EXPOSURE TO CARBON MONOXIDE IN AN UNDERGROUND TRACKLESS MINE DURING THE PERIOD MAY 2012 – DECEMBER 2012

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A study report submitted to the Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, in partial accomplishment of the requirements for the degree of Master of Public Health (Occupational Hygiene).

DECLARATION

I, Jacobus Johannes van Staden, declare that this report is based upon my own research studies. The work is being submitted for the degree of Master of Public Health in the field of Occupational Hygiene at the University of the Witwatersrand, Johannesburg. The work submitted according to my information, has not been submitted before for any qualification or examination at this or any other university.

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ABSTRACT

Objectives: This study identified the risk to CO exposure from unburnt hydrocarbons and explosives used daily underground at a mechanized platinum mine. Existing CO personal measurements over a six month period were utilised to develop a framework or management tool that will assist mine managers and occupational medical practitioners to evaluate and prioritise occupational risk to CO when reference is made to national and international limits including biological indices.

Methods: This study employed a retrospective record review of secondary data emanating from records of the compulsory wearing of gas detection devices underground. The widely used NIOSH method 66904 was used to assess CO exposure which stipulates that a portable direct gas reading instrument will be used.

Results: Exposure results to carbon monoxide ranged from 0 ppm to 40 ppm and confirmed a non-risk occupational exposure index when compared to the time weighted OEL of 30 ppm (Median for total group 0.05). The overall arithmetic mean of 1.6 ppm was higher than the overall mean personal gas concentration of 0.05 ppm. Although the highest percentage of proportional measurements were in the range of 35 and 50 ppm for the occupation, trackless stoper the median result was still far below the OEL range at 0.19 ppm.

Conclusions: The results have shown that personal exposure levels over an eight hour equivalent shift compared to two generally used OELs were exceeded. These levels of over-exposure were however not as great as was expected and the majority of the results did not exceed all three applicable OELs for CO exposure over an 8-hour equivalent. Measurements exceeding the South African OEL of 30 PPM were 0.03 % in total. Of particular interest is that no measurement exceeded the OHSA (USA) limit of 50 ppm. Additionally from the data contained in this report it is evident that all of the data utilization scenarios (literature research, field observations, interviews and data

information gathering) can be calculated, reported and utilised in a Carbon Monoxide Management System.

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ABBREVIATIONS

ACGIH	American Conference of Governmental Industrial Hygienists
BAT	Biologische Arbeitsstoff-Toleranzwerte
BEI	Biological Exposure Index
BMVG	Biological Monitoring Value Guidance
CAD	Coronary Artery Disease
CFK	Coburn Foster Kane
CO	Carbon Monoxide
COHb	Carboxyhaemoglobin
COP	Code of Practise
DMR	Department of Minerals and Resources
DOL	Department of Labour
EPA	Environmental Protection Agency
FEV1	Forced Expiratory Volume in one second
GDI	Gas Detection Device
Hb	Haemoglobin
HSE	Health Safety & Environmental
IARC	International Agency for Research on Cancer
IDLH	Immediately Dangerous to Life and Health
ILO	International Labour Organisation
IQR	Inter Quartile Range
LOAEL	Lowest Observed Adverse Effect Level
MHSA	Mine Health & Safety Act
MIN	Minutes
NH_3	Ammonia
NIOH	National Institute for Occupational Health

NIOSH	National Institute for Occupational Safety and Health (USA)
NO	Nitrogen Oxide
NO_2	Nitrogen Dioxide
OEL	CL Occupational Exposure Limit – Control Limit
OEL	Occupational Exposure Limit
OEL-TWA	Occupational Exposure Limit - Time Weighted Average
OHS	Occupational Health and Safety
OSHA	Occupational Safety and Health Administration
PEL	Permissible Exposure Limits
ppm	parts per million
RSA	Republic of South Africa
SABS	South African Bureau of Standards
SANAS	South African National Accreditation System
SANS	South African National Standards
SD	Standard Deviation
STEL	Short Term Exposure Limit
STEL	Short Term Exposure Limit
TLV	Threshold Limit Value
TLV	Threshold Limit Value
TM3	Trackless Mechanised Mining
TWA	Time Weighted Average
TWA	Time Weighted Average
USA	United States of America
WHO	World Health Organisation
WMC	Western Mining Company

CHAPTER 1:

1. INTRODUCTION

In South Africa, mines are obligated to compile with the requirements of the guideline for the compilation of a Mandatory Codes of Practices (COPs) for flammable gasses under the current Mine Health and Safety Act (MHSA) (South Africa, Department of Minerals and Resources, 1997). These codes of practice are prepared in accordance with the Department of Minerals and Resources (DMR) guideline ref. DME 16/3/2/1-A2, South Africa. The Department of Minerals and Resources (2002) provided the *Standard for the establishment of a mandatory code of practice for the prevention of flammable explosions in mines other than coal mines,* which further refers to flammable gas as methane gas, hydrogen gas, carbon monoxide (CO) and/or any other natural flammable gas that may be liberated in the underground workings. The purpose of the code is to document the practices and procedures to be applied to address occupational risks due to exposure to flammable gas. Exposure to flammable gas is a health and safety concern and typically has to be dealt with through strategies which embrace engineering controls, elimination, substitution, administrative controls and personal protection.

Personal monitoring of a flammable gas involves an instrument which, when switched on at the point of issue, will remain operating for the duration of the working shift. It is designed to determine the concentration of flammable gas present in the atmosphere in parts per hundred by volume and the instrument is equipped with visual and/or audible alarms or both and must comply with Standards South Africa, 1990; *Combustible-gas sensing and measuring instruments principally for use in mines part 1: battery-operated hand held and transportable instruments in adherence to* Standards of South Africa. (SANS 1515-1-1990).

Over exposure to gasses especially the inhalation of it remains scant as no conclusive occupational exposure data is available for fugitive gas exposure emissions (Mainiero, 2000). Despite the monitoring requirement for flammable gasses, very little personal occupational exposure data to CO exist for subjects working in an underground platinum mine. This is a major limitation currently in South African mines and the focal point of this project. Daily personal CO measurements are mainly compared to acute safety limits which are based on explosive ranges and not toxic levels over a prolonged period. This scenario finds application in most South African mines and surface operations even though measurements are logged over most shifts.

The purpose of this study is to identify and prioritize occupations exposed to CO. In addition, the study seeks to compare these CO exposures to international and national occupational exposure limits. The study examined personal sampling measurements at a mechanized mine resulting in a management tool addressing over exposure to CO. The modern day mining environment has an increasing trend of removing subjects from the working face and introducing mechanized mining methods. The introduction of this method however increases the additional load of diesel equipment, which in turn contributes to the overall CO burden due to the poor efficiency of diesel engines and the ability to burn cleaner tail pipe gasses.

2. Literature review

Workers involved with underground activities are regularly exposed to substances such as tail pipe exhaust emissions, gas generation form explosives, rock drill mist and other gas constituents on a daily basis, while performing their daily work. Occupational exposure to these airborne contaminants may increase the worker's risk to obstructive pulmonary disorders and blasting fumes exposure (Bakke et al., 2004) in particular increasing workers risk to develop respiratory illnesses and lung obstructions. In a study investigating the effect of blasting gasses on tunnel workers the researchers reported that over several days of exposure, the workers showed a marked downward trend in lung capacity function and FEV_1 (forced expiratory volume in one second) indicating a negative impact when employees come in contact with gasses liberated from explosive usage with a resultant symptomatic impact on the respiratory system (Bakke et al., 2004).

The main route exposure to gasses mainly exist via inhalation, a minimal alternative way is through skin contact. The removal of these toxic substances from the body typically transpires by a degree of excretion (De Souza & Katsabanis, 2004). The configuration of the gasses, dose and length of interval of exposure, and the detail that mine workers exposure to contaminant mixtures as opposed to single substances, can cause diverse effects on the miners health. Effects can vary from nausea, skin irritation, difficulty in breathing to cancer. According to De Souza & Katsabnis (2004), blasting fumes result in decrease work capacity of the cardiovascular, respiratory system and other various organ functions. The ignition gasses (Nitrogen Oxide (NO), Nitrogen Dioxide (NO_2), Ammonia (NH_3) and Carbon Monoxide (CO)) released during the blast process can have a detrimental bearing on the miner's wellbeing. It is therefore significant to designate the occupational exposure levels of CO measured on a daily basis, as in this study.

2.1 *Carbon Monoxide (CO) and its health effects*

The lethal risk to carbon monoxide exposure results from the fact that it has no colour, taste or odour which emanates from unburnt hydrocarbons and as a residue from blasting operations. CO is the combined effect of incomplete oxidation of carbon post explosives detonation. The National Institute of Occupational Safety and Health (NIOSH) has referenced CO levels at 1368 mg/m^3 as Immediately Dangerous to Life and Health (IDLH) with a 40 mg/m^3 deemed to be a safe exposure value over a working 8-hour shift (Pelham *et al.,* 2002). Local legislation depicts values over a ceiling and prolonged period, reference to Table 1, selected values and OELs per country indicates exposure values against listed BEI and OEL limits.

Adverse effects to health from CO liberation are due to formation of carboxyhemoglobin (COHb) when CO binds with hemoglobin inhibiting the uptake of oxygen in the blood. Hemoglobin (Hb) possesses the likelihood to bind 240 times greater to CO as opposed to oxygen when entering the body. Good evidence exists between CO expired air and adsorbed concentrations of CO before the onset of hypoxia which progresses when underground employees are exposed to elevated concentrations of CO (Pelham et al., 2002).

