Appraisal of medical and exposure data to estimate the occupational carcinogenic risk in coal mines: a pilot study

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It all starts here ™

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PREFACE

Article format was decided upon for this mini-dissertation with accordance to the General Academic Rules (Rules A.13.7.3) of the North-West University. For the sake of uniformity, the entire mini-dissertation was done according to the guidelines of the chosen journal for possible publication, i.e. “Annals of Occupational Hygiene”. This journal requires that the references be set out in Vancouver style. The list of references are given at the end of each chapter in alphabetical order. Details regarding the specifications and referencing for the journal are specified and can be found at the beginning of Chapter 3 in the author’s instructions. The preferred language of this mini-dissertation is English and the document has been proof-read and edited by a competent person. The researcher is aware of the journal’s name change in 2017 to “Annals of Work Exposures and Health”.

Chapter 1 provides a brief overview of the coal mining environment and mining methods used in the coal mining industry. The problem statement, research objectives and the research question are included in this section. Chapter 2 comprises a thorough discussion of the health risks associated with working in a coal mine, the various occupational carcinogens potentially present in the coal mining environment, as well as the cancer types caused when exposed thereto. Mining techniques are also discussed to portray an improved image of how occupational carcinogen exposure can lead to the development of cancer. Chapter 3 is written in article format where tables and figures comprehensively represent the results retrieved from the historical data. Chapter 4 is the concluding chapter with a further discussion concerning the results, recommendations and limitations of the study.

In order to prevent confusion, please note that the occupation descriptions retrieved from the historical medical data and historical exposure monitoring data were not identical, and the researcher had to generate a reliable comparison between the different occupation descriptions in order to equate the individual data sets. The comparison can be seen in Chapter 3 under Supplementary Material.

AUTHORS' CONTRIBUTIONS

The study was planned and executed by a team of researchers. The contribution of each researcher is listed below:

Name	Contribution
Miss. L Myburgh	1. Principle researcher 2. Designing and planning of the study 3. Application for HREC (Health Research Ethics Committee) approval 4. Literature researches, interpretation of data and writing of article 5. Writing of mini-dissertation
Prof. FC Eloff	1. Supervisor 2. Assisted with approval of protocol, the interpretation of results and documentation of the study 3. Provided guidance with specific aspects of this study 4. Assisted with the design and planning of the study 5. Professional input and recommendations 6. Assisted with communication with the mine 7. Review of the mini-dissertation
Mr. SJL Linde	1. Co-supervisor 2. Assisted with approval of protocol, the interpretation of results and documentation of the study 3. Provided guidance with specific aspects of this study 4. Assisted with the design and planning of the study 5. Professional input and recommendations 6. Review of the mini-dissertation

The following is a statement from the supervisors that confirms each individual's role in the study:

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

_____ _____

Prof. FC Eloff Mr. SJL Linde

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I would like to express my profound gratitude to my parents for the opportunity to study, for their guidance, patience, love and support and always encouraging me to be the best I can be. **Dankie Mamma en Pappa! Ek is lief vir julle.**

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SUMMARY

Title: Appraisal of medical and exposure data to estimate the occupational carcinogenic risk in coal mines: a pilot study.

Background: The coal mining environment presents the occupational hygienist with numerous challenges which need to be overcome on a daily basis. Workers employed in either underground or opencast coal mines run the risk of being exposed to countless hazards. Accidents, explosions, poor underground ventilation, and the development of respiratory diseases are a few of the risks and hazards workers can be exposed to. Exposure to occupational carcinogens adds to the list of hazards present in a coal mine, and exposure can occur through inhalation, ingestion or even skin contact.

Aims and objectives: The study aimed to provide an improved understanding of the various occupational carcinogens, as well as the carcinogenic risk present in the South African coal mining environment through the appraisal of historical medical and exposure monitoring data. This study also aimed to establish if a relationship exists between occupational exposure to carcinogens and the development of cancer among coal mine workers. Cancer incidence, in this study, refers to the proportion of coal mine workers who developed cancer during a particular time period (i.e. 2009-2015) and not to the number of new cancer cases occurring in the coal mine worker population during a specific time period (CDC, 2012).

Methods: Published literature was evaluated to identify occupational carcinogens present in a coal mine, as well as the cancer types linked to the occupational exposure to these carcinogens. Historical medical data was assessed to determine the cancer types and the frequency at which they occurred among the coal miners from ten coal mines. Historical exposure monitoring data and risk assessments were used to determine the highest exposed groups in specifically an underground coal mining environment due to the higher risk involved when compared to an opencast coal mine. Lastly, the relationship between the diagnosed cancer incidences and the exposure of coal mine workers to the identified occupational carcinogens were established. Effect size, including odds ratios (OR) and relative risk (RR), were used to describe the relationships between the various factors involved in occupational carcinogen exposure as well as the development of cancer. Ethical approval from the Health Research Ethics Committee (HREC) of the North-West University was obtained (NWU-00069-16-A1).

Results: Various occupational carcinogen exposures, such as respirable dust (coal mine dust and crystalline silica dust) liberated during day-to-day coal mining processes, were identified and retrieved from the results. The historical medical data showed the diagnosis of various cancer types in numerous occupations in the ten coal mines. Prostate cancer had the highest incidence

rate (40.7%) of the 32 total cancer incidences and respiratory cancers had the second highest incidence rate (37.5%). The multi-task worker, mostly responsible for production activities, had the highest exposure to occupational carcinogens of all the occupations, as well as the highest cancer incidence rate (25%) of the 32 total cancer incidences. The risk of developing cancer was similar at all mine types with ratios indicated as 1.02 in 1 000 workers (underground (UG)), 1.25 in 1 000 workers (opencast (OC)), and 1.24 in 1 000 workers (combination mine (OC + UG).

***Conclusions*:** Historical data confirmed the presence of various occupational carcinogens (coal mine dust and silica dust) in a coal mining environment, as well as the risk of developing occupational cancer among coal mine workers. The occupations presenting the highest risk to workers for the development of cancer, as well as the exposure to occupational carcinogens were the multi-task worker and the maintenance occupations.

Keywords: occupational exposure; occupational carcinogen; occupational hygiene; occupational carcinogen exposure; cancer; coal mine; historical data

OPSOMMING

Titel: Evaluasie van mediese- en blootstellingsdata om die karsinogeniese risiko van werk in ‘n steenkoolmyn te bepaal: ‘n loodsstudie.

Agtergrond: Die steenkoolmynbedryf bied ‘n groot verskeidenheid uitdagings aan die beroepshigiënis op ‘n daaglikse basis. Werkers wat deel vorm van die werksmag van ‘n ondergrondse- of oopgroef-steenkoolmyn loop die risiko vir blootstelling aan menigte gevare. Ongelukke, ontploffings, swak ondergrondse ventilasie, en die ontwikkeling van respiratoriese siektes is slegs ‘n paar van die gevare waaraan werkers blootgestel kan word. Beroepsblootstelling aan karsinogene kan bygevoeg word tot die lys van risiko’s reeds teenwoordig in ‘n steenkoolmyn, en blootstelling kan plaasvind deur inaseming-, ingestie-, of selfs velblootstelling.

Doelstellings en doelwitte: Hierdie studie se doel was om ‘n beter begrip te kry van die verskeie karsinogene en die karsinogeniese risiko teenwoordig in die Suid-Afrikaanse steenkoolmynbedryf, deur historiese mediese- en blootstellingsdata te evalueer. Nog ‘n doel van hierdie studie was om te bepaal of ‘n verband bestaan tussen die beroepsblootstelling aan karsinogene en die ontwikkeling van kanker by steenkoolmynwerkers. Kankergevalle, in hierdie studie, verwys na die proporsie steenkoolmynwerkers wat kanker ontwikkel het gedurende ‘n spesfieke tydperk (o.a. 2009-2015) en nie die aantal nuwe kankergevalle in die steenkoolwerker populasie nie (CDC, 2012).

Metodes: Reeds gepubliseerde literatuur is bestudeer om die karsinogene wat moontlik teenwoordig is in ‘n steenkoolmyn te identifiseer en die kanker-tipes gekoppel aan die beroepsblootstelling van die karsinogene te bepaal. Statistiese analise van die historiese data het meestal bestaan uit beskrywende statistiek (gemiddeld, minimum, maksimum, frekwensies, persentasies). Historiese mediese data is geanaliseer om die kanker-tipes en die frekwensies waarvolgens hulle gediagnoseer is, onder die werkers van 10 steenkoolmyne, te bepaal. Historiese blootstellingsdata en risikoramings is ook gebruik om die hoogste blootgestelde beroepsgroepe te bepaal in ‘n ondergrondse steenkoolmyn as gevolg van die hoër risiko teenwoordig in vergelyking met ‘n oopgroef-steenkoolmyn. Laastens is die verhouding tussen die gediagnoseerde kankergevalle en die blootstelling van die steenkoolmynwerkers aan die karsinogene bepaal. Effekgroottes, wat waarskynlikheids verhoudings (odds ratios) en relatiewe risiko’s (relative risks) ingesluit het, is gebruik om die verhoudings tussen verskeie faktore, betrokke by beroepsblootstelling aan karsinogene, sowel as die ontwikkeling van kanker te bepaal. Etiese goedkeuring is ontvang vanaf die “Health Research Ethics Committee (HREC)” van die Noordwes-Universiteit (NWU-00069-16-A1).

Resultate: Die teenwoordigheid van verskeie beroepsblootstellings aan karsinogene (steenkoolstof en silika stof) wat vrygestel word gedurende dag-tot-dag steenkoolmyn-prosesse is vanaf die resultate verkry. Die historiese mediese data het die diagnose van verskeie kanker-tipes in talle beroepe, bekleë deur steenkoolmynwerkers, uitgewys. Die voorkoms van prostaatkanker was die hoogste (40.7%) van die 32 kankergevalle en die respiratoriese kankers het die tweede hoogste aantal gevalle gehad (37.5%). Die multi-taak werker, wat verantwoordelik is vir produksie-aktiwiteite, het die hoogste blootstelling aan karsinogene gehad, sowel as die hoogste kankervoorkoms (25%) van die 32 totale kankergevalle. Die risiko vir kankerontwikkeling was soortgelyk met die verhoudings aangedui as - 1.02 uit 1 000 werkers (UG); 1.25 uit 1 000 werkers (OC); 1.24 uit 1 000 werkers (OC + UG).

***Gevolgtrekkings*:** Historiese data het die teenwoordigheid van verskeie karsinogene (steenkoolstof en silika stof) bevestig asook die risiko vir die ontwikkeling van kanker onder die werkers. Die beroepe wat die hoogste risiko het vir die ontwikkeling van kanker, sowel as die beroepsblootstelling aan karsinogene was die multi-taak werkers en die beroepe verantwoordelik vir die onderhoud in die myn.

Sleutelwoorde: beroepsblootstelling; beroepsblootstelling aan karsinogene; beroepshigiëne; kanker; steenkoolmyn; historiese data

LIST OF SYMBOLS AND ABBREVIATIONS

^{214}Po	Polonium-214, radon radioactive decay product
^{218}Po	Polonium-218, radon radioactive decay product
^{222}Rn	Radon 222 isotope
ACGIH	American Conference of Governmental Industrial Hygienists
As	Arsenic
ATSDR	Agency for Toxic Substances and Disease Registry
Be	Beryllium
C_2HCl_3	Trichloroethylene
CANSA	Cancer Association of South Africa
CCOHS	Canadian Centre for Occupational Health and Safety
Cd	Cadmium
CH_4	Methane
CM	Continuous miner
CWP	Coal Workers' Pneumoconiosis
DME	Department of Minerals and Energy
DMR	Department of Mineral Resources
DNA	Deoxyribonucleic acid
DoL	Department of Labour, New Zealand
DPM	Diesel Particulate Matter
ELF EMF	Extremely Low-Frequency ElectroMagnetic Fields
EMRS	Electronic Medical Record System
EU	European Union
GLOBOCAN	Global Burden of Cancer Study
HCS	Hazardous Chemical Substance
HEG	Homogenous Exposure Group
HSE	Health and Safety Executive
IACR	International Association of Cancer Registries
IARC	International Agency for Research on Cancer
ICD-10	International Classification of Diseases, Tenth Revision
IEA	International Energy Agency
IMSIF	Illinois Mine Subsidence Insurance Fund
MHSA	Mine Health and Safety Act, South Africa
MSDS	Material Safety Data Sheet
NCR	National Cancer Registry
NHLS	National Health Laboratory Service

NIOH	National Institute for Occupational Health
NIOSH	National Institute for Occupational Safety and Health
NTP	National Toxicology Program
OC	Opencast coal mine
OC + UG	Combination mine incorporating underground and opencast mining
OEL	Occupational Exposure Limit
OR	Odds Ratio
OSHA	Occupational Safety and Health Administration
PAH	Polycyclic aromatic hydrocarbons
PPE	Personal Protective Equipment
RAE	Relative Asbestos Effect
RR	Relative Risk
SA	South Africa
SAMOHP	South African Mines Occupational Hygiene Programme
Stats SA	Statistics South Africa
tHS	theHealthSource
UG	Underground coal mine
US	United States
USA	United States of America
UVR	Ultraviolet radiation
WCA	World Coal Association
WCI	World Coal Institute
WEC	World Energy Council
WHO	World Health Organisation
δ_{OR}	Standardised difference of odds ratio

STANDARD UNITS

%	percentage
µg/m^3	microgram per cubic metre
Hz	Hertz
km^2	square kilometres
m	meters
mg/m^3	milligram per cubic metre
Mt	million tonnes
ppm	parts per million
R	South African Rand

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CHAPTER 1: INTRODUCTION

1.1 Overview

Coal mining is a high risk occupation where coal miners are exposed to various hazardous substances, including carcinogens, and occupational exposure to these substances may lead to the development of occupational illnesses and cancer (Maiti and Bhattacherjee, 1999; Donoghue, 2004; Schneider, 2014). Due to the thousands of people employed by South African coal mines, it is crucial to focus on the health risks associated with occupational carcinogen exposure in a coal mine as well as the measures implemented to control and/or minimise these exposures (WCI, 2009; Chamber of Mines of South Africa, 2015).

The aim of this study is to evaluate the occupational carcinogenic risk in South African coal mines. In order to achieve this, historical medical data and historical exposure monitoring data were evaluated to determine if a correlation existed between the reported cancer incidences found in the medical data and the exposure of workers to carcinogenic substances found in the exposure monitoring data. Cancer incidence, in this study, refers to the proportion of coal mine workers who developed cancer during a particular time period (i.e. 2009-2015) and not to the number of new cancer cases occurring in the coal mine worker population during a specific time period (CDC, 2012).

1.2 Problem statement

Coal mining is an ancient occupation that has long been considered laborious and of extremely high risk (Donoghue, 2004). Coal miners working directly at the coal face, where extraction of coal occurs, have an especially high risk of being exposed to a variety of health and safety hazards (Edmonds and Kerr, 1960; WCI, 2009). Safety hazards can range from rock falls, to fires and explosions, whereas health hazards can include exposure to various hazardous substances with the potential of causing occupational illnesses (Donoghue, 2004; CCOHS, 2009).

Mining of coal occurs either above ground in open cast mines or underground in deep mines (WCA, 2013). Underground mining processes involve a much higher health and safety risk than opencast mining due to difficulties associated with the ventilation with clean air, the removal of hazardous substances and dust particles as well as the mining activities performed by the workers (WCI, 2009). Underground and opencast mine workers are regularly exposed to larger amounts of hazardous substances and dust particles than the general population, which increases the risk of occupational disease and illness (Maiti and Bhattacherjee, 1999; Schneider, 2014).

According to the Chamber of Mines of South Africa (2015) the average number of people employed in the coal mining industry increased from 50 327 to 87 768 between 2004 and 2013. Coal is utilised in the production of almost 40% of the world's electricity, with South Africa relying on coal for more than 80% of its electricity production (WCI, 2009; Chamber of Mines of South Africa, 2015). South African coal mines produced 260 million tons of coal in 2014, which represents an increase of 126% from the 115 million tons produced in 1980 (Stats SA, 2012). Therefore, it is important to consider the possible health risks and hazards involved in the coal mining industry as the demand for coal has increased tremendously (Chamber of Mines, 2015; Stats SA, 2015).

Airborne hazardous substances, which can refer to dust, smoke, gases or fumes, can pose a risk either through inhalation (Unsted, 2001; León-Mejía *et al*., 2014) which can potentially cause occupational lung diseases, or skin contact which can cause skin irritation or sensitisation (Baxter and Waldron, 1989). Occupational exposure to airborne and other pollutants can include non-carcinogenic as well as carcinogenic substances (Siemiatycki *et al*., 2004). Non-carcinogenic substances are defined as substances that show no carcinogenic effects when workers are exposed to them in low concentrations. The reason for the absence of adverse effects is that the body has a threshold below which it is able to recover from the exposure. The dose-response curve of carcinogenic substances shows no threshold, referring to the accumulation of all recurring exposures which the body does not recover from and the fact that any exposure, even at a very low dose, will increase the risk of developing cancer (Masters, 1998; Nazaroff and Alvarex-Cohen, 2001).

Carcinogens are defined as agents that induce carcinogenesis which ultimately lead to the development of cancer. Carcinogenesis is a multistage process involving malfunctioning in a number of normal cellular processes. At molecular and cellular level, respectively, critical proteins will be altered and the proliferation of cells will follow. Cancer is a disease characterised by mutation, cell proliferation and abnormal cell growth and the formation of benign or malignant neoplasms (Gregus, 2013; Klaunig, 2013).

Carcinogenic effectiveness or potency can be assessed by using a linear model (see Figure 1-1). The linear model implies that exposure to a carcinogenic substance at any level will have an increase in cancer risk. The associated cancer risk will increase proportionally with an increase in exposure (Schoen, 2012). Although no dose occurs with absolutely zero risk, the risk will decrease proportionally with a decreasing dose (Eaton and Gilbert, 2013).

Due to the delay between exposure to a carcinogen and the first sign of an adverse effect, it is difficult to establish the initial cause of certain occupational cancers (Schneider, 2014). Another contributing factor to cancer development is the exposure to carcinogens outside the working

environment. Occupational cancer is a leading cause of death worldwide even though exposures to occupational carcinogenic chemicals are largely preventable (Tulchinsky and Varavikova, 2014; Takala, 2015). Occupational carcinogens are one of the many hazards coal miners are exposed to and it they have attracted substantial attention due to the damaging effects they can have on occupational health (McCormack and Shüz, 2012; León-Mejía *et al.*, 2014).

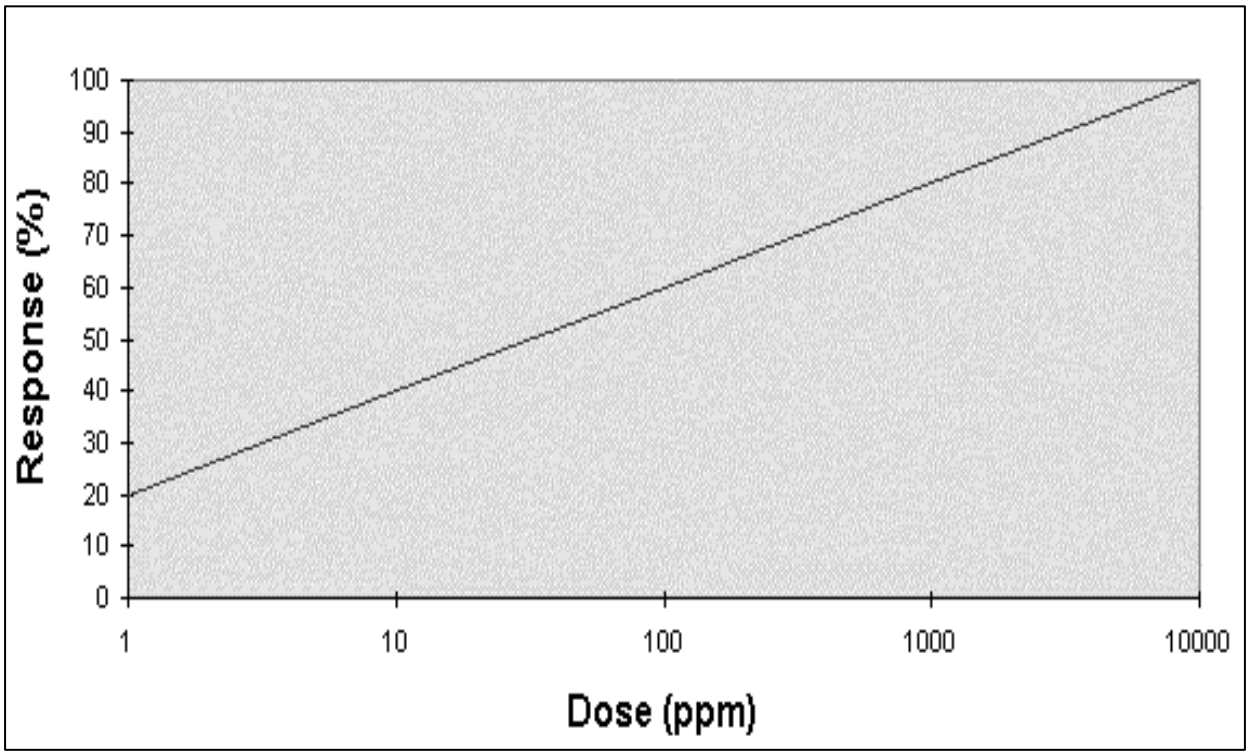


Figure 1-1: Linear model explaining the effectiveness of carcinogens (Environ, 1986)

Major class action lawsuits in South Africa and globally have considerable legal implications for major mining companies. These lawsuits focus the attention on the health risks associated with working in a mine - be it a coal mine or gold mine – as well as the health risks affecting the general population and the environment (Jamasmie, 2016; Povtak, 2016). An example of a South African class action lawsuit – involving up to half a million mine workers – that will be taking place in the near future, is the silicosis class action lawsuit against the gold mining companies (Jamasmie, 2016).

According to previously published literature, the following occupational carcinogens have been identified to potentially be present in coal mines (refer to Table 1-1).

Table 1-1: List of occupational carcinogens potentially present in a coal mine

Occupational carcinogen	Reference(s)
Arsenic	IARC*, 2012a
Asbestos	Driscoll *et al*., 2004 IARC*, 2012a Takala, 2015
Beryllium	IARC*, 2012a
Cadmium	IARC*, 2012a
Coal mine dust	Swaen *et al*., 1985; Swaen *et al*., 1995 Brown *et al*., 1997 IARC*, 1997
Crystalline silica (Quartz)	Borm and Tran, 2001 NIOSH, 2011 Jenkins *et al*., 2013
Diesel engine exhaust (including diesel particulate matter (DPM))	Claxton, 2014 IARC*, 2014a
Extremely low-frequency electromagnetic fields (ELF EMF)	Gilman *et al.*, 1985 IARC*, 2002
Polycyclic aromatic hydrocarbons (PAHs)	IARC*, 2010
Radon (^{222}Rn)	IARC*,1988
Trichloroethylene	IARC*, 2014b
Ultraviolet radiation (UVR)	IARC*, 1992 IARC*, 2012b
Welding-related exposures	IARC*, 1990 Siemiatycki *et al.*, 2004

***** IARC The International Agency for Research on Cancer

The abovementioned literature indicates that coal mine workers are exposed to a variety of carcinogens over the period of their employment through various routes of exposure (IARC, 1997; Jenkins *et al*., 2013; Hung *et al*., 2014; León-Mejía *et al.*, 2014). The South African Mine Health and Safety Act (MHSA) (29 of 1996) indicates the importance for employers to protect the health and safety of all workers at a mine. This creates the need to establish, maintain, and record occupational health and safety data.

The Department of Mineral Resources (DMR) considers an occupational hygiene database, which includes medical and exposure monitoring data, as essential to determine the relationship

between worker exposure and the development of occupational related diseases. Other factors that will encourage the proper maintenance of such a database are the general lack of information relating to the occurrence of exposure to hazardous substances, as well as the inability to determine the relationship between exposure and the development of occupational diseases. The biggest concern is that corrective action is mostly focused on the symptom rather than the cause (DME, 2002).

A medical surveillance system must be implemented and well maintained by the employer and periodic medical examinations should be performed as seen to be fit. All medical examination reports must be recorded to ensure that sufficient information is available in order to eliminate, control and minimise the health risk and hazards to which the workers are or may be exposed to. Recording of these medical examinations will also allow the employer to prevent, detect and treat occupational diseases (MHSA, 1996).

Due to the thousands of people employed by South African coal mines, it is crucial to focus on the risk associated with occupational carcinogen exposure. Protecting the workers from unnecessary occupational carcinogen exposure will prevent or reduce the development of cancer later in life. This research study could lead to further investigations to ensure that mining companies have the required knowledge concerning the protection of worker health against unwanted exposure to carcinogens and the development of occupational cancers. The understanding and awareness of health risks initiated by occupational carcinogen exposure in coal mines can also be improved immensely by this research study. The aforementioned factors could also result in the improvement of occupational health monitoring programmes utilised by mining companies in South Africa to ensure the optimal protection of worker health.

1.3 Research aim and objectives

1.3.1 Aim of the study

To appraise the historical medical data of ten thermal coal mines, as well as the historical exposure data of one high risk underground thermal coal mine in South Africa in order to evaluate the occupational carcinogenic risk in coal mines.

1.3.2 Objectives of the study

- To perform a comprehensive literature study in order to identify occupational carcinogens potentially present in a coal mine, as well as the cancer types linked to the occupational exposure thereto.

- To assess the workers' historical medical data received from ten South African thermal coal mines to determine the types of cancer that were diagnosed as well as the frequencies at which they occurred.

- To assess the historical exposure monitoring data and risk assessments received from the high risk South African underground thermal coal mine:

(a) To determine which workers can be identified as the highest exposed groups; and

(b) To determine if these groups have received the necessary attention in terms of monitoring and control of exposure.

Underground mining poses a much higher health risk than opencast mining as mentioned previously and the high risk South African underground thermal coal mine was used to describe the highest exposed groups found in a coal mine.

- To establish if a relationship exists between the cancer incidences in the historical medical data and the exposure of coal mine workers to the corresponding carcinogens that may lead to the specific types of cancer by using basic descriptive statistics as well as effect sizes.

1.4 Research question

Various studies have linked carcinogen exposure to an occupational environment, such as a coal mine, to the development of several types of cancer (Driscoll *et al.*, 2004; Graber, 2012; Rushton *et al.*, 2012; IACR (International Association of Cancer Registries), 2014; Van Tongeren, 2015).

Therefore it is crucial to ask the following question:

Does a relationship exist between occupational carcinogen exposure and the development of occupational cancer in the South African coal mines used for this study?

1.5 References

Baxter PJ, Waldron HA. (1989) The introduction and monitoring of occupational diseases. *In* Waldon HA, editor. Occupational Health Practice. London, UK: Butterworths. p. 41-72. ISBN 0 407 33702 4.

Borm PJA, Tran L. (2001) From quartz hazard to quartz risk: the coal mines revisited. *Ann Occup Hyg*; **46**: 25-32.

Brown AM, Christie D, Taylor R, *et al*. (1997) The occurrence of cancer in a cohort of New South Wales coal miners. *Aust NZ J Publ Heal*; **21**: 29-32.

CCOHS (Canadian Centre for Occupational Health and Safety). (2009) Hazard and risk. Available from: URL: https://www.ccohs.ca/oshanswers/hsprograms/hazard_risk.html (accessed 27 February 2016)

CDC (Centers for Disease Control and Prevention). (2012) Section 2: Morbidity frequency measures. Available from: URL: https://www.cdc.gov/ophss/csels/dsepd/ss1978/lesson3/section2.html (accessed 12 April 2017)

Chamber of Mines of South Africa. (2015) Facts and figures 2013/2014. Available from: URL: http://www.chamberofmines.org.za/media-room/facts-and-figures (accessed 28 April 2015)

Claxton LD. (2014) The history, genotoxicity, and carcinogenicity of carbon-based fuels and their emissions. Part 3: Diesel and gasoline. *Mutat Res*; **763**: 30-85.

DME (Department of Minerals and Energy). (2002) SAMOHP (South African Mines Occupational Hygiene Programme): Codebook. Available from: URL: http://www.mhsc.org.za/sites/default/files/Guide%20line%20SAMHOP%20_codebook.pdf (accessed 12 June 2015)

Donoghue AM. (2004) Occupational health hazards in mining: an overview. *Occup Med*; **54**: 283-289.

Driscoll T, Steenland K, Prüss-Üstün A, *et al*. (2004) Occupational carcinogens: assessing the environmental burden of disease at national and local levels. Environmental burden of disease series, no. 6. Available from: URL: http://www.who.int/quantifying_ehimpacts/publications/en/ebd6.pdf?ua=1 (accessed 21 April 2015)

Eaton DL, Gilbert SG. (2013) Principles of toxicology. *In* Klaassen CD. editor. Casarett and Doull's Toxicology: The basic science of poisons. 8th ed. China: McGraw-Hill Education. p. 13-48. ISBN 978 0 07 176925 9.

Edmonds OP, Kerr DS. (1960) Observations of the occupational life history of the coal-face worker at two collieries. *Brit J Ind Med*; **17**: 234-237.

Environ. (1986) Elements of toxicology and chemical risk assessment: a handbook for non-scientists, attorneys and decision makers. Washington, DC: Environ Corporation. ISBN 0 89116 468 5.

Gilman P, Ames RG, McCawley MA. (1985) Leukemia risk among U.S. white male coal miners: A case-control study. *J Occup Environ Med*; **27**.

Graber JMA. (2012) Morbidity and mortality among underground coal miners. Available from: URL: http://pqdtopen.proquest.com/doc/1286732006.html?FMT=ABS&pubnum=3551418 (accessed 17 November 2015)

Gregus Z. (2013) Mechanisms of toxicity. *In* Klaassen CD. editor. Casarett and Doull's Toxicology: The basic science of poisons. 8th ed. China: McGraw-Hill Education. p. 49-122. ISBN 978 0 07 176925 9.

Hung YP, Teng CJ, Liu CJ, *et al*. (2014) Cancer risk among patients with coal workers' pneumoconiosis in Taiwan: A nationwide population-based study. *Int J Cancer*; **134**: 2910-2916.

IACR (International Association of Cancer Registries). (2014) Cancer incidence in five continents (Volume X): IARC Scientific Publications No. 164. Available from: URL: https://www.iarc.fr/en/publications/pdfs-online/epi/sp164/CI5volX_Full.pdf (accessed 14 May 2015)

IARC (International Agency for Research on Cancer). (1988) Monographs on the evaluation of carcinogenic risks to humans (Volume 43): Man-made mineral fibres and radon. Available from: URL: http://monographs.iarc.fr/ENG/Monographs/vol43/mono43.pdf (accessed 28 April 2015)

IARC (International Agency for Research on Cancer). (1990) Monographs on the evaluation of carcinogenic risks to humans (Volume 49): Chromium, nickel and welding. Available from: http://monographs.iarc.fr/ENG/Monographs/vol49/mono49.pdf (accessed 1 February 2016)

IARC (International Agency for Research on Cancer). (1992) Monographs on the evaluation of carcinogenic risks to humans (Volume 55): Solar and ultraviolet radiation. Available from: URL: http://monographs.iarc.fr/ENG/Monographs/vol55/mono55.pdf (accessed 3 February 2016)

IARC (International Agency for Research on Cancer). (1997) Monographs on the evaluation of carcinogenic risks to humans (Volume 68): Silica, some silicates, coal dust and para-amid fibrils. Available from: URL: http://monographs.iarc.fr/ENG/Monographs/vol68/mono68.pdf (accessed 16 June 2016)

IARC (International Agency for Research on Cancer). (2002) Monographs on the evaluation of carcinogenic risks to humans (Volume 80): Non-ionizing radiation, Part 1: Static and extremely low-frequency (ELF) electric and magnetic fields. Available from: URL: http://monographs.iarc.fr/ENG/Monographs/vol80/mono80.pdf (accessed 7 January 2016)

IARC (International Agency for Research on Cancer). (2010) Monographs on the evaluation of carcinogenic risks to humans (Volume 92): Some non-heterocyclic polycyclic aromatic hydrocarbons and some related exposures. Available from: URL: http://monographs.iarc.fr/ENG/Monographs/vol92/mono92.pdf (accessed 22 April 2015)

IARC (International Agency for Research on Cancer). (2012a) Monographs on the evaluation of carcinogenic risks to humans (Volume 100C): Arsenic, metals, fibres, and dusts. Available from: URL: http://monographs.iarc.fr/ENG/Monographs/vol100C/mono100C.pdf (accessed 28 April 2015)

IARC (International Agency for Research on Cancer). (2012b) Monographs on the evaluation of carcinogenic risks to humans (Volume 100D): Radiation. Available from: URL: http://monographs.iarc.fr/ENG/Monographs/vol100D/index.php (accessed 14 March 2016)

IARC (International Agency for Research on Cancer). (2014a) Monographs on the evaluation of carcinogenic risks to humans (Volume 105): Diesel and gasoline engine exhausts and some nitroarenes. Available from: URL: http://monographs.iarc.fr/ENG/Monographs/vol105/mono105.pdf (accessed 22 April 2015)

IARC (International Agency for Research on Cancer). (2014b) Monographs on the evaluation of carcinogenic risks to humans (Volume 106): Trichloroethylene, tetrachloroethylene, and some other chlorinated agents. Available from: URL: http://monographs.iarc.fr/ENG/Monographs/vol106/index.php (accessed 6 January 2016)

Jamasmie C. (2016) South Africa allows biggest ever class action against gold giants to go ahead. Available from: URL: http://www.mining.com/south-africa-allows-biggest-ever-class-action-lawsuit-against-gold-giants-to-go-ahead/ (accessed 5 September 2016)

Jenkins WD, Christian WJ, Mueller G, Robbins KT. (2013) Population cancer risks associated with coal mining: a systematic review. *Plos One*; **8**: 1-12.

Klaunig JE. (2013) Chemical carcinogenesis. *In* Klaassen CD. editor. Casarett and Doull's Toxicology: The basic science of poisons. 8th ed. China: McGraw-Hill Education. p. 393-443. ISBN 978 0 07 176925 9.

León-Mejía G, Quintana M, Debastiani R, *et al*. (2014) Genetic damage in coal miners evaluated by buccal micronucleus cytome assay. *Ecotox Environ Safe*; **107**: 133-139.

Maiti J, Bhattacherjee A. (1999) Evaluation of risk of occupational injuries among underground coal mine workers through multinomial logit analysis. *J Safety Res*; **30**: 93-101.

Masters GM. (1998) Introduction to environmental engineering and science. Englewood, NJ: Prentice Hall. p. 117-157. ISBN 9 780 131553 84 2.

McCormack VA, Schüz J. (2012) Africa's growing cancer burden: environmental and occupational contributions. *Cancer Epidem*; **36**: 1-7.

MHSA (Mine Health and Safety Act and Regulations). (1996) Act 29 of 1996. Lexis Nexis. ISBN 978 0 409 12279 4.

Nazaroff WW, Alvarex-Cohen L. (2001) Environmental engineering science. NY: John Wiley and Sons. p. 396-397, 569-573. ISBN 9 78 0471144 9 46.

NIOSH (National Institute for Occupational Safety and Health). (2011) Current Intelligence Bulletin 64: Coal mine dust exposures and associated health outcomes. Available from: URL: http://www.cdc.gov/niosh/docs/2011-172/pdfs/2011-172.pdf (accessed 2 March 2015)

Povtak T. (2016) Class action lawsuits. Available from: URL: https://www.asbestos.com/mesothelioma-lawyer/class-action-lawsuit.php (accessed 5 September 2016)

Rushton L, Hutchings SJ, Fortunato L, *et al*. (2012) Occupational cancer burden in Great Britain. *Brit J Cancer*; **107**: S3-S7.

Schneider MJ. (2014) Introduction to public health. Burlington, MA: Jones and Bartlett Learning. ISBN 978 1 4496 8887 5.

Schoen D. (2012) Threshold vs. non-threshold carcinogens. Available from: URL: http://standards.nsf.org/apps/group_public/download.php/18366/threshold%20carcinogens%20vs%20non-threshold%20carcinogens.pdf (accessed 5 March 2016)

Siemiatycki J, Richardson L, Straif K, *et al*. (2004) Listing occupational carcinogens. *Environ Health Persp*; **112**: 1447-1459.

Stats SA (Statistics South Africa). (2012) National Accounts: Mineral accounts for South Africa (1980-2009). Available from: URL: http://www.statssa.gov.za/publications/D04052/D040522009.pdf (accessed 1 February 2016)

Stats SA (Statistics South Africa). (2015) The importance of coal. Available from: URL: http://www.statssa.gov.za/?p=4820 (accessed 7 January 2016)

Swaen GMH, Aerdts CWHM, Sturmans F, *et al*. (1985) Gastric cancer in coal miners: a case-control study in a coal mining area. *Brit J Ind Med*; **42**:627-630.

Swaen GMH, Meijers JMM, Slangen JJM. (1995) Risk of gastric cancer in pneumoconiotic coal miners and the effect of respiratory impairment. *Occup Environ Med*; **52**: 606-610.

Takala J. (2015) Eliminating occupational cancer. *Ind Health*; **53**: 307-309.

Tulchinsky TH, Varavikova EA. (2014) The new public health. London, UK: Elsevier, Inc. ISBN 9780 12 415766 8.

Unsted AD. (2001) Airborne pollutants. *In* Guild R, Ehrlich RI, Johnston JR, Ross MH, editors. A handbook on occupational health practice in the South African mining industry. Braamfontein(SA): SIMRAC. p. 85-118. ISBN 1 919853 02 2.

Van Tongeren M. (2015) Occupational carcinogen exposure in Canada. *J Occup Environ Med*; **72**: 4-5.

WCA (World Coal Association). (2013) Coal mining. Available from: URL: http://www.worldcoal.org/coal/coal-mining/ (accessed 15 March 2015)

WCI (World Coal Institute). (2009) The coal resource: a comprehensive overview of coal. Available from: URL: http://www.worldcoal.org/bin/pdf/original_pdf_file/coal_resource_overview_of_coal_report%2803-06-2009%.pdf (accessed 1 May 2015)

CHAPTER 2: LITERATURE STUDY

In Chapter 1 a brief overview was given to outline the problem presented in this study. In Chapter 2 the important key points of the study will be discussed in further detail. A more in-depth look will focus on coal composition and formation, the various mining methods used (underground and opencast) and the health risks that are presented with each, and lastly the occupational carcinogens and cancer types that may be a concern in the coal mining industry will also be discussed.

2.1 Coal – the world's most important energy source

Coal is utilised as a major energy source worldwide and is known as one of the fastest growing energy sources when compared to gas, oil and nuclear energy. It is crucial to understand the composition and location of different coal types, which in turn has an effect on the potential health risks created when exposed thereto occupationally (Huang *et al*., 2005; Thompson, 2005; WCI, 2009; WEC, 2013).

2.1.1 Composition and formation of coal

Coal is a sedimentary organic rock composed mainly of carbon, hydrogen and oxygen and is formed from accumulated decaying plant material subjected to high temperatures and pressures, as well as various physical and chemical changes over many millions of years (WHO, 1986; WCI, 2009). The inorganic portion of coal is composed of several minerals and trace elements, which may include metals such as aluminium, arsenic, nickel and cadmium, but they only represent a small fraction of the coal matter (Huang *et al.*, 2005). Some of these trace elements can be carcinogenic, especially when present in the form of coal mine dust (Naghadehi *et al.*, 2014).

The quality of a coal deposit is determined by the temperature, pressure and the time it takes for the coal to transform and mature from peat to lignite to bituminous coal and finally anthracite (WCI, 2009). As the quality or rank of coal increases, the ratio of carbon to other minerals and trace elements increases (Naghadehi *et al.*, 2014). Lower ranked coals are typically softer materials due to a higher moisture content, whereas higher ranked coals are generally a harder material with a black colour and a low moisture content. Anthracite is categorised into the highest coal rank whereas lignite and subbituminous coals fall into the lowest ranks (WCI, 2009).

2.1.2 Uses of coal

It is estimated that about two-thirds of coal produced globally is used for power generation, which includes electricity and commercial heat (Pooe, 2011; IEA, 2015). In addition to being the primary source of electricity in South Africa, coal also provides the country with a third of its liquid fuel requirements (WCI, 2009; Pooe, 2011).

Coal is also essential in the iron and steel production industries as well as cement manufacturing. Other uses of coal include chemical production, i.e. benzene and creosote oil from coal by-products, and can also be considered an essential ingredient in various products including

- activated carbon used in kidney dialysis machines and water filtration systems;
- carbon fibre used in construction; and
- silicon metal used in silicone production and also utilised in the manufacturing of lubricants, resins and cosmetics (WCI, 2009).

2.1.3 Coal mining in South Africa

South Africa relies on coal for over 90% of its energy production and more than 70 operational collieries are needed in order to feed this tremendous usage of energy (WCI, 2009; Pooe, 2011). Production of coal in South Africa is largely performed by five mining groups, namely: BHP Biliton, Anglo Coal, Exxaro, Sasol and Xstrata (DME, 2010; Pooe, 2011). In 2013, coal production overtook gold production as the largest contributor to the South African economy with a R51 billion contribution compared to gold's R31 billion and will continue to have a valuable impact on the economy as long as the estimated 116 years of coal reserves last (StatsSA, 2015).

2.1.3.1 Geology of South African coal mines

Major coal reserves are located throughout South Africa, but mostly found in the Mpumalanga, the Northern Free State, Gauteng and Limpopo provinces (Naidoo, 2002; Pooe, 2011). Coal reserves found in South Africa were deposited during a 35 million year geological time period, and consist of mostly bituminous coal, with seams typically bounded by shale or sandstone units (Naidoo, 2002; Thompson, 2005; Pone *et al.*, 2007).

The Highveld coalfield, which consists of the best producing underground coal mines in South Africa, covers approximately 7 000 square kilometres (km^2) and is situated in the Mpumalanga province (Dougall, 2010).

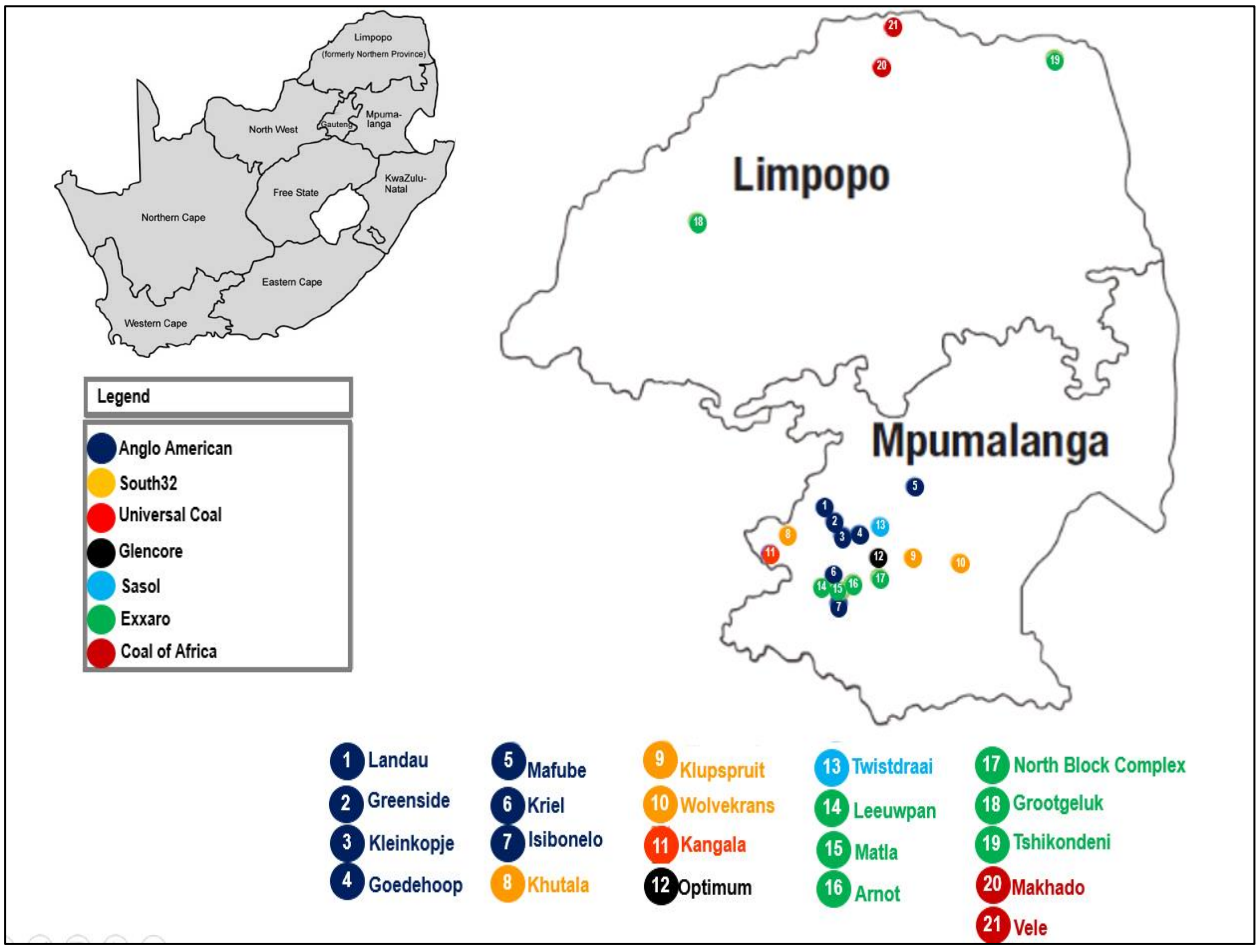


Figure 2-1: Map indicating the location of coal mines in the Limpopo and Mpumalanga provinces of South Africa
(Chamber of Mines of South Africa, 2015)

2.1.3.2 Global coal production

Global coal demand was over 4 050 Mt in 2009 according to the World Coal Institute (WCI) and coal production only 4 030 Mt, making the global demand for coal higher than the production thereof (WCI, 2009). Large coal producing countries are not confined to one region and South Africa with a reserve of more than 30 000 Mt and production of 250 Mt in 2014, falls under the top ten alongside China, the USA (United States of America), and India (WCI, 2009; Pooe, 2011; IEA, 2015; WCA, 2016a). The major coal producers of the world are shown in Table 2-1 below.

Table 2-1: Major coal producers for 2013 to 2015 (IEA, 2015)

	Year (Mt)		
	2012	**2013**	**2014**
People's Republic of China	3532.5	3843.6	3747.5
USA	932.3	903.7	916.2
India	602.9	610.0	668.4
Australia	430.8	458.9	491.2
Indonesia	444.5	487.7	470.8
Russian Federation	329.4	326.0	334.1
SA	258.6	256.3	253.2

2.1.3.3 Employment in the coal mining industry

The coal mining industry employs around 7 million people worldwide of which 90% is in developing countries, including South Africa. Large scale coal mines provide a significant source of economical wealth in rural and surrounding areas by creating employment and opportunities for the local community (WCI, 2009; Petsonk *et al.*, 2013).

Data of 2014 showed that approximately 200 000 workers were employed in the coal mining industry in the United States (Naghadehi *et al.* 2014) and roughly 100 000 in the South African coal mining industry (StatsSA, 2014).

2.1.4 Coal mining processes

Mining of coal occurs either above ground in opencast mines or underground in deep mines and the choice of mining method largely depends on the geology of the coal deposit and the relative mining costs (Thompson, 2005; WCI, 2009; WCA, 2013). Underground mining processes account for about 60% of global coal production, although in several countries, including Australia and the USA, opencast mining operations can be responsible for 60 to 80% of coal production (WCI, 2009; WCA, 2016a). In South Africa 51% of coal mining occurs underground and 49% at opencast operations (DME, 2010).

Underground mining processes involve a much higher health and safety risk than opencast mining due to difficulties associated with provision of clean air, the removal of hazardous substances and dust particles, as well as the mining activities performed by the workers (WCI, 2009; WCA, 2016b).

In sections 2.2 and 2.3 a brief overview of the respective mining methods for underground and opencast coal mining will be discussed and the health risks that are presented by each.

2.2 Underground coal mining

The main methods of underground coal mining include longwall, as well as room and pillar mining and the choice of technique is mostly site specific but economic factors also need to be considered. Both techniques may be used in a single mine depending on the aforementioned factors (WCI, 2009). Both the abovementioned underground mining techniques generate high levels of coal mine dust (WCA, 2013). Due to the variability in the different mining techniques, it is important to identify the sources and composition of the dust that might be responsible for exposure risks to underground mine workers (Attfield and Wagner, 2005).

2.2.1 Mining techniques

2.2.1.1 Longwall mining

Three variations of longwall mining exist, and include: longwall mining with top coal caving, extended height single pass longwall mining, and multi-slice longwall mining (Dougall, 2010). Longwall mining involves the use of mechanical shearers for the extraction of coal from a section of the coal face (usually where a thick coal seam is involved), which can vary in length from 100 to 350 m (Dougal, 2010; WCA, 2013). As soon as the coal has been extracted, the roof which is held up by hydraulically-powered supports is allowed to collapse (WCI, 2009). When thin coal seams need to be extracted, retreat or advance longwall mining is used (Dougall, 2010). A typical layout of longwall mining is shown in Figure 2-2 below. Longwall mining involves thorough planning to ensure favourable geology exists throughout the entire section before coal is extracted. This will ensure a higher quality coal as well as over 75% of the coal deposit being extracted with less contaminants present (WCI, 2009; WCA, 2016a).

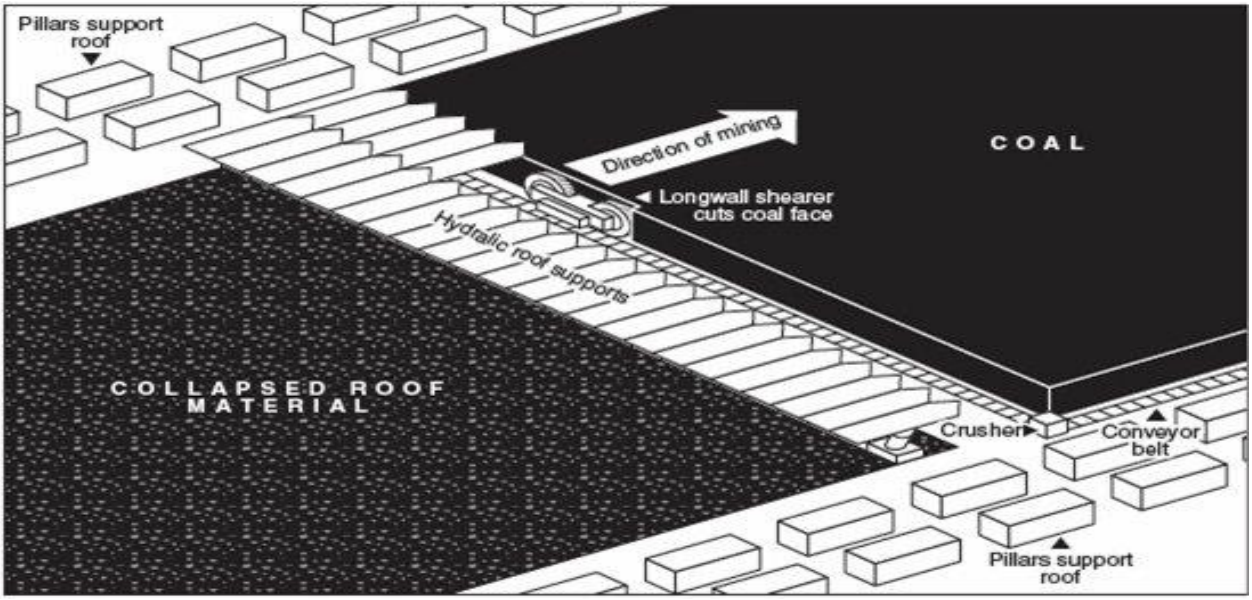


Figure 2-2: A typical longwall mining layout (Hem, 2015)

2.2.1.2 Room and pillar mining

Another underground mining method is room and pillar mining where coal deposits are mined by cutting a room into the coal seam with the use of a continuous miner (CM) and leaving a support pillar, usually composed of coal, to prevent the roof from collapsing (Petsonk and Attfield, 2005; Dougal, 2010). An example of a room and pillar mining layout is shown in Figure 2-3.

These pillars may consist of approximately 40% of the total coal seam and can be recovered by what is known as 'retreat mining' or longwall mining (as discussed in section 2.2.1.1), where coal is mined from the pillars and the roof is allowed to collapse (Singh, 1997; WCI, 2009).

Room and pillar mining is the method used more than 90% of the time in South African underground coal mines due to its inherent safety and low operating costs (Dougall, 2010).

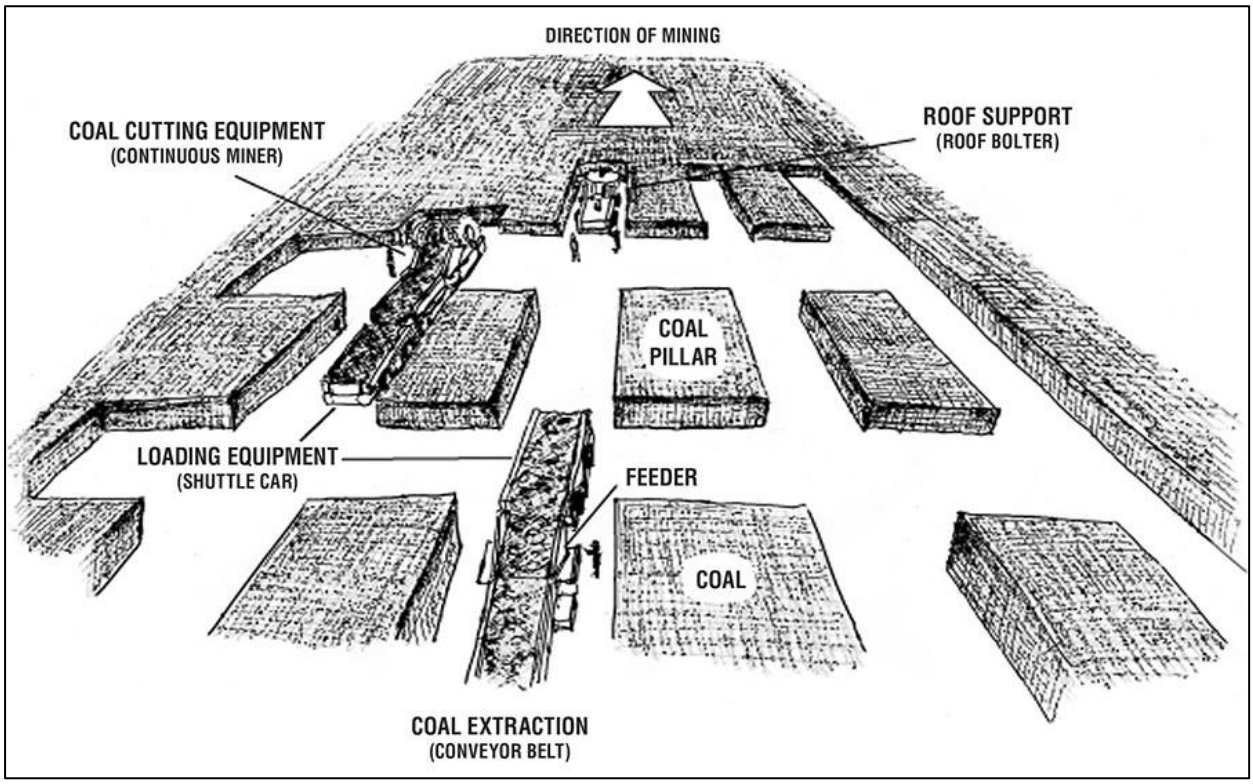


Figure 2-3: A typical room and pillar mining layout (IMSIF, 2016)

2.2.2 Work activities performed in underground coal mining

Coal mining activities are grouped into different categories according to the location where the work is performed and a worker does not necessarily spend an entire work shift performing only one of these activities (Petsonk and Attfield, 2005).

Face workers are active in the underground removal of coal from the coal face and usually fall under the highest exposed workers where dust exposure is concerned. Non-face workers are included in other mining activities related to ventilation control, rock dusting, and maintenance and transport procedures (Petsonk and Attfield, 2005; Mamuya *et al.*, 2006; Dougall, 2010). Rock dusters distribute powdered sandstone along the walls of the underground mine tunnels to reduce the danger of spontaneous combustion and explosions. Surface workers are usually maintenance workers or welders exposed to welding fumes and low concentrations of dust (Petsonk and Attfield, 2005).

2.3 Opencast (surface) coal mining

Opencast mining – also known as surface or opencut mining – recovers a higher proportion of the coal deposit than underground mining, since 90% or more of the coal can be extracted (WCI, 2009). It was estimated in 2002 that opencast mines provided 50% of the produced coal in South

Africa and the most widely used mining techniques are strip mining or terrace mining (Thompson, 2005)

Opencast coal mining is performed when a coal seam lies close to the surface and involves a typical sequence of operations. Layers of vegetation and rock – referred to as overburden - are removed by drilling holes, blasting and removal thereof to reveal the coal seam underneath. Mining of the coal seam involves further drilling and blasting which increase the risk of dust exposure (Kohler, 2005; WCI, 2009). Opencast coal mine workers can also be exposed to high levels of respirable coal mine dust and drill operators run the risk of being exposed to silica dust when the overburden contains crystalline silica or quartz (Petsonk and Attfield, 2005).

2.3.1 Mining techniques

2.3.1.1 Strip mining

The removal of overburden above a layer of coal, followed by the extraction of the exposed coal seam is referred to as strip mining and is a method used widely in the South African coal mining industry. This method is mainly used for selective extraction of coal deposits that are located in relatively shallow seams (Thompson, 2005; Hustrulid, 2016).

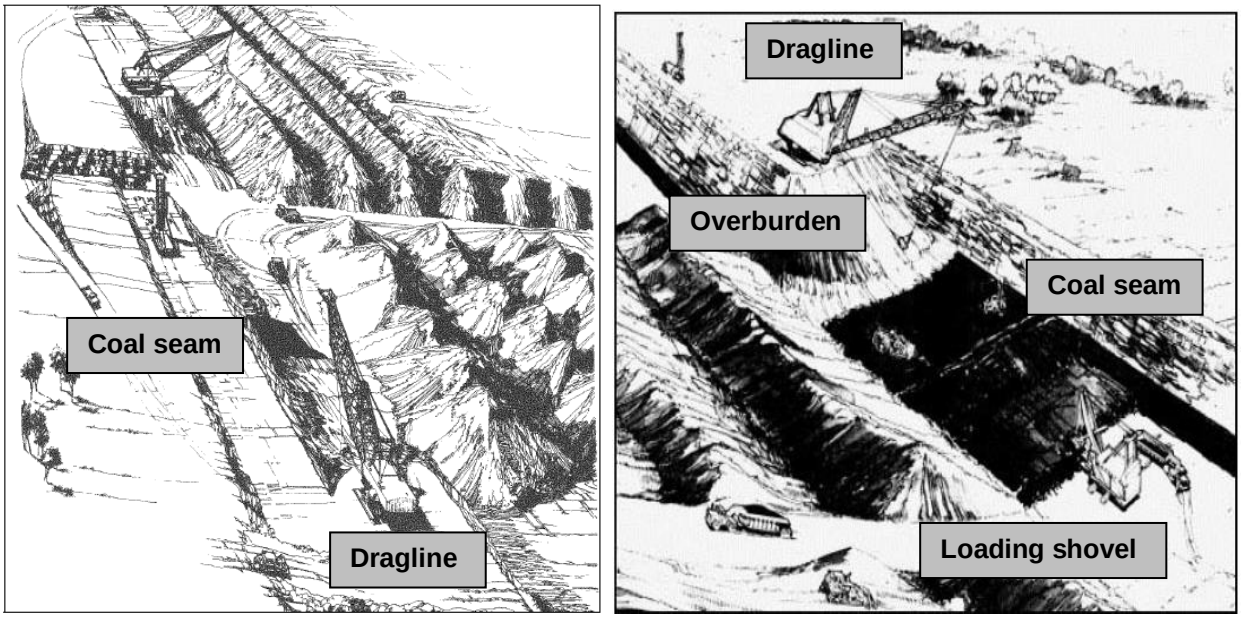


Figure 2-4: A typical layout of strip mining with draglines (on top of overburden) (Thompson, 2005)

Operational cycles of strip mining mostly consist of (refer to Figure 2-4):

- Loosening of overburden by explosives and removal thereafter by draglines;
- Once the coal seam is exposed, drilling and loading thereof commence by a loading shovel;
- Lastly, the mined coal deposit is transported to a coal preparation plant or final location of use by a large haul truck or conveyors (Thompson, 2005; WCI, 2009; Hustrulid, 2016).

Strip mining has several advantages over underground mining, including higher productivity and increased recovery of coal (Thompson, 2005).

2.3.1.2 Terrace mining

In deeper more complex coal deposits, coal seams can be accessed by removing the overburden in a series of horizontal layers from the top downwards, and is called terrace mining. Mining starts at the topmost horizontal layer or bench, and as soon as an adequate amount of floor space has been cleared, mining of the next bench starts (Thompson, 2005).

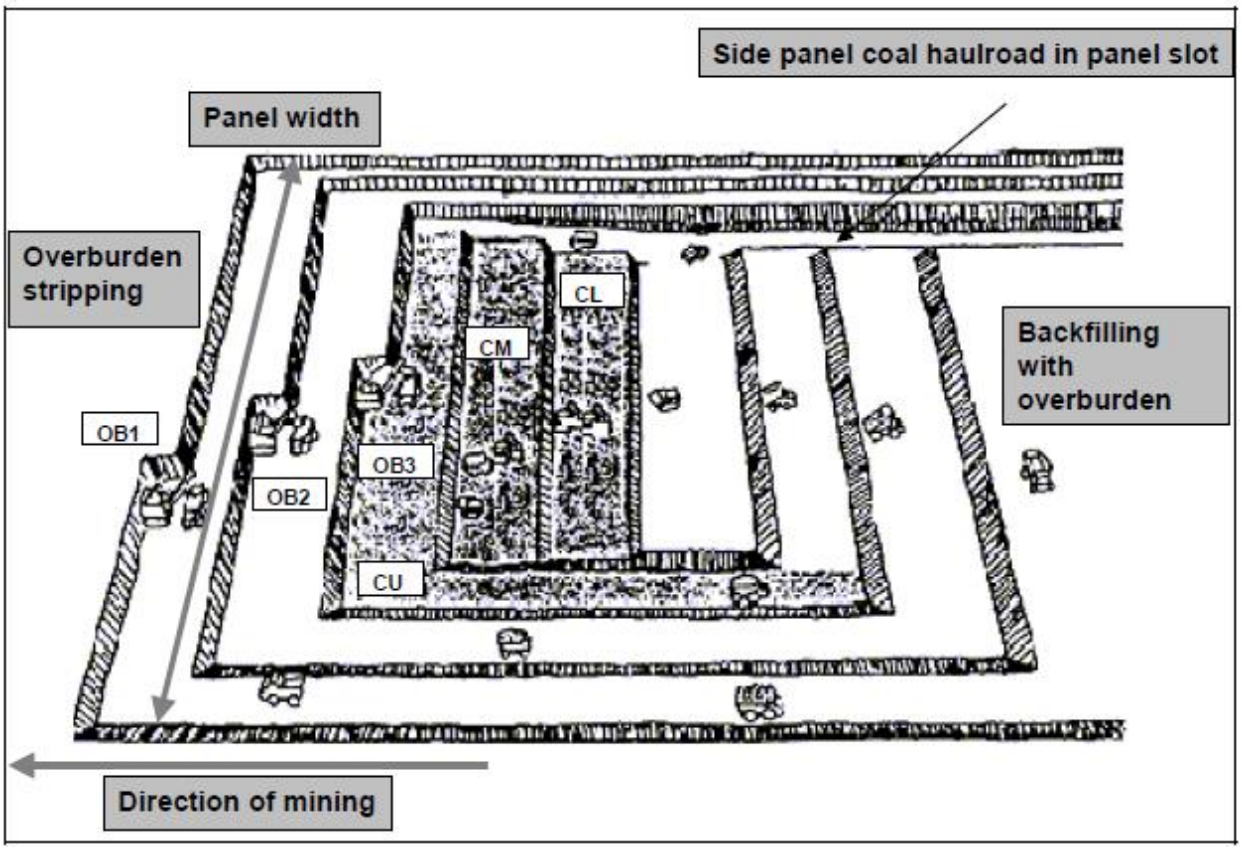


Figure 2-5: A typical terrace mining layout showing the benches (OB1-3) and coal seams (CU, CM, CL) (Thompson, 2005)

2.4 Occupational exposure in the coal mining environment

Occupational exposure is defined as the contact between the human body and a hazardous agent or harmful working environment (Driscoll *et al.*, 2004). Several coal mining activities release large quantities of coal dust and other harmful substances into the surrounding environment and this complex mixture presents one of the most important occupational hazards for the health of coal mine workers (Jenkins *et al.*, 2013; León-Mejía *et al*., 2014).

South African mines use the SAMOHP-codebook – also referred to as the South African Mines Occupational Hygiene Programme – to determine under which work activity a coal mine worker will be categorised. This categorisation is achieved by dividing workers into HEGs or homogenous exposure groups, and is defined according to classification bands (as shown in Table 2-2 below). Different codes are assigned for each work activity, for example a general miner has the code 20305 and a miner's assistant 20504, and the codes are further divided under the HEG classification bands. Dividing mine workers into HEG's enables monitoring of workers who experience comparable exposure scenarios to harmful substances, where any sub-group will represent the exposure of the other workers in the group (DME, 2002).

Table 2-2: Classification bands indicating the HEGs (A, B, C) of worker exposure to airborne pollutants

Classification bands	
Category	**Personal exposure level**
A	Exposures ≥ the OEL* or mixtures of exposures ≥ 1
B	Exposures ≥ 50% of the OEL* and < OEL* or mixtures of exposures ≥ 0.5 and < 1
C	Exposures ≥ 10% of the OEL* and < 50% of the OEL* or mixtures of exposures ≥ 0.1 and < 0.5

* OEL: Occupational Exposure Limit

2.4.1 Occupational health risks and hazards

Coal mining history is strewn with ample evidence of cave-ins, explosions, accidents and various respiratory and other occupational diseases identifying it as a dangerous occupation (Une *et al.*, 1995; Brown *et al.*, 1997; Worku, 2004; Naghadehi *et al.*, 2014). Exposure to large amounts of harmful substances among coal mine workers across all coal producing continents is significantly more than the general population is ever likely to come across (Naghadehi *et al.*, 2014; Schneider, 2014). Coal mine workers are the first to suffer from adverse health effects related to their

occupational exposure, where everyday low doses of the same harmful substances may cause unrecognised effects in susceptible individuals in the general population (Schneider, 2014; WCA, 2016a).

Everyday mining operations in underground, as well as opencast coal mines expose workers to large amounts of harmful substances. These hazards and risks can include the following:

- Coal and other dusts from sources, including transport vehicles, loading and unloading of coal, and coal extraction processes (Mamuya *et al.*, 2006; WCI, 2009; DoL, 2011);
- Noise from equipment used in transport and coal extraction processes (WCI, 2009; DoL, 2011);
- Methane (CH_4) which is a highly explosive gas is released from the coal seam during mining operations (WCI, 2009);
- Diesel exhaust fumes and DPM (diesel particulate matter) occurring from diesel vehicles used for transportation, materials handling as well as other support operations (Muzyka *et al.*, 2003; Belle, 2008); and
- Spontaneous combustion, or the burning of coal occurs when extracted coal comes into contact with atmospheric air. This oxidation process is exothermic, and if the continued heat release is not dissipated, coal combusts or burns (Thompson, 2005; Pone *et al.*, 2007; Lang and Fu-bao, 2010).

Coal mining has been known to cause a magnitude of occupational illnesses due to exposure to some of the abovementioned substances. These illnesses can vary from respiratory diseases, such as coal workers' pneumoconiosis (CWP), silicosis, asbestosis, or skin irritation related diseases such as dermatitis, to occupational cancers including, but not limited to, lung and bladder cancer (Finkelman *et al.*, 2002; DoL, 2011; Petsonk *et al.*, 2013; Naghadehi *et al.*, 2014).

2.4.2 Occupational disease surveillance

Occupational disease surveillance or health monitoring of workers in a coal mine should be of top priority for employers according to the Mine Health and Safety Act of South Africa and therefore it forms part of the process shown below in Figure 2-6 (MHSA, 1996).

Below, the various factors that can influence the exposure dose in an occupational setting, as well as the pathway that eventually leads to the development of a disease, such as cancer, is represented graphically. The quantity of a substance a worker can be exposed to (exposure concentration), the amount of time the worker is exposed to a substance (exposure duration), as

well as the frequency of exposure play a role in the total dose of a substance a worker can be exposed to. Additive, synergistic or co-exposure are modifying factors mentioned in Figure 2-6 and will be discussed at a later stage (refer to section 2.6.3) (Thorne, 2013).

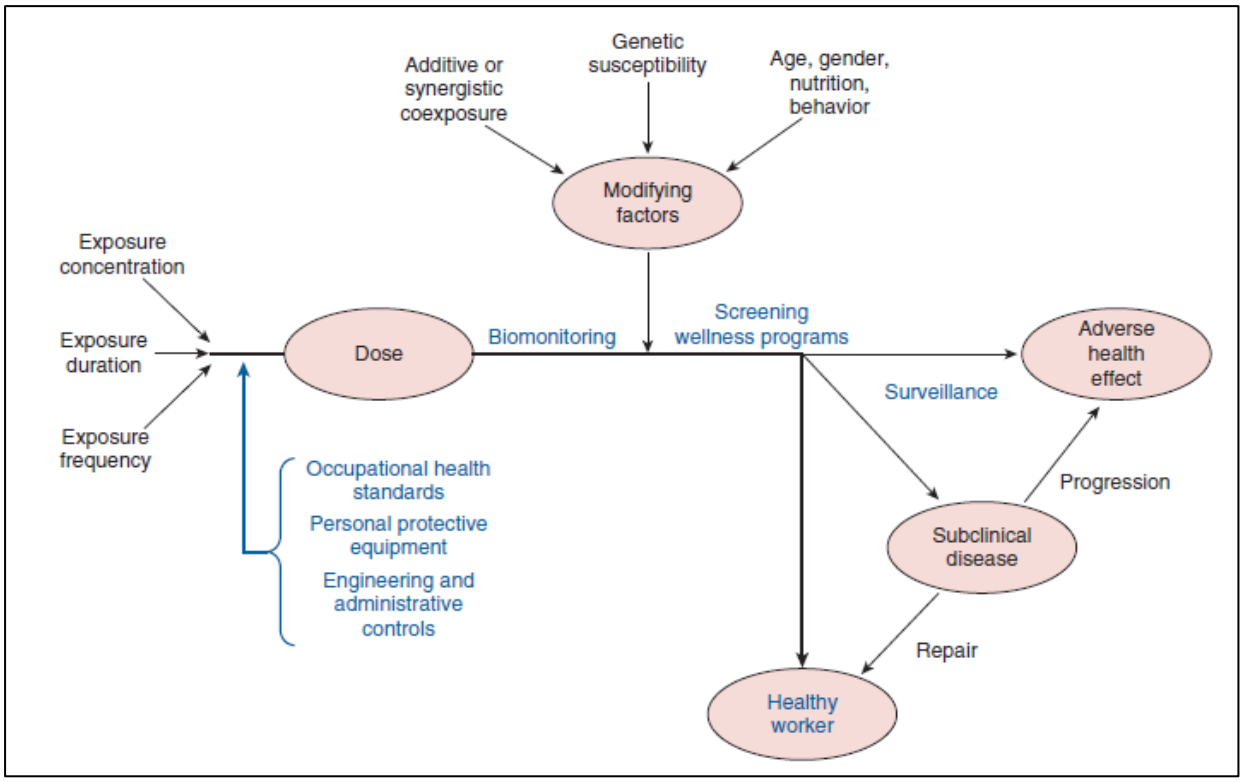


Figure 2-6: Pathway from exposure to disease, showing modifying factors and opportunities for intervention (Thorne, 2013)

Occupational health monitoring of particularly dust exposure has been practised worldwide in coal mines in order to comply with legal requirements. The Department of Mineral Resources (DMR) – formerly the Department of Minerals and Energy (DME) – is responsible for prescribing legislative schedules and methods used in occupational health monitoring in South African coal mines (Naidoo, 2002). However, monitoring of occupational health is lacking across the African continent due to the workers often originating from neighbouring countries, and thus if they return home ill, linking their disease to the original occupational exposure and attributing accountability becomes a great challenge (DME, 2002; McCormack and Schüz, 2012).

In South Africa one of the sources of occupational disease surveillance – the PATHAUT database – is an autopsy program for deceased miners to determine if the cause of death was related to occupational exposure (Antao and Pinheiro, 2015). The 2013 PATHAUT report focused mainly on respiratory related disease being the cause of death, and included silicosis, asbestosis, lung cancer, as well as mesothelioma (Ndlovu *et al.*, 2014).

2.5 Occupational carcinogen exposure and carcinogenesis

International research has found that a wide range of occupational related factors are associated with an increase in cancer risk (DoL, 2011; Jenkins *et al.*, 2013). Due to the substantial number of workers in the global and South African coal mining industry and the various sources of occupational carcinogen exposures, it is important to identify all of these carcinogenic sources and the health effects they might produce. By identifying and controlling these sources the health of all persons exposed will be safeguarded (WCI, 2009; Petsonk *et al.*, 2013; Naghadehi *et al.* 2014; StatsSA, 2014).

Occupational cancer incidences and other illnesses in mining do not occur as isolated events, and as a result they are not reported with the same degree of certainty as injuries caused by accidents (Kohler, 2005). In South Africa specifically, cancer incidence and exposure to occupational carcinogens are mostly underreported because of the lack of nationwide cancer surveillance networks (Singh *et al.*, 2015).

2.6 Carcinogens and carcinogenesis

2.6.1 Cancer – disease of chaos

Cancer is known as a disease of chaos due to the disturbance of the normal biological order within the body (Weinberg, 2007). The chaotic environment has a disruptive effect on various repair and adaptive mechanisms, including the expression of critical cell proteins (Klaunig, 2013).

Cancer is a large group of diseases characterised by the presence of malignant or cancer cells. These cells have uncontrolled growth and tend to invade surrounding tissues or organs and can metastasize to other body sites (Myers, 2009; Klaunig, 2013).

2.6.2 Carcinogenesis and latent period of cancer development

Carcinogenesis or the development of cancer cells in the human body is a process that is not well understood partly due to the latent period that exists before adverse effects first start appearing, as well as the multiple pathways the process of carcinogenesis can follow (Patnaik, 1999; Driscoll *et al.*, 2004). Studies over the years have shown that exposures to certain agents can increase the risk of developing certain cancers but unfortunately it is not always possible to link the development of cancer to a particular exposure (Driscoll *et al.*, 2004).

A human carcinogen - usually an external factor or agent - is defined as any substance or event capable of producing cancer in humans (Patnaik, 1999; Weinberg, 2007). When observing the etiologic or causative mechanisms of cancer, it can be concluded that a large majority of cancers

are caused by external factors, and therefore it is important to take occupational carcinogenic exposures into consideration (Weinberg, 2007).

The contribution of external environmental factors is further exaggerated by increased exposure time due to longer working hours in a hazardous occupational setting, and in various industrial sectors, including coal mines, there is an increase in exposure to carcinogens (McCormack and Schüz, 2012; Jenkins *et al.*, 2013).

Cancer development is characterised by long latency periods following occupational exposure to carcinogens and this contributes to the difficulty in allocating the direct cause of the reported cancer incidence. This is one of the main reasons occupational carcinogen exposure often ends up as an overlooked element when compared to accident and injury prevention in a mining environment (DoL, 2011; McClellan *et al.*, 2012).

2.6.3 Co-carcinogens and co-carcinogenesis

A large number of carcinogenic factors exist and these may be categorised into solitary carcinogens and co-carcinogens. Chronic exposure or even a single high-dose exposure to a solitary carcinogen may initiate the development of cancer (Hecker, 1975). Co-carcinogens are substances that are incapable of producing cancer by themselves, but have the ability to aggravate or enhance the carcinogenic effects of other substances or carcinogens (Eaton, 2005; Porta, 2008; Eaton and Gilbert, 2013). This may also result in a synergistic or antagonistic effect between the individual substances (Falk and Jurgelski, 1979; Taeger *et al.*, 2015). In the event where exposure to a solitary carcinogen occurs first and exposure to a co-carcinogen follows, cancer development may also be initiated, and this process is called co-carcinogenesis (Hecker, 1975). Synergism refers to the scenario where a worker is exposed to two or more carcinogenic substances simultaneously which may result in a greater adverse effect than the sum of the effects of the individual substances (CCOHS, 2013).

An example of co-carcinogenesis is the inhalation of particulate matter such as coal dust in the presence of PAHs (polycyclic aromatic hydrocarbons). This interaction enhances the transportation of PAHs into the deeper structures of the respiratory system through inhalation, where their carcinogenic effects may arise (Falk and Jurgelski, 1979). Another more recent study suggested the synergistic effect of smoking cigarettes and working as a coal miner leads to an increased risk of lung cancer (Taeger *et al.*, 2015). Arsenic is also considered to be a co-carcinogen, because it potentiates the carcinogenic effect of benzo(a)pyrene and ultraviolet radiation (UVR) (Liu, 2005; Salnikow and Zhitkovich, 2008).

2.6.3.1 Smoking and the combined exposure to carcinogens

Smoking of tobacco is considered one of the most significant risk factors for the development of lung cancer and may increase this risk by three to ten-fold (Tomaskova *et al.*, 2012). Work in a coal mine may increase the risk of the development of not only lung cancer, but several other cancers due to the exposure to occupational carcinogens (Jenkins *et al.*, 2013). Due to the long latency period of human lung cancers, it is usually difficult to establish the true relationship to occupational carcinogen exposures (Leikauf, 2013).

2.6.3.1.1 Smoking and exposure to asbestos

Previous studies established a measure to determine the ratio of the relative risk of developing lung cancer due to asbestos exposure in non-smokers to that in smokers. This ratio can be labelled as the relative asbestos effect (RAE). The multiplicative hypothesis suggests synergism between smoking and asbestos exposure, and identifies the RAE as equal to 1, while a RAE of greater than 1 indicates less synergism (Liddell, 2001; Berry and Liddell, 2004).

Another study found that the combined exposure or synergistic effect of asbestos and smoking increased the risk of developing lung cancer 50-fold. The reason for this tremendous increase is that the two respective carcinogens induce similar types of DNA mutations in addition to the statement that asbestos enhances the mutagenic effect of tobacco smoke (IARC, 2004; Stenius, 2012).

A recent study indicated a positive additive synergistic effect between asbestos exposure and smoking and little evidence of an interaction on a multiplicative scale, as indicated by the multiplicative hypothesis in Liddell's study (2001). Additive synergism refers to the interaction between two or more substances, where the effects can be greater or equal to the sum of the individual substances (Ngamwong *et al.*, 2015).

2.6.3.1.2 Smoking and exposure to radon

Radon is one of the many chemical exposures that can be encountered in the coal mining environment and can also be linked to respiratory cancer development. Unfortunately, when a coal mine worker is exposed to tobacco smoke in addition to radon or radon progeny, it increases the risk of developing lung cancer (Leikauf, 2013).

2.6.3.1.3 Smoking and exposure to arsenic

The combined effect of tobacco smoking and arsenic exposure indicated a consistent synergistic effect in various studies in relation to the development of lung cancer (IARC, 2004; Leikauf, 2013).

2.6.3.1.4 Smoking and exposure to cadmium

A synergistic effect was demonstrated between smoking and cadmium exposure and may lead to the development of renal cancer (Shalat and Mohr, 2005).

2.6.3.2 PAHs and the combined exposure to carcinogens

Exposure to diesel engine exhaust fumes is considered to be one of the exposure sources of PAHs in the coal mining industry (Gawkrodger, 2004). PAH exposure may also be combined with various other exposures in a coal mining environment (Gawkrodger, 2004; Monforton, 2006).

2.6.3.2.1 PAHs and exposure to coal mine dust

Respirable coal mine dust has a relatively large surface area due to its small aerodynamic size and porous nature. Due to this characteristic, PAH vapours or PAHs have the ability to attach to coal mine dust and other particles in the air and can enter the lungs when inhaled. (ATSDR, 1995; Naghadehi *et al.*, 2014)

2.6.3.2.2 PAHs and UV radiation

Combined exposure to PAHs and ultraviolet (UV) radiation categorises UV-radiation as a co-carcinogen to PAHs, and may lead to the development of skin cancer (Gawkrodger, 2004).

2.6.3.2.3 PAHs and DPMs

Diesel particulate matter, widely known as DPMs, contains a surface that has a high affinity for adsorbing PAHs. Due to DPMs small diameter of less than 1 µm, it is able to penetrate deep into the structures of the lungs during inhalation (Monforton, 2006).

2.6.3.3 Arsenic and the combined exposure to carcinogens

Exposure to low concentrations of arsenic enhances the mutagenicity of other carcinogens by interrupting the normal repair of DNA and can - with long-term exposure - lead to the development of cancer (Salnikow and Zhitkovich, 2008).

2.6.3.3.1 Arsenic and benzo(a)pyrene

Benz(a)pyrene is a known component of coal mine dust as well as diesel engine exhaust fumes (Swaen *et al.*, 1995; Liu, 2005). With the combined exposure to benzo(a)pyrene and arsenic, the mutagenic properties of benzo(a)pyrene is potentiated and may lead to the development of lung cancer (Liu, 2005).

2.6.3.3.2 Arsenic and UV radiation

Arsenic, which has strong mutagenic properties, seems to act as a co-carcinogen with the combined exposure to UV-radiation and may lead to the development of skin cancer (Gawkrodger, 2004; Cohen *et al.*, 2005).

2.6.4 Comorbidities

Comorbidities are defined as the simultaneous presence of two chronic diseases, and can present a problem where exposure to carcinogens in a coal mine is concerned (Stevenson and Lindberg, 2015). Exposure to dust, for example, can lead to respiratory disease, and the effect of such a disease is exaggerated when it is presented together with another chronic disease, such as emphysema. Dust-related respiratory diseases, such as coal worker's pneumoconiosis (CWP), can lead to the development of lung cancer, especially when occupational dust exposure is paired with cigarette smoking (Sangani and Ghio, 2011; Petsonk *et al.*, 2013; Hung *et al*, 2014).

2.6.5 Worldwide cancer incidence, prevalence and mortality rates

The GLOBOCAN project aims to provide approximations of prevalence, incidence and mortality rates of the major cancer types for 184 countries across the world. New cancer cases reported in 2012 by this project were more than 14 million, of which more than half were male related cancers. According to their last report published in 2012, lung cancer incidence was estimated to be the highest in men and breast cancer incidence the highest in women. For both sexes, lung cancer remained the highest incidence cancer type (IARC, 2016).

2.7 Occupational carcinogen exposure

More than 200 different types of cancer are currently present worldwide and in South Africa, tracheal, bronchial and lung cancers are the top causes of death in humans according to CANSA (Cancer Association of South Africa) (Herbst, 2014; Herbst, 2017). Environmental, as well as occupational environments, such as a coal mine, pose a risk of exposure to various carcinogens and numerous cancers have been linked to these exposures (Finkelman *et al.*, 2002; Donbak *et al.*, 2005; McCormack and Schüz, 2012). The SUMER survey – which refers to the French acronym for Medical Surveillance of Occupational Risks – reported in 2003 that skilled (30%) and unskilled (22.5%) manual workers were the most at risk of exposure to carcinogens when compared to skilled craft occupations (11%) and managerial staff (3%). Young workers (in apprentice and training occupations) as well as workers in the maintenance/repair trades were most at risk (Mengeot, 2007).

Due to the difficulty in retrieving relevant occupational related information about cancer it is not always possible to determine the direct cause of exposure. Another challenge is created due to the influence of various occupational related factors and can include the total exposure dose to a carcinogen, the potency of the carcinogen and the possibility of exposure to other carcinogenic substances (Driscoll *et al.*, 2004).

In South Africa, the National Cancer Registry (NCR) within the National Health Laboratory Service (NHLS) is the principal cancer surveillance system and maintains the largest source of cancer data in the country (Singh *et al.*, 2015). One of the main problems however, is the absence of or limited data available on trends in cancer incidence. The only population-based cancer registry is in the former Transkei region of the Eastern Cape Province, founded in the early 1980s (Somdyala *et al.*, 2015).

For this research study, occupational carcinogens that may be present in a coal mining environment will be identified, along with the organs targeted when exposed thereto, as well as the exposure sources of each carcinogen. Labelling of the type of risk each carcinogen presents will be done by using the IARC (International Agency for Research on Cancer) classification system. The IARC is known for the most influential carcinogenic hazard assessments (Goldsmith, 2000; McClellan *et al.*, 2012; Beiki, 2015).

2.8 Classification of carcinogens

2.8.1 Carcinogenic classification systems

Various international bodies - including the IARC, ACGIH (American Conference of Governmental Industrial Hygienists) and the EU (European Union) - have developed classification systems to classify carcinogens according to their individual carcinogenic characteristics (Henny, 2013). The IARC distinguishes between four main groups used to classify the carcinogenic potential of a substance (as seen in Table 2-3). Classification by the ACGIH divides carcinogens or chemicals into five categories, ranging from Group A1 to Group A5 (Schinkel, 2009). The EU classification has three categories (category 1A, 1B and 2), which is based on the amount of available data derived from human studies with a definite link between exposure and cancer incidence. Thus, chemicals classified in group 1 of IARC, A1 of ACGIH and in category 1A of EU are used to categorise the definite link between human exposure and cancer incidence (Henny, 2013).

The main activity of the IARC is to identify and classify carcinogens and it has been able to classify many different agents, mixtures or exposure circumstances as carcinogenic (shown in Table 2-3) (Henny, 2013). For such an agent to be classified as carcinogenic, sufficient evidence is needed linking the occupational exposure to the development of cancer in humans (Driscoll *et al.*, 2004; Duffus *et al.*, 2009). The IARC is seen as the most reliable internationally recognized

classification system for carcinogens (Goldsmith, 2000; Beiki, 2015). Although the IARC classifications are not always accepted, the research supporting their findings usually outweigh the findings of other classification systems (Duffus *et al.*, 2007; Duffus *et al.*, 2009; Samet, 2015). Agents classified as Group 2A or 2B carcinogens are seen as probable and possible carcinogens, respectively, because of the lack of sufficient experimental evidence in humans. Therefore, it is necessary to include these agents in further research studies to ensure that more evidence can be collected to ensure the safety of all exposed workers (Henny, 2013).

In this study the IARC classification system will be used to determine in which group the identified carcinogens found in a coal mine can be categorised. Only Group 1, Group 2A and Group 2B carcinogens will be evaluated further, with the exception of coal mine dust (Group 3 carcinogen).

Table 2-3: Agents classified by the IARC Monographs, Volumes 1-112 (IARC, 2015)

Group	Classification	Number of agents
1	Carcinogenic to humans	116
2A	Probably carcinogenic to humans	73
2B	Possibly carcinogenic to humans	287
3	Not classifiable as to its carcinogenicity to humans	503
4	Probably not carcinogenic to humans	1

2.9 Identified carcinogens for coal mining environment

Using previously published literature, the following carcinogens - including their exposure sources, IARC classification, specific organ toxicity and adverse effects - have been identified as possible risks to coal mine workers (refer to Table 1-1).

2.9.1 Crystalline silica (Quartz)

2.9.1.1 Exposure source(s)

Silica is a mineral present in copious amounts in the earth's crust and can exist in either crystalline or non-crystalline forms. Quartz - one of the crystalline forms - can occur as a component of various types of rock (Banks, 2005). These rocks can include sandstone, metallic ore rocks, coal-bearing rocks as well as graphite (WHO, 1986). Quartz is the principal source of exposure in several occupations, especially in the mining industry, and exposure to respirable fractions often exceed the recommended standards (Wagner and Hearl, 2005; Naghadehi *et al.*, 2014).

Modern mining processes – such as drilling and the extraction of coal - cause silica-containing particles to become airborne. Settled silica-containing dust on various work surfaces can become a secondary source of exposure (WHO, 1986; Naghadehi *et al.*, 2014). The amount of quartz

present in a coal mining environment can vary depending on the mine type, location in the mine and the type of process performed (Tomaskova *et al*., 2012). An increase in occupational exposure may occur with thin-seam coal mining, due to larger quantities of the silica-containing rock being mined with the coal (NIOSH, 2011; Petsonk *et al.*, 2013).

2.9.1.2 IARC Classification and organ toxicity

Crystalline silica, also referred to as silicon dioxide, has been classified as a Group 1 carcinogen by the IARC (IARC, 1997). Occupational exposure to respirable crystalline silica raises a concern as it may cause silicosis, a primary pulmonary illness, and may even progress into lung cancer if exposure is of a chronic nature (Borm and Tran, 2001; Donbak *et al.*, 2005; NIOSH, 2011).

2.9.2 Radon (^{222}Rn)

2.9.2.1 Exposure source(s)

Radon, a colourless, odourless, inert gas is found in substantial amounts in the environment in several isotopic forms, of which Radon-222 (^{222}Rn) is one of the most prominent (IARC, 1988; Russi, 2005). The radon isotope ^{222}Rn as well as its radioactive decay daughter products ^{218}Po (polonium-218) and ^{214}Po (polonium-214) attach themselves to other particles, such as coal mine dust. Inhalation of these particles – which emits alpha radiation – into the lungs damages the epithelial lining of the respiratory system which can progress to lung cancer (Veiga *et al*., 2006; Stayner and Graber, 2011; ATSDR, 2012).

2.9.2.2 IARC Classification and organ toxicity

Radon decay products are classified as Group 1 carcinogens by the IARC (1988) and it has been shown that 10% of lung cancers are attributable to radon exposure from different sources ranging from medical applications to occupational exposure (Hoel, 2013). A 2006 study indicated that underground coal miners had a statistically significant risk of developing lung cancer when exposed to radon, and another study showed a potential link with the development of leukaemia (Velga *et al.*, 2006; Hoel, 2013).

2.9.3 Polycyclic aromatic hydrocarbons (PAHs)

2.9.3.1 Exposure source(s)

Polycyclic aromatic hydrocarbons or PAHs is commonly defined as a large class or group of organic compounds that is composed of carbon and hydrogen and consists of two or more fused aromatic rings. Contained in the PAH-group of compounds are individual PAHs that possess

carcinogenic properties and some of these individual compounds can be found in powdered bituminous coal or coal mine dust (NTP, 2014).

Occupational exposure to PAHs – through inhalation and skin contact – can occur in various industries and processes, including steel and iron foundries, gas production from coal, and exposure to diesel engine exhaust fumes (Gawkrodger, 2004).

2.9.3.2 IARC Classification and organ toxicity

These individual PAHs can include benzo(a)pyrene, classified as a Group 1 carcinogen as well as benz(a)anthracene derivatives, which are classified as Group 2A carcinogens (Gibbs, 1997; IARC, 2010). Benzo(a)pyrene mainly targets the lung and the upper respiratory system when inhaled and may cause cancer of these areas (NTP, 2014).

Occupational exposure to PAHs has been linked to the increased risk of developing various other cancers, including gastric, bladder and non-melanoma skin cancer (Falk and Jurgelski, 1979; Kammer *et al.*, 2011). Dermal exposure is another concern in the development of skin cancer due to the high lipid solubility of especially benzo(a)pyrene (Boström *et al.*, 2002). Unfortunately, it is difficult to evaluate individual carcinogenicity of PAHs because of the complex mixtures it is found in the occupational environment, especially in diesel engine exhausts (NTP, 2014).

2.9.4 Coal mine dust

2.9.4.1 Exposure source(s)

Coal mining is the principal occupation that is exposed to coal mine dust and the workers involved with the extraction of coal at the coal face tend to have the highest risk of exposure. A factor that plays an important role in the amount of dust generated is the mining methods used during extraction (refer to section 2.2 for underground mining methods and section 2.3 for opencast mining methods). Underground coal mining tends to have the highest risk of dust exposure as mentioned previously (refer to section 1.2) and other workers may be exposed through the handling and processing of coal (Wagner and Hearl, 2005).

In addition to coal mine dust, miners are exposed to other carcinogenic substances that may lead to respiratory cancers, and include silica, diesel engine exhaust and radon gas (Stayner and Graber, 2011). Coal mine dust can also contain various carcinogenic substances, including silica, benzo(a)pyrene, and trace metals such as cadmium and chromium (Swaen *et al.*, 1995).

2.9.4.2 IARC Classification and organ toxicity

Coal mine dust is classified as a Group 3 carcinogen by the IARC (1997) and various studies suggest that exposure to especially bituminous and lignite coal dusts has the potential to cause gastric cancer in humans (Whong *et al*., 1983; Swaen *et al.*, 1985; Swaen *et al.*, 1995; Brown *et al*., 1997; Finkelman *et al.*, 2002; Graber, 2012). This occurs due to inhaled coal particles reaching the digestive system through the pulmonary clearance system. These particles are introduced to the acidic environment of the stomach which causes the formation of mutagens or carcinogenic products by activating the nitrosation process (Whong *et al.*, 1983; Finkelman *et al*., 2002; Donbak *et al.*, 2005). The risk of gastric cancer increases with normal lung function due to the amount of coal mine dust that reaches the stomach. Lung function is optimal in a healthy worker compared to a worker with pneumoconiosis; thus the risk of developing gastric cancer is increased in a worker with normal lung function (Swaen *et al.*, 1995).

Coal workers' pneumoconiosis (CWP) is known to be induced by excessive or long term exposure to coal mine dust. A recent study found that patients diagnosed with CWP had an increased risk of all cancers including lung, oesophagus, stomach, other digestive cancers, skin, as well as genitourinary cancers (Hung *et al*, 2014). Although coal mine dust is classified as a Group 3 carcinogen, it will be included in this study due to the various research studies already documented indicating the potential link between human exposure and cancer incidence.

2.9.5 Diesel engine exhaust

2.9.5.1 Exposure source(s)

Stanton *et al.* (2007) and McClellan *et al.* (2012) defined diesel engine exhaust as a multifaceted mixture of vapours, gases and particulates with the main exposure source derived from equipment powered by diesel engines. Diesel engines are sources of driving power used in a large variety of vehicles in coal mines and because of the mobility of these vehicles the exhaust fumes are spread over a larger area in an underground coal mine (Unsted, 2001). The functioning of these combustion engines leads to the formation of a mixture of elemental carbon, PAHs and carbon monoxide (IARC, 2014a).

Diesel engine exhaust is composed of solid and liquid particles, and DPM (diesel particulate matter) - a physical aerosol component thereof - consists of solid carbon particles with the ability to attract and adsorb other substances such as PAHs (Muzyka *et al.*, 2003; Belle, 2008). DPM is small enough (less than 1 µm) to penetrate deep into the structures of the respiratory system. Exposure to DPM mostly depends on the number and size of vehicles present in a work environment, the workload of the diesel vehicles as well as the efficacy of the ventilation and control methods implemented in an underground coal mine (Monforton, 2006; Belle, 2008).

The highest risk of DPM and diesel engine exhaust exposure occurs during belt move operations or belt extensions where an increased number of diesel engines are present, but these processes do not necessarily occur on a daily basis. Airborne DPM, particularly in an underground coal mine, is not eliminated from the environment without effort and will not settle to the ground easily due to gravity, thus contaminating other work environments downwind from the source (Belle, 2008).

2.9.5.2 IARC Classification and organ toxicity

Exposure to diesel engine exhaust may lead to acute adverse effects and may include eye irritation and an alteration in lung function (Claxton, 2014). Diesel engine exhaust as a whole is classified as a Group 1 carcinogen with the potential to cause lung cancer when inhaled as well as an enhanced risk of bladder cancer (Muzyka *et al*., 2003; Attfield *et al.*, 2012; Claxton, 2014; IARC, 2014a). Free radicals are produced in the tissues of the respiratory system when diesel engine exhaust exposure occurs through inhalation and may lead to the development of lung cancer (Muzyka *et al.*, 2003; Claxton, 2014). Various types of PAHs can be present in the particulate phase of diesel engine exhaust and are classified as anything from Group 1 to Group 3 carcinogens when inhaled (Schenker, 1980; Claxton, 2014) (refer to section 2.9.3).

2.9.6 Trichloroethylene (C_2HCl_3)

2.9.6.1 Exposure source(s)

Trichloroethylene is a non-flammable solvent that is used for cleaning and degreasing of metal parts and may be used in the mining industry during certain maintenance procedures (Shen, 2013; IARC, 2014b). Joining and mending of conveyor belts in coal mines are performed by using vulcanising or gluing agents containing trichloroethylene (European Commission, 2015).

2.9.6.2 IARC Classification and organ toxicity

Acute adverse effects to trichloroethylene exposure can vary from irritation of the mucous membranes and contact dermatitis when skin exposure is experienced (Lundberg *et al.*, 2005). Trichloroethylene is classified as a Group 1 carcinogen through dermal and inhalation exposure and it is known for increasing the risk of certain cancers including brain, kidney, liver, and non-Hodgkin lymphoma (Demers, 2005; Kipen and Wartenbeg, 2005; IARC, 2014b).

2.9.7 Arsenic (As)

2.9.7.1 Exposure source(s)

Arsenic is an environmental contaminant and can be found in soil, water, and airborne particles (Salnikow and Zhitkovich, 2008). Release of arsenic from soil can occur during mining activities (transport processes and coal mining) and coal mine dust is considered a source thereof in many parts of the world (Yudovich and Ketris, 2005; IARC, 2012a; Jenkins *et al.*, 2013; Majzlan *et al.*, 2014). Bituminous and lignite coals are estimated to contain the highest arsenic concentrations, but this will depend on the location of the coal basins (Yudovich and Ketris, 2005).

Occupational arsenic exposure can be encountered in other industries, including the manufacturing and application of pesticides, glassware manufacturing, as well as lead, copper and zinc smelting where arsenic is presented as a by-product (Franzblau, 2005).

2.9.7.2 IARC Classification and organ toxicity

Occupational exposure of arsenic usually occurs through ingestion, inhalation or skin contact and according to the IARC is classified as a Group 1 carcinogen (IARC, 2012a). Exposure to arsenic and its related compounds can increase the risk of developing various cancers ranging from liver to prostate cancer (Gawkrodger, 2004; IARC, 2012a). Exposure to arsenic through inhalation can lead to the development of lung cancer, while exposure by ingestion of contaminated water can lead to skin, liver and bladder cancer (Salnikow and Zhitkovich, 2008). Arsenic is also known as a co-carcinogen due to its inhibitory actions on DNA repair and enhances the mutagenicity of agents such as ultraviolet (UV) radiation and benzo(a)pyrene, as mentioned in section 2.6.3.3 (Russi, 2005; Salnikow and Zhitkovich, 2008). A synergistic effect in promoting lung cancer development is also created when arsenic exposure occurs simultaneously with cigarette smoking (Russi, 2005).

2.9.8 Cadmium (Cd)

2.9.8.1 Exposure source(s)

Cadmium is an element that can be present as an impurity in coal or coal mine dust due to the fact that it is also found in the earth's crust as a natural occurring element (IARC, 2012a; Kretsinger *et al.*, 2013). No mineral or metal is mined specifically for its cadmium content (Franzblau, 2005). Occupational exposure can present itself through inhalation of cadmium-containing welding fumes during maintenance activities in a mine or inhalation of coal mine dust (Franzblau, 2005; Jenkins *et al.*, 2013).

2.9.8.2 IARC Classification and organ toxicity

The health risk involved with cadmium exposure is mainly due to its classification as a Group 1 carcinogen (IARC, 2012a). Cadmium toxicity targets mainly the kidney and is a well-known cause of kidney disease as well as renal cancer worldwide (Shalat and Mohr, 2005; Kretsinger *et al.*, 2013). Exposure through inhalation increases the risk of developing lung cancer, and another study also indicated the increased risk of developing breast cancer in women as well as the development of prostate cancer in men (McElroy *et al.*, 2006; Clapp *et al.*, 2008; Kretsinger *et al.*, 2013). Combined exposure of cadmium and tobacco smoking creates a synergistic effect as discussed in section 2.6.3.

2.9.9 Beryllium (Be)

2.9.9.1 Exposure source(s)

Beryllium is a lightweight metal sometimes contained in coal, and can enter surface water through the leaching of coal piles (Kreiss, 2005). Occupational exposure to beryllium may also occur through inhalation of welding fumes when welding fluxes contain Be as an additive (IARC, 2012a).

Non-sparking tools are manufactured using beryllium-copper alloys and are recommended for use in an environment – for example an underground coal mine – containing flammable dust and gases, such as coal mine dust and methane gas. Beryllium alloys are non-ferrous which means that they are softer and can be worn out quicker than conventional tools causing the release of beryllium particles into the air, increasing the inhalation exposure of workers in a coal mine (OSHA, 2002; Grainger Inc, 2013). Although these materials are enclosed with a protective casing preventing exposure to beryllium, improper maintenance and cleaning of these tools can lead to potential beryllium exposure (ATSDR, 2002).

2.9.9.2 IARC Classification and organ toxicity

Beryllium poses a risk due to its Group 1 carcinogen classification (IARC, 2012a). Inhalation exposure to beryllium and beryllium compounds, as well as beryllium-containing dusts may lead to an increase in lung cancer incidences (IARC, 2012a; Kretsinger *et al.*, 2013). A marker used for beryllium dust or fume exposure that has been linked to an increase in lung cancer rates is acute beryllium pneumonitis (Balmes, 2005; Klaunig, 2013). Skin contact to beryllium in other industries, such as electronic manufacturing, can lead to hypersensitivity reactions presenting itself as contact dermatitis (Kaplan *et al.*, 2013; Kretsinger *et al.*, 2013).

2.9.10 Extremely low-frequency electromagnetic fields (ELF EMF)

2.9.10.1 Exposure source(s)

Electric and magnetic fields are generated together and are referred to as electromagnetic fields (EMF). Magnetic fields increase in strength when they are combined with an electric current, but both fields will decrease in strength as the distance from the source increases (Martin and Ducatman, 2005). Underground coal miners represent an occupational group that is exposed to ELF EMF from the high-voltage power distribution lines which are strung overhead or fixed to the sidewalls in the mine tunnels as well as converters and step-down transformers necessary for powering mining equipment (Mogodi, 2012). ELF EMF is also produced by the 50-60 Hz currents used in welding and can also pose a potential occupational exposure risk (IARC, 1990).

2.9.10.2 IARC Classification and organ toxicity

A statistically significant risk of developing leukaemia, myelogenous leukaemia and chronic lymphocytic leukaemia was indicated due to the long-term occupational exposure (25 years or more of underground mining) to electromagnetic fields (Gilman *et al.*, 1985; Feychting *et al.*, 1997). An increased risk of developing brain cancer has been found in men who are exposed to ELF EMF, and included occupations such as electrician, welder, technician and engineer (Demers, 2005). Extremely low-frequency magnetic fields are classified as Group 2B carcinogens and extremely low-frequency electric fields as Group 3 carcinogens (IARC, 2002).

2.9.11 Asbestos

2.9.11.1 Exposure source(s)

Asbestos is a collective term for naturally occurring mineral silicate fibres of the serpentine and amphibole groups (Unsted, 2001). Mineral silicate fibres may be either fibrous or non-fibrous and are known for their small diameter and robustness, which causes them to persist in lung tissue (Unsted, 2001; IARC, 2012a).

Although the use of asbestos was banned in South Africa in 2008 the occurrence of asbestos-related diseases and cancers are still documented in those exposed to it years ago (Kazan-Allen, 2008; HSE, 2015). A wide range of occupations, including insulation, shipbuilding, iron and steel industries, as well as power generation were exposed to asbestos (Mengeot, 2007). Occupational exposure may still occur from secondary sources in the mining industry such as asbestos used for insulation purposes in older buildings (White, 2001; Mengeot, 2007).

2.9.11.2 IARC Classification and organ toxicity

Asbestos is classified by the IARC as a Group 1 carcinogen and exposure may lead to lung cancer or mesothelioma, which is a type of cancer affecting the lining of the chest or abdominal cavity (Unsted, 2001; IARC, 2012a). Even with the ban of asbestos in several countries worldwide, more than 2 000 malignant mesothelioma deaths are still reported each year in the United States (Thorne, 2013).

Inhalation exposure of asbestos is not only known for causing lung cancer or malignant mesothelioma, but is also known for causing asbestosis, which is a type of fibrotic lung disease (Matos and Boffetta, 1994). Asbestosis is mostly caused by long-term inhalation of asbestos fibres with a diameter of less than 0.15 µm and a length of 2 µm, and mesothelioma is caused by crocidolite or blue asbestos fibres with a length of 5 µm or more and a diameter of less than 0.5 µm (Mets *et al.*, 2011; Leikauf, 2013).

2.9.12 Welding-related exposures

2.9.12.1 Exposure source(s)

The welding process comprises the joining of metal materials through fusion by using a filler material and various types of energy, resulting in the formation of an alloy. Occupational inhalation exposure occurs from airborne contaminants rising from welding fumes and largely depends on the materials used and the type of energy used in the process (IARC, 1990; Pavlisko *et al.*, 2014). Airborne contaminants that can be contained in the welding fumes include various carcinogenic substances such as benzo(a)pyrene, lead, nickel, chromium, ozone and arsenic, to name a few. Ultraviolet radiation (UVR) produced during all electric arc welding processes is another form of hazardous occupational exposure which could lead to the development of ocular melanoma (IARC, 1992; IARC, 2012b).

2.9.12.2 IARC Classification and organ toxicity

Welding fumes are classified as a Group 2B carcinogen and UVR specifically from arc welding as a Group 2A carcinogen. Lung cancer, bladder cancer as well as skin cancer have been reported due to welding-related exposures, with welders seen as the largest occupational group with exposure to artificial sources of UVR (IARC, 1990; IARC, 1992; Ruder *et al.*, 2005).

2.9.13 Ultraviolet radiation (UVR)

2.9.13.1 Exposure source(s)

Occupational exposure to UVR falls under an important category of occupational exposure, but due to the recreational and leisure-related exposure to the sun, it is difficult to determine the relation of occupational exposure to the development of skin cancer (Gawkrodger, 2004). Exposure to UVR from sunlight or solar radiation will mostly be a concern in workers employed at an opencast coal mine, especially groups of workers responsible for drilling (Mines Inspectorate, 2010; CCOHS, 2016). Artificial sources of UVR can also raise a concern during occupational exposure, and can include exposure during electric arc welding processes as well as indoor lighting sources (Gawkrodger, 2004; Mines Inspectorate, 2010; Young and Rushton, 2012).

2.9.13.2 IARC Classification and organ toxicity

UVR from outdoor sunlight exposure is classified by the IARC as a Group 1 carcinogen as there is sufficient evidence available suggesting the development of various types of skin cancer in humans when exposed to UVR (IARC, 2012b; CCOHS, 2016). The different types of skin cancers can include Lentigo Maligna, which is associated with prolonged exposure to sunlight in outdoor occupations, or squamous cell carcinoma - also related to long-term sunlight exposure – but usually occurs in persons older than 55 years. Skin cancers related to sun exposure mostly have a latent period of two or three decades. (Gawkrodger, 2004)

Occupational exposure to UVR from welding is a potential factor in the development of non-melanoma skin cancer (Gawkrodger, 2004). As mentioned in section 2.9.12.2, UVR exposure - specifically from arc welding – is classified as a Group 2A carcinogen (IARC, 1992).

2.10 Summary of carcinogens and cancer types

In Table 2-4, a summary is given on the abovementioned carcinogens (refer to section 2.9.1 to section 2.9.13), their IARC carcinogen classification, and their respective cancer types that may occur when carcinogenic exposure occurs in a coal mine.

2.11 Diagnostic methods for cancer diagnosis

Various diagnostic processes are used by mining companies as preventative as well as legislative measures for diagnosing various occupational diseases (DME, 2003; DOL, 2009). The diagnostic tests specifically used for respiratory diseases – such as silicosis or lung cancer – can include chest X-rays and lung function tests (DOL, 2009; SASOM, 2011).

Table 2-4: List of carcinogens with the respective type(s) of cancer caused due to occupational exposure

		Cancer types												
	IARC Group	**Lung**	**Laryn-geal**	**Leukae-mia**	**Gastric**	**Bladder**	**Skin**	**Brain**	**Renal**	**Liver**	**Lym-phoma**	**Pros-tate**	**Breast**	**Meso-thelioma**
Silica	**1**	•												
Radon gas	**1**	•		•										
PAHs		•			•	•	•					•		
Benzo(a)pyrene	**1**													
Benz(a)anthracene	**2A**													
Coal mine dust	**3**		•		•							•		
Diesel engine exhaust	**1**	•				•						•		
Trichloroethylene	**1**							•	•	•	•	•		
Arsenic	**1**	•				•	•			•		•		
Cadmium	**1**	•							•			•	•	
Beryllium	**1**	•												
ELF EMF	**2B**			•				•						
Asbestos	**1**	•												•
Welding related		•				•	•							
Welding fumes	**2B**	•				•								
UVR exposure	**2A**						•							
UVR (outdoor sun)	**1**						•							

IARC: International Agency for Research on Cancer
PAH: Polycyclic Aromatic Hydrocarbons
ELF EMF: Extremely low-frequency electromagnetic fields
UVR: Ultraviolet radiation

2.12 Importance of research study

Occupational cancer prevention - and ultimately elimination thereof- should be considered as top priority by the world's coal mining sectors. According to the ILO (International Labour Organisation) deaths caused by occupational cancer globally every year are twice the number caused by occupational accidents (Takala, 2015).

Cancer caused by occupational exposures is largely preventable and the exposure to occupational carcinogens in a coal mine poses a risk to the health of all exposed workers. It is therefore essential to investigate the risk of developing occupational cancer during employment in a coal mine in order to achieve the prevention of occupational cancer and to identify solutions for action.

As mentioned in this literature review (also refer to Table 2-4 for a summary), various carcinogenic exposure sources exist in the coal mining environment. Therefore, it is important to consider the health-related consequences with regard to the exposure of coal mine workers in their occupational environments. Also, the necessary precautions that should be taken to prevent or minimise the health risks caused by occupational exposure should be considered and reviewed regularly.

2.13 References

Antao VC, Pinheiro GA. (2015) Surveillance of occupational respiratory diseases in developing countries. *Semin Respir Care Med*; **36**: 449-454.

ATSDR (Agency for Toxic Substances and Disease Registry). (1995) Toxicological profile for polycyclic aromatic hydrocarbons. Available from: URL: http://www.atsdr.cdc.gov/toxprofiles/tp69.pdf (accessed 4 August 2016)

ATSDR (Agency for Toxic Substances and Disease Registry). (2002) Toxicological profile for Beryllium. Available from: URL: http://www.denix.osd.mil/cmrmd/upload/ATSDRTOXICOLOGICALPROFILEFORBERYLLIUM.PDF (accessed 3 February 2015)

ATSDR (Agency for Toxic Substances and Disease Registry). (2012) Case studies in environmental medicine (CSEM): radon toxicity. Available from: URL: http://www.atsdr.cdc.gov/csem/csem.asp?csem=8&po=4 (accessed 5 May 2015)

Attfield M, Wagner GR. (2005) Coal Worker's Pneumoconiosis. *In* Levy BS, Wagner GR, Rest KM, Weeks JL, editors. Preventing occupational disease and injury. Wash, DC: American Public Health Association. p. 166-170. ISBN 0 87553 0435.

Attfield MD, Schleiff PL, Lubin JH, *et al*. (2012) The Diesel Exhaust in Miners Study: a cohort mortality study with emphasis on lung cancer. *J Natl Cancer Inst*; **104**: 869-883.

Balmes JR. (2005) Chronic beryllium disease and cobalt-related interstitial lung disease (Hard-Metal Disease and Diamond Polisher's Lung Disease). *In* Rosenstock R, Cullen MR, Brodkin CA, Redlich CA, editors. Textbook of clinical occupational and environmental medicine. London: Elsevier, Inc. p. 357-363. ISBN 0 7216 8974 4.

Banks DE. (2005) Silicosis. *In* Rosenstock R, Cullen MR, Brodkin CA, Redlich CA, editors. Textbook of clinical occupational and environmental medicine. London: Elsevier, Inc. p. 380-392. ISBN 0 7216 8974 4.

Beiki O. (2015) The first 50 years of International Agency for Research on Cancer (2015-1965). *Basic Clin Can Res*; **7**: 1.

Belle BK. (2008) Use of baseline personal DPM exposure data for mine ventilation planning – A South African Journey. 12th US/North American Mine Ventilation Symposium 2008. p. 481-485. ISBN 978 0 615 20009 5.

Berry G, Liddell FDK. (2004) The interaction of asbestos and smoking in lung cancer: A modified measure of effect. *Ann Occup Hyg*; **48**: 459-462.

Borm PJA, Tran L. (2001) From quartz hazard to quartz risk: the coal mines revisited. *Ann Occup Hyg*; **46**: 25-32.

Brown AM, Christie D, Taylor R, *et al*. (1997) The occurrence of cancer in a cohort of New South Wales coal miners. *Aust NZ J Publ Heal*; **21**: 29-32.

CCOHS (Canadian Centre for Occupational Health and Safety). (2013) Synergism. Available from: URL: http://www.ccohs.co.za/oshanswers/chemicals/synergism.html (accessed 3 August 2016)

CCOHS (Canadian Centre for Occupational Health and Safety). (2016) Skin cancer and sunlight. Available from: URL: https://www.ccohs.ca/oshanswers/diseases/skin_cancer.html (accessed 14 March 2016)

Chamber of Mines of South Africa. (2015) Coal: Location and geology. Available from: URL: http://www.chamberofmines.org.za/sa-mining/coal (accessed 23 July 2016)

Clapp RW, Jacobs MM, Loechler EL. (2008) Environmental and occupational causes of cancer: New evidence, 2005-2007. *Rev Environ Health*; **23**: 1-37.

Claxton LD. (2014) The history, genotoxicity, and carcinogenicity of carbon-based fuels and their emissions. Part 3: Diesel and gasoline. *Mutat Res*; **763**: 30-85.

Cohen DE, Bassiri S, Forrester BG, Nethercott J. (2005) Skin cancers. *In* Rosenstock R, Cullen MR, Brodkin CA, Redlich CA, editors. Textbook of clinical occupational and environmental medicine. London: Elsevier, Inc. p. 811-824. ISBN 0 7216 8974 4.

Demers PA. (2005) Brain neoplasms. *In* Rosenstock R, Cullen MR, Brodkin CA, Redlich CA, editors. Textbook of clinical occupational and environmental medicine. London: Elsevier, Inc. p. 806-810. ISBN 0 7216 8974 4.

DME (Department of Minerals and Energy). (2002) SAMOHP (South African Mines Occupational Hygiene Programme): Codebook. Available from: URL: http://www.mhsc.org.za/sites/default/files/Guide%20line%20SAMHOP%20_codebook.pdf (accessed 12 June 2015)

DME (Department of Minerals and Energy). (2003) Mandatory code of practice for an occupational health programme on personal exposure to airborne pollutants. Available from: URL:

https://www.google.co.za/url?sa=t&rct=j&q=&esrc=s&source=web&cd=5&cad=rja&uact=8&ved=0ahUKEwiE9fyM-_rOAhXCLcAKHYF5BzQQFggyMAQ&url=http%3A%2F%2Fclaybrick.org%2Fsites%2Fdefault%2Ffiles%2Fdownloads%2Flegislation%2Fcops%2FCOP%252306%2520AirbornePollutants.pdf&usg=AFQjCNGnN2E9rpJCfECNpwa6THOoPVInKQ&sig2=KtNDOr5FlaiEJophaeaqSg (accessed 6 September 2016)

DME (Department of Minerals and Energy). (2010) Coal resources. Available from: URL: http://www.energy.gov.za/files/coal_frame.html (accessed 17 June 2016)

DOL (Department of Labour). (2009) Guide on worker's health protection – through the good handling and use of crystalline silica dust and products containing it. Available from: URL: https://www.google.co.za/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0ahUKEwjV7LuJ__rOAhVKGsAKHXP8DiwQFggaMAA&url=http%3A%2F%2Fwww.labour.gov.za%2FDOL%2Fdownloads%2Fdocuments%2Fuseful-documents%2Foccupational-health-and-safety%2FOHS_Silica%2520Pamphlet.pdf&usg=AFQjCNGwpFg1o3K6u1ttS3mhJxfWBeXE_A&sig2=KWrpW3yYvMBXWk44xKNDZw&bvm=bv.131783435,d.d24 (accessed 6 September 2016)

DoL (Department of Labour). (2011) Occupational Health Action Plan to 2013: Workplace health and safety strategy for New Zealand to 2015. ISBN 0 478 39107 7.

Donbak L, Rencuzogullari E, Yavuz A, Topaktas M. (2005) The genotoxic risk of underground coal miners from Turkey. *Mutat Res*; **588**: 82-87.

Dougall AW. (2010) Review of current and expected underground coal mining methods and an evaluation of the best practices associated with these. Dissertation: University of the Witwatersrand.

Driscoll T, Steenland K, Prüss-Üstün A, *et al*. (2004) Occupational carcinogens: assessing the environmental burden of disease at national and local levels. Environmental burden of disease series, no. 6. Available from: URL: http://www.who.int/quantifying_ehimpacts/publications/en/ebd6.pdf?ua=1 (accessed 21 April 2015)

Duffus JH, Templeton DM, Nordberg M. (2007) Glossary of terms used in toxicology. *Pure Appl Chem*; **79**:1153-1344.

Duffus JH, Templeton DM, Nordberg M. (2009) Concepts in Toxicology. Cambridge: RSC Publishing. ISBN 978 0 85404 1572.

Eaton DL, Gilbert SG. (2013) Principles of toxicology. *In* Klaassen CD, editor. Casarett and Doull's Toxicology: The basic science of poisons. 8th ed. China: McGraw-Hill Education. p. 13-48. ISBN 978 0 07 176925 9.

Eaton DL. (2005) Toxicology. *In* Rosenstock R, Cullen MR, Brodkin CA, Redlich CA, editors. Textbook of clinical occupational and environmental medicine. London: Elsevier, Inc. p. 83-118. ISBN 0 7216 8974 4.

European Commission. (2015) Chemical Safety Report: Trichloroethylene. Available from: URL: http://ec.europa.eu/DocsRoom/documents/10925/attachments/1/translations/en/renditions/native. (accessed 3 February 2016)

Falk HL, Jurgelski W. (1979) Health effects of coal mining and combustion: carcinogens and cofactors. *Environ Health Persp*; **3**: 203-226.

Feychting M, Forssen U, Floderus B. (1997) Occupational and residential magnetic field exposure and leukemia and central nervous system tumors. *Epidemiology*; **8**: 384-389.

Finkelman RB, Orem W, Castranova V, *et al*. (2002) Health impacts of coal and coal use: possible solutions. *Int J Coal Geol*; **50**: 425-443.

Franzblau A. (2005) Cadmium. *In* Rosenstock R, Cullen MR, Brodkin CA, Redlich CA, editors. Textbook of clinical occupational and environmental medicine. London: Elsevier, Inc. p. 955-957. ISBN 0 7216 8974 4.

Gawkrodger DJ. (2004) In-depth review: Occupational skin cancers. *Occup Med*; **54**: 458-463.

Gibbs GW. (1997) Estimating residential polycyclic aromatic hydrocarbon (PAH) related lung cancer risks using occupational data. *Ann Occup Hyg*; **41**: 49-53.

Gilman P, Ames RG, McCawley MA. (1985) Leukemia risk among U.S. white male coal miners: A case-control study. *J Occup Environ Med*; **27**.

Goldsmith DF. (2000) Linking environmental cancer with occupational epidemiology research: the role of the International Agency for Research on Cancer (IARC). *J Environ Pathol Toxicol Oncol*; **19**: 171-175.

Grainger Inc. (2013) Non-sparking tools. Available from: URL: https://www.grainger.com/content/qt-non-sparking-tools-381 (accessed 3 February 2016)

Hecker E. (1975) Cocarcinogens and cocarcinogenesis (with a note on synergistic processes in carcinogenesis). *In* Bierwolf D, Fey F, Graffi A, Hecker E, Van der Helm K, Kammer K, Magee PN, Micheel B, Munk K, Nakahara W, Pegg AE, Preussmann R, Schramm T, Sugano H, Swann PF, Wunderlich V, Yosida TH, authors. Handbuch der allgemeinen Pathologie: Geschwülste – Tumors II. Heidelberg: Springer-Verlag Berlin. p. 651-676. ISBN 978 3 642 80854 8.

Hem P. (2015) Longwall mining. Available from: URL: http://technology.infomine.com/reviews/longwallmining/welcome.asp?view=full (accessed 23 July 2016)

Henny D. (2013) Carcinogens: Different classifications. Available from: URL: http://www.prevor.com/en/carcinogens-different-classifications (accessed 3 February 2016)

Herbst MC. (2014) Top 20 cancer deaths by cause for South Africa – 2000 (revised). Available from: URL: http://www.cansa.org.za/files/2014/07/20-Top-Cancers-as-Cause-of-Death-2000.pdf (accessed 22 April 2015)

Herbst MC. (2017) CANSA (Cancer Association of South Africa) – Fact sheet on the top ten cancers per population group. Available from: URL: http://www.cansa.org.za/files/2017/03/Fact-Sheet-Top-Ten-Cancers-per-Population-Group-in-SA-NCR-2012-web-Feb-2017.pdf (accessed 22 April 2017)

Hoel DG. (2013) Toxic effects of radiation and radioactive materials. *In* Klaassen CD, editor. Casarett and Doull's Toxicology: The basic science of poisons. 8th ed. China: McGraw-Hill Education. p. 1113-1130. ISBN 978 0 07 176925 9.

HSE (Health and Safety Executive). (2015) Health and safety statistics: Annual report for Great Britain 2014/15. Available from: URL: http://www.hse.gov.uk/statistics/overall/hssh1415.pdf (accessed 3 February 2016)

Huang X, Li W, Attfield MD, *et al*. (2005) Mapping and prediction of Coal Worker's Pneumoconiosis with Bioavailable Iron Content in bituminous coals. *Environ Health Persp*; **113**: 964-968.

Hung YP, Teng CJ, Liu CJ, *et al*. (2014) Cancer risk among patients with coal workers' pneumoconiosis in Taiwan: A nationwide population-based study. *Int J Cancer*; **134**: 2910-2916.

Hustrulid WA. (2016) Strip mining. Available from: URL: https://global.britannica.com/technology/strip-mining (accessed 4 July 2016)

IARC (International Agency for Research on Cancer). (1988) Monographs on the evaluation of carcinogenic risks to humans (Volume 43): Man-made mineral fibres and radon. Available from: URL: http://monographs.iarc.fr/ENG/Monographs/vol43/mono43.pdf (accessed 28 April 2015)

IARC (International Agency for Research on Cancer). (1990) Monographs on the evaluation of carcinogenic risks to humans (Volume 49): Chromium, nickel and welding. Available from: http://monographs.iarc.fr/ENG/Monographs/vol49/mono49.pdf (accessed 1 February 2016)

IARC (International Agency for Research on Cancer). (1992) Monographs on the evaluation of carcinogenic risks to humans (Volume 55): Solar and ultraviolet radiation. Available from: URL: http://monographs.iarc.fr/ENG/Monographs/vol55/mono55.pdf (accessed 3 February 2016)

IARC (International Agency for Research on Cancer). (1997) Monographs on the evaluation of carcinogenic risks to humans (Volume 68): Silica, some silicates, coal dust and para-amid fibrils. Available from: URL: http://monographs.iarc.fr/ENG/Monographs/vol68/mono68.pdf (accessed 16 June 2016)

IARC (International Agency for Research on Cancer). (2002) Monographs on the evaluation of carcinogenic risks to humans (Volume 80): Non-ionizing radiation, Part 1: Static and extremely low-frequency (ELF) electric and magnetic fields. Available from: URL: http://monographs.iarc.fr/ENG/Monographs/vol80/mono80.pdf (accessed 7 January 2016)

IARC (International Agency for Research on Cancer). (2004) Monographs on the evaluation of carcinogenic risks to humans (Volume 83): Tobacco smoke and involuntary smoking. Available from: URL: http://monographs.iarc.fr/ENG/Monographs/vol83/mono83.pdf (accessed 13 July 2016)

IARC (International Agency for Research on Cancer). (2010) Monographs on the evaluation of carcinogenic risks to humans (Volume 92): Some non-heterocyclic polycyclic aromatic hydrocarbons and some related exposures. Available from: URL: http://monographs.iarc.fr/ENG/Monographs/vol92/mono92.pdf (accessed 22 April 2015)

IARC (International Agency for Research on Cancer). (2012a) Monographs on the evaluation of carcinogenic risks to humans (Volume 100C): Arsenic, metals, fibres, and dusts. Available from: URL: http://monographs.iarc.fr/ENG/Monographs/vol100C/mono100C.pdf (accessed 28 April 2015)

IARC (International Agency for Research on Cancer). (2012b) Monographs on the evaluation of carcinogenic risks to humans (Volume 100D): Radiation. Available from: URL: http://monographs.iarc.fr/ENG/Monographs/vol100D/index.php (accessed 14 March 2016)

IARC (International Agency for Research on Cancer). (2014a) Monographs on the evaluation of carcinogenic risks to humans (Volume 105): Diesel and gasoline engine exhausts and some nitroarenes. Available from: URL: http://monographs.iarc.fr/ENG/Monographs/vol105/mono105.pdf (accessed 22 April 2015).

IARC (International Agency for Research on Cancer). (2014b) Monographs on the evaluation of carcinogenic risks to humans (Volume 106): Trichloroethylene, tetrachloroethylene, and some other chlorinated agents. Available from: URL: http://monographs.iarc.fr/ENG/Monographs/vol106/index.php (accessed 6 January 2016)

IARC (International Agency for Research on Cancer). (2015) Agents classified by the IARC Monographs, volumes 1-114. Available from: URL: http://monographs.iarc.fr/ENG/Classification/ (accessed 22 April 2015)

IARC (International Agency for Research on Cancer). (2015) GLOBOCAN 2012: Estimated cancer incidence, mortality and prevalence worldwide in 2012. Available from: URL: http://globocan.iarc.fr/Pages/fact_sheets_populations.aspx (accessed 6 September 2016)

IEA (International Energy Agency). (2015) Key coal trends – Excerpt from: Coal information. Available from: URL: https://www.iea.org/publications/freepublications/publication/KeyCoalTrends.pdf (accessed 17 June 2016)

IMSIF (Illinois Mine Subsidence Insurance Fund). (2016) What is mine subsidence? Available from: URL: http://www.imsif.com/about-mine-subsidence/what-is-mine-subsidence (accessed 23 July 2016)

Jenkins WD, Christian WJ, Mueller G, Robbins KT. (2013) Population cancer risks associated with coal mining: a systematic review. *Plos One*; **8**: 1-12.

Kammer R, Tinnerberg H, Eriksson K. (2011) Evaluation of a tape-stripping technique for measuring dermal exposure to pyrene and benzo(a)pyrene. *J Environ Monitor*; **13**: 2165-2175.

Kaplan BLF, Sulentic CEW, Holsapple MP, Kaminski NE. (2013) Toxic responses of the immune system. *In* Klaassen CD, editor. Casarett and Doull's Toxicology: The basic science of poisons. 8th ed. China: McGraw-Hill Education. p. 559-638. ISBN 978 0 07 176925 9.

Kazan-Allen L. (2008) South Africa bans asbestos. Available from: URL: http://ibasecretariat.org/lka_sa_asb_ban_08.php (accessed 3 February 2016)

Kipen HM, Wartenberg D. (2005) Lymphohematopoietic malignancies. *In* Rosenstock R, Cullen MR, Brodkin CA, Redlich CA, editors. Textbook of clinical occupational and environmental medicine. London: Elsevier, Inc. p. 744-756. ISBN 0 7216 8974 4.

Klaunig JE. (2013) Chemical carcinogenesis. *In* Klaassen CD, editor. Casarett and Doull's Toxicology: The basic science of poisons. 8th ed. China: McGraw-Hill Education. p. 393-443. ISBN 978 0 07 176925 9.

Kohler JL. (2005) Mining. *In* Rosenstock R, Cullen MR, Brodkin CA, Redlich CA, editors. Textbook of clinical occupational and environmental medicine. London: Elsevier, Inc. p.201-214. ISBN 0 7216 8974 4.

Kreiss K. (2005) Beryllium and cobalt. *In* Rosenstock R, Cullen MR, Brodkin CA, Redlich CA, editors. Textbook of clinical occupational and environmental medicine. London: Elsevier, Inc. p. 950-954. ISBN 0 7216 8974 4.

Kretsinger RH, Uversky VN, Permyakov EA. (2013) Encyclopedia of Metalloproteins. NY:Springer. eISBN 978 1 4614 1533 6.

Lang L, Fu-bao Z. (2010) A comprehensive hazard evaluation system for spontaneous combustion of coal in underground mining. *Int J Coal Geol*; **82**: 27-36.

Leikauf GD. (2013) Toxic responses of the respiratory system. *In* Klaassen CD, editor. Casarett and Doull's Toxicology: The basic science of poisons. 8th ed. China: McGraw-Hill Education. p. 691-732. ISBN 978 0 07 176925 9.

Liddell FDK. (2001) The interaction of asbestos and smoking in lung cancer. *Ann Occup Hyg*; **45**: 341-356.

Liu S. (2005) Effects of arsenic on DNA repair and cell cycle checkpoints: involvement in arsenic co-mutagenesis and co-carcinogenesis. Dissertation: University of Cincinnati.

Lundberg I, Hogstedt C, Lidén C, Nise G. (2005) Organic solvents and related compounds. *In* Rosenstock R, Cullen MR, Brodkin CA, Redlich CA, editors. Textbook of clinical occupational and environmental medicine. London: Elsevier, Inc. p. 991-1009. ISBN 0 7216 8974 4.

Majzlan J, Drahota P, Filippi M. (2014) Parageneses and crystal chemistry of arsenic minerals. *In* Bowell RJ, Alpers CN, Jamieson HE, Nordstrom DK, Majzlan J, editors. Reviews in mineralogy and geochemistry (volume 79): Arsenic – environmental geochemistry, mineralogy, and microbiology. p. 17-184. ISBN 9 780 939950 94 2.

Mamuya SHD, Bratveit M, Mwaiselage *et al*. (2006) High exposure to respirable dust and quartz in a labour-intensive coal mine in Tanzania. *Ann Occup Hyg*; **50**: 197-204.

Martin CJ, Ducatman AM. (2005) Non-ionizing radiation. *In* Rosenstock R, Cullen MR, Brodkin CA, Redlich CA, editors. Textbook of clinical occupational and environmental medicine. London: Elsevier, Inc. p. 870-879. ISBN 0 7216 8974 4.

Matos E, Boffetta P. (1994) Other diseases. *In* Pearce N, Matos E, Vainio H, Boffetta P, Kogevinas M, editors. Occupational cancer in developing countries: IARC Scientific Publications No. 129. Lyon, France: International Agency for Research on Cancer. p. 129-142. ISBN 92 832 2129.

McClellan RO, Hesterberg TW, Wall JC. (2012) Evaluation of carcinogenic hazard of diesel engine exhaust needs to consider revolutionary changes in diesel technology. *Regul Toxicol Pharm*; **63**: 225-258.

McCormack VA, Schüz J. (2012) Africa's growing cancer burden: environmental and occupational contributions. *Cancer Epidem*; **36**: 1-7.

McElroy JA, Shafer MM, Trentham-Dietz A, *et al*. (2006) Cadmium exposure and breast cancer risk. *J Natl Cancer Inst*; **98**: 869-873.

Mengeot MA. (2007) Occupational cancer: The Cinderella disease. Belgium: European Union Trade Institute for Research and Education. ISBN 978 2 87452 074 7.

Mets JT, Murphy JP, Acutt J. (2011) Occupational medicine. *In* Hattingh S, Acutt J, Berg Z, editors. Occupational health: management and practice for health practitioners. Cape Town, SA: Juta and Company Ltd. p. 180-246. ISBN 978 0 70218 674 5.

MHSA (Mine Health and Safety Act and Regulations). (1996) Act 29 of 1996. Lexis Nexis. ISBN 978 0 409 12279 4.

Mines Inspectorate. (2010) Safety bulletin 93: Sunlight and other ultraviolet radiation risk management. Available from: URL: http://webcache.googleusercontent.com/search?q=cache:SGMTZiyAcuEJ:www.minex.org.nz/documents/QLD%2520Safety%2520Bulletin%252093%2520Sunlight%2520and%2520other%2520ultraviolet%2520radiation%2520risk%2520management.pdf+&cd=14&hl=en&ct=clnk&gl=za (accessed 14 March 2016)

Mogodi P. (2012) Analysis of energy consumption, economics and management at New Denmark Colliery. Available from: URL: http://mobile.wiredspace.wits.ac.za/handle/10539/13079 (accessed 4 January 2016)

Monforton C. (2006) Weight of the evidence or Wait for the evidence? Protecting underground miners from diesel particulate matter. *Am J Public Health*; **96**: 271-276.

Muzyka V, Bogovski S, Scheepers P, *et al*. (2003) Effects of occupational exposure to diesel exhaust on porphyrin metabolism in lymphocytes of workers employed at black coal and oil-shale mines. *Am J Ind Med*; **44**: 70-74.

Myers T. (2009) Cancer. *In* Myers T, editor. Mosby's Dictionary of medicine, nursing and health professions. Missouri: Elsevier Inc. p. 285. ISBN 978 0 323 04937 5.

Naghadehi MZ, Sereshki F, Mohammadi F. (2014) Pathological study of the prevalence of silicosis among coal miners in Iran: A case history. *Atmos Environ*; **83**: 1-5.

Naidoo N. (2002) Respiratory health of South African coal miners. Dissertation: The University of Michigan.

Ndlovu N, Boshomane J, Davies T, *et al*. (2014) Pathology Division Surveillance Report (PATHAUT): Demographic data and disease rates for January to December 2013. Available from: URL: http://www.nioh.ac.za/assets/files/PathautReport2013.pdf (accessed 6 September 2016)

Ngamwong Y, Tangamornsuksan W, Lohitnavy O, *et al*. (2015) Additive synergism between asbestos and smoking in lung cancer risk: A systematic review and meta-analysis. *Plos One*; **10**: 1-19.

NIOSH (National Institute for Occupational Safety and Health). (2011) Current Intelligence Bulletin 64: Coal mine dust exposures and associated health outcomes. Available from: URL: http://www.cdc.gov/niosh/docs/2011-172/pdfs/2011-172.pdf (accessed 2 March 2015)

NTP (National Toxicology Program). (2014) Report on carcinogens, thirteenth edition. Available from: URL: http://ntp.niehs.nih.gov/ntp/roc/content/profiles/polycyclicaromatichydrocarbons.pdf (accessed 14 May 2015)

OSHA (Occupational Safety and Health Administration). (2002) OSHA 3080: Hand and power tools. Available from: URL: https://www.osha.gov/Publications/osha3080.html (accessed 3 February 2016)

Patnaik P. (1999) A comprehensive guide to the hazardous properties of chemical substances. NY: John Wiley. ISBN 0 471 29175 7.

Pavlisko EN, Boffetta P, Roggli VL. (2014) Lung cancer (exposure assessment, pathology, and epidemiology). *In* Anttila S, Boffetta P, editors. Occupational cancers. London: Springer. p.181-210. ISBN 978 1 4471 2825 0.

Petsonk EL, Attfield MD. (2005) Respiratory diseases of coal mines. *In* Rosenstock R, Cullen MR, Brodkin CA, Redlich CA, editors. Textbook of clinical occupational and environmental medicine. London: Elsevier, Inc. p. 393-407. ISBN 0 7216 8974 4.

Petsonk EL, Rose C, Cohen R. (2013) Coal mine dust lung disease: new lessons from an old exposure. *Am J Respir Crit Care Med*; **187**: 1178-1185.

Pone JDN, Hein KAA, Stracher GB, *et al*. (2007) The spontaneous combustion of coal and its by-products in the Witbank and Sasolburg coalfields in South Africa. *Int J Coal Geol*; **72**: 124-140.

Pooe D. (2011) The South African coal mining industry: A need for more efficient and collaborative supply chain. *J Transp Supply Chain Manage*; **5**: 316-336.

Porta M. (2008) Cocarcinogen. Porta M, editor. *In* A Dictionary of Epidemiology. Madison, NY: Oxford University Press. ISBN 978 019 531449 6.

Ruder AM, Carreón T, Ward EM, *et al*. (2005) Bladder cancer. *In* Rosenstock R, Cullen MR, Brodkin CA, Redlich CA, editors. Textbook of clinical occupational and environmental medicine. London: Elsevier, Inc. p. 757-766. ISBN 0 7216 8974 4.

Russi MB. (2005) Malignancies of the respiratory tract and pleura. *In* Rosenstock R, Cullen MR, Brodkin CA, Redlich CA, editors. Textbook of clinical occupational and environmental medicine. London: Elsevier, Inc. p. 727-740. ISBN 0 7216 8974 4.

Salnikow K, Zhitkovich A. (2008) Genetic and epigenetic mechanisms in metal carcinogenesis: nickel, arsenic, and chromium. *Chem Res Toxicol*; **21**: 28-44.

Sangani RG, Ghio AJ. (2011) Lung injury after cigarette smoking is particle related. *Int J Chron Obstruct Pulmon Dis*; **6**: 191-198.

SASOM (The South African Society of Occupational Medicine). (2011) Spirometry in industry. ISBN 978 1 919727 72 1.

Schenker MB. (1980) Diesel exhaust – an occupational carcinogen. *J Occup Med*; **22**: 41-46.

Schinkel LANL. (2009) Known and suspected human carcinogens – Carcinogens reference list. Available from: URL: https://www.ehs.uci.edu/programs/sop_library/CARCIN.pdf (accessed 3 February 2016)

Schneider MJ. (2014) Introduction to public health. Burlington, MA: Library of Congress. p. 339-350. ISBN 978 1 4496 8887 5.

Shalat SL, Mohr SN. (2005) Renal cancer. *In* Rosenstock R, Cullen MR, Brodkin CA, Redlich CA, editors. Textbook of clinical occupational and environmental medicine. London: Elsevier, Inc. p. 767-772. ISBN 0 7216 8974 4.

Shen DD. (2013) Toxicokinetics. *In* Klaassen CD, editor. Casarett and Doull's Toxicology: The basic science of poisons. 8th ed. China: McGraw-Hill Education. p. 367-390. ISBN 978 0 07 176925 9.

Singh E, Ruff P, Babb C, *et al*. (2015) Establishment of a cancer surveillance program: the South African experience. *Lancet Oncol*; **16**: e414-e421.

Singh RD. (1997) Principles and practices of modern coal mining. New Delhi, India: New Age International. p. 146-149. ISBN 81 224 09741.

Somdyala NIM, Maxwell Parkin D, Sithole N, Bradshaw D. (2015) Trends in cancer incidence in rural Eastern Cape Province; South Africa, 1998-2012. *Int J Cancer*; **136**: E470-474.

Stanton DW, Unsted D, Belle DK. (2007) Diesel particulate matter. *In* Stanton DW, Kielblock J, Schoeman JJ, Johnston JR, editors. Handbook on mine occupational hygiene measurements. Braamfontein(SA): Mine Health and Safety Council; p.39-43.

Stats SA (Statistics South Africa). (2014) Mining industry 2012 – Report No. 20-01-02 (2012). Available from: URL: http://www.statssa.gov.za/?page_id=1854&PPN=Report-20-01-02 (accessed 23 July 2016)

Stats SA (Statistics South Africa). (2015) The importance of coal. Available from: URL: http://www.statssa.gov.za/?p=4820 (accessed 7 January 2016)

Stayner LT, Graber JM. (2011) Does exposure to coal dust prevent or cause lung cancer. *Occup Environ Med*; **68**: 167-168.

Stenius U. (2012) Combined effect of carcinogens. Available from: URL: http://toxikolog.se/wp-content/uploads/2012/02/SFT2012SteniusSFT-Web.pdf (accessed 16 August 2015)

Stevenson A, Lindberg CA. (2015) Comorbidity. *In* Stevenson A, Lindberg CA, editors. New Oxford American Dictionary. 3rd ed. Madison, NY: Oxford University Press. eISBN 978 0199 89153 5.

Swaen GMH, Aerdts CWHM, Sturmans F, *et al*. (1985) Gastric cancer in coal miners: a case-control study in a coal mining area. *Brit J Ind Med*; **42**:627-630.

Swaen GMH, Meijers JMM, Slangen JJM. (1995) Risk of gastric cancer in pneumoconiotic coal miners and the effect of respiratory impairment. *Occup Environ Med*; **52**: 606-610.

Taeger D, Pesch B, Kendzia B, *et al*. (2015) Lung cancer among coal miners, ore miners and quarrymen: smoking-adjusted risk estimates from the synergy pooled analysis of case-control studies. *Scand J Work Environ Health*; **41**: 467-477.

Takala J. (2015) Eliminating occupational cancer. *Ind Health*; **53**: 307-309.

Thompson RJ. (2005) South African Colliery Managers Association – Project SACMA 01/03: Surface strip coal mining handbook. ISBN 0 620 34115 7.

Thorne PS. (2013) Occupational toxicology. *In* Klaassen CD, editor. Casarett and Doull's Toxicology: The basic science of poisons. 8th ed. China: McGraw-Hill Education. p. 1391-1412. ISBN 978 0 07 176925 9.

Tomaskova H, Jirak Z, Splichalova A, Urban P. (2012) Cancer incidence in Czech black coal miners in association with Coalworker's Pneumoconiosis. *Int J Occup Med Environ Health*; **25**: 137-144.

Une H, Esaki H, Osajima K, Ikui H, Kodama K, Hatada K. (1995) A prospective study on mortality among Japanese coal miners. *Ind Health*; **33**: 67-76.

Unsted AD. (2001) Airborne pollutants. *In* Guild R, Ehrlich RI, Johnston JR, Ross MH, editors. A handbook on occupational health practice in the South African mining industry. Braamfontein(SA): SIMRAC. p. 85-118. ISBN 1 919853 02 2.

Velga LHS, Amaral ECS, Colin D, Koifman S. (2006) A retrospective mortality study of workers exposed to radon in a Brazilian underground coal mine. *Radiat Environ Biophys*; **45**: 125-134.

Wagner GR, Hearl FJ. (2005) Mineral dusts: Asbestos, silica, coal, manufactured fibres. *In* Rosenstock R, Cullen MR, Brodkin CA, Redlich CA, editors. Textbook of clinical occupational and environmental medicine. London: Elsevier, Inc. p. 1073-1086. ISBN 0 7216 8974 4.

WCA (World Coal Association). (2013) Coal mining. Available from: URL: http://www.worldcoal.org/coal/coal-mining/ (accessed 15 March 2015)

WCA (World Coal Association). (2016a) Coal mining. Available from: URL: http://www.worldcoal.org/coal/coal-mining (accessed 17 June 2016)

WCA (World Coal Association). (2016b) Mining safety. Available from: URL: http://www.worldcoal.org/coal/coal-mining/mining-safety (accessed 4 July 2016)

WCI (World Coal Institute). (2009) The coal resource: a comprehensive overview of coal. Available from: URL: http://www.worldcoal.org/bin/pdf/original_pdf_file/coal_resource_overview_of_coal_report%2803-06-2009%.pdf (accessed 1 May 2015)

WEC (World Energy Council). (2013) World Energy Resources: Coal. Available from: URL: https://www.worldenergy.org/wp-content/uploads/2013/10/WER_2013_1_Coal.pdf (accessed 5 September 2016)

Weinberg RA. (2007) The biology of cancer. NY: Taylor and Francis. ISBN 0 8153 4076 1.

White N. (2001) Occupational lung disease. *In* Guild R, Ehrlich RI, Johnston JR, Ross MH, editors. A handbook on occupational health practice in the South African mining industry. Braamfontein, SA: SIMRAC. p.119-142. ISBN 1 919853 02 2.

WHO (World Health Organisation). (1986) Recommended health-based limits in occupational exposure to selected mineral dusts (silica, coal). Geneva, Switzerland: Schüler SA. ISBN 92 4 120734 5.

Whong WZ, Long R, Ames RG, Ong TM. (1983) Role of nitrosation in the mutagenic activity of coal dust: a postulation for gastric carcinogenesis in coal miners. *Environ Res*; **32**: 298-304.

Worku Z. (2004) A statistical analysis of common occupational diseases among South African miners from 2000 to 2003. *Occ Health Southern Afr*; **Sept/Oct**: 16-21.

Young C, Rushton L. (2012) Occupational cancer in Britain: Skin cancer. *Brit J Cancer*; **107**: S71-S75.

Yudovich YE, Ketris MP. (2005) Arsenic in coal: a review. *Int J Coal Geol*; **61**: 141-196.

CHAPTER 3: ARTICLE

In Chapter 3, the research study's results will be discussed in detail in the form of an article, with a brief introduction including the problem addressed during the study, as well as the general aim and objectives. The referencing style used for this study was done according to the journal *Annals of Occupational Hygiene* and will be discussed in further detail below. The researchers are aware that the name of the journal will be changed to "Annals of Work Exposures and Health" from 2017.

Annals of Occupational Hygiene– Author's instructions

Annals of Occupational Hygiene publishes original research and development material that helps reduce risk of ill-health resulting from work. The author's instructions are as follows:

Structure

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

Units and symbols

SI units must be used, though their equivalent in other systems may be given as well.

Figures

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

Tables

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

References

References should only be included which are essential to the development of an argument or hypothesis, or which describe methods for which the original account is too long to be reproduced. Only publications which can be obtained by the reader should be referenced. At the end of the paper, references should be listed in alphabetical order by name of first author, using the Vancouver Style of abbreviation and punctuation. ISBNs should be given for books and other publications where appropriate. Internet material can be referred to if it is likely to be permanently available and the date on which it was last accessed should be given. References will not be checked editorially, and their accuracy is the responsibility of authors. References in the text should be in the form Jones (1995), or Jones and Brown (1995), or Jones *et al*. (1995) if there are more than two authors.

Examples:

Reference to a journal publication: Simpson AT, Groves JA, Unwin J, Pinay M. (2000) Mineral oil metal working fluids (MWFs) – Development of practical criteria for mist sampling. *Ann Occup Hyg*; **44**: 165-72.

Reference to a book: Vincent JH. (1989) Aerosol sampling: science and practice. Chichester, UK: John Wiley. ISBN 0 471 92175 0.

Reference to a chapter in an edited book: Swift DL, Cheng Y-S, Su Y-F, Yeh H-C. (1994) Ultrafine aerosol deposition in the human nasal and oral passages. *In* Dodgson J, McCallum RI, editors. Inhaled Particles VII. Oxford: Elsevier Science. p. 77-81. ISBN 0 08 040841 9 H.

Reference to an Internet source: Morse SS. (1995) Factors in the emergence of infectious diseases. Emerg Infect Dis [serial online] 1995 Jan-Mar; 1(1). Available from: URL: http://www.cdc.gov/ncidod/EID/eid.htm (accessed 25 Oct 2010)

Ethics

Authors must produce original data for inspection, if requested by the editor. Possible fraud may be referred to the authors' institutions.

Appraisal of medical and exposure data to estimate the occupational carcinogenic risk in coal mines: a pilot study

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(Justification found below for length of article exceeding 5 000 words)

Keywords: occupational carcinogen exposure; cancer; coal mine; historical data

Statement

Due to the nature of this study and its contents, which include the use of historical medical data as well as historical exposure data, the length of the article exceeds 5 000 words (as previously shown). This was necessary to ensure that the purpose as well as the results produced from this research study were clarified thoroughly.

For the purpose of providing all the relevant information to the reader/examiner, the length has to exceed the 5 000 word limit.

3.1 Abstract

***Objectives*:** This study aimed to provide an improved understanding about the various occupational carcinogens as well as the carcinogenic risk present in the South African coal mining environment through the appraisal of historical medical and exposure monitoring data. It also aimed to establish if a relationship exists between the cancer incidences in the historical medical data and the exposure to occupational carcinogens. Cancer incidence, in this study, refers to the proportion of coal mine workers who developed cancer during a particular time period (i.e. 2009-2015) and not to the number of new cancer cases occurring in the coal mine worker population during a specific time period (CDC, 2012).

Methods: Previously published literature was reviewed to identify occupational carcinogens present in a coal mine as well as the cancer types linked to the occupational exposure to these carcinogens. Historical medical data was assessed to determine the cancer types and the frequency at which they occurred among the coal miners from ten coal mines. Historical exposure monitoring data and baseline risk assessments were used to determine the highest exposed groups in specifically an underground coal mining environment due to the higher risk involved when compared to an opencast coal mine. Lastly, the relationship between the diagnosed cancer incidences and the exposure of coal mine workers to the identified occupational carcinogens was established. Ethical approval from the Health Research Ethics Committee (HREC) of the North-West University was applied for and received (NWU-00069-16-A1).

Results: Various occupational carcinogen exposures, such as respirable dust (coal mine dust and crystalline silica dust), released during day-to-day coal mining processes were identified and retrieved from the results. The historical medical data showed the diagnosis of various cancer types in numerous occupations in a coal mine. Prostate cancer had the highest incidence rate (40.7%) of the 32 total cancer incidences and respiratory cancers had the second highest incidence rate (37.5%). The multi-task worker, mostly responsible for production activities, had the highest exposure to occupational carcinogens of all the occupations as well as the highest cancer incidence rate (25%) of the 32 total cancer incidences. The risk of developing cancer was similar at all mine types (underground (UG), open cast (OC) and combination mine (UG + OC)) with ratios indicated as 1.02 in 1 000 workers (UG), 1.25 in 1 000 workers (OC), and 1.24 in 1 000 workers (OC + UG).

Pneumoconiosis – or more specifically coal workers' pneumoconiosis (CWP) – and dermatitis presented a high incidence amongst multi-task workers. These workers are categorised under a high risk group for exposure to coal mine dust which lead to the development of CWP and ultimately lung cancer (Sangani and Ghio, 2011; Petsonk *et al.*, 2013; Hung *et al.*, 2014). Allergic contact dermatitis showed the highest incidence among multi-task workers (16.9%).

***Conclusions*:** This study confirmed the presence of various occupational carcinogens in a coal mining environment as well as the risk of the development of occupational cancer among coal mine workers. The occupations found to be most at risk of the development of cancer as well as the exposure to occupational carcinogens, were the multi-task worker and the maintenance occupations. When compared to South African statistics of cancer incidences diagnosed under the general population (NIOH, 2011) it was determined that the development of prostate cancer under coal mine workers was twice as high as for a person from the general population. The risk for developing lung cancer – one of the respiratory cancers – is three times more for a coal mine worker than for a person from the general population. Thus, for both prostate and lung cancer, the risk of developing these cancer types may be higher for coal mine workers, than for the general population.

3.2 Introduction

3.2.1 Coal mining in South Africa

South Africa relies on a high volume of coal production to support the tremendous need for electricity in the country. Therefore, it is important to consider the possible health risks and hazards involved in the coal mining industry as the demand for coal has increased immensely (WCI, 2009; Chamber of Mines, 2015; Stats SA, 2015).

3.2.2 Coal mining techniques

Mining of coal occurs either above ground in open cast mines or underground in deep mines (WCA, 2013). Underground mining processes involve a much higher health and safety risk than opencast mining due to difficulties associated with the ventilation of clean air, the removal of hazardous substances and dust particles as well as the mining activities performed by the workers (WCI, 2009). Underground and opencast mine workers are exposed to larger amounts of hazardous chemical substances and dust particles on a more frequent basis than the general population which increases the risk of occupational disease and illness (Maiti and Bhattacherjee, 1999; Schneider, 2014).

Modern underground mining techniques such as longwall or continuous mining generate high levels of coal mine dust (Petsonk and Attfield, 2005; WCA, 2013). Longwall mining involves the use of mechanical shearers for the extraction of coal from a section of the coal face, which can vary in length from 100 to 350 meters. Another underground mining method is room and pillar mining where coal deposits are mined by cutting a room into the coal seam with the use of a continuous miner (CM) and leaving a support pillar, usually composed of coal, to prevent the roof from collapsing (Petsonk and Attfield, 2005). Opencast coal mining is performed when a coal seam lies close to the surface and involves a typical sequence of operations involving drilling and blasting, which increases the risk of dust exposure (Kohler, 2005; Petsonk and Attfield, 2005).

3.2.3 Health risks associated with coal mining

Airborne hazardous chemical substances, which can refer to dust, smoke, gases or fumes, can pose a risk either through inhalation (Unsted, 2001; León-Mejía *et al*., 2014) which can potentially cause occupational lung diseases, skin contact which can cause skin irritation or sensitisation (Baxter and Waldron, 1989), or ingestion which can lead to gastrointestinal problems such as gastric cancer (Jenkins *et al.*, 2013). Occupational exposure to airborne and other pollutants can include non-carcinogenic as well as carcinogenic substances (Siemiatycki *et al*., 2004). Non-carcinogenic substances are defined as substances that do not lead to the development of cancer when workers are exposed to them in low concentrations. Cancer will not develop if the

substance lacks the ability to produce cancer as well as when the body has a threshold that enables it to recover from the exposure. Carcinogenic substances have the opposite effect, due to the dose-response curve of these substances showing no threshold. Thus, recurring exposures to carcinogenic substances, and any other exposure, even at a very low dose, will increase the risk of developing cancer (Masters, 1998; Nazaroff and Alvarex-Cohen, 2001).

Due to the delay between exposure to a carcinogen and the first sign of an adverse effect – also referred to as the latent period – it is difficult to establish the initial cause of certain occupational cancers (Schneider, 2014). Another contributing factor to cancer development is the exposure to carcinogens outside the working environment such as environmental pollution, diet and tobacco smoking. Occupational cancer is a leading cause of death worldwide even though exposures to occupational carcinogenic chemicals are largely preventable (Tulchinsky and Varavikova, 2014; Takala, 2015). Occupational carcinogens are some of the many hazards coal miners are exposed to and it has attracted substantial attention for the damaging effects it can have on a worker's health (McCormack and Shüz, 2012; León-Mejía *et al.*, 2014).

Major class action lawsuits in South Africa and globally have considerable legal implications for major mining companies. These lawsuits focus the attention on the health risks associated with working in a mine - be it a coal or gold mine – as well as the health risks affecting the general population and the environment. An example of a South African class action lawsuit – involving up to half a million mine workers – that will be taking place in the near future is the silicosis class action lawsuit against the gold mining companies (Jamasmie, 2016; Povtak, 2016).

3.2.4 Occupational carcinogens in a coal mine

According to previously published literature, the following occupational carcinogens have been identified to potentially be present in coal mines (Table 3-1).

Table 3-1: List of occupational carcinogens potentially present in a coal mine

Occupational carcinogen	IARC Carcinogen classification	Reference(s)
Crystalline silica (Quartz)	Group 1	Borm and Tran, 2001 NIOSH, 2011 Jenkins *et al.*, 2013
Radon (^{222}Rn)	Group 1	IARC[a],1988
Polycyclic aromatic hydrocarbons (PAHs)	Group 1 -2A	IARC[a], 2010
Coal mine dust (CMD)	Group 3	Swaen *et al.*, 1985; Swaen *et al.*, 1995 Brown *et al.*, 1997 IARC[a], 1997
Diesel engine exhaust	Group 1	Claxton, 2014

Occupational carcinogen	IARC Carcinogen classification	Reference(s)
		IARC[a], 2014a
Trichloroethylene	Group 1	IARC[a], 2014b
Arsenic	Group 1	IARC[a], 2012a
Cadmium	Group 1	IARC[a], 2012a
Beryllium	Group 1	IARC[a], 2012a
Extremely low-frequency electromagnetic fields (ELF EMF)	Group 2B	Gilman *et al.*, 1985 IARC[a], 2002
Asbestos	Group 1	Driscoll *et al.*, 2004 IARC[a], 2012a Takala, 2015
Welding-related exposures	Group 2A (Welding fumes) Group 2B (UVR)	IARC[a], 1990 Siemiatycki *et al.*, 2004
Ultraviolet radiation (UVR)	Group 1	IARC[a], 1992 IARC[a], 2012b

[a] IARC The International Agency for Research on Cancer

The abovementioned literature indicates that coal mine workers are exposed to a variety of carcinogens over the period of their employment through various routes of exposure (IARC, 1997; Jenkins *et al*., 2013; Hung *et al*., 2014; León-Mejía *et al.*, 2014). Coal mine dust and crystalline silica are two of the most common exposures in the coal mining industry, produced by modern mining processes such as drilling and coal extraction (Wagner and Hearl, 2005; Naghadehi *et al.*, 2014). Crystalline silica exposure can lead to silicosis and ultimately lung cancer, whereas coal mine dust exposure can lead to coal workers' pneumoconiosis (CWP) and various other cancers including gastric, oesophagus and prostate (Donbak *et al.*, 2005; Clapp *et al.*, 2008; NIOSH, 2011; Graber, 2012; Hung *et al*, 2014). PAHs are defined as a large class of organic compounds composed of carbon and hydrogen, consisting of two or more fused aromatic rings. Individual PAHs, such as benzo(a)pyrene, that possess carcinogenic properties can be found in powdered bituminous coal, and occupational exposure can ultimately lead to the development of various cancers, including in the prostate, lung and bladder (Falk and Jurgelski, 1979; Clapp *et al.*, 2008; IARC, 2010; Kammer *et al.*, 2011; NTP, 2014).

Diesel engine exhaust, which is composed of solid and liquid particles, and DPM (diesel particulate matter) becomes a concern in a mining environment where activities are performed requiring diesel intensive operations. Exposure to diesel engine exhaust may eventually lead to the development of lung or prostate cancer (Muzyka *et al.*, 2003; Belle, 2008; Clapp *et al.*, 2008).

Exposure to other carcinogens, as listed in Table 3-1, can occur from maintenance procedures such as welding (cadmium, beryllium, ultraviolet radiation (UVR)) and degreasing of metal parts (trichloroethylene), the mining and extraction of coal (arsenic, radon), high-voltage power distribution lines used in underground mines (ELF EMF), insulation of older buildings (asbestos),

as well as natural (opencast coal mines) and artificial sources (welding) of ultraviolet radiation (UVR) (Gilman *et al.*, 1985; IARC, 1990; IARC, 1992; Feychting *et al.*, 1997; Velga *et al.*, 2006; Mengeot, 2007; Clapp *et al.*, 2008; IARC, 2012a; Jenkins *et al.*, 2013; Shen, 2013; IARC, 2014b; Majzlan *et al.*, 2014; CCOHS, 2016).

The South African Mine Health and Safety Act (MHSA) (29 of 1996) indicates the importance for employers to protect the health and safety of all workers at a mine. This creates the need to establish, maintain, and record occupational health and safety data.

3.2.5 Control of occupational carