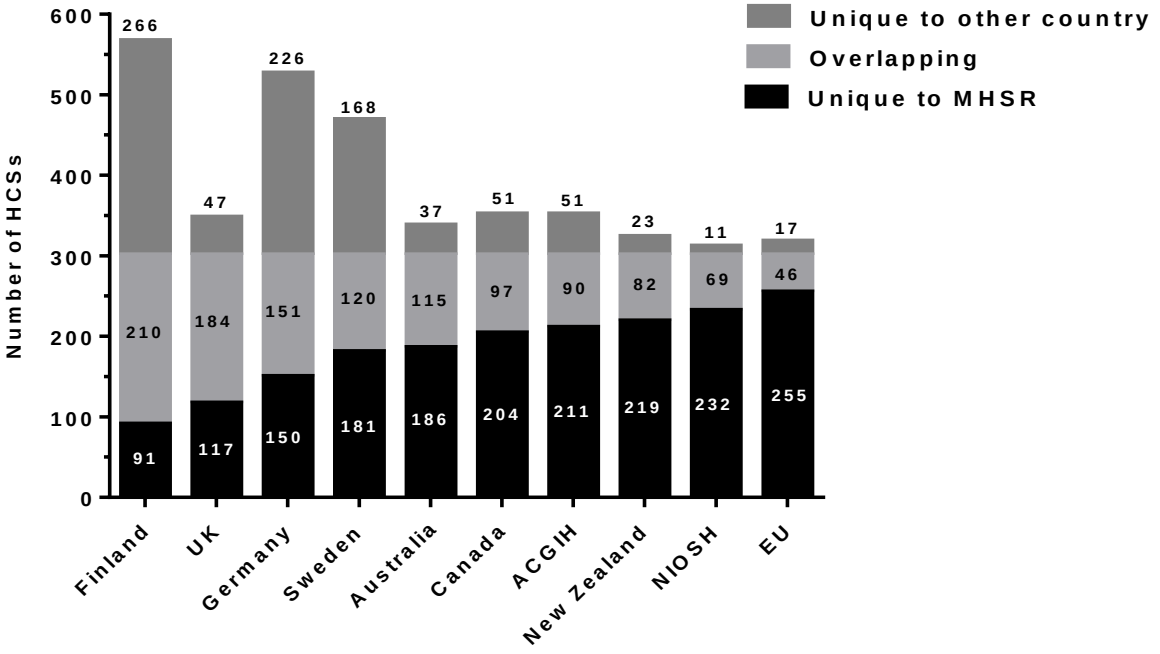

Figure 2: Disparities and similarities of the HCSs STEL coverage between the MHSR and the ten developed selected countries/organisations. The overlapping numbers of HCSs are depicted in descending order from left to right.

Figure 2 illustrates coverage similarities of STELs between South Africa MHSR with that of the developed countries/organisations. As with the RHCS, when compared to the MHSR, Finland ranks second highest with STEL overlapping by 210 HCSs. Similar to the RHCS, the EU (46 HCSs) and NIOSH (69 HCSs) had the lowest number of overlapping HCSs. In general, out of the ten countries/organisations, eight and seven of the countries/organisations had a higher number of HCSs that were unique to the RHCS and MHSR respectively, than that of the overlapping HCSs.

3.2 STEL levels

3.2.1 Geometric means method

The comparison of overall STEL level by geometric means (GMs) method was done between South Africa and the developed countries/organisations (i.e. the developed countries/organisations ÷ South Africa). The GMs ratios have been listed in Table 2 according to their compared reference country. The STEL overall levels were also compared between the two South African lists.

Table 2: Geometric means of ratios based on overlapping HCSs between the RHCS and MHSR and the various developed countries/organisations. The geometric means depicted in ascending order from top to bottom.

RHCS as reference country			**MHSR as reference country**		
Country/Organisation	**GM**	**N**	**Country/Organisation**	**GM**	**n**
Sweden	0.606	161	Sweden	0.643	120
Germany	0.664	125	Germany	0.769	151
Finland	0.752	227	Finland	0.784	210
EU	0.759	46	EU	0.876	46
Canada	0.833	100	ACGIH	0.923	90
ACGIH	0.886	91	UK	0.946	184
UK	0.903	197	NIOSH	0.959	69
MHSR	0.936	292	Canada	0.966	97
NIOSH	0.941	68	Australia	1.024	115
Australia	0.972	114	New Zealand	1.101	82
New Zealand	1.026	80			

GM refers to geometric means, n = number of overlapping HCSs.

The GMs ratio of 0.936 demonstrates how the overall STEL levels in the MHSR are slightly lower than those in the RHCS. It was also noticed that all the countries/organisations had GMs ratios below one; with the GMs ratios ranging from 0.972 to 0.664, with the exception of New Zealand (GMs ratio = 1.026). Sweden had the lowest overall level of STELs with a GMs ratio of 0.606.

With the MHSR as the reference list, the overall level of STEL comparison was slightly different. The countries/organisations with lower overall levels of STELs ranged between 0.966 and 0.643 in GMs ratio, with Sweden (GM = 0.643) having had the lowest overall STEL level. Two countries/organisations had overall STEL levels which were higher than that of the MHSR STELs, namely Australia (GMs = 1.024) and New Zealand (GMs = 1.101).

3.2.2 Interval method

The individual levels of STEL numeric values were compared between the individual South African STELs and the developed countries/organisations STELs.

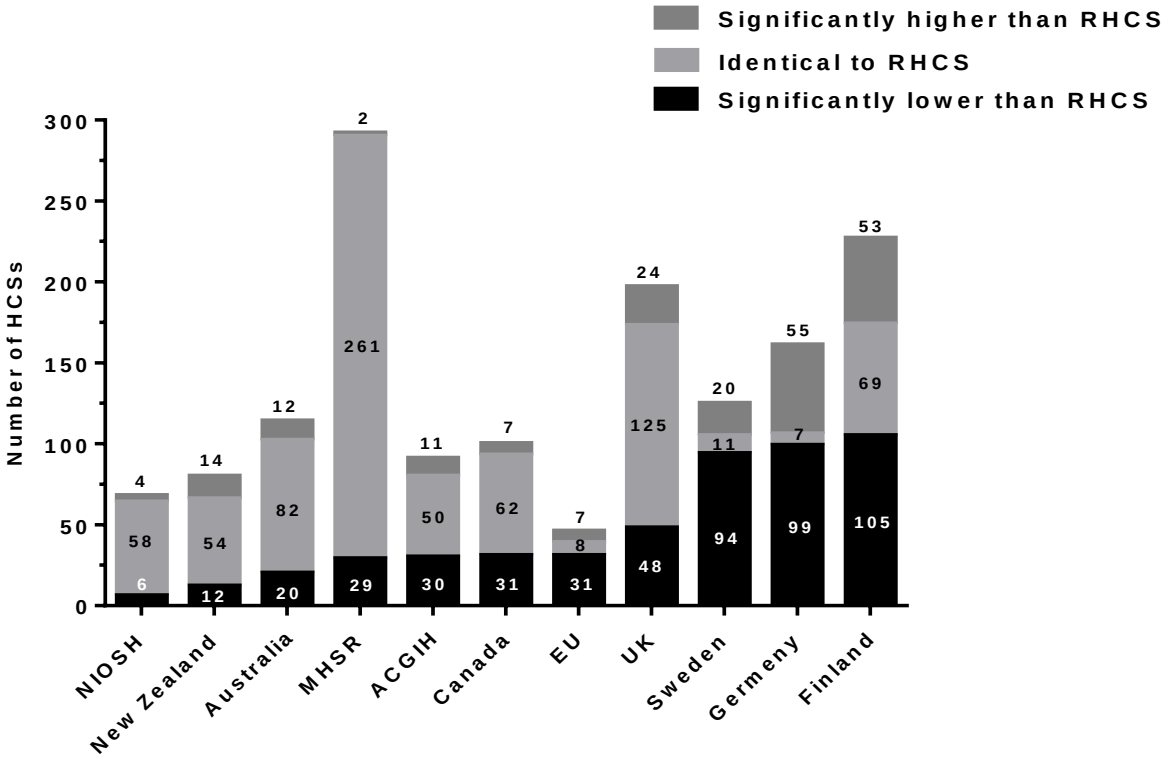

Figure 3: Comparison of STEL numeric values by interval method between the RHCS and the MHSR and ten developed countries/organisations, with the RHCS as the reference country/organisation. Figure bars arranged according to ascending significantly lower than the RHCS numbers.

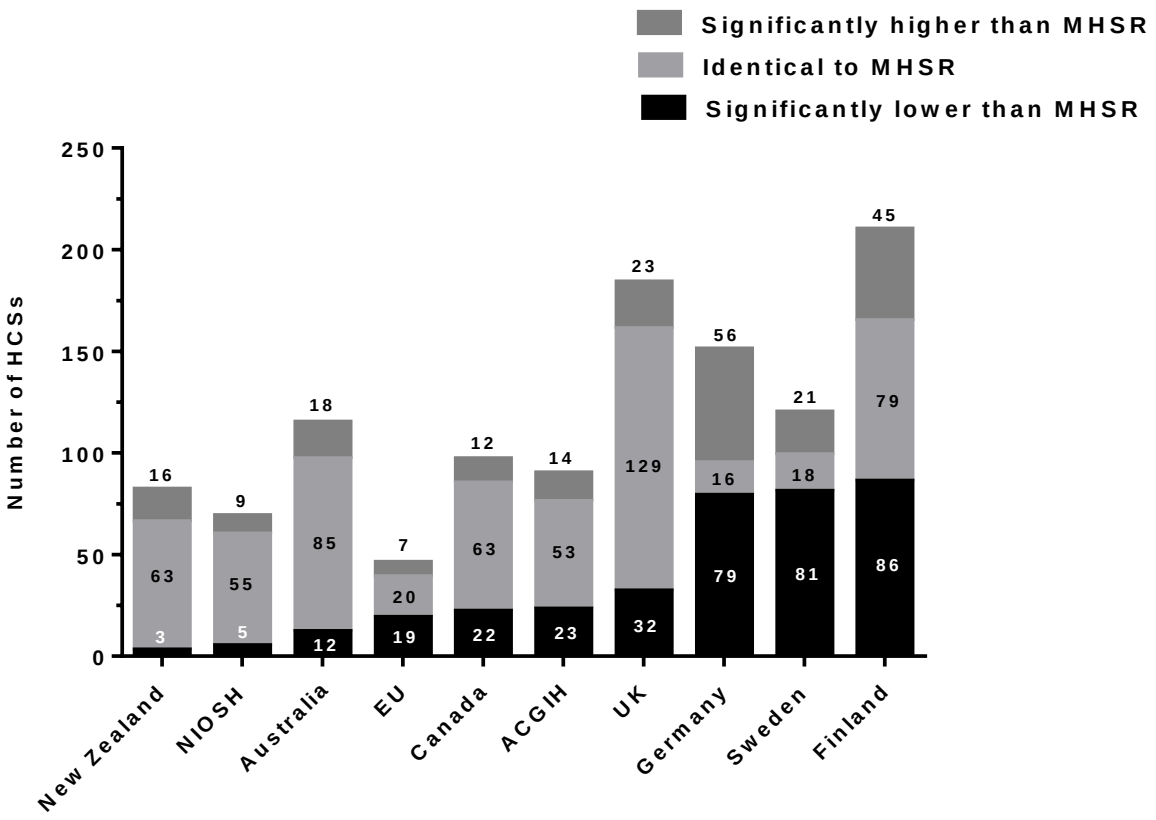

Figure 4: Comparison of STEL numeric values by interval method between the MHSR and ten developed countries/organisations, with the MHSR as the reference country. Figure bars arranged according to ascending significantly lower than RHCS numbers.

Figure 4 depicts the comparison of the individual STEL numeric values in reference to the MHSR. Following the RHCS (see Figure 3) the second country/organisation that had the highest percentage of identical HCS STELs to those of the MHSR was the NIOSH with 80%. In contrast, the country/organisation with the lowest number of identical STEL values was Germany; with 11% identical HCSs. Germany and Sweden are the two countries/organisations which had the highest number of STEL values which were significantly lower than that of the MHSR, with 49% and 65% HCSs respectively. Therefore, Sweden had the lowest overall STEL levels compared to those of the MHSR.

4. Discussion

In this study, the STELs as contained in the RHCS were compared with those listed in the MHSR with the aim to correlate the relationship between the two, considering they are both governing South Africa's OHS. The two South African STEL lists were then individually compared with the ten selected leading developed countries/organisations, with each one of the South African STEL list serving as a base of comparison.

Generally, there is a discrepancy between the countries/organisations regarding coverage of the listed HCSs, as is depicted in Figure 1 and 2. This is shown by the 7 out of 10 countries/organisations that have a <50% overlap with the HCSs of both the RHCS and MHSR. Finland, the UK and Germany (only MHSR) are the three countries/organisations that had the highest number of HCS that overlapped with the 328 HCSs of the RHCS and MHSR. The UK is known to be the source of OEL adoption for the RHCS (PHSC, 2009) which corresponds with the results of the UK having one of the highest number of HCSs that overlaps with the RHCS STELs. While Finland and Germany had one of the highest overlap with the RHCS/MHSR, they also had the highest number of HCSs that were unique to their countries/organisations. This was also true Sweden, which in contrast had a <50% overlap with the RHCS/MHSR. After comparing the two South African Regulations, it was also found that the RHCS and the MHSR have the highest overlap of HCSs with each other. This was anticipated as they are meant to restate a common law of OHS regardless of whether the workers are miners or form part of the general work population. However, it should be noted that the MHSR did have a higher number of HCSs uniquely regulated by it, possibly explained by the difference is regulating agencies i.e. the DoL and the DMR and the slight differences in industry structure which led to the slight differences in HCS prioritisation (Ding *et al*., 2011).

Even with such revealed similarities of coverage, the discrepancies still outweigh the similarities, with results in Figure 1 and 2 showing general disparities in STEL coverage by <5 of the countries/organisations. This significant disparity in STEL coverage between South Africa and the developed countries/organisations and amongst the countries/organisations in general, could possibly be explained by the wide varying number of HCSs that are regulated by each country/organisation. The

entries range from 63 HCSs for the EU to 476 HCSs for Finland. These differences in the number and selection of HCSs could possibly be explained by the varying availability of resources needed for use of evaluating the occurrence of HCSs per country/organisation. The resources may not be as readily available from one country to another, usually depending on its state of development (developed vs. developing countries). However, these discrepancies may also be an indication of a country's/organisations own initiative in HCS selection and identification based on their own risk assessments and managements (Ding *et al*., 2011).

Setting the appropriate level of a STEL is a complex process that tends to vary between countries/organisations. These varying processes, therefore, lead to varying STEL levels between countries/organisations. Amongst these varying processes are, varying toxicological evaluation assessments, prioritisations and variation in the consideration of socio-economic and, technical and health factors (Ding *et al*., 2011; Ding, 2013). Furthermore, apart from varying derivation processes, another proposed explanation that may contribute significantly to the level of STELs, is the time lag between updates (Ding *et al*., 2011).

Comparisons of the overall STEL levels were made by means of the GMs method and the interval method. Having compared the RHCS and the MHSR by use of GMs ratios, it was confirmed that the overall level of STELs in the RHCS was higher than that listed in the MHSR. This is expected since the MHSR STEL values were last updated in the year 2006, while those in the RHCS remain unchanged since 1995 (with the exception of crystalline silica). When the RHCS STEL levels were compared with that of the ten developed countries/organisations, all of the countries/organisations had GMs ratios of less than one, with the exception of New Zealand. This one exception of less stringent STELs than that of the RHCS could be explained by how most of the revisions of New Zealand's publications are usually of the contents of the publication rather than that of the actual OEL values, including the STEL values (MBIE, 2013). Generally though, >5 of the countries/organisations had STEL levels that were lower than that of the RHCS; more stringent and protective STELs. This was predictable because when compared to most developed countries, South Africa as a developing country is considered to exhibit a poor OHS system, including the out-dated STELs (Nyuwayhid, 2004; Puplampu and Quartey,

2012). This trend of discrepancies in STEL levels between South Africa and the developed countries/organisation was also anticipated based on Viljoen's (2012) findings and conclusions on TWA levels. In contrast, Sweden had the lowest STEL GMs (0.664), suggesting that it had the most stringent overall STEL level. This ranking agrees with a prior study by Viljoen (2012) which also had Sweden ranking the lowest in GMs (0.487). Therefore, Swedish OELs may in this sense be considered one of the most sufficiently effective and scientifically up-to-date pragmatic OELs (Schenk *et al*, 2008*a*; Ding *et al*., 2011). This consideration being based on the rationale that lower OELs are generally more protective of human health (Schenk *et al*., 2008*a*).

The comparison of overall STEL levels with the MHSR also proved general disparities. Most aspects were similar to those found during comparison with the RHCS, including ranking orders of countries/organisations (with slight variations), and the range of GMs ratios. However, one aspect worth noting was the difference in GMs ranking of the Australian STELs, from a GMs ratio of <1 for comparison with the RHCS to a GMs ratio of >1 for comparison with the MHSR. This difference was anticipated due to the time lag of updating of the STEL levels between the RHCS and the MHSR; with the MHSR STEL levels being more stringent than those of the RHCS.

Having compared overall STEL levels by use of the interval method, the similarities and disparities in STEL levels between South Africa and the ten developed countries/organisations were further clarified. The interval method results corresponded with the results of the GMs method, which depicted how New Zealand had not only one of the highest number of identical STEL levels with the RHCS, but also how it had a higher number of significantly higher STEL levels compared to the rest of the other developed countries/organisations. This then proves that >5 countries/organisations had overall STEL levels that were lower than that of the RHCS STELs. This interval method for the MHSR also corresponded with the GMs method with New Zealand and Australia having a higher number of significantly higher STEL levels compared to the rest of the other developed countries. However, with the MHSR the NIOSH proved to rather have an overall level of STELs that were higher than that of the MHSR, which does not correspond with the GMs method.

Therefore, with the interval method seven countries/organisations had significantly lower overall STEL levels (i.e. a higher number of HCSs with levels <95% interval), which still concluded that there are disparities in overall STEL levels between South Africa and the developed countries/organisations.

5. Conclusion

The results of this study confirm that there is significant disparity of STEL coverage between the RHCS and the ten selected developed countries/organisations, where ≥5 countries/organisations had an overlap of <50% of HCSs with the RHCS. This is also true for comparison with the MHSR, where seven countries/organisations had a <50% overlap with the HCSs of the MHSR. There are also significant disparities in the STEL level based on the GMs methods, where nine and eight countries/organisations had lower STEL levels when compared to the RHCS and MHSR respectively. The interval method proved the same results of STEL overall level as those achieved by the GMs method which confirmed that there were disparities between South African STEL levels and those of developed countries/organisations, with the overall STEL levels of >5 developed countries/organisations being lower. The aforementioned concludes that there are disparities (differences) in both coverage and level of STELs between South Africa and the selected developed countries/organisations. This conclusion corresponds with that made by Viljoen (2012) based on her study of comparison of time-weighted averages (TWAs) coverage and level. This thereby corroborates the conclusion that South African STELs are inadequate to regulate acute exposure from HCSs and thereby minimising the potential risks of adverse health effects manifesting following short-term acute exposure to HCSs in the workplace.

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7. Supplementary material

HCSs duplicate removal

Listed below is the list of all the removed synonyms of the HCSs that were removed from the RHCS in order to avoid adding duplicates of chemical values in the study data.

List of alphabetic synonyms that occurred in the South African Regulations for Hazard Chemical Substances (RHCS).

Substance in RHCS	CAS no.	Removed synonym
1,1,1-Trichloroethane (CL)	71-55-6	Methyl chloroform
1,1-Dichloroethane	75-34-3	Ethylidene dichloride
1,2-Dichloroethane	107-06-2	Ethylene dichloride
1,2-Dihydroxyethane vapour	107-21-1	Ethylene glycol vapour
1-Chloro-2,3-epoxypropane	106-89-8	Epichlorohydrin
1-Methoxy propan-2-ol	107-98-2	Propylene glycol monomethyl ether
2,3-Epoxypropyl isopropyl ether	4016-14-2	Isopropyl glycidyl ether
2,4 DES	136-78-7	Sodium 2,4-dichlorophenoxyethyl sulphate
2,4,5-T (ISO)	93-76-5	2,4,5-Trichlorophenoxyacetic acid
2,4-D	94-75-7	2,4-Dichlorophenoxyacetic acid
2-Aminoethanol	141-43-5	Ethanolamine
2-Aminopyridine	504-29-0	2-Pyridylamine
2-Chloroethanol	107-07-3	Ethylene chlorohydrin
2-Cl-6-trichloromethyl pyridine total dust	1929-82-4	Nitrapyrin total dust
3-Chloropropene	107-05-1	Allyl chloride
4,4'-Diaminodiphenylmethane (DADPM)	101-77-9	4,4'-Methylenedianiline, MDA
5-Methyl hexan-2-one	110-12-3	Methyl isoamyl ketone

Allyl glycidyl ether (AGE)	106-92-3	1-Allyl-2,3-epoxypropyl ether
alpha Methyl styrene	98-83-9	2-Phenylpropene
Aminodimethyl-benzene	1300-73-8	Xylidine
Azinphos-methyl (ISO)	86-50-0	Guthion
Bis-(2-ethylhexyl) phthalate	117-81-7	Di-(2-ethylhexl) phthalate
Bornan-2-one	76-22-2	Camphor, synthetic
Bromochloromethane	74-97-5	Chlorobromomethane
Bromoethane	74-96-4	Ethyl bromide
Bromoform	75-25-2	Tribromomethane
Bromomethane	74-83-9	Methyl bromide
Bromotriflouromethane	75-63-8	Trifluorobromomethane
Butan-1-ol	71-36-3	n-Butyl alcohol
Butan-2-ol	78-92-2	sec-Butyl alcohol
Butan-2-one	78-93-3	Methyl ethyl ketone
Caprolactam dust Caprolactam vapour	105-60-2	1,6-Hexanolactam
Carbon tetrabromide	558-13-4	Tetrabromomethane
Chloroethane	75-00-3	Ethyl chloride
Chloroform	67-66-3	Trichloromethane
Chloromethane	74-87-3	Methyl chloride
Chloropicrin	76-06-2	Trichloronitromethane
Cryofluorane (INN)	76-14-2	1,2-Dichlorotetrafluoroethane
Cumene	98-82-8	Isopropyl benzene
Cyclonite (RDX)	121-82-4	Hexahydro-1,3,5-trinitro-1,3,5-triazine
Cyhexatin (ISO)	13121-70-5	Tricyclohexyl tin hydroxide
DDT (Dichlorodiphenyltrichloroethane	50-29-3	1,1,1-Trichlorobis (chlorophenyl) ethane

DDVP	62-73-7	Dichlorvos
Derris, commercial	83-79-4	Rotenone
Diacetone alcohol	123-42-2	4-Hydroxy-4-methyl-2-pentanone
Dichloromethane	75-09-2	Methylene chloride
Dibrom 1,2-Dibromo-2,2-dichloroethyldimethyl Phosphate	300-76-5	Naled
Dibutyl Hydrogen Phosphate	107-66-4	Di-n-butyl phosphate
Dicyclopentadienyl iron	102-54-5	Ferrocene
Diethyl ether	60-29-7	Ethyl ether
Diethyl ketone	96-22-0	Pentan-3-one
Diisopropyl ether	108-20-3	Isopropyl ether
Dimethoxymethane	109-87-5	Methylal
Dinitro-o-cresol	534-52-1	2-Methyl-4,6-dinitrophenol
Diphosphorus pentasulphide	1314-80-3	Phosphorus pentasulphide
Disulphur decafluoride	5714-22-7	Sulphur pentachloride
Disulphur dichloride	10025-67-9	Sulphur monochloride
Ethanethiol	75-08-1	Ethyl mercaptan
Ethyl butyl ketone	106-35-4	Heptan-3-one
Ethyl silicate	78-10-4	Tetraethyl orthosilicate
Ethylene dinitrate	628-96-6	Ethylene glycol dinitrate
Flourotrichloromethane	75-69-4	Trichlorofluoromethane
Glycerol trinitrate	55-63-0	Nitroglycerine
Hexone	108-10-1	Methyl isobutyl ketone
Hexylene glycol	107-41-5	2-Methylpentane-2,4-diol
Iodomethane	74-88-4	Methyl iodide
Isoamyl acetate	123-92-2	Isopentyl acetate
Isoamyl alcohol	123-51-3	3-Methylbutan-1-ol
Isobutyl alcohol	78-83-1	2-Methylpropan-1-ol

Isophorone	78-59-1	3,5,5-Trimethylcyclohex-2-enone
Isopropyl alcohol	67-63-0	Propan-2-ol
Manganese cyclopentadienyl tricarbonyl	12079-65-1	Tricarbonyl (eta-cyclopentadienyl) manganese (as Mn)
m-Dihydroxybenzene	108-46-3	Resorcinol
Mesityl oxide	141-79-7	4-Methylpent-3-and-2-one
Methanol	67-56-1	Methylal alcohol
Methyl isobutyl carbinol	108-11-2	4-Methylpentan-2-ol
Methyl parathion	298-00-0	Parathion-methyl (ISO)
Methyl propyl ketone	107-87-9	2-Pentanone
Methyl silicate	681-84-5	Tetramethyl orthosilicate
Methyl styrene (all isomers)	25013-15-4	Vinyl toulenes, all isomers
Mevinphos (ISO)	7786-34-7	Phosdrin
n-Amyl Acetate	628-63-7	Pentyl acetate
Nickel carbonyl	13463-39-3	Tetracarbonylnickel (as Ni)
Nitric oxide	10102-43-9	Nitrogen monoxide
n-Methyl-n,2,4,6-tetranitro aniline	479-45-8	Tetryl
n-Propanol	71-23-8	Propan-1-ol
p-Benzoquinone	106-51-4	Quinone
p-Dihydroxybenzene	123-31-9	Hydroquinone
Perchloroethylene	127-18-4	Tetrachloroethylene
Phenylethylene	100-42-5	Styrene, monomer, Vinyl benzene (CL)
Picric acid	88-89-1	2,4,6-Trinitrophenol
Propargyl alcohol	107-19-7	Prop-2-yn-1-o
Propylene dinitrate	6423-43-4	Propylene glycol dinitrate
sec-Amyl Acetate	626-38-0	1-Methylbutyl acetate
Silane	7803-62-5	Silicon tetrahydride

tert-Butyl Alcohol	75-65-0	2-Methylpropan-2-ol
trans But-2-enal	4170-30-3	Crotonaldehyde
Tri-o-Cresyl phosphate	78-30-8	Tri-o-tolyl phosphate
y-BHC (ISO)	58-89-9	Lindane

CAS non-designated HCSs

To avoid a significant decrease in data sample, HCSs that did not have CAS number designated to them were also considered in this study. Below are their numbers.

Total number of short-term exposure limits (STELs) in each individual list and the corresponding number of chemicals without assigned CAS numbers.

Country/Organisation	Total no. of STELs	No of chemicals without CAS
MHSR	301	6
NIOSH	80	none
ACGIH	141	none
UK	231	4
Sweden	288	5
Germany	377	15
EU	63	none
Australia	152	2
Finland	476	9
Canada	148	1
New Zealand	105	none

HCS removal

The following chemicals were removed due to their Units being impossible to covert, all owing to their lack of, or varying molecular weight which was needed to convert the units from ppm to mg/m^3 or *vice versa*.

The list of removed STELs not part of the study database.

STELs REMOVED
Canada
Gasoline (86290-81-5)
Liquified petroleum gas (68476-85-7)
NIOSH
Chloroform (67-66-3)
ACGIH
Gasoline (86290-81-5)
OSHA
#Butadiene (106-99-0)

() CAS number; # OSHA had only one STEL value listed in their Toxic and Hazardous Substance list which was not considered for this study.

Comparison of South African ceiling exposure limits with those of developed countries

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Abstract

Introduction: Occupational exposure limits (OELs) are established with the purpose of regulating hazardous chemical substances (HCS) while simultaneously minimising adverse effects resulting from such HCSs found in the workplace. Ceiling limits (CLs) are intended to protect against very short periods of very high exposures resulting in acute effects. In South Africa, while two national government departments govern occupational health and safety (OHS), only one department, applicable to the mining industry – the Mine Health and Safety Regulation (MHSR), publishes CLs. There are no known updates on the CL values since 1996, thus deeming the CLs in the MHSR as out-dated by more than a decade. However, the effectiveness of any category of OEL in controlling risk is largely dependent on scientifically up-to-date OELs. Therefore, the aim of this study was to determine the extent of effectiveness of South African CLs which was achieved by comparing them with those of nine leading developed countries/organisations based on coverage and level. The study was performed by reviewing and comparing the latest published lists of CL of the nine developed countries/organisations with those listed in the South African MHSR.

Method: Coverage comparison was achieved by categorising the HCSs as either, unique to the Mine Health and Safety Regulation (MHSR), overlapping or unique to the other country/organisation. The overall CL level comparison was achieved by use of the geometric means (GMs) method and interval method. Both these methods proved the extent of level difference between the South African CLs with those of the developed countries/organisations. The nine countries/organisations included were, Australia, Canada (British Columbia), Finland, Japan, New Zealand, Sweden, and United States of America (NIOSH, OSHA and ACGIH).

Results and Discussion: There are significant similarities in CL coverage between the MHSR and the nine selected developed countries/organisations. Five of the developed countries/organisations had a >50% overlap in HCSs with those of the MHSR. While conclusions on the overall CL levels were contradictory between the GMs and interval methods, a conclusion was made based on judgement from the thorough observation of the raw data and based on literature on the lack of change of most acute OELs over time, that there were significant similarities in CL levels between the MHSR and the developed countries/organisations.

Conclusion: There are significant similarities in both coverage and level of CLs between South Africa and the selected developed countries/organisation. This thereby concludes that South African CLs are adequate enough to regulate acute exposure from HCSs and thereby minimising the potential risks of adverse health effects manifesting following acute exposure to HCSs in the workplace.

Key words: Occupational exposure limits (OELs), comparison, South Africa, developed countries/organisations, hazardous chemical substances (HCSs), CL coverage, geometric means (GMs) method, interval method

1. Introduction

Dating as far back as the 15th century, airborne dusts and chemicals were known to bring about disease and injury, this including both acute and chronic illness (Paustenbach *et al*., 2011). While a time-weighted average (TWA) alone is considered sufficient enough for most hazardous chemical substances (HCSs), their control does not account for the protection of acute effects arising from exposure over shorter periods of time. Rather, the two occupational exposure limits (OELs) that accounted for such acute exposures are STELs and ceiling limits (CLs) (Schenk, 2011). STELs usually restrict exposure over an allowable 15 minutes period, while CLs are intended to protect against acute effects concerning even shorter periods than that of the STELs (Schenk, 2011). Unlike the TWA and STEL, the CL do not permit excursions above the set limit suggesting that their limit is never exceeded during any time of a working day (Howard, 2005; ACGIH, 2015) and, therefore, are set to avoid the occurrences of adverse health stemming from acute exposure. The publication of the first list of acute OELs (i.e. including CLs) dates back to 1912. This publication included a list of acute exposure limits for 20 HCSs corresponding to four categories of limits, namely rapidly fatal, dangerous in 30 minutes to one hour, 30 minutes to one hour without disturbances and only minimal symptoms observed (Paustenbach, 2000).

Another OEL amongst others which are also intended for shorter durations of exposure to HCSs are the immediately dangerous to life and health (IDLH) values. These IDLHs are defined by the National Institute for Occupational Safety and Health (NIOSH) as one that poses a threat of exposure to airborne contaminants when that exposure is likely to cause death or immediate or delayed permanent adverse health effects or prevent escape from such an environment (EHS, 2012; NIOSH, 2014). However, further investigation of IDLH as an exposure limit is beyond the scope of this study.

South Africa as a developing country has two national government departments governing occupational health and safety (OHS) and publishing OELs. However only one of the departments publishes CLs. Specifically these CLs are published by the Department of Mineral Resources (DMR), in the Mine Health and Safety Act (No. 29 of 1996), listed in the Mine Health and Safety Regulation (MHSR). The DMR only

publishes OELs that are applicable to the mining industry. While the source of influence on the coverage and level of the CLs listed in the MHSR is unknown, the CLs were published in the year 1996. The first amendment of the MHS Act was done in the years 2002 and 2006; however no known amendments were made on the listed CL values themselves (DMR, 1996; South Africa, 2002). This, therefore, deems MHSR CLs as out-dated by a decade. This vast time lag in the updating and subsequent use of such out-dated CLs then compromises the usefulness of the CLs as risk management tools. Scientifically up-to-date CLs are, therefore, necessary in order to dictate the effectiveness of assessing and controlling very short-term exposure to HCSs (Howard, 2005). While a trend in the gradual decrease of OEL level is usually observed with most TWAs over time, Schrenk (1947) noticed that most acute OELs, as listed by Kobert in 1912, are still accepted by most countries/organisations today, with exception to some HCSs which are more toxic in nature which have considerably decreased in level (Cook, 1987).

While a blind eye has been turned to acute HCS poisoning, which is normally considered as a non-occupational circumstance (Heihachiro, 2002), attempts can still be made to increase awareness to it and also control its occurrence. It is without a doubt that CLs in South Africa do not receive an appreciable amount of attention, shown by absence of their use in the Regulation of Hazardous Chemical Substances (RHCS), authorised by the Department of Labour (DoL). This RHCS governs the OHS of the general work population, which accounts for a significant percentage of the South African work population. This suggests that an appreciable number of workers are not at all protected from potential acute exposure resulting from irritating gases which are normally assigned CLs.

Both workers in the mining sector and those in the general work population are entitled to the same human dignity and decent working environment, therefore, attempts have to be made to overcome such shortfall of the acute exposure awareness. However, before any attempts can be made to try and improve the OHS system in South Africa and create awareness for such acute exposure, it is deemed necessary that South Africa’s CLs be compared with that of leading developed countries/organisations. This comparison will allow for the analysis of disparities or similarities in HCS coverage and level for CL just as it was done for the STEL

values. Once the extent of disparities, if any, have been uncovered, then attempts can be made to update the MHSR and also publish it under the RHCS.

Therefore, the aim of this study entails the comparison of South African CLs with that of selected developed countries/organisations based on the variables of coverage (frequency and selection) of individual HCSs and level (concentration) of CLs set for different HCSs.

2. Methods

2.1 Database of CLs

The MHSR OELs are listed in the Mine Health and Safety Regulation (MHSR) 22.9, under the authority of the Mine Health and Safety Act (No. 29 of 1996). The MHSR has TWA, STEL and CL values assigned to their HCSs; however, only the CL values were used in this study. The CL values are in some cases (as with the MHSR) placed under the STEL column, however, with a notation C preceding the value to notify that it is a CL. In such cases the value (i.e. the one with a C notation preceding the value) was considered a CL value only and not as a STEL value or both a CL and STEL value. This was also the case for values assigned under the STEL column, but with a side noted comment that stipulated that it was a CL value.

While there are duplicates of HCSs in the MHSR list, none of the duplicates were assigned CL values, therefore, no duplicates had to be removed before commence of the study as was the case with the STEL comparison study. Another issue that was experienced during the study was the use or non-use of a CAS (Chemical Abstracts Service) number. A CAS number is a unique numeral combination that identifies a HCS (Ding *et al*., 2011). While its system is convenient in the minimising of confusion during HCS naming, not all HCSs are assigned an individual CAS number; therefore, the CL database used for this study also included individual HCSs that were not specified with CAS numbers (Supplementary data). The reason behind the inclusion is to represent fully the exact amount of HCSs with CL values within all the countries/organisations.

For the developed countries' lists, there was collection of the most recent published lists of OELs, collected by published form, via websites or through personal communication with the relevant regulatory agencies or representatives of regulatory

agencies. The selection and number of developed countries included in this study was based on the availability of data and dominance in literature. Some countries only publish their documents, including OEL lists, in their native languages (language other than English), thus language was taken into consideration during this selection process. Ten countries/organisations were considered for this study.

Spread sheets were used to complete the CL values of all the different countries/organisations systematically. The final database of the CL values contained ten sets of CL lists. The HCSs were listed based on nomenclature and units. Conversion of the units for some HCSs could not be achieved, therefore, the HCS were also excluded from the database, but noted (Supplementary material). For HCSs that had isomers or fractions (respirable and inhalable) that were also designated CL values, all the values were added to the lists. Most countries/organisations do not take into consideration nor assign IDLH values to HCSs. However, as stated earlier IDLH values, which are also intended for shorter durations of exposure to HCSs, may be just a useful tool in the field of occupational hygiene. While their values as listed by the NIOSH were not included in the study database, they will be discussed for further insight (Supplementary material).

2.2 Coverage of substances

The comparison of the CLs was done between the MHSR and that of the other nine countries. For the comparison between the South African lists with that of a developed country, analysis was made to determine the number of overlapping HCSs (i.e. substances that appeared on both lists). All the other HCSs that appeared in only one of the lists to be compared were not included during the analysis and were, therefore, considered as unique HCS for that particular county. This shed light on the HCSs that are a common hazard and prevalent in most countries while also highlighting those HCSs that are solely regulated by certain countries.

2.3 Level of CLs

A comparison between the overall levels of CLs from different countries/organisations was made by making use of the geometric means (GMs) method. In addition to making use of the GMs method, another method was utilised for further comparison between the level differences, taking into consideration values

in close proximity to one another which were considered as “different” during GMs analysis. The method was recently implemented by Tynkkynen *et al*. (2015) for establishing the differences in EU and Finnish OEL levels. The method involved using a 95-105% interval to determine disparity and similarity between levels of TWAs and STELs of HCSs. This method was further referred to as the Interval Method.

2.3.1 Geometric means method

For each HCS, the measure between its values on the two lists was considered as the best indicator of their difference. These differences in CL values on the two lists were compared statistically by use of the GMs method as used by Hansson (1997), Schenk *et al*. (2008*a*), Ding *et al*. (2011) and Viljoen (2012). Further explanation on the importance and illustration of the method is explained by Hansson (1997), Schenk *et al*. (2008*a*), Ding *et al*. (2011) and Viljoen (2012).

For comparison between two lists, comparison was made only between HCSs that appear on both lists. These overlapping HCSs, for the CL values, yielded a complete and comprehensive database that was used for comparison. This way, the absence of the unique HCS (i.e. HCS that only appear on one of the lists and not both), did not influence the average level of similarity or disparity of the overlapping HCS concentrations. The GMs method was used to compare the overall levels of CLs from the different countries relative to the MHSR.

2.3.2 Interval method

This method involved the use of a 95-105% interval to determine disparities and similarities between levels of substances. Further explanation and examples of the methods’ use can be obtained from a study by Tynkkynen *et al*. (2015).

3. Results

3.1 CL coverage

The results of CL coverage comparison between the South African MHSR with that of the nine selected developed countries/organisations are shown in Figure 1. The coverage was categorised as overlapping or unique, with unique being either unique to the MHSR or unique to the developed country/organisation. The highest overlapping of HCS coverage was with the ACGIH with 19 HCSs (33.9%). The two

countries/organisations that had the lowest overlap are Finland and OSHA with 3 and 5 HCSs overlaps, respectively. While Canada's list had one of the highest overlaps with the MHSR, it also had the highest number of unique HCSs (46 HCSs).

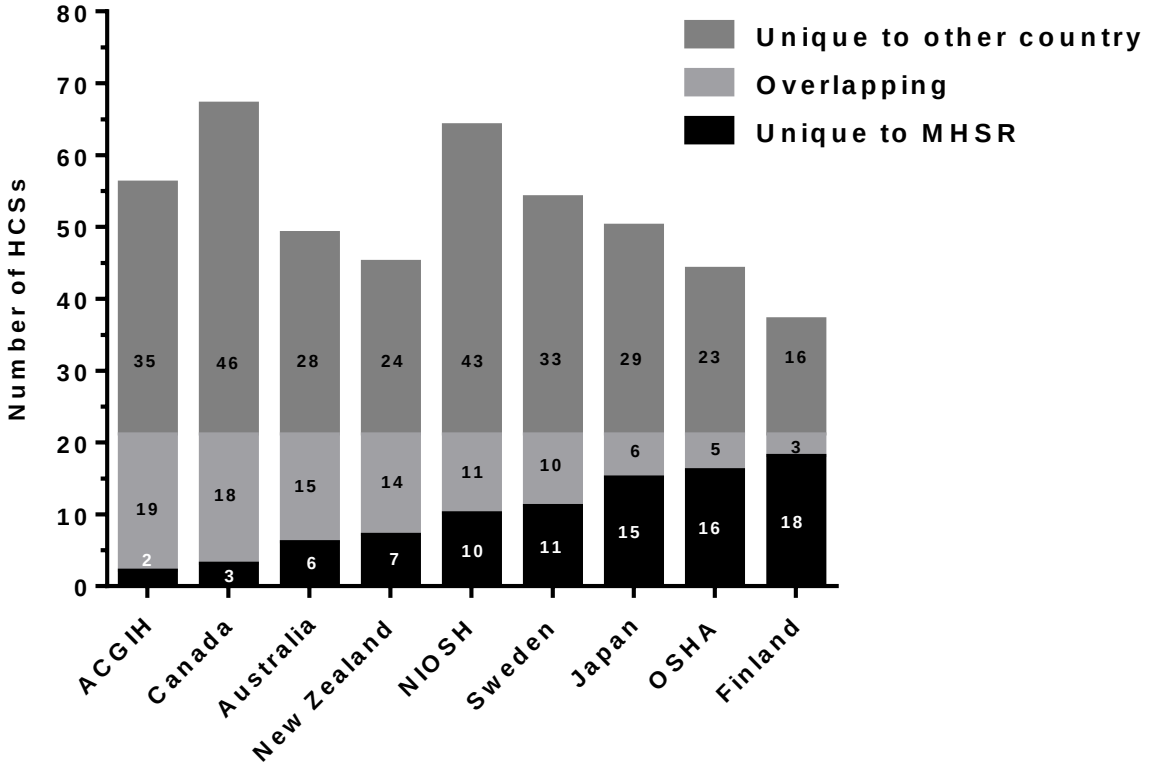

Figure 1: Disparities and similarities of the HCSs CL coverage between the MHSR and nine developed selected countries/organisations. The overlapping numbers of HCSs are depicted in descending order from left to right.

3.2 CL levels

3.2.1 Geometric means method

The comparison of overall CL level by geometric means (GMs) method was done between South Africa and the developed countries/organisations. The GMs ratios have been listed in Table 2 with the MHSR as the reference country.

Table 1: Geometric means of ratios based on overlapping HCSs between the MHSR and the various developed countries/organisations. The geometric means depicted in ascending order from top to bottom.

Country/Organisation	GM	N
ACGIH	0.836	19
Japan	0.837	6
Sweden	0.909	10
Canada	0.949	18
NIOSH	0.999	11
OSHA	1.000	5
Australia	1.031	15
Finland	1.063	3
New Zealand	1.137	14

GM refers to geometric means, n = number of overlapping HCSs.

The countries/organisations overall level of CLs ranged between 0.836 and 1.137. Five countries/organisations had GMs ratios that were <1, with the ACGIH having the lowest overall level of CLs. The OSHA was the country/organisation that had GMs ratio of one, thus deeming their overall CL levels as equivalent to that of the MHSR. Three countries/organisations had overall CL levels which were higher than that of the MHSR CLs, namely Australia (GM = 1.031), Finland (GM = 1.063) and New Zealand (GM = 1.137).

3.2.2 Interval method

This method compared the individual levels of CL numeric values between the MHSR and the nine developed countries/organisations. Figure 2 shows that 100% of CLs of the OSHA were identical to those of the MHSR. The two countries that had the lowest number of HCSs that were identical to the MHSR are Sweden (40%) and New Zealand (50%). The ACGIH, Sweden and Canada had the highest percentage of CL values which were significantly lower than that of the MHSR, with 33%, 30% and 17% of HCSs respectively. Therefore, ACGIH had the lowest overall CL levels compared to those of the MHSR.

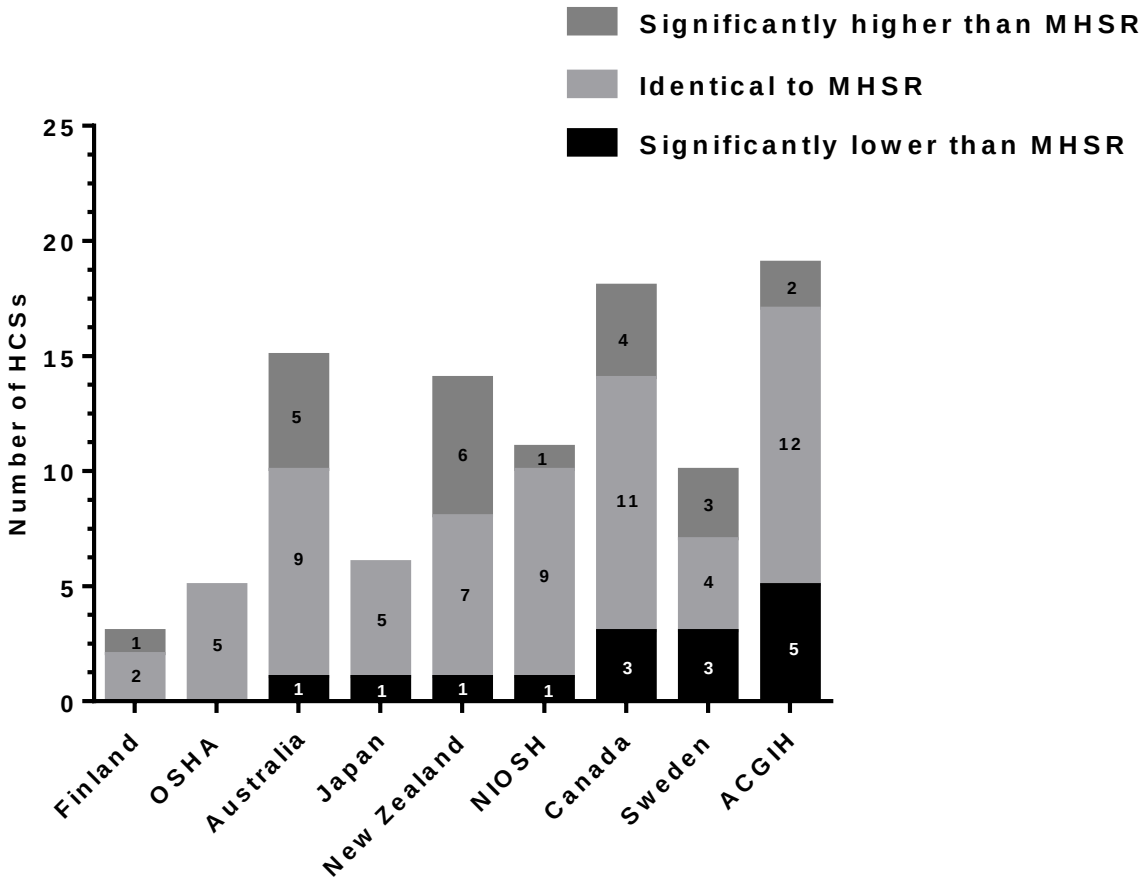

Figure 2: Comparison of CL numeric values by interval method between the MHSR and nine developed countries/organisations, with the MHSR as the reference country/organisation. Figure bars arranged according to ascending lower than MHSR numbers.

4. Discussion

In this study, the CL values as listed in the MHSR were compared with those listed by various leading developed countries/organisations with the aim to determine similarities and/or disparities of CLs between South Africa as a developing country and the nine selected developed countries/organisations.

Generally, there is no significant disparity in CL coverage between the MHSR and the developed countries/organisations. As depicted in Figure 1, there are similarities where ≥5 of the developed countries/organisations had a >50% of HCSs that overlap with those listed in the MHSR. Only four countries/organisations had a <50% of HCSs that overlapped with the MHSR HCSs. The ACGIH was the

country/organisation that had the highest number of overlapping with 19 HCSs. This substantiates the published literature stating that the ACGIH continues to be most influential worldwide even today (Schenk, 2011). This major influence by the ACGIH may as well serve as reason as to why there are significant similarities in CL coverage. In addition it was also noticed by Schrenk (1947) that most of the acute OELs as listed by Kobert in 1912 are still accepted and used by many countries/organisations (Schenk, 2011). This then explains why there were similarities in CL coverage as opposed to the significant disparities noticed for TWA coverage (Viljoen, 2012) and STEL coverage. Another reason for such similarities in CL coverage can be possibly explained by the low number of HCSs regulated by each country/organisation, where countries/organisations are likely to select and prioritise similar or identical HCSs to be assigned CL. The HCS entries by the countries/organisations range from 15 to 64, which is considerably narrow compared to the entries of the TWAs (Viljoen, 2012) and STEL.

Having compared the overall CL levels by use of both the GMs method and interval method, there seemed to be discrepancies in the conclusion of the overall level of CL between the countries/organisations. By use of the GMs method, there seemed to be significant disparities of CL level between the countries/organisations. This resulted from the 5 out of 9 countries/organisations that had GMs ratios that were < 1, thus suggesting that ≥5 countries/organisations had CL levels that were lower than those of the MHSR. In contrast, results attained by the interval method concluded that there were significant similarities in CL level between the countries/organisations. This can be noticed from the only 2 out of 9 countries/organisations that had CL levels that were lower than that of the MHSR. These differences in conclusions on the overall level of CLs can be explained by the difference in the approaches of the GMs method and interval methods. The GMs method takes into account every difference in the numeric values and thus considers two similar numbers as different (e.g. 4.9 and 5.0 are considered different with the GMs method). In contrast the interval method erases slight differences in the numerical value (e.g. 4.9 and 5.0 are considered as identical with the interval method). While the two methods had results that corresponded when comparison was done for STELs, the lack of correspondence with the CL comparison could have possibly been influenced by the low sample size of the CL database. Nevertheless,

with judgement having been made based by observing the raw data and from taking into account literature stated by Paustenbach *et al*. (2011) which suggested that there seems to be lack of change for most acute OELs, it can be concluded that there are significant similarities in the CL level. This conclusion was also made from the motivation that there was a significantly higher number (i.e. >50% of HCSs that overlap with those listed in the MHSR) of CL levels that were identical to those of the MHSR than for all the nine developed countries/organisations.

While conclusions on the overall CL levels were contradictory between the GMs and interval method, agreeing conclusions were made on the countries/organisations that had the highest and lowest overall CL levels via both the GMs and interval method. By analysis with the GMs method and interval method, results in Table 1 and Figure 2, both depict New Zealand to have the highest overall CL levels. This can be validated by the lack of changes to the OEL values in the New Zealand publication, but with rather a higher focus on the changing of the contents of the publication. The country/organisation with the most stringent CL levels was the ACGIH; attributed by the fact that they are said to be based purely on a health-based approach; an approach which promotes lower exposure limits which correlate with higher protection of human health (Schenk *et al*., 2008*a*).

It can then be concluded that there were significant similarities for both CL coverage and level where >5 of the developed countries/organisations had a >50% of HCSs that overlapped with the HCSs of the MHSR and where the CL levels were generally similar to those of the MHSR. This thereby supports the literature as stated by Paustenbach (2011) which mentioned the trend of lack of change of most acute exposure limit values as listed originally by Kobert in 1912.

5. Conclusion

The results of this study confirm that there was no significant disparity, but rather significant similarity of CL coverage between the MHSR and the nine selected developed countries/organisations, where five of the countries/organisations had a >50% of overlapping HCSs with the MHSR. While conclusions on the overall CL level were contradictory between the GMs and interval method, it was concluded based on thorough observation of the raw CL data and reviewed literature (Paustenbach *et al*., 2011), that there were significant similarities in CL level. These

significant similarities in CL level were also corroborated by the >5 countries/organisations that had CL levels that were similar or identical to those of the MHSR. Therefore, it was concluded that South African CLs are adequate enough to regulate acute exposure from HCSs and thereby minimising the potential risks of adverse health effects that manifest following very short-term exposure to HCSs in the workplace. However, addition of more HCS assigned CL values is needed specifically for the more toxic HCSs.

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7. Supplementary material

CAS non-designated HCSs

To avoid a significant decrease in data sample, HCSs that did not have CAS number designated to them were also considered in this study. Below is their numbers.

Total number of ceiling limits in each individual list and the corresponding number of chemicals without assigned CAS numbers.

Country/Organisation	Total no. of CLs	No of chemicals without CAS
MHSR	21	none
NIOSH	54	1
ACGIH	54	none
OSHA	28	2
Sweden	43	none
Germany	15	none
Australia	43	1
Finland	19	none
Canada	64	none
New Zealand	38	none
Japan	35	none

HCS removal

The following chemicals were removed due to their Units being impossible to covert, all owing to their lack of, or varying molecular weight which was needed to convert the units from ppm to mg/m^3 or *vice versa*.

The list of removed CLs not part of the study database.

CLs REMOVED
MHSR
Flammable gas (methane/hydrogen) (-)
Gasoline (8006-61-9)
Hydrogen (1333-74-0)
Methane (74-82-8)
Oxygen (7782-44-7)
NIOSH
Cyanides (as CN) (-)
Diethylene dioxide (12-91-1)
Ethylene oxide (75-21-8)
Sweden
Ammonium (7664-41-7)
Diisocyanates (822-06-0; 4098-71-9; 101-68-8; 3173-72-6; 26471-62-5; 584-84-9; 91-08-7)
Monoisocyanates (28178-42-9; 75-13-8; 624-83-9; 103-71-9)
Enzyme, subtilisins (1395-21-7; 9014-01-1)

() CAS number; # OSHA had only one STEL value listed in their Toxic and Hazardous Substance list which was not considered for this study.

Immediately dangerous to life or health (IDLH) values

The concept of using respirators to protect workers in situations of emergencies was discussed as early as in the 1940s. As a result in 1947, the National Institute for Occupational Safety and Health (NIOSH) and the Occupational Safety and Health Administration (OSHA) jointly initiated the development of such exposure limits. This joint effort was called the Standards Completion programme (SCP). These exposure limits are referred to as immediately dangerous to life or health (IDLH) values.

IDLH values were developed with the purpose of aiding in the determining of a concentration at which a worker can escape an IDLH condition without injury or irreversible health effects in the event of respiratory protective equipment failure. An IDLH condition is defined by the NIOSH as a situation that poses a threat of exposure to airborne contaminants when that exposure is likely to cause death or immediate or delayed permanent adverse health effects or prevent escape from such an environment. Originally, the SCP had developed 387 IDLH values but as time progressed, the NIOSH solely continued to review, document and revise the IDLH values; with their latest IDLH values published in the year 2004 (see Appendix 6.4).

For further information on the SCP, discussion of the original IDLH values, current IDLH values and revision criteria for determining the IDLH value, can be found at the following link:

http://www.cdc.gov/niosh/idlh/idlhintr.html

While it may not be worthwhile for South Africa to adopt all the IDLH limits as assigned for the various HCSs, a few of the limits may be of importance with regards to the structures of the industries operating in South Africa currently. For instance, an IDLH limit may serve a great purpose in commonly experienced oxygen-deficient atmospheres, which have less than 19.5 % oxygen by volume at sea level, which are considered as IDLH environment. Other examples of environments where IDLH situations may occur include entry into unventilated silos, boilers, tanks, sewers, etc., all which are common environments which are experienced in the South African work industry. This concept of IDLH and its limits would serve as an important tool when addressing and risk managing for issues under the confined spaces of the

General Safety Regulations and that of ventilation under Environmental Regulations for Workplaces as stipulated under the OHSA and Regulations (85 of 1993).

Immediately dangerous to life and health (IDLH) original and current values.

Substance	Original IDLH Value	Revised IDLH Value (2004)
Acetaldehyde	10,000 ppm	2,000 ppm
Acetic acid	1,000 ppm	50 ppm
Acetic anhydride	1,000 ppm	200 ppm
Acetone	20,000 ppm	2,500 ppm [LEL]
Acetonitrile	4,000 ppm	500 ppm
Acetylene tetrabromide	10 ppm	8 ppm
Acrolein	5 ppm	2 ppm
Acrylamide	Unknown	60 mg/m^3
Acrylonitrile	500 ppm	85 ppm
Aldrin	100 mg/m^3	25 mg/m^3
Allyl alcohol	150 ppm	20 ppm
Allyl chloride	300 ppm	250 ppm
Allyl glycidyl ether	270 ppm	50 ppm
2 Aminopyridine	5 ppm	5 ppm [Unch]
Ammonia	500 ppm	300 ppm
Ammonium sulfamate	5,000 mg/m^3	1,500 mg/m^3
n-Amyl acetate	4,000 ppm	1,000 ppm
sec-Amyl acetate	9,000 ppm	1,000 ppm
Aniline	100 ppm	100 ppm [Unch]
o-Anisidine	50 mg/m^3	50 mg/m^3 [Unch]
p-Anisidine	50 mg/m^3	50 mg/m^3 [Unch]
Antimony compounds (as Sb)	80 mg Sb/m^3	50 mg Sb/m^3
ANTU	100 mg/m^3	100 mg/m^3 [Unch]

Arsenic (inorganic compounds, as As)	100 mg As/m^3	5 mg As/m^3
Arsine	6 ppm	3 ppm
Azinphosmethyl	20 mg/m^3	10 mg/m^3
Barium (soluble compounds, as Ba)	1,100 mg Ba/m^3	50 mg Ba/m^3
Benzene	3,000 ppm	500 ppm
Benzoyl peroxide	7,000 mg/m^3	1,500 mg/m^3
Benzyl chloride	10 ppm	10 ppm [Unch]
Beryllium compounds (as Be)	10 mg Be/m^3	4 mg Be/m^3
Boron oxide	N.E.	2,000 mg/m^3
Boron trifluoride	100 ppm	25 ppm
Bromine	10 ppm	3 ppm
Bromoform	Unknown	850 ppm
1,3-Butadiene	20,000 ppm [LEL]	2,000 ppm [LEL]
2-Butanone	3,000 ppm	3,000 ppm [Unch]
2-Butoxyethanol	700 ppm	700 ppm [Unch]
n-Butyl acetate	10,000 ppm	1,700 ppm [LEL]
sec-Butyl acetate	10,000 ppm	1,700 ppm [LEL]
tert-Butyl acetate	10,000 ppm	1,500 ppm [LEL]
n-Butyl alcohol	8,000 ppm	1,400 ppm [LEL]
sec-Butyl alcohol	10,000 ppm	2,000 ppm
tert-Butyl alcohol	8,000 ppm	1,600 ppm
n-Butylamine	2,000 ppm	300 ppm
tert-Butyl chromate	30 mg/m^3 (as CrO3)	15 mg Cr(VI)/m^3
n-Butyl glycidyl ether	3,500 ppm	250 ppm
n-Butyl mercaptan	2,500 ppm	500 ppm
p-tert-Butyltoluene	1,000 ppm	100 ppm

Cadmium dust (as Cd)	50 mg Cd/m^3	9 mg Cd/m^3
Cadmium fume (as Cd)	9 mg Cd/m^3	9 mg Cd/m^3[Unc h]
Calcium arsenate (as As)	100 mg As/m^3	5 mg As/m^3
Calcium oxide	Unknown	25 mg/m^3
Camphor (synthetic)	200 mg/m^3	200 mg/m^3 [Unch]
Carbaryl	600 mg/m^3	100 mg/m^3
Carbon black	N.E.	1,750 mg/m^3
Carbon dioxide	50,000 ppm	40,000 ppm
Carbon disulfide	500 ppm	500 ppm [Unch]
Carbon monoxide	1,500 ppm	1,200 ppm
Carbon tetrachloride	300 ppm	200 ppm
Chlordane	500 mg/m^3	100 mg/m^3
Chlorinated camphene	200 mg/m^3	200 mg/m^3 [Unch]
Chlorinated diphenyl oxide	Unknown	5 mg/m^3
Chlorine	30 ppm	10 ppm
Chlorine dioxide	10 ppm	5 ppm
Chlorine trifluoride	20 ppm	20 ppm [Unch]
Chloroacetaldehyde	100 ppm	45 ppm
alpha-Chloroacetophenone	100 mg/m^3	15 mg/m^3
Chlorobenzene	2,400 ppm	1,000 ppm
o-Chlorobenzylidene malononitrile	2 mg/m^3	2 mg/m^3 [Unch]
Chlorobromomethane	5,000 ppm	2,000 ppm
Chlorodiphenyl (42% chlorine)	10 mg/m^3	5 mg/m^3
Chlorodiphenyl (54% chlorine)	5 mg/m^3	5 mg/m^3 [Unch]
Chloroform	1,000 ppm	500 ppm
1-Chloro-1-nitropropane	2,000 ppm	100 ppm
Chloropicrin	4 ppm	2 ppm

beta-Chloroprene	400 ppm	300 ppm
Chromic acid and chromates	30 mg/m^3 (as CrO3)	15 mg Cr(VI)/m^3
Chromium (II) compounds [as Cr(II)]	N.E.	250 mg Cr(II)/m^3
Chromium (III) compounds [as Cr(III)]	N.E.	25 mg Cr(III)/m^3
Chromium metal (as Cr)	N.E.	250 mg Cr/m^3
Coal tar pitch volatiles	700 mg/m^3	80 mg/m^3
Cobalt metal, dust and fume (as Co)	20 mg Co/m^3	20 mg Co/m^3 [Unch]
Copper (dusts and mists, as Cu)	N.E.	100 mg Cu/m^3
Copper fume (as Cu)	N.E.	100 mg Cu/m^3
Cotton dust (raw)	N.E.	100 mg/m^3
Crag (r) herbicide	5,000 mg/m^3	500 mg/m^3
Cresol (o, m, p isomers)	250 ppm	250 ppm [Unch]
Crotonaldehyde	400 ppm	50 ppm
Cumene	8,000 ppm	900 ppm [LEL]
Cyanides (as CN)	50 mg/m^3 (as CN)	25 mg/m^3 (as CN)
Cyclohexane	10,000 ppm	1,300 ppm [LEL]
Cyclohexanol	3,500 ppm	400 ppm
Cyclohexanone	5,000 ppm	700 ppm
Cyclohexene	10,000 ppm	2,000 ppm
Cyclopentadiene	2,000 ppm	750 ppm
2,4-D	500 mg/m^3	100 mg/m^3
DDT	N.E.	500 mg/m^3
Decaborane	100 mg/m^3	15 mg/m^3
Demeton	20 mg/m^3	10 mg/m^3
Diacetone alcohol	2,100 ppm	1,800 ppm [LEL]
Diazomethane	2 ppm	2 ppm [Unch]

Diborane	40 ppm	15 ppm
Dibutyl phosphate	125 ppm	30 ppm
Dibutyl phthalate	9,300 mg/m^3	4,000 mg/m^3
o-Dichlorobenzene	1,000 ppm	200 ppm
p-Dichlorobenzene	1,000 ppm	150 ppm
Dichlorodifluoromethane	50,000 ppm	15,000 ppm
1,3-Dichloro 5,5-dimethylhydantoin	Unknown	5 mg/m^3
1,1-Dichloroethane	4,000 ppm	3,000 ppm
1,2-Dichloroethylene	4,000 ppm	1,000 ppm
Dichloroethyl ether	250 ppm	100 ppm
Dichloromonofluoromethane	50,000 ppm	5,000 ppm
1,1-Dichloro 1-nitroethane	150 ppm	25 ppm
Dichlorotetrafluoroethane	50,000 ppm	15,000 ppm
Dichlorvos	200 mg/m^3	100 mg/m^3
Dieldrin	450 mg/m^3	50 mg/m^3
Diethylamine	2,000 ppm	200 ppm
2-Diethylaminoethanol	500 ppm	100 ppm
Difluorodibromomethane	2,500 ppm	2,000 ppm
Diglycidyl ether	25 ppm	10 ppm
Diisobutyl ketone	2,000 ppm	500 ppm
Diisopropylamine	1,000 ppm	200 ppm
Dimethyl acetamide	400 ppm	300 ppm
Dimethylamine	2,000 ppm	500 ppm
N,N-Dimethylaniline	100 ppm	100 ppm [Unch]
Dimethyl 1,2-dibromo 2,2-dichlorethyl phosphate	1,800 mg/m^3	200 mg/m^3
Dimethylformamide	3,500 ppm	500 ppm
1,1-Dimethylhydrazine	50 ppm	15 ppm

Dimethylphthalate	9,300 mg/m^3	2,000 mg/m^3
Dimethyl sulfate	10 ppm	7 ppm
Dinitrobenzene (o, m, p isomers)	200 mg/m^3	50 mg/m^3
Dinitroocresol	5 mg/m^3	5 mg/m^3 [Unch]
Dinitrotoluene	200 mg/m^3	50 mg/m^3
Di sec-octyl phthalate	Unknown	5,000 mg/m^3
Dioxane	2,000 ppm	500 ppm
Diphenyl	300 mg/m^3	100 mg/m^3
Dipropylene glycol methyl ether	Unknown	600 ppm
Endrin	2,000 mg/m^3	2 mg/m^3
Epichlorohydrin	250 ppm	75 ppm
EPN	50 mg/m^3	5 mg/m^3
Ethanolamine	1,000 ppm	30 ppm
2-Ethoxyethanol	6,000 ppm	500 ppm
2-Ethoxyethyl acetate	2,500 ppm	500 ppm
Ethyl acetate	10,000 ppm	2,000 ppm [LEL]
Ethyl acrylate	2,000 ppm	300 ppm
Ethyl alcohol	15,000 ppm	3,300 ppm [LEL]
Ethylamine	4,000 ppm	600 ppm
Ethyl benzene	2,000 ppm	800 ppm [LEL]
Ethyl bromide	3,500 ppm	2,000 ppm
Ethyl butyl ketone	3,000 ppm	1,000 ppm
Ethyl chloride	20,000 ppm	3,800 ppm [LEL]
Ethylene chlorohydrin	10 ppm	7 ppm
Ethylenediamine	2,000 ppm	1,000 ppm
Ethylene dibromide	400 ppm	100 ppm
Ethylene dichloride	1,000 ppm	50 ppm

Ethylene glycol dinitrate	500 mg/m^3	75 mg/m^3
Ethyleneimine	100 ppm	100 ppm [Unch]
Ethylene oxide	800 ppm	800 ppm [Unch]
Ethyl ether	19,000 ppm [LEL]	1,900 ppm [LEL]
Ethyl formate	8,000 ppm	1,500 ppm
Ethyl mercaptan	2,500 ppm	500 ppm
N-Ethylmorpholine	2,000 ppm	100 ppm
Ethyl silicate	1,000 ppm	700 ppm
Ferbam	N.E.	800 mg/m^3
Ferrovanadium dust	N.E.	500 mg/m^3
Fluorides (as F)	500 mg F/m^3	250 mg F/m^3
Fluorine	25 ppm	25 ppm [Unch]
Fluorotrichloromethane	10,000 ppm	2,000 ppm
Formaldehyde	30 ppm	20 ppm
Formic acid	30 ppm	30 ppm [Unch]
Furfural	250 ppm	100 ppm
Furfuryl alcohol	250 ppm	75 ppm
Glycidol	500 ppm	150 ppm
Graphite (natural)	N.E.	1,250 mg/m^3
Hafnium compounds (as Hf)	Unknown	50 mg Hf/m^3
Heptachlor	700 mg/m^3	35 mg/m^3
n-Heptane	5,000 ppm	750 ppm
Hexachloroethane	300 ppm	300 ppm [Unch]
Hexachloronaphthalene	2 mg/m^3	2 mg/m^3 [Unch]
n-Hexane	5,000 ppm	1,100 ppm [LEL]
2-Hexanone	5,000 ppm	1,600 ppm
Hexone	3,000 ppm	500 ppm

sec Hexyl acetate	4,000 ppm	500 ppm
Hydrazine	80 ppm	50 ppm
Hydrogen bromide	50 ppm	30 ppm
Hydrogen chloride	100 ppm	50 ppm
Hydrogen cyanide	50 ppm	50 ppm [Unch]
Hydrogen fluoride (as F)	30 ppm	30 ppm [Unch]
Hydrogen peroxide	75 ppm	75 ppm [Unch]
Hydrogen selenide (as Se)	2 ppm	1 ppm
Hydrogen sulfide	300 ppm	100 ppm
Hydroquinone	Unknown	50 mg/m^3
Iodine	10 ppm	2 ppm
Iron oxide dust and fume (as Fe)	N.E.	2,500 mg Fe/m^3
Isoamyl acetate	3,000 ppm	1,000 ppm
Isoamyl alcohol (primary and secondary)	10,000 ppm	500 ppm
Isobutyl acetate	7,500 ppm	1,300 ppm [LEL]
Isobutyl alcohol	8,000 ppm	1,600 ppm
Isophorone	800 ppm	200 ppm
Isopropyl acetate	16,000 ppm	1,800 ppm
Isopropyl alcohol	12,000 ppm	2,000 ppm [LEL]
Isopropylamine	4,000 ppm	750 ppm
Isopropyl ether	10,000 ppm	1,400 ppm [LEL]
Isopropyl glycidyl ether	1,000 ppm	400 ppm
Ketene	Unknown	5 ppm
Lead compounds (as Pb)	700 mg Pb/m^3	100 mg Pb/m^3
Lindane	1,000 mg/m^3	50 mg/m^3
Lithium hydride	55 mg/m^3	0.5 mg/m^3
L.P.G.	19,000 ppm [LEL]	2,000 ppm [LEL]

Magnesium oxide fume	N.E.	750 mg/m^3
Malathion	5,000 mg/m^3	250 mg/m^3
Maleic anhydride	Unknown	10 mg/m^3
Manganese compounds (as Mn)	N.E.	500 mg Mn/m^3
Mercury compounds [except (organo) alkyls, as Hg]	28 mg Hg/m^3	10 mg Hg/m^3
Mercury (organo) alkyl compounds(as Hg)	10 mg Hg/m^3	2 mg Hg/m^3
Mesityl oxide	5,000 ppm	1,400 ppm [LEL]
Methoxychlor	N.E.	5,000 mg/m^3
Methyl acetate	10,000 ppm	3,100 ppm [LEL]
Methyl acetylene	15,000 ppm [LEL]	1,700 ppm [LEL]
Methyl acetylenepropadiene mixture	15,000 ppm	3,400 ppm [LEL]
Methyl acrylate	1,000 ppm	250 ppm
Methylal	15,000 ppm [LEL]	2,200 ppm [LEL]
Methyl alcohol	25,000 ppm	6,000 ppm
Methylamine	100 ppm	100 ppm [Unch]
Methyl (namyl) ketone	4,000 ppm	800 ppm
Methyl bromide	2,000 ppm	250 ppm
Methyl Cellosolve (r)	2,000 ppm	200 ppm
Methyl Cellosolve (r) acetate	4,000 ppm	200 ppm
Methyl chloride	10,000 ppm	2,000 ppm
Methyl chloroform	1,000 ppm	700 ppm
Methylcyclohexane	10,000 ppm	1,200 ppm [LEL]
Methylcyclohexanol	10,000 ppm	500 ppm
o-Methylcyclohexanone	2,500 ppm	600 ppm
Methylene bisphenyl isocyanate	100 mg/m^3	75 mg/m^3
Methylene chloride	5,000 ppm	2,300 ppm

Methyl formate	5,000 ppm	4,500 ppm
5-Methyl 3-heptanone	3,000 ppm	100 ppm
Methyl hydrazine	50 ppm	20 ppm
Methyl iodide	800 ppm	100 ppm
Methyl isobutyl carbinol	2,000 ppm	400 ppm
Methyl isocyanate	20 ppm	3 ppm
Methyl mercaptan	400 ppm	150 ppm
Methyl methacrylate	4,000 ppm	1,000 ppm
Methyl styrene	5,000 ppm	700 ppm
Mica	N.E.	1,500 mg/m^3
Molybdenum (insoluble compounds, as Mo)	N.E.	5,000 mg Mo/m^3
Molybdenum (soluble compounds, as Mo)	N.E.	1,000 mg Mo/m^3
Monomethyl aniline	100 ppm	100 ppm [Unch]
Morpholine	8,000 ppm	1,400 ppm [LEL]
Naphtha (coal tar)	10,000 ppm [LEL]	1,000 ppm [LEL]
Naphthalene	500 ppm	250 ppm
Nickel carbonyl (as Ni)	7 ppm	2 ppm
Nickel metal and other compounds (as Ni)	N.E.	10 mg Ni/m^3
Nicotine	35 mg/m^3	5 mg/m^3
Nitric acid	100 ppm	25 ppm
Nitric oxide	100 ppm	100 ppm [Unch]
p-Nitroaniline	300 mg/m^3	300 mg/m^3 [Unch]
Nitrobenzene	200 ppm	200 ppm [Unch]
p-Nitrochlorobenzene	1,000 mg/m^3	100 mg/m^3
Nitroethane	1,000 ppm	1,000 ppm [Unch]
Nitrogen dioxide	50 ppm	20 ppm
Nitrogen trifluoride	2,000 ppm	1,000 ppm

Nitroglycerine	500 mg/m^3	75 mg/m^3
Nitromethane	1,000 ppm	750 ppm
1-Nitropropane	2,300 ppm	1,000 ppm
2-Nitropropane	2,300 ppm	100 ppm
Nitrotoluene (o, m, p isomers)	200 ppm	200 ppm [Unch]
Octachloronaphthalene	Unknown	Unknown [Unch]
Octane	5,000 ppm	1,000 ppm [LEL]
Oil mist (mineral)	N.E.	2,500 mg/m^3
Osmium tetroxide (as Os)	1 mg Os/m^3	1 mg Os/m^3 [Unch]
Oxalic acid	500 mg/m^3	500 mg/m^3 [Unch]
Oxygen difluoride	0.5 ppm	0.5 ppm [Unch]
Ozone	10 ppm	5 ppm
Paraquat	1.5 mg/m^3	1 mg/m^3
Parathion	20 mg/m^3	10 mg/m^3
Pentaborane	3 ppm	1 ppm
Pentachloronaphthalene	Unknown	Unknown [Unch]
Pentachlorophenol	150 mg/m^3	2.5 mg/m^3
n-Pentane	15,000 ppm [LEL]	1,500 ppm [LEL]
2-Pentanone	5,000 ppm	1,500 ppm
Perchloromethyl mercaptan	10 ppm	10 ppm [Unch]
Perchloryl fluoride	385 ppm	100 ppm
Petroleum distillates (naphtha)	10,000 ppm	1,100 ppm [LEL]
Phenol	250 ppm	250 ppm [Unch]
p-Phenylene diamine	Unknown	25 mg/m^3
Phenyl ether (vapor)	N.E.	100 ppm
Phenyl etherbiphenyl mixture (vapor)	N.E.	10 ppm
Phenyl glycidyl ether	Unknown	100 ppm

Phenylhydrazine	295 ppm	15 ppm
Phosdrin	4 ppm	4 ppm [Unch]
Phosgene	2 ppm	2 ppm [Unch]
Phosphine	200 ppm	50 ppm
Phosphoric acid	10,000 mg/m^3	1,000 mg/m^3
Phosphorus (yellow)	N.E.	5 mg/m^3
Phosphorus pentachloride	200 mg/m^3	70 mg/m^3
Phosphorus pentasulfide	750 mg/m^3	250 mg/m^3
Phosphorus trichloride	50 ppm	25 ppm
Phthalic anhydride	10,000 mg/m^3	60 mg/m^3
Picric acid	100 mg/m^3	75 mg/m^3
Pindone	200 mg/m^3	100 mg/m^3
Platinum (soluble salts, as Pt)	N.E.	4 mg Pt/m^3
Portland cement	N.E.	5,000 mg/m^3
Propane	20,000 ppm [LEL]	2,100 ppm [LEL]
n-Propyl acetate	8,000 ppm	1,700 ppm
n-Propyl alcohol	4,000 ppm	800 ppm
Propylene dichloride	2,000 ppm	400 ppm
Propylene imine	500 ppm	100 ppm
Propylene oxide	2,000 ppm	400 ppm
n-Propyl nitrate	2,000 ppm	500 ppm
Pyrethrum	5,000 mg/m^3	5,000 mg/m^3 [Unch]
Pyridine	3,600 ppm	1,000 ppm
Quinone	300 mg/m^3	100 mg/m^3
Rhodium (metal fume and insoluble compounds, as Rh)	N.E.	100 mg Rh/m^3
Rhodium (soluble compounds, as Rh)	N.E.	2 mg Rh/m^3

Ronnel	5,000 mg/m^3	300 mg/m^3
Rotenone	Unknown	2,500 mg/m^3
Selenium compounds (as Se)	Unknown	1 mg Se/m^3
Selenium hexafluoride	5 ppm	2 ppm
Silica, amorphous	N.E.	3,000 mg/m^3
Silica, crystalline (respirable dust)	N.E.	
cristobalite/tridymite:		25 mg/m^3
quartz/tripoli:		50 mg/m^3
Silver (metal dust and soluble compounds, as Ag)	N.E.	10 mg Ag/m^3
Soapstone	N.E.	3,000 mg/m^3
Sodium fluoroacetate	5 mg/m^3	2.5 mg/m^3
Sodium hydroxide	250 mg/m^3	10 mg/m^3
Stibine	40 ppm	5 ppm
Stoddard solvent	29,500 mg/m^3	20,000 mg/m^3
Strychnine	3 mg/m^3	3 mg/m^3 [Unch]
Styrene	5,000 ppm	700 ppm
Sulfur dioxide	100 ppm	100 ppm [Unch]
Sulfuric acid	80 mg/m^3	15 mg/m^3
Sulfur monochloride	10 ppm	5 ppm
Sulfur pentafluoride	1 ppm	1 ppm [Unch]
Sulfuryl fluoride	1,000 ppm	200 ppm
2,4,5-T	Unknown	250 mg/m^3
Talc	N.E.	1,000 mg/m^3
Tantalum (metal and oxide dust, as Ta)	N.E.	2,500 mg Ta/m^3
TEDP	35 mg/m^3	10 mg/m^3
Tellurium compounds (as Te)	N.E.	25 mg Te/m^3
Tellurium hexafluoride	1 ppm	1 ppm [Unch]

TEPP	10 mg/m^3	5 mg/m^3
Terphenyl (o, m, p isomers)	Unknown	500 mg/m^3
1,1,1,2-Tetrachloro 2,2-difluoroethane	15,000 ppm	2,000 ppm
1,1,2,2-Tetrachloro 1,2-difluoroethane	15,000 ppm	2,000 ppm
1,1,2,2-Tetrachloroethane	150 ppm	100 ppm
Tetrachloroethylene	500 ppm	150 ppm
Tetrachloronaphthalene	Unknown	Unknown [Unch]
Tetraethyl lead (as Pb)	40 mg Pb/m^3	40 mg Pb/m^3 [Unch]
Tetrahydrofuran	20,000 ppm [LEL]	2,000 ppm [LEL]
Tetramethyl lead (as Pb)	40 mg Pb/m^3	40 mg Pb/m^3 [Unch]
Tetramethyl succinonitrile	5 ppm	5 ppm [Unch]
Tetranitromethane	5 ppm	4 ppm
Tetryl	N.E.	750 mg/m^3
Thallium (soluble compounds, as Tl)	20 mg Tl/m^3	15 mg Tl/m^3
Thiram	1,500 mg/m^3	100 mg/m^3
Tin (inorganic compounds, as Sn)	400 mg Sn/m^3	100 mg Sn/m^3
Tin (organic compounds, as Sn)	Unknown	25 mg Sn/m^3
Titanium dioxide	N.E.	5,000 mg/m^3
Toluene	2,000 ppm	500 ppm
Toluene 2,4-diisocyanate	10 ppm	2.5 ppm
o-Toluidine	100 ppm	50 ppm
Tributyl phosphate	125 ppm	30 ppm
1,1,2-Trichloroethane	500 ppm	100 ppm
Trichloroethylene	1,000 ppm	1,000 ppm [Unch]
Trichloronaphthalene	Unknown	Unknown [Unch]
1,2,3-Trichloropropane	1,000 ppm	100 ppm
1,1,2-Trichloro 1,2,2-trifluoroethane	4,500 ppm	2,000 ppm

Triethylamine	1,000 ppm	200 ppm
Trifluorobromomethane	50,000 ppm	40,000 ppm
2,4,6-Trinitrotoluene	1,000 mg/m^3	500 mg/m^3
Triorthocresyl phosphate	40 mg/m^3	40 mg/m^3 [Unch]
Triphenyl phosphate	N.E.	1,000 mg/m^3
Turpentine	1,500 ppm	800 ppm
Uranium (insoluble compounds, as U)	30 mg U/m^3	10 mg U/m^3
Uranium (soluble compounds, as U)	20 mg U/m^3	10 mg U/m^3
Vanadium dust	70 mg/m^3 (as V2O5)	35 mg V/m^3
Vanadium fume	70 mg/m^3 (as V2O5)	35 mg V/m^3
Vinyl toluene	5,000 ppm	400 ppm
Warfarin	350 mg/m^3	100 mg/m^3
Xylene (o, m, p isomers)	1,000 ppm	900 ppm
Xylidine	150 ppm	50 ppm
Yttrium compounds (as Y)	N.E.	500 mg Y/m^3
Zinc chloride fume	4,800 mg/m^3	50 mg/m^3
Zinc oxide	2,500 mg/m^3	500 mg/m^3
Zirconium compounds (as Zr)	500 mg Zr/m^3	25 mg Zr/m^3

ppm = parts per million; LEL = lower explosive limit; mg/m^3 = milligram per cubic meter in air [Unch] = unchanged concentration; N.E. = No effect

CHAPTER 5
CONCLUDING CHAPTER

In this chapter, conclusions will be made based of the aims, objectives and hypotheses of this study. Recommendations on attempts to improve and protect workers from acute exposure of HCSs, controlled by the use of STELs and CLs, and the resulting adverse effects will be discussed. Lastly, the limitations as experienced during the study and suggestions on future studies will be discussed.

5.1 Conclusions

The aim of this study was to compare the STELs and CLs of the South African Regulation for Hazardous Chemical Substance (RHCS) with that of the Mine Health and Safety Regulation (MHSR) and then with that of 12 leading developed countries/organisations based on the variables of (i) coverage (frequency and selection) of individual HCSs and (ii) level (concentration) of STELs and CLs set for different HCSs. This study was a follow up study to that of Viljoen (2012) which compared South African OEL-TWAs (both from the RHCS and MHSR) with that of other developing countries/organisations (BRICS) and developed countries/organisations in order to establish the extent of disparities and/or similarities between South Africa and the selected developing and developed countries/organisations. Viljoen (2012) recommended that a future study on STELs comparison be made which would yield a more representative assessment of the levels of overall OELs set by different countries/organisations. Therefore, while this study was a follow-up study based on recommendation by Viljoen (2012), a few adjustments had been made, including firstly the addition of comparison with another category of OELs, the CL, secondly the disregard of comparison with other developing countries/organisations because based on the literature, most of the developing countries still demonstrate challenges with their own OHS, just as in South Africa (Wang *et al*., 2011; Tevlin, 2012; Dudarev *et al*., 2013) and lastly the addition of a few developed countries/organisations, including the EU, New Zealand, Sweden and the NIOSH (USA). Having made such addition and thus carried out the study as stated above, the objective of the study had been met.

Regarding the comparison of overall STEL coverage and level, it was hypothesised that there is significant disparity of STEL coverage and level between the RHCS/MHSR, and the ten developed countries/organisations, where ≥5 of the developed countries/organisations have a <50% overlap with RHCS/MHSR HCSs and the STEL levels are lower (<1 GMs ratio and/or <95% interval of a compared HCSs level) than that of South Africa's STELs (Hypothesis 1). Having carried out the study and comparing the South African STELs with that of the developed countries/organisations, it was concluded that there is significant disparity of STEL coverage between the South African STELs and those of the selected developed countries/organisations. This was noticed from the ratio of the lower number of HCS overlapping with the RHCS and MHSR to the higher number of HCSs that were unique to the RHCS and MHSR. A number of >5 countries/organisations had a <50% overlap with the total number of HCSs of the RHCS and MHSR. This trend was noticed for eight (RHCS) and seven (MHSR) countries/organisations. Having also compared the STEL levels of the RHCS and MHSR with those of the ten selected developed countries/organisations, it was also concluded that there are significant disparities in STEL levels, where most of the countries/organisations had STEL levels that were lower than that of the RHCS and the MHSR. By use of the GMs method, there were nine (RHCS) and eight (MHSR) countries/organisations which had GMs ratios that were <1 (I.e. there were lower than that of the RHCS and the MHSR). The results obtained via analysis by the interval method also agreed with the conclusion made on there being significant disparities in overall STEL levels, where >5 of the developed countries/organisations had more STEL levels that were significantly lower than that of the RHCS and MHSR (i.e. a higher number of HCSs with levels <95% interval).

Therefore hypothesis 1 is accepted that there are significant disparity of STEL coverage and level between the RHCS/MHSR, and the ten developed countries/organisations, where ≥5 of the developed countries/organisations have a <50% overlap with RHCS/MHSR HCSs and the STEL levels are lower (<1 GMs ratio and/or <95% interval of a compared HCSs level) than that of South Africa's STELs.

The hypothesis on CL coverage and level stated that there is significant disparities in CL coverage and level between the MHSR and the nine developed

countries/organisations, where ≥5 of the developed countries/organisations have a <50% overlap with the MHSR HCSs and CL levels are lower (<1 GMs ratio and/or <95% interval of a compared HCSs level) than that of South Africa's CLs (Hypothesis 2). Having compared the CL coverage of the nine developed countries/organisations with that of the MHSR, it was concluded that there are in contrast significant similarities between South African CL coverage and that of the selected developed countries/organisations. This was observed from the five countries/organisations that had a >50% overlap with the total number of MHSR HCSs. Regarding comparison for overall CL levels between the countries/organisations, there were contradictory findings. There were significant disparities with the GMs method and significant similarities with the interval method. However, based on judgements made from the observation of the raw data and on prior literature that highlighted the trend of lack of change in level for most acute OELs (Paustenbach *et al*., 2011), it was concluded that there are significant similarities in CL levels between South Africa and the nine developed countries/organisations. Based on the raw data, it was observed that for most countries/organisations most HCSs had the highest number of HCS levels that were identical to those of the MHSR. This is then followed by the low number of those HCS levels which were significantly higher CL levels and then followed by the lowest number of HCS levels having significantly lower CL levels than that of the MHSR.

Therefore, hypothesis 2 which stated that here are significant disparities in CL coverage and level between the MHSR and the nine developed countries/organisations, where ≥5 of the developed countries/organisations have a <50% overlap with the MHSR HCSs and CL levels are lower (<1 GMs ratio and/or <95% interval of a compared HCSs level) than that of South Africa's CLs, is hereby rejected.

Reflecting on the aforementioned remarks of coverage and level of STELs, it can be deduced that South African STEL vales are by far inadequate to protect workers from exposure to HCSs and the resulting adverse effects that come with it. Regarding the CL values, not much progress worldwide has been made on their review, possibly explained by their narrow dose-response relationship; the low concentration that is needed to elicit an acute adverse health effect (NLM, 2015).

Therefore, because most CL values are of the same or similar overall level, it can be concluded that South African CLs are adequate to protect workers from acute exposure to irritant gases.

5.2 Recommendations

OELs for both long-term and short-term can be effective tools in assisting to control exposure to health hazards, however, the effectiveness of controlling exposure to HCSs is largely dependent on scientifically up-to-date OELs. The DoL committee, the Technical Committee number 7 (TC7), is underway with the process of reviewing (amongst other regulations) the RHCS, 1995 (R: 1179). According to their revised work plan, their first draft of the RHCS table is to be submitted by March 2016. Therefore, as contribution to the reviewing process, and having considered the overall adequacy of the South African OELs when compared to that of leading developed countries/organisations, the following recommendations are made:

Recommendation 1: The synonyms (duplicates) of HCSs listed in the RHCS need to be removed. This is especially necessary for the HCSs that are listed using different nomenclature under Tables 1 and 2 (e.g. 1,1,1-Trichloroethane (CL) versus Methyl chloroform) which is likely to cause confusion.

Recommendation 2: CAS numbers need to be assigned to the HCSs as listed in Annexure 1 of the OHS Act. The assigning of CAS number will simultaneously eradicate the issue of having duplicates (Recommendation 1) and thus of misidentification of HCSs.

Strong emphasis is given to the abovementioned limitations which were also made in a previous study (Viljoen, 2012) thus undoubtedly highlighting the importance and relevance to their being implemented with the aim to forge the way forward in the field of OHS in South Africa.

Recommendation 3: With the RHCS and MHSR restating as common law in the field of OHS, it is advisable that their contents be similar, if not the same. This is especially necessary for the TWAs and STELs value which are listed by both Regulations. Considering that the Regulations have significant similarities in both coverage and level, it would be advisable that the TWA and STELs definitions be

clearly stated and similar in both the RHCS and MHSR. Specifically regarding the STEL definition which clearly states that the exposure excursion above the TWA-OEL should be no more than four times a day, with at least 60 minutes between successive exposures in the MHSR, but is, however, not stated in the RHCS.

Recommendation 4: Ceiling limit (CLs) values need to be added into the RHCS considering that all workers, regardless of their working demographic, be it underground, or on water, may potentially experience acute exposure from irritant gases.

Recommendation 5: Regular review of the STEL and CL list is advised in order to avoid leaving workers vulnerable to HCSs exposure and thus increasing the statistic of ODs, occupational injuries and deaths, which in turn compromises South Africa's economy. With South Africa developing as a country, it is advisable that the TWAs be reviewed every two years in order to keep up with the forever transitioning OHS field and with the leading developed countries/organisations which tend to have their TWAs levels gradually decrease over time with the aim to keep the protection of the health of workers a priority. Regarding the CLs, a longer review period can be used because throughout the years, since the establishment of CLs, no significant change on CL coverage and level has been noticed. This can also be noticed from the similarities in CL coverage and level between the decade old CLs listed in the MHSR versus those listed by developed countries/organisations.

Recommendation 6: While it seems less likely to occur that South Africa would develop its own STELs and CL, it is advised that adoption be made from (i) the ACGIH, which continues to be used as a source updating OELs for most other developed countries/organisations, it updates its STELs and CLs annually and is said to exhibit purely health-based OELs, (ii) Sweden because it ranks in the top three for stringent STELs and CLs and, in contrast to the ACGIH, has STELs and CLs values which were set taking into account economic and technical feasibility, or (iii) Japan ranks in the top three of stringent CLs and will thereby serve well for the adoption of the CLs when necessary. Japan's CLs are also known to be health-based OELs. While the adoption of the entire STEL and CL value publication of a particular country/organisation may not be possible based on differences in social context, South Africa's list (based on coverage and level) can be a product of the

combination of several countries/organisations. Upon compilation of the South African STEL and CL list, reference ought to be made as to where and how the STEL and CL selection and levels were achieved.

5.3 Limitations

During this study there were a few limiting factors which are worth noting, including:

- Having to pair the correct CAS number to the HCSs listed in the RHCS which are not assigned CAS numbers, this limitation was also experienced in a prior similar study.
- Some OEL publications that were used in the study were written in native languages other than English, which made it a challenge to translate the content of the publication.

The abovementioned limitations were also experienced in a prior similar study (Viljoen, 2012).

- Having to figure out the different ways of how the STEL and CL values were presented by the different countries/organisations.
    - NIOSH and Sweden had STEL or CL values of varying exposure periods, where some values had to be excluded from the study.
    - Finland had the term “kattoarvo” under the remarks column which signified that the value listed under the 15 min column (the STEL column) was actually a CL value.
    - Australia defined its CL values as peak limitations, where the CL value was listed under the TWA column with the term “peak limitation” written next to the value.
    - Germany had its publication fully written in German and made it a challenge to figure out that the STEL values were calculated by multiplying the value under the “Arbeitsplatzgrenzwert” column with the first value under the “Spitzenbegr” column. The CL value on the other hand was obtained by multiplying the very same “Arbeitsplatzgrenzwert” value with the value appearing between the symbol “= =”.

- Some countries/organisations did not have both the STEL and CL values listed in their publication, but rather one of the OEL categories thereby decreasing the number of countries/organisations that were used for the individual comparison of STEL and CL values.

5.4 Future studies

After conducting this study and that of Viljoen (2012), it can be concluded that South African TWAs and STELs are inadequate to protect workers from HCS exposure. While the CLs are considered as adequate to protect the health of workers from HCS exposure and do not differ much from those of international standards, there is room for improvement. This then makes it necessary for South African OELs to be reviewed. Even upon review of the South African OELs, the following study can be done:

- Comparison can be made between the new and reviewed South African OELs and those of the leading developed countries/organisations as selected by Viljoen (2012) and for this study, to analyse if the new OELs (TWAs, STELs and CLs) are of international standard and thereby adequate to protect South African workers from exposure to HCSs and the resulting adverse health effects.

5.5 References

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APPENDICES

Links to OEL lists

The following links can be followed in order to obtain the lists that were used for this study:

Australia	http://www.safeworkaustralia.gov.au/sites/SWA/about/Publications/Documents/772/Workplace-exposure-standards-airborne-contaminants.pdf
Canada (BC)	http://www2.worksafebc.com/Publications/OHSRegulation/GuidelinePart5.asp?ReportID=32895&_from=regulation.healthandsafetycentre.org
EU	http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2000:142:0047:0050:EN:PDF (2000/39/EC) http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:038:0036:0039:EN:PDF (2006/15/EC) http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:338:0087:0089:EN:PDF (2009/161/EC)
Finland	https://www.julkari.fi/bitstream/handle/10024/116148/URN_ISBN_978-952-00-3479-5.pdf?sequence=1
Germany	http://www.baua.de/cae/servlet/contentblob/666762/publicationFile/55588/TRGS-900.pdf
Japan	http://joh.sanei.or.jp/pdf/E56/E56_5_14.pdf
New Zealand	http://www.business.govt.nz/worksafe/information-guidance/all-guidance-items/workplace-exposure-standards-and-biological-exposure-indices/workplace-exposure-standards-and-biological-indices-2013.pdf
NIOSH	http://www.cdc.gov/niosh/docs/2005-149/pdfs/2005-149.pdf
Sweden	http://www.av.se/dokument/inenglish/legislations/eng1118.pdf

UK	http://www.hse.gov.uk/pUbns/priced/eh40.pdf

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To whom it may concern,

I hereby confirm that ER Maponya has made use of my services regarding the translation of the English summary contained in the mini-dissertation, "Comparison of South African short-term and ceiling exposure limits with those of developed countries", to Afrikaans and that the references in the document have been checked during the following period: 26–31 October 2015.

Kind regards,

Esmé Harris

ENGLISH LANGUAGE EDITING CERTIFICATE

This is to certify that the English Language of the dissertation by

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