Symptomatic signs of over exposure to CO reveal the following; indications of headaches, disorientation, fatigue, nausea, acuity or perception degradation and confusion. Research by Gulumian et al., (2007) advocate that exposure to elevated levels of CO will be lethal for underground workers. Literature suggests that over exposure to high concentrations targets the brain, cardio vascular system and training muscles which are more prone for sensitivity to CO exposure (Pelham et al., 2002) especially considering the latent effects of the substance. Scientific evaluations have presented a variety of indicators related with detailed concentrations of COHb. Decreased levels of COHb alter visual acuity with dilation of arteries. Increased COHb levels revealed symptoms of nausea, dizziness and headaches. Researchers have also revealed a positive relationship to an increased metabolic work rate and higher CO uptake as opposed to a resting state (Pelham et al., 2002). Therefore mine workers are at greater risk of developing hypoxia and other adverse health effect due to their hard, physical work activities and inadequate ventilation methods resulting in poor dilution of gasses emanating from explosives residue and diesel equipment being used underground.

Studies conducted on oxygen conveyance in the blood with CO as an inhibitor during increased metabolic work have indicated venous oxygen tightness degradation when exposed to CO, resulting in an elevated heart rhythm with a resultant work efficiency decrease. Predisposed employees suffering from coronary artery disease (CAD) are at risk with limited cardiovascular capability, increasing their risk to angina. Acknowledging the risk on the cardio vascular system, employees exposure to low levels of CO have been linked with diminished neuro-psychological output, resulting in difficulties concomitant with concentration, remembrance, perceptive planning, and data processing (Pelham et al., 2002)

Table 1 *Selected occupational exposure limits and biological exposure indices by country*

Jurisdiction	***8 hour TWA ppm***	***Short-term limit values (STEL)***	***Ceiling value***	***COHb***	***End-tidal breath (end-exhaled air) CO***
OSHA, USA	50 ppm (PEL)				
ACGIH, USA	25 ppm (TLV)			3.5% (BEI)	20 ppm
Germany	30 ppm			5% (BAT)	
Sweden	35 ppm	100 ppm (15 mins)			
HSE, UK	30 ppm	200 ppm (15 mins)		Target is < 5%	30 ppm (BMGV)
MHSAct, RSA	30 ppm		100 ppm		
OHSA, RSA	50 ppm	300 ppm (15 mins)		<8% (BEI)	40 ppm

Notes:

1. HSE UK. Smoking complicates the interpretation of the Biological Monitoring Guidance Value (BMGV) in individuals particularly if the smoking has occurred during shift time, biological screening on a cluster principle will still be valuable in establishing the control effectiveness.
2. The Biologische Arbeitsstoff-Toleranzwerte (BAT) value is valid for non-smokers and is used as a biological monitoring guidance value. The BAT value does not apply to pregnant workers (due to inadequate data to evaluate risk). The BAT Value Documentation states that "In practice with the discovery of COHb concentrations at or above 5% intensified monitoring of the air of the workplace with regard to CO....should be carried out." Medical enquiries (history-taking) should be done to clarify the cause and to find a remedy.
3. The ACGIH concludes in its documentation of the BEIs [2001] that CO reveals not to have significant and constant properties on fit, young participants with a COHb less than 10%. Continued COHb levels of 5 – 10% might have a detrimental metabolic work outcome of duties necessitating a certain level of attentiveness (e.g. operating an aircraft). The capacity to perform strenuous physical exertion may be reduced at values around 5%. Decreased exercise time to angina has been witnessed at concentrations in the region of 3% with elevated ventricular arrhythmias hovering at 6%. Continual personal exposure to carbon monoxide throughout pregnancy can contribute to diminished birth mass and low mental ability observed under offspring. The ACGIH, COHb level of 3.5% is set to protect against the above effects.

4. The OSHA, USA, PEL of 50 ppm was reviewed and OHSA intended to establish a permissible exposure limit 8 - hour TWA of 35 ppm and a upper limit of 200 ppm but this has not been enforced due to a remand by the USA Circuit Court of Appeals (www.CDC.gov.niosh/pel88/630-08.html).

The ILO Encyclopaedia [1998] lists particularly susceptible workers as those with reduced oxygen transport capacity because of anaemia or haemoglobin abnormalities; those with increased oxygen needs (e.g. fever, hyperthyroidism or pregnancy); workers with systemic hypoxia due to respiratory or cardiac disease; and workers with coronary artery disease (CAD). Individuals with generalised or cerebral atherosclerosis may also be susceptible.

The World Health Organisation (WHO) adds to this list – foetuses and persons using curative or leisure substances having effects on the brain are two, but notes that little empirical evidence exists on which to specify health effects in relation to environmental exposure levels (WHO, 1999).

This list contains many diseases, some of which are common in the general population, but there are insufficient data to use them for the determination of workplace standards. Two conditions deserve particular attention, however: cardiovascular effects; and pregnancy.

3. Cardiovascular effects

At levels of about 4-5% COHb small decrements in work capacity have been shown under maximal exercise conditions (WHO EHC 213, 1999; ACGIH, 2001; Leikauf & Prows, 2001). Coronary artery disease (CAD) is of greater clinical concern and the group of individuals with CAD is viewed as the most sensitive risk group by the WHO (EHC 213, 1999).

COHb levels in the range of 2.9 - 6% have been associated with shortened exercise duration before onset of angina, and at 6% the number and complexity of exercise-induced arrhythmias increased in people with CAD (WHO EHC 213, 1999; ACGIH, 2001; Leikauf & Prows, 2001). It should be noted that the consequence of these outcomes on populations at work is not clear (ACGIH, 2001).

4. Pregnancy

There are two considerations: the pregnant worker; and the foetus. Theoretically, pregnant workers are considered a susceptible group for adverse effects of CO exposure. However data on maternal health effects are scant and less focused on than possible foetal effects. Adverse outcomes of CO on the foetus are well established in animal studies, which revealed negative signs mainly occurring at maternal COHb concentrations above 15% (Leikauf & Prows, 2001), but extrapolating from animal studies the lowest observable adverse effect level (LOAEL) could be as low as 10 ppm (or COHb of 1.82%) for continuous exposure to CO.

5. Occupational exposure limits and BEIs

When reference is made to Table 1 (Selected Occupational Exposures Limits & Biological Exposure Indices by country) occupational exposure limits and biological limit values from a number of developed countries and South Africa can be compared. The Appendix to Patty's Toxicology Volume 8 (Leikauf & Prows, 2001) contains many more country-specific standards but they are similar to the ones shown in Table 1, comparisons to the various eight hour TWAs range from 25 ppm to 50 ppm, with statutory limits between 30 – 50 ppm; and COHB from 3.5% to 8%. The ACGIH is the most stringent and it aims to avert adversarial neurobehavioral variations, uphold cardiovascular workout volume and deliver a superior degree of protection for persons predominantly vulnerable to the effects and over exposure conditions of CO, comprising of expecting female employees (i.e. the foetus) including employees diagnosed with respiratory anomalies and chronic cardiovascular ailments. Most jurisdictions have a BEI for COHb of 5% and so the OHS Act level of < 8% is on the high side. A target BEI of 5% would seem reasonable, but should be interpreted in consideration of the factors below.

The BEIs are usually end of shift values used to identify worksites where over-exposure may have occurred and to protect susceptible groups. Exceedance of these values should not be taken to mean that clinical effects - "gassing" in a medical sense - have occurred due to workplace exposure because smokers have an average COHb level of 4% and can reach 8% (WHO EHC 213, 1999); some urban commuters have CO exposure in excess of 35ppm (WHO EHC 213, 1999); and that COHb levels and clinical effects have great individual variability at the same CO exposure levels (WHO EHC 213, 1999; ACGIH, 2001). Consequently, exceedences should primarily be used to identify worksites and practices that lead to possible over-exposure to CO rather than to define workers affected by CO.

6. The MHSA OELs and approximate COHb levels

The Coburn–Foster-Kane (CFK) equation is widely accepted when interpretations are made to comparisons between exhaled air and blood CO levels. Patty's Toxicology states that "The equation is valid over a wide range of conditions, including large differences in CO levels, durations of exposure, and exercise conditions." (Leikauf & Prows, 2001, p.112) There are, however, a number of competing modified – and usually simplified - equations with advantages and disadvantages (Leikauf & Prows, 2001; Lloyd & Rowe, 1999). The modified NIOSH equation can be used to calculate approximate COHb levels to derive an equivalent BEI under exposure conditions of 30 ppm and 100 ppm as stipulated in the Mine Health and Safety Act, bearing mind that individual factors, workload and duration of exposure influence the COHb level.

As can be seen in Table 1, the MHSA ceiling value of 100 ppm is particularly stringent (100 ppm is usually a short-term limit value, STEL over 15 minutes). Exceedance of the 100 ppm ceiling and even STEL does not indicate that "gassing" has occurred or that medical monitoring is required; it is set so that potentially high exposure settings can be identified in order to reduce exposure or to temporarily remove workers from exposure or both. Assessment of COHb and symptoms is a more useful measure of uptake of CO and need for medical monitoring than exceedance of the STEL.

Biological monitoring is well established in the determination of recent exposure to carbon monoxide (CO) by individuals (EPA, 2000). Two methods are commonly used: measurement of blood carboxyhemoglobin (COHb); and CO in end-tidal exhaled breath after standardised breath hold manoeuvre. The COHb in blood is utilised as the validated biomarker of exposed individuals to carbon monoxide (ACGIH, 2001), especially in clinical settings and hospital environments. Blood COHb levels are exact and meticulously related to the devices of toxicity (WHO, 2000). The COHb level is largely a function of endogenous production (a minor contributor) and the exposure level of the carbon monoxide (CO) gas by inhalation, extent of exposure level and alveolar aeration. Carbon monoxide is expired unaffected via the lungs, as a gas through exhaled air, and has therefore been used in practice as an indirect measure of COHb levels. Carbon monoxide in expired breath offers a quick precise non-invasive, feasible, cheap, quick screening method that can be used in practice in various occupational and emergency settings (Jarvis et al., 1980; Jarvis et al., 1986; WHO, 2000).

Exhaled air has been used successfully as a screening method to determine carbon monoxide exposure in emergency medical settings (Kurt et al., 1990), and various occupational settings. This method has also been used as a test of tobacco smoke intake in clinical settings and smoking cessation programs (Wald et al., 1981; Corradi & Mutti, 2005). It has also been used for immediate determination of CO exposure in individual patients as well as a triage tool when large groups of patients are suspected of carbon monoxide exposure (Kurt et al., 1990).

CO measurement in exhaled air is particularly recommended in settings where rapid collection of blood and determination of COHb levels is not feasible. Rapid collection of blood is necessary as the elimination half-life of carbon monoxide in blood is 3-5 hours, thus a delay in collecting blood results in underestimates of exposure; and a delay in determination of COHb levels means that prompt assessment of exposure and institution of remedial actions are not possible.

CO in exhaled air can be used in occupational settings to overcome the limitations associated with COHb. Carbon monoxide in end-tidal breath is used in a Biological Monitoring Guidance Value of the United Kingdom's Health and Safety Executive (HSE, 2011) and is thus an accepted instrument for biological screening of exposure to carbon monoxide. The ACGIH (2001) has also published a BEI for end-exhaled air (the BEI is 20 ppm at end of shift).

CHAPTER 2: MATERIALS AND METHODS

2.1 Study Aim

The main objective of this study was to identify and prioritize mining occupations exposed to CO and to compare these exposure levels to international and national occupational exposure limits. It is further expected that this study could contribute to better interpretation of the results with intervention levels and control strategies that will provide a bracket of safety for particularly susceptible workers. These include: pregnant workers and those with respiratory diseases, smokers and subjects diagnosed with coronary artery diseases who work underground on a daily basis.

The study also aims to mitigate personal CO exposure through a framework or management tool that will assist mine managers and occupational medical practitioners to evaluate and prioritise occupational risk to CO when reference is made to national and international limits including biological indices. The study objectives are listed below:

2.2 Study Objectives

1. To deduce a profile of the top 10 risk occupations from daily CO exceedences over a six month period above the OEL for exposure to CO;
2. To describe personal CO exposures in the top ten high risk occupations during the period May 2012 – December 2012 in a mechanised mine over a three shift period.
3. To compare personal CO exposures at an underground platinum mechanised mine during the period May 2012 – December 2012 to national and international OELs (Occupational Exposure Limits)

2.3 Study Rationale

Occupational exposure of workers, and particularly women, to CO in the work environment remains problematic in terms of the probable adverse effects on their reproductive health (Alfred, et al., 1991:546-559). It is important that the extent to which these subjects are exposed will be assessed especially referring to the acute toxicity of CO. Work done by Apte et al., (1999) suggested further exposure mitigation by careful investigation to various alarm limits as an early warning indicator. Current CO exposure monitoring is very safety oriented by nature and fails to address prolonged toxicity and acknowledgement to literature when dose concentrations and short term excursions are brought into consideration. The study will also contribute to improve control strategies and procedures aimed at reducing occupational exposure to CO in this work environment especially looking at the latent effect of CO over a prolonged period. It is envisaged that this study will contribute to sensitising, awareness raising and improving control strategies and procedures aimed at reducing personal gas concentration levels to CO. The intention and study deliverables are also envisaged to alert management when subjects are exposed to CO with reference to OEL settings and at what levels an over exposure requires a clinical observation.

2.3.1 Study design

This study employed a retrospective record review of data already collected, emanating from the compulsory wearing of gas detection devices underground with automatic download when the subjects exit from the workings underground.

2.3.2 Study population and sampling

The study population included a total number of seven hundred and forty eight (748) subjects working over a three shift system (day, afternoon and night shift) which were identified to participate in this study as reflected in Table 2, Job categories and staff compliment. Reflecting upon the study population of 748 subjects identified a 50% prevalence was assumed amongst exposed occupations due to the scant literature existing for underground worker exposure to gasses. It is therefore important and fit for this study to have determined the occupational exposure levels of CO from unburnt hydrocarbons to which mineworkers are exposed to during their eight to nine hour working shift.

For the overall aim of this study, workers issued with a personal gas detection device as per the mine's Mandatory Code of Practice (DMR, Guideline for the compilation of a mandatory code of practise for the prevention of flammable gas explosions in mines other than coal mines, 16/3/2/1 - A2) were selected. The results of the study were associated to current OEL's of the Mine Health and Safety Act, 1996 (Act No. 29 of 1996) and Occupational Health and Safety Act, 1993 (act No. 85 of 1993).

Table 2 *Job Categories and Staff Complements*

Job Category	**Compliment**
Boilermaker Plater	28
Construction	90

Job Category	Compliment
Construction Team Supervisor	15
Human Resource Development Officer	1
Mine Overseer	2
Survey and Sampling assistant	13
Trackless drill rig operator	115
Trackless roofbolt operator	209
Trackless Stoper	82
Trackless Sweeper	215
Ventilation construction team leader	6
Total	748

2.3.3 Measurement instruments

The widely used NIOSH method 66904 was used to assess CO exposure which stipulates that a portable direct gas reading instrument will be used. The gas detection instrument conformed to SABS 1515 specifications for battery operated portable personal units. The devices are capable of continuously sensing and were able to give either a clearly audible or clearly visible warning or both when an atmosphere contained 30 PPM or more of CO in the general atmosphere. Calibration of the gas detection instruments were done in accordance with the calibration procedure prescribed by the original equipment manufacturer on a daily basis.

This study was a retrospective record review study of already measured data emanating from the compulsory apparel of gas detection devices underground with automatic download when the subjects exit from the workings underground. The study population included twelve risk occupations consisting of 3906 gas readings. The downloading sequence of gas data is depicted in Fig.1 Personal gas download sequence. The data gas download sequence indicates personal gas detection instruments within the lamp room of the mine. Instruments are calibrated to a known concentration span gas and downloadable on a central server once the instruments return from underground. These results are logged against each occupation on a daily basis over a 6 month period and were scrutinized as part of the project scope.

Figure 1 Personal gas downloads sequence

2.3.4 Personal gas detection devices

The actual instrument is a portable hand-held spot or continuous instrument which allows the employee to measure the presence and gas concentration over an entire shift period. For gas concentrations exceeding occupational exposure limits, a full scale meter or an over-range indication will be shown. Clearly audible and visible alarms will also be activated should these instruments be placed in an environment comprising of a concentration level of flammable/noxious gas which equals or exceeds the alarm set point.

2.3.5 Measurements for this study

The platinum mining sector consists of a large work force underground with a significant amount of subjects issued with a personal gas sampling device on a daily basis. A total amount of 6633 personal measurements to CO is taken daily within the working environments underground as compelled by current legislation within a large mining operation. The use of early warning devices are currently prescribed by the Mine Health and Safety Act (MHSA) 29 of 1996, Section 11, will be used to assess exposure to CO on a daily basis with reference to OEL's.

This study analyzed 9798 records of personal measurements to CO and will contribute to improve control strategies and procedures aimed at reducing occupational exposure to CO in this work environment especially looking at the latent effect of CO over a prolonged period.

2.3.6 Risk Ranking Methodology

To prioritise occupations with the biggest risk of over exposure to CO, the risk ranking in Table 3 were used indicating the classification band against the category of occupation. Sample retrieval was done over three underground shifts of the mine, results were randomly retrieved from the working shift (7-9 hours) on a daily basis and categorized as per the following risk ranking methodology:

Table 3 *Risk Ranking Methodology*

Category (of occupation)	Classification band
A – Red	Exposure ≥ than the OEL
B – Orange	Exposure ≥ than 50 % the OEL
C – Green	Exposure ≥ than 10% the OEL and < 50% of the OEL

2.4 Information Gathering and Hazard Characterization

The first step in identifying occupational exposure to CO underground was a thorough identification of the various occupations with a personal CO monitor allocated as per mandatory code of practice for flammable gasses. Personal exposure results obtained from an electronic database were scrutinized against substantial scientific evidence, constituting detrimental health outcomes to CO.

Exposure utilization mainly consisted of comparisons made to OELs and BEI's for CO. An exposure assessment tool (Annexure A - Summary calculations and results for a random collection of 20 samples) were utilised to assess the top 10 risk occupations or exposure to CO over a time weighted average of 8 hours.

The collation of data from the exposure assessment tool were assessed and compared to existing scientific literature, regulatory OELs, particularly reviewing articles, published books and established databases listing exposure risk rankings to CO, including long term and short excursions to CO. An example of the exposure hazard capturing tool is displayed in Table 4, Gas download parameters in a tabular format as obtained from the gas instrument downloads.

Table 4 *Gas downloads parameters*

Date and Time	Gas	TWA	Shaft	Coy No	Name	Occupation	Shift
2013/03/01 05:22:15	CO	3.27	Bathopele			TM3 Stoper	Rotating
2013/03/01 05:22:21	CO	3.75	Bathopele			Construction Team Supervisor	Morning
2013/03/01 05:22:35	CH4	0	Bathopele			TM3 Stoper	Stoper
2013/03/01 05:22:38	CO	0.81	Bathopele			TM3 Stoper	Rotating
2013/03/01 05:22:39	CO	3.19	Bathopele			TM3 Stoper	Stoper
2013/03/01 05:22:59	CH4	1.39	Bathopele			TM3 Stoper	Rotating
2013/03/01 05:23:09	CH4	0.98	Bathopele			TM3 Stoper	Rotating
2013/03/01 05:23:26	CH4	0	Bathopele			TM3 Stoper	Rotating
2013/03/01 05:23:34	CO	1.97	Bathopele			Construction	M/S
2013/03/01 05:23:40	CH4	0	Bathopele			Construction	M/S
2013/03/01 05:23:40	CO	0	Bathopele			Construction	M/S
2013/03/01 05:23:45	CO	1.25	Bathopele			Construction Team Supervisor	Rotating
2013/03/01 05:23:59	CH4	-0.02	Bathopele			TM3 Stoper	Rotating
2013/03/01 05:24:01	CH4	0	Bathopele			Construction	M/S
2013/03/01 05:24:01	CO	0	Bathopele			Construction	M/S
2013/03/01 05:24:07	CH4	0	Bathopele			Construction Team Supervisor	Rotating
2013/03/01 05:24:07	CO	0	Bathopele			Construction Team Supervisor	Rotating
2013/03/01 05:24:26	CH4	0	Bathopele			Construction Team Supervisor	Rotating
2013/03/01 05:24:26	CO	0	Bathopele			Construction Team Supervisor	Rotating
2013/03/01 05:24:34	CH4	0.95	Bathopele			Construction	M/S
2013/03/01 05:24:37	CO	119.18	Bathopele			Construction	M/S
2013/03/01 05:24:44	CH4	0	Bathopele			TM3 Stoper	Rotating
2013/03/01 05:24:47	CH4	1.08	Bathopele			Construction Team Supervisor	Rotating

Personal information omitted as part of – privileged confidentiality

In addition to the time weighted average (TWA) sampling conducted utilization of personal data (for an individual) to determine the individuals daily Time Weighted Average (TWA) to personal CO exposure concentration were carefully conducted.

In order to predict concentrations, TWA values were determined by obtaining the sum of the exposure throughout a work shift to CO in relation to parts-per-million and dividing by an eight-hour period, fig.2 Personal concentration values illustrates the exposure concentrations to a dotted reference OEL value. The term "8-hour reference period" relates to the procedure whereby the occupational exposures in any 24-hour period are treated as equivalent to a single exposure for 8 hours (the 8-hour time-weighted average (TWA) exposure).

The 8-hour TWA may be represented mathematically by: C1XT1 + C2XT2 +……Cn x Tn/8 (where C1 is the occupational exposure and T1 is the associated exposure in any 24 hour period. An example used from Table 4. Gas download parameters would be calculated as follow; the employee works for 5h22min underground in which the employee is exposed to CO. The average exposure during that period was measured 5 ppm. The 8-hour TWA therefore would be: 5.22h x 5ppm /8 = 3.2ppm

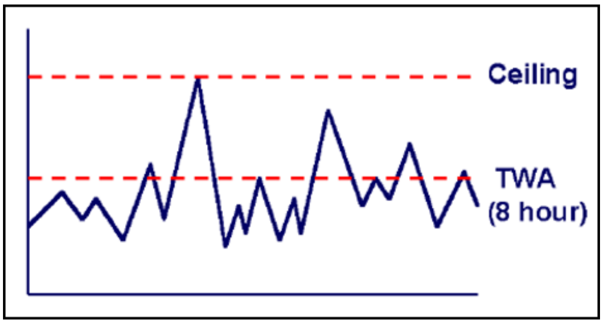

Figure 2 *Personal Carbon Monoxide concentration values*

OSHA has allocated some, but not all, toxic constituents with a ceiling level. This relates to the uppermost level of a toxic substance for which an unshielded worker should ever be exposed, even for a very short duration as depicted in fig. 3 Ceiling Value display.

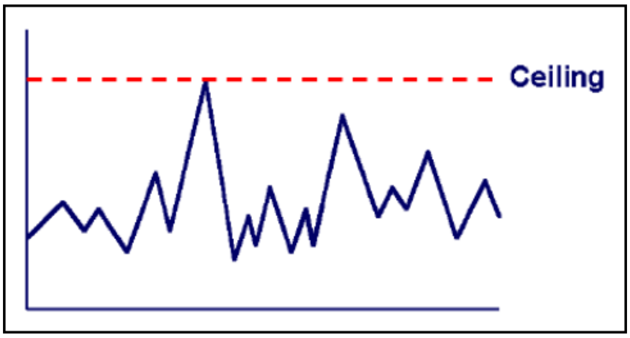

Figure 3 *Ceiling Value display*

The data recorded by the personal worn gas detector can be easily manipulated to produce a summary report, to monitor this indicator or Short Term Exposure Limit (STEL). Toxic constituents may have short-term exposure boundary, which are higher placed when compared to eight hour TWA. The STEL value as indicated in fig.3 STEL and Ceiling values as a TWA fraction is the extreme average level of concentration to which an unprotected or unshielded employee may be exposed to in any fifteen-minute bracket during the day.

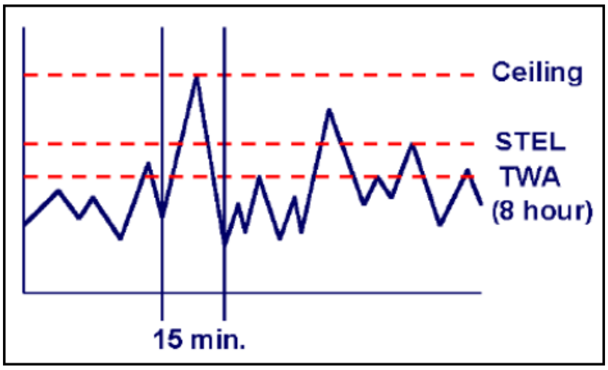

Figure 4 *STEL and Ceiling Carbon Monoxide values as a TWA fraction*

Any occurrence in which the average STEL level is over the permissible level within a fifteen minute portion and isolated from each other by at least sixty minutes the OEL-TWA 8 hour is no longer valid and should not be used.

2. 5 Data Analysis

Descriptive analyses were utilised, deploying the S-PLUS (version 8.1) and SAS System Software package (version 9.1). To define methods of central tendency and distribution of the measurements, medians and arithmetic means (AM) were used. Carbon monoxide measurements were assessed against three reference values: 25 ppm (American Conference of Governmental Industrial Hygienists Threshold Limit Value); 30 ppm (South African Department of Mineral Resources OEL) 50 ppm (OHSA RSA).

Exposure levels of CO concentrations can best be defined utilising distributions lognormally. In addition, box and whisker plots will be used to visually illustrate the spread of the CO concentrations as well as to compare CO exposures to national and international standards. The broad horizontal mark is the median, the box end units are the 25 and 75% quartiles and the end of the mark from the boxes are the minimum and maximum measurements, excluding outliers which are shown as circles.

2.6 Ethical Issues

Permission to use routinely collected mine data was obtained from the mine management. (See Appendix E). Ethical approval to conduct these analyses was acquired directly at the HREC (Human Research Ethics Committee-M10105) through the University of the Witwatersrand (see Appendix D).

In the secondary data analysis, general ethical principles of anonymity were upheld by storing data in the form of case identification, without names or other identifying information. In addition, results are reported as group results, in order to protect any identifying information.

2.7 Funding

No specific funding was required as all data and collection formed part of an internal programme. Where necessary the researcher self-funded the costs associated with printing and binding the document as well as transport-related costs associated with meeting the supervisor.

CHAPTER 3: RESULTS

3.1 Results

Nine thousand seven hundred and eighty nine (9798) personal gas exposure results were collected from May 2012-December 2012 during typical mining activities from a single underground platinum mine utilising trackless mechanised mining methods.

3.1.1 Top ten exposed risk occupations

Eight-hour TWA personal gas concentrations for all risk occupations compared to the risk ranking methodology can be deduced for the top ten risk occupations and can be described from high to low as the following; trainee underground, trackless load and haul dump operator, trackless stoper, mine overseer team leader, trackless sweeper, developer, vent construction team leader, trackless drill operator, construction, general miner, and developing machine operator.

The distribution of the personal exposure results of the risk occupations are depicted in Fig 5. Box and whisker plot evaluating TWA personal measurements for risk occupations in a trackless mechanised mine which included values of zero.

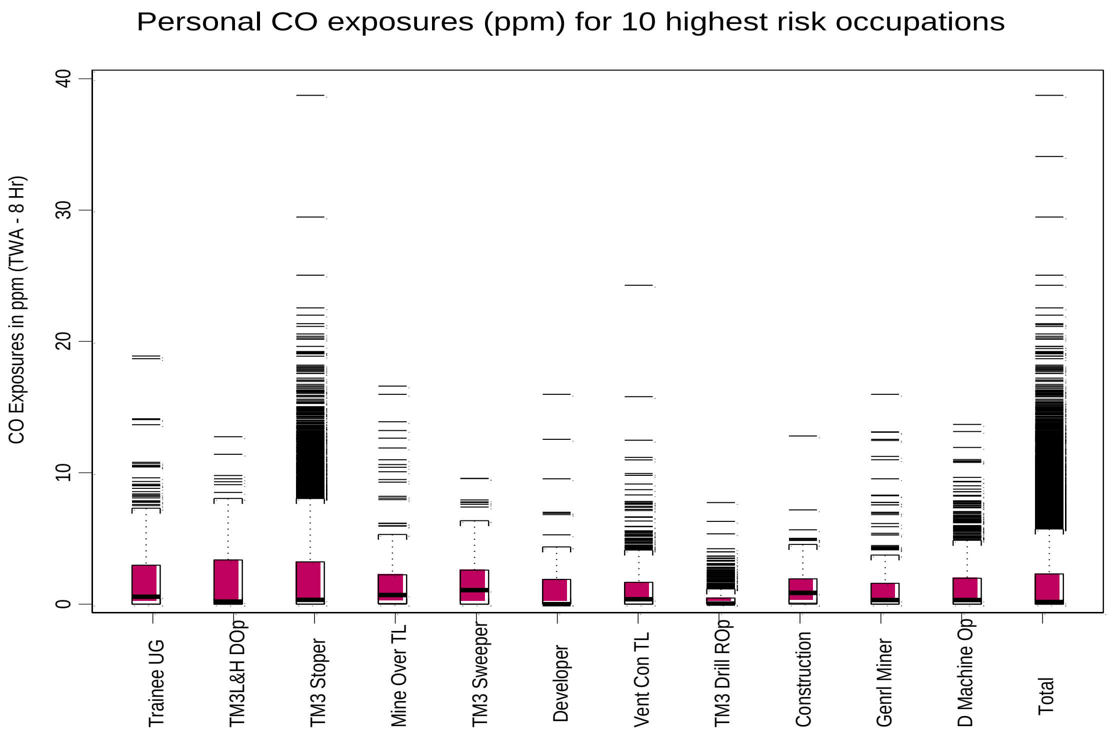

Fig.5. Box and whisker plot evaluating TWA personal concentrations for risk occupations in a trackless mechanised mine.

The data is displayed in Table 5. Eight-hour TWA personal gas exposures (parts per million) shows higher exposure for the occupation trainee underground based upon the arithmetic mean of 2.15 ppm compared to 1.26 ppm to that of the least exposed of the ten risk occupation namely the developing machine operator. The overall arithmetic mean time weighted average (TWA) carbon monoxide concentration were 1.36 ppm with the median at 0.05 ppm and 95th percentile at 4.33 ppm respectively.

Table 5. Eight-hour TWA personal gas exposures (parts per million)

High to low position	Occupation	Number of measurements	Minimum	Maximum	Inter quartile range (IQR)	Arithmetic mean	Median	95th percentile
1	Trainee Underground	341	0	18.90	2.97	2.15	0.56	6.74
2	TM3 Load Haulage Dumper Operator	246	0	12.75	3.36	1.94	0.19	5.41
3	TM3 Stoper	4868	0	102.11	3.22	1.82	0.19	5.26
4	Mine Overseers Team Leader	340	0	16.59	2.19	1.66	0.69	3.88
5	TM3 Sweeper	211	0	9.57	2.53	1.54	1.07	4.08
6	Developer	76	0	15.97	1.77	1.50	0.00	4.25
7	Ventilation Construction Team Leader	948	0	180.78	3.22	1.36	0.37	3.22
8	TM3 Drill Rig Operator	301	0	19.46	0.46	1.31	0.00	4.59
9	Construction	205	0	12.81	3.25	1.29	0.86	3.25
10	General Miner	380	0	15.97	3.50	1.26	0.31	3.50
11	Developing Machine	1873	0	13.68	1.97	1.26	0.31	3.75

	Operator							
	Total	43670	0	409.98	1.88	1.36	0.05	4.33

TWA personal exposure concentrations for all ten occupations are shown in Table 5. Eight-hour TWA personal gas exposures (parts per million). Imputed data were utilised to determine means and SDs and TWA measurements for assessment with the exposure values. The risk occupation trainee underground was measured with the highest concentration exposure over a six month period (0.56 ppm). The eight hour TWA values in Fig.5 indicates a box and whisker plot, the broad horizontal border is the median, the box borders are the 25 and 75% quartiles and the end of the outlines from the boxes are the minimum and maximum values, excluding that outliers are shown as narrow horizontal lines. Personal TWA gas exposures for all risk occupations are shown in Table 5, Eight-hour TWA personal gas exposures (parts per million). Imputed data were used to calculate arithmetic means, 95th percentiles and TWA concentrations to compare with the OELs. The distribution of instantaneous maximum results was higher for the occupation ventilation construction (180.78 ppm), compared to the highest risk occupation, ventilation trainee (18.90 ppm). For all risk occupations the measured TWA concentrations in Fig. 6 Personal gas exposure measurement comparisons with OELs displays the median expressed as 0% due to no readings exceeding the Mine Health and Safety Act’s OELs of 30 ppm. There were also no TWA exceedences recorded against the Department of Labour (DOL) OEL of 50 ppm and also none of the quantities surpassed the well-known and often used value of the American Conference of Governmental Industrial Hygienists (ACGIH) TLV-TWA of 25 ppm.

Substantial portions of the measurement data exceeded the ceiling limit in place of 100 ppm. Instantaneous personal CO exposures in Table 6 (TWA personal CO exposure as (%) of risk occupations in an underground mine May 2012-December 2012) identified were moderately low: only 7% of the measurements exceeded the 25 ppm range for the occupation TM3 stoper with the highest concentrations measured at 4% exceeding 50 ppm for the collective sampling set of measurements. The occupation ventilation construction team leader ranked 7th highest risk based with 1% measurements exceeding the 50 ppm bracket.

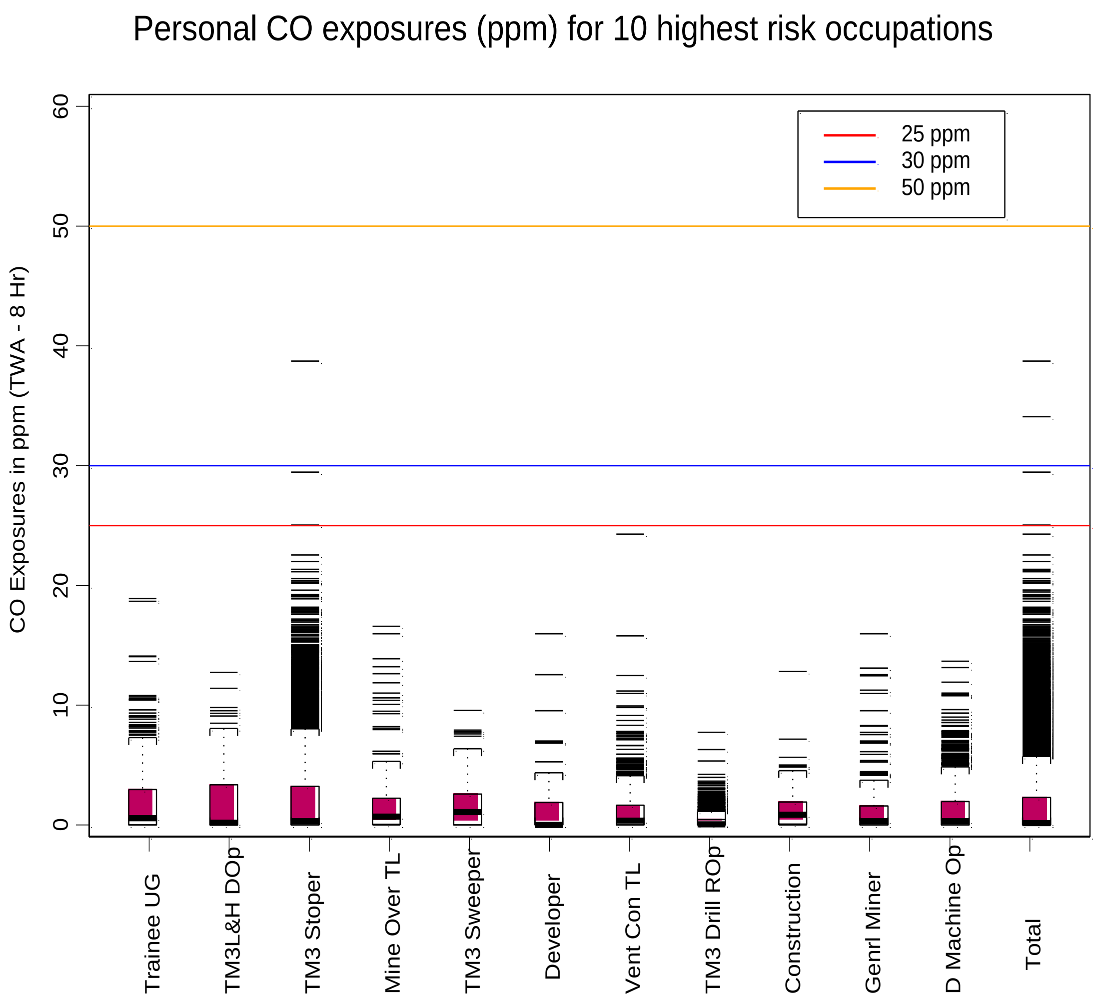

Fig. 6 Personal gas exposure measurement comparisons with OELs

Table 6. TWA personal CO exposure as (%) of risk occupations in an underground mine May 2012-December 2012

High to low position	Occupation	n	Number and Proportion of measurements (%) exceeding 25 ppm	Number and Proportion of measurements (%) exceeding 30 ppm	Number and Proportion of measurements (%) exceeding 50 ppm	Number and Proportion of measurements between 25 and 30 ppm	Number and Proportion of measurements between 35 and 50 ppm
1	Trainee Underground	341	0	0	0	0	0
2	TM3 Load Haulage Dumper Operator	246	0	0	0	0	0
3	TM3 Stoper	13641	7 (0.05)	5 (0.04)	4 (0.03)	2 (0.02)	1 (0.01)
4	Mine Overseers Team Leader	340	0	0	0	0	0
5	TM3 Sweeper	211	0	0	0	0	0
6	Developer	76	0	0	0	0	0
7	Ventilation Construction Team Leader	948	1 (0.11)	1 (0.11)	1 (0.11)	0	0
8	TM3 Drill Rig Operator	701	0	0	0	0	0
9	Construction	205	0	0	0	0	0
10	General Miner	380	0	0	0	0	0
11	Developing Machine Operator	1873	0	0	0	0	0
	Total	43670	16 (0.04)	12 (0.03)	8 (0.02)	4 (0.01)	4 (0.01)

CHAPTER 4: DISCUSSION, CONCLUSION AND RECOMMENDATIONS

4.1 Discussion

The project describes personal underground CO exposure concentrations of ten risk occupations over a six month period in a South African mechanised mine, and determined whether subjects are at risk of over-exposure when comparisons are made to various OEL's. The results have shown that personal exposure levels over an eight hour equivalent shift compared to two generally used OELs were exceeded. These levels of over-exposure were however not as great as was expected. The majority of the time weighted exposure results did not exceed all three applicable OELs for CO exposure over an hour equivalent.

Measurements exceeding the South African OEL of 30 PPM; 0.03 % total. Additionally from the data contained in this report it is evident that all of the data utilization scenarios (literature research, field observations, interviews and data information gathering) can be calculated, reported and utilised in a Carbon Monoxide Management System. The literature with regards to personal exposure monitoring is limited but does provide suggestive indications that CO will always be present in underground mechanized mine emanating from unburnt hydrocarbons. Personal carbon monoxide exposure ranges from 0 ppm to 40 ppm and confirms a non-risk occupational exposure index when compared to the time weighted OEL of 30 ppm (Median for total group 0.05). The overall arithmetic mean of 1.6 ppm was higher than the overall mean personal gas concentration of 0.05 ppm. Although the highest percentage of proportional measurements were in the brackets between 35 and 50 ppm for the occupation TM3 stoper with the median result that was still far below the OEL range at 0.19 ppm.

Although the mechanisms for sensible monitoring platforms must take both short and long-term exposure threats into consideration, it equally remains important to have three independent exposure measurements and alarm types that must be taken into account for an effective Carbon

Monoxide Management Program, i.e.: Ceiling Level (CL), Time Weighted Average (TWA) and Short Term Exposure Limit (STEL).

It remains imperative to establish the residual quantity of any toxic substance possibly present in the work environment and also to assess any mixed exposures levels on individuals. The concentrations and levels of toxic substances present will establish controls to mitigate the risk, procedures and personal protective equipment, which must be utilised. The best plan of action is to eradicate or perpetually control exposures through engineering, workplace mitigating controls, ventilation engineering, or other safety related measures. Employees not protected may not receive exposure levels of toxic substances, which exceed Permissible Exposure Limit (PEL) concentrations. On-going observing is necessary to ensure that exposure concentrations have not altered in a way that necessitates the use of altered or more demanding procedures or equipment.

4.2 The use of existing occupational exposure limits and BEI'Ss

A limitation related particularly to gas exposure assessments within the mining industry is the reliance on existing occupational exposure limits as a benchmark for acceptable or over-exposure assessments. The BEIs are usually end of shift values used to identify worksites where over-exposure may have occurred and to protect susceptible groups. Exceedance of these values should not be taken to mean that clinical effects - "gassing" in a medical sense - have occurred due to workplace exposure. Smokers have an average COHb level of 4% and can reach 8% (WHO EHC 213, 1999); some urban commuters have CO exposure in excess of 35ppm (WHO EHC 213, 1999]; and that COHB levels and clinical effects have great individual variability at the same CO exposure levels (WHO EHC 213, 1999; ACGIH, 2001). Consequently, exceedance should primarily be used to identify worksites and practices that lead to possible over-exposure to CO rather than to define workers affected by CO. This point is made in a number of the background documents to occupational standards. Clinical observation should not routinely follow exposures above the OEL - TWA or ceiling values as discussed above. In particular, exceedance of a ceiling value of 100 ppm should not be taken to mean that over exposure to CO has occurred. The ceiling value is a workplace control value to indicate that potentially dangerous exposure is present so that interventions to reduce exposure can be implemented or to monitor air levels more closely to ascertain whether they remain high.

As discussed above OELs are not suitable for benchmarks for clinical observation. This is particularly true for STELs and ceiling values. The uptake of CO and the levels of CO and COHb in blood are a function of many factors but importantly of physical activity and duration of exposure. Short periods of exposure at or moderately above the ceiling level of 100 ppm, even with heavy physical activity, will not result in adverse effects or clinical indications for observation in the majority of workers. According to Figure 47.1 in Patty's Toxicology it could take up to 100 minutes at 100 ppm CO exposure for the average person to reach a COHb level of 5%; and up to 50 minutes at 200ppm (Leikauf & Prows., 2001).

4.3 Limited research data

The existing research data on underground personal gas exposures is generally scant, particularly as far as dose-effect relationship studies are concerned. Gas exposure data for underground workers are often conducted using a data set which is based upon ceiling and acute levels as opposed to a weighted average with good comparison to existing OELs. The majority of these studies are retrospective and their accuracy might be affected by recall bias and often does not allow validation of crucial details regarding the extent and nature of workers' exposure to various airborne pollutants which sometimes acts on a cumulative or synergistic basis. This study overcame this limitation by the use of calibrated sensors to CO and applying correction factors for any cross sensitivities in order to obtain accurate results to deduce health exposures.

Due to the limited time and resources available for this study only one mine of a possible two trackless mines in the region were sampled, located in the North West Province and Limpopo respectively. This could have introduced an element of bias, and although the main working activities are believed to be similar in all, some of the mines utilises different explosives and lower sulphur diesel which would require additional and unique analyses. Also, the specific shaft layout, personnel compliments, work volumes and control measures implemented (such as ventilation systems) are varied and this might impact on the exposure. Some of the limitations related specifically to the assessment of over exposures to CO were:

Firstly, it is important to note that due to the limited resources available for this study only preliminary measurements could be conducted as part of this initial appraisal. A large number of samples, taken over many days and different scenarios, would have been necessary to cater for the large temporal and spatial variability in chemical concentrations and obtain a more accurate reflection of the true exposures in this work environment. The assessment conducted during this study may be regarded as a basic survey with screening level measurements performed in order to obtain crude quantitative information with the aim of assessing and controlling exposures that deemed to be unacceptable. In addition, the number of airborne gasses that could be sampled for was limited, therefore it was decided to focus the attention on those that, following the information gathering and underground surveys, appeared to present the most obvious risk to reproductive health and coronary artery disease, namely CO. It is however possible that other toxic gasses, which were not sampled or analysed for, might be present in this particular work environment (Oxides of Nitrogen). The underground mining environment currently liberates various different gasses (some in minute quantities) which could potentially affect upper respiratory problems.

4.4 Conclusion and Recommendations

A potential medical surveillance program can be implemented to monitor exposed subjects carboxyhemoglobin (COHb) levels, should they be exposed to Carbon Monoxide concentrations as indicated in the discussion session. The implementation of such a Carbon Monoxide Management Assistance Tool will require:

- Additional alarm levels being established and programmed for the Gas Detection Device (GDI) instrument
- Subjects being re-educated on the meaning of the different alarm levels and training in terms of the correct action to be taken after a specific alarm; and
- Near real-time download of the GDI instrument after completion of the working shift for:
  - Data calculation and corrective action management purposes, and
  - Employee submission for medical surveillance purposes.

When linking the subjects exposure history to the employee's "Medical Records", care should be taken not to only record the TWA OEL concentrations but also the following exposure indicators:

- Number of times that the STEL (100 ppm for 15 minutes) was exceeded during the day, week, month, quarter, year or duration of employment history;
- Number of times that the STEL value (100 ppm for 15 minutes) exceeded 4 or more times during the working shift for the last week, month, quarter, year or duration of employment history;
- Number of times that a Carbon Monoxide exposure of > 400 ppm was experienced during the day, week, month, quarter, year or duration of employment history;
- Number of times that a Carbon Monoxide exposure of > 200 ppm was experienced for more than 15 minutes during the day, week, month, quarter, year or duration of employment history;
- Number of times that a Carbon Monoxide exposure of > 100 ppm was experienced for more than 30 minutes during the day, week, month, quarter, year or duration of employment history; and
- Number of times that a Carbon Monoxide exposure of > 60 ppm was experienced for more than 60 minutes during the day, week, month, quarter, year or duration of employment history.

The WMC Environment, Health & Safety Management System make some recommendations to this regard in their document entitled "Underground Ventilation Major Hazard Standards (MHS-18, DocsOpen Ref: 57159, 20/06/2001)". The recommendations included:

a) Employees are not allowed to receive over exposure to the STEL limit constantly for greater than 15 minutes, or exceeding more than four such stages per work day (page 9 of 18);
b) A short duration of an hour must remain amongst consecutive exposures at the STEL reading (page 9 of 18);
c) Over exposure greater than the eight-hour TWA of 30 ppm should be sensibly evaluated if a 5% COHb are set as a safe limit (page 10 of 18);
d) The following guidelines reflected in table 7, CO Concentration time exposure, and evaluation mechanism of short-term duration exposure for Carbon Monoxide is offered as being (page 10 of 18):

Table 7. CO Concentration time exposure

Concentration value(i) **(ppm)**	**Exposure duration (ii)** **(Minutes)**
200	15
100	30
60	60

(i) Short-term durations must never exceed 400 ppm.

(ii) This extent indicates the amount of exposure concentration averaged over the eight-hour shift, considering no additional source of exposure to carbon monoxide.

In addition, data can also be manipulated to assist in the formulation of the following Carbon Monoxide Management Assistance Tool (see Appendix C, for an example of calculated results) e.g.:

Step 1: Employee shift representative to investigate and rectify conditions should a CO concentration of 30 PPM (at any one time) be recorded.

Step 2: Employee shift representative to immediately withdraw from the working place (should the OEL-C (100 PPM) be recorded) for at least 60 minutes, before returning to the working place to rectify conditions.

Step 3: Employee shift representative to completely withdraw from the working place (for the remainder of the working shift), should the following Carbon Monoxide concentrations be experienced:

- STEL value (100 ppm for 15 minutes) exceeded 4 or more times during the working shift;
- > 400 ppm during any one time during the working shift;
- > 200 ppm being experienced for more than 15 minutes during the working shift;
- > 100 ppm being experienced for more than 30 minutes during the working shift;
- > 60 ppm being experienced for more than 60 minutes during the working shift.

Step 4: A Management investigation will be required, should any of the parameters as indicated in step 3 be present.

Step 5: A Management investigation will be required should the TWA OEL (30 PPM) be exceeded at the end of the shift.

The main aim of this study was to classify and evaluate the risk to CO exposure from unburnt hydrocarbons and explosives used daily underground at a mechanized mine. The intention of exposure evaluation was also intended to develop a framework (Annexure A and B) that will assist mine managers to evaluate and prioritise occupational risk to CO when reference is made to national and international limits including biological indices. From the data contained in this report it is evident that all of the data utilization scenarios (as indicated in the objective) can be calculated, reported and utilized in a Carbon Monoxide Management System.

Additionally, it should not be assumed that significant occupational exposure has necessarily occurred as non-occupational exposures may result in COHb values at this level; hence gassing in an occupational hygiene sense may not have occurred either. As discussed above OELs are not suitable for benchmarks for clinical observation. This is particularly true for STELs and Ceiling values. The uptake of CO and the levels of CO and COHb in blood are a function of many factors but importantly of physical activity and duration of exposure. Short periods of exposure at or moderately above the Ceiling level of 100 ppm, even with heavy physical activity, will not result in adverse effects or clinical indications for observation in the majority of workers.

Biological monitoring is well established in the determination of recent exposure to carbon monoxide (CO) by individuals (EPA, 2000). Two methods are commonly used: measurement of blood carboxyhemoglobin (COHb); and CO in end-tidal exhaled breath after standardised breath hold manoeuvre.

COHb in blood is utilised most commonly as biomarker of worker exposure to carbon monoxide (ACGIH, 2001), especially in clinical settings and hospital environments. Blood COHb levels are exact and meticulously connected to the devices of toxicity (WHO, 2000). Carbon monoxide is excreted unaffected through the lungs, as a gas through exhaled air, and has therefore been used in practice as an indirect measure of COHb. Carbon monoxide in exhalation air offers a swift precise non-invasive, practicable, inexpensive, screening method that can be used in practice in various occupational and emergency settings (Jarvis et al., 1980; Jarvis et al., 1986; WHO, 2000) and is recommended for the use of underground employee over exposure assessments.

CO measurement in exhaled air is particularly recommended in settings where rapid collection of blood and determination of COHb levels is not feasible ideally for use in a mining environment. Rapid collection of blood is necessary as the elimination half-life of carbon monoxide in blood is 3-5 hours, thus a delay in collecting blood results in underestimates of exposure; and a delay in determination of COHb levels means that prompt assessment of exposure and institution of remedial actions are not possible.

CO in exhaled air can be used in occupational settings to overcome the limitations associated with COHb. Carbon monoxide in end-tidal breath is used in a Biological Monitoring Guidance Value of the UK's Health and Safety Executive (HSE, 2011) and is thus an accepted method for biological screening of carbon monoxide especially in an occupational health setting. The ACGIH (2001) has also published a BEI for end-exhaled air (the BEI is 20 ppm at end of shift).

The use of CO in end-exhaled air for biological monitoring has a strong scientific basis, has logistical advantages over COHb and is supported by credible occupational health agencies. Consequently the researcher is of the opinion that it is suitable for monitoring of exposure to CO provided the issues that affect reliability are taken care of. Some examples are listed below, but this list is not exhaustive.

Using this screening test requires caution in interpretation of results as several factors affect validity of the results namely:

End- tidal-exhaled- air carbon monoxide concentration needs to be measured (i.e. alveolar concentration). The procedure requires 15-20 seconds of breath holding. Breath needs to be collected soon after cessation of exposure. The sample should be collected in an environment removed from external sources of CO.

Admittance for clinical observation when COHb values are around 7% is not recommended. There are three reasons for this recommendation:

(1) Non-occupationally exposed smokers may have COHb levels up to 8% [WHO EHC 213, 1999]

(2) The majority of workers with COHb levels around 7% and even higher will not have clinical features that require medical intervention

(3) In the absence of poisoning (i.e. significant clinical features) the clinical course following CO exposure is one of steady improvement and not clinical deterioration making hospital clinical observation unnecessary in asymptomatic workers or those with mild symptoms e.g. headache with normal mental status.

As was shown in Table 1, COHb standards less than 7% are common, but these are set to protect susceptible groups, not to identify individuals for medical intervention. This is because CO does not poses huge and constant ill health symptoms amongst voluntary subjects with a COHb level below 10% (ACGIH, 2001). Many publications have tables of health effects relative to COHb levels (ILO Encyclopaedia, 1998; Leikauf & Prows, 2001; ATSDR, 2009; WHO EHC 213, 1999) and all show that for otherwise healthy non-pregnant subjects levels of COHb between 10 – 20% are associated with mild symptoms and clinically insignificant neurobehavioral features which do not require hospital-based medical observation over time.

There are some provisos to this recommendation. The first is where exposure to a mixture of gasses has occurred. CO exposure may occur with exposure to simple asphyxiants and nitrogen compounds. In these settings the COHb will underestimate the effects of exposure and clinical deterioration can occur many hours after exposure to some nitrogen compounds. The second is when the exposed individual has CAD or is pregnant. Even at COHb levels as low as 3%, workers with CAD may experience angina on exertion and at around 6% have increased ventricular arrhythmias. Workers with CAD and an elevated COHb level should be screened by a physician to determine whether admittance for observation is indicated. Pregnant women with elevated CO levels should also be screened by a doctor to elicit symptoms as symptomatic pregnant workers should be considered for oxygen therapy

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Appendix A – Summary calculations and results for a random selection of 20 samples.

Sample Number	1	2	3	4	5	6	7	8	9	10
Instrument Serial Number	10340	10350	10350	10350	10350	17723	17723	17723	17723	17723
Date of sampling	2012/01/04	2012/01/06	2012/01/07	2012/01/08	2012/01/10	2012/01/19	2012/01/21	2012/01/22	2012/01/24	2012/01/25
CO TWA (ppm) for shift	3.37	12.61	2.12	3.80	5.95	113.65	24.87	9.00	12.62	19.76
CO OEL (30 ppm)	30	30	30	30	30	30	30	30	30	30
% of TWA OEL (30 ppm) per shift	11.2%	42.0%	7.07%	12.68%	19.85%	378.82%	82.90%	30.01%	42.06%	65.88%
No. of times the OEL-C Has been exceeded.	0	0	0	0	0	75	5	0	0	0

Sample Number	11	12	13	14	15	16	17	18	19	20
Instrument Serial Number	17723	10350	10350	10350	10350	10350	10350	17010	17010	17010
Date of sampling	2012/01/26	2012/01/12	2012/01/13	2012/01/18	2012/01/19	2012/01/20	2012/01/21	2012/02/03	2012/02/04	2012/02/05
CO TWA (ppm) for shift	14.53	52.69	0.20	#VALUE!	9.13	9.75	2.38	3.49	7.29	1.95
CO OEL (30 ppm)	30	30	30	30	30	30	30	30	30	30
% of TWA OEL (30 ppm) per shift	48.44%	175.65%	0.66%	#VALUE!	30.44%	32.51%	7.92%	11.63%	24.31%	6.51%
No. of times the OEL-C Has been exceeded.	0	18	0	0	0	0	0	0	1	0

Appendix B – Summary of exposure indicators for a random selection of 20 samples.

Haemoglobin Test (Number of results):	1	2	3	4	5	6	7	8	9	10
Instrument Serial Number	10340	10350	10350	10350	10350	17723	17723	17723	17723	17723
Date of sampling	2012/01/04	2012/01/06	2012/01/07	2012/01/08	2012/01/10	2012/01/19	2012/01/21	2012/01/22	2012/01/24	2012/01/25
Concentration > 30 ppm exceeded "n" times	0	0	0	0	1	154	111	6	18	32
TWA OEL (30 ppm) exceeded	0	0	0	0	0	1	0	0	0	0
OEL-C (100 ppm) Exceeded "n" times	0	0	0	0	0	75	5	0	0	0
STEL (100 ppm for 15 Minutes) exceeded "n" times	0	0	0	0	0	26	0	0	0	0
Concentration > 400 ppm exceeded "n" times	0	0	0	0	0	51	0	0	0	0
Concentration > 200 ppm for 15 minutes exceeded "n" times	0	0	0	0	0	26	0	0	0	0
Concentrations > 100 ppm for 30 minutes exceeded "n" times	0	0	0	0	0	3	0	0	0	0
Concentrations > 60 ppm for 60 minutes exceeded "n" times	0	0	0	0	0	0	0	0	0	0

Haemoglobin Test (Number of results):	11	12	13	14	15	16	17	18	19	20
TWA OEL (30 ppm) exceeded	17723	10350	10350	10350	10350	10350	10350	17010	17010	17010
OEL-C (100 ppm) Exceeded "n" times	2012/01/26	2012/01/12	2012/01/13	2012/01/18	2012/01/19	2012/01/20	2012/01/21	2012/02/03	2012/02/04	2012/02/05
Concentration > 30 ppm exceeded "n" times	0	504	0	0	0	0	8	20	5	0

TWA OEL (30 ppm) exceeded	0	1	0	#VALUE!	0	0	0	0	0	0
OEL-C (100 ppm) Exceeded "n" times	0	18	0	0	0	0	0	0	1	0
STEL (100 ppm for 15 Minutes) exceeded "n" times	0	0	0	0	0	0	0	0	0	0
Concentration > 400 ppm exceeded "n" times	0	0	0	0	0	0	0	0	1	0
Concentration > 200 ppm for 15 minutes exceeded "n" times	0	0	0	0	0	0	0	0	0	0
Concentrations > 100 ppm for 30 minutes exceeded "n" times	0	0	0	0	0	0	0	0	0	0
Concentrations > 60 ppm for 60 minutes exceeded "n" times	0	0	0	0	0	0	0	0	0	0

Appendix C – Example of results for the establishment of a Carbon Monoxide Management Assistance Tool

Proposed Action to be taken	1	2	3	4	5	6	7	8	9	10
Instrument Serial Number	10340	10350	10350	10350	10350	17723	17723	17723	17723	17723
Date of sampling	2012/01/04	2012/01/06	2012/01/07	2012/01/08	2012/01/10	2012/01/19	2012/01/21	2012/01/22	2012/01/24	2012/01/25
Short term exposure above 30 ppm investigation to be conducted by crew	**No**	**No**	**No**	**No**	**No**	**YES**	**YES**	**YES**	**YES**	**YES**
Immediate withdrawal for 60 minutes before re-entry, due to OEL-C being exceeded	**No**	**No**	**No**	**No**	**No**	**YES**	**YES**	**No**	**No**	**No**
Complete withdrawal, due to STEL exceeded 4 or more times during any one shift	**No**	**No**	**No**	**No**	**No**	**YES**	**No**	**No**	**No**	**No**
Complete withdrawal, due to 400 ppm exposures being experienced during the shift	**No**	**No**	**No**	**No**	**No**	**YES**	**No**	**No**	**No**	**No**
Complete withdrawal, due to >200 ppm being experienced for more than 15 minutes during any one shift	**No**	**No**	**No**	**No**	**No**	**YES**	**No**	**No**	**No**	**No**
Complete withdrawal, due to >100 ppm being experienced for more than 30 minutes during any one shift	**No**	**No**	**No**	**No**	**No**	**YES**	**No**	**No**	**No**	**No**
Complete withdrawal, due to >60 ppm being experienced for more than 60 minutes during any one shift	**No**	**No**	**No**	**No**	**No**	**No**	**No**	**No**	**No**	**No**
Management investigation required, due to TWA OEL exceeding 30 ppm for the shift	**No**	**No**	**No**	**No**	**No**	**YES**	**No**	**No**	**No**	**No**

Proposed Action to be taken	11	12	13	14	15	16	17	18	19	20
Instrument Serial Number	17723	10350	10350	10350	10350	10350	10350	17010	17010	17010
Date of sampling	2012/01/26	2012/01/12	2012/01/13	2012/01/18	2012/01/19	2012/01/20	2012/01/21	2012/02/03	2012/02/04	2012/02/05
Short term exposure above 30 ppm investigation to be conducted by crew	**No**	**YES**	**No**	**No**	**No**	**No**	**YES**	**YES**	**YES**	**No**
Immediate withdrawal for 60 minutes before re-entry, due to OEL-C being exceeded	**No**	**YES**	**No**	**No**	**No**	**No**	**No**	**No**	**YES**	**No**
Complete withdrawal, due to STEL exceeded 4 or more times during any one shift	**No**	**No**	**No**	**No**	**No**	**No**	**No**	**No**	**No**	**No**
Complete withdrawal, due to 400 ppm exposures being experienced during the shift	**No**	**No**	**No**	**No**	**No**	**No**	**No**	**No**	**YES**	**No**
Complete withdrawal, due to >200 ppm being experienced for more than 15 minutes during any one shift	**No**	**No**	**No**	**No**	**No**	**No**	**No**	**No**	**No**	**No**
Complete withdrawal, due to >100 ppm being experienced for more than 30 minutes during any one shift	**No**	**No**	**No**	**No**	**No**	**No**	**No**	**No**	**No**	**No**
Complete withdrawal, due to >60 ppm being experienced for more than 60 minutes during any one shift	**No**	**No**	**No**	**No**	**No**	**No**	**No**	**No**	**No**	**No**
Management investigation required, due to TWA OEL exceeding 30 ppm for the shift	**No**	**YES**	**No**	#VALUE!	**No**	**No**	**No**	**No**	**No**	**No**

Appendix D – Ethical Approval

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M140349

NAME: (Principal Investigator) Mr JJ van Staden

DEPARTMENT: School of Public Health
Anglo American Mines, Rusternburg, Northwest province

PROJECT TITLE: Exposure to carbon monoxide in an underground trackless mine during the period May 2012- December 2012

DATE CONSIDERED: 28/03/2014

DECISION: Approved unconditionally

CONDITIONS:

SUPERVISOR: Dr A Swanepoel

APPROVED BY: Professor PE Cleaton-Jones, Chairperson, HREC (Medical)

DATE OF APPROVAL: 14/05/2014

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Secretary in Room 10004, 10th floor, Senate Hou
University.
I/we fully understand the conditions under which I am/we are authorized to carry out the above-mentioned resea
and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated, from
research protocol as approved, I/we undertake to resubmit the application to the Committee. **I agree to subm**

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

Appendix E – Permission Letter from Employer

AngloAmerican

PLATINUM

ANGLO PLATINUM LIMITED
Rustenburg Platinum Mines Limited

MAIN OFFICES
Klipfontein
Rustenburg
0292
South Africa

29 November 2013

TO WHOM IT MAY CONCERN:

CONFIRMATION OF EMPLOYMENT FOR JACOBUS JOHANNES VAN STADEN (99000656)

This serves to confirm that **JACOBUS JOHANNES VAN STADEN (99000656)** is a Permanent Employee of Anglo Platinum.

PersNo	99000656	Jacobus Johannes Van Staden			
Empl Group	Mines: Active Emp		Empl Subgroup	Snr Management(TP)	
Pers Area	HR51	RS Central Services	Pers SubArea	Safety & Health	
Start	01.10.2011	to 31.12.9999	Chng	06.10.2011	BATCHJOBS

Enterprise structure

CoCode	R000	Rustenburg Platinum Mine			
Pers.area	HR51	RS Central Services	Subarea	SH01	Safety & Health
Cost Ctr	R0010	Occupational Hygiene	Bus. Area		

Personnel structure

EE group	A	Mines: Active Emp	Payr.area	TP	Snr Management(TP)
EE subgroup	TP	Snr Management(TP)	Contract		

Organizational plan

Percentage	100,00	
Position	70314465	OCCHYGIENEMN
		Occupational Hygiene..
Job key	99004100	OCCHYGIENEMN
		Occupational Hygiene..
Org. Unit	11000010	M64000001083
		M64000001083 Occu..
Org.key	HR51SH01	

Administrator

Group	HR51	
PersAdmin	AA	Centr serv
Time	T01	Central Services A
PayrAdmin	P01	UMO ADMIN
Supervisor		

Permission is granted to obtain internal records for his study at WITS.

Yours sincerely

B DOYLE
OCCUPATIONAL HYGIENE MANAGER

A member of the Anglo American plc group

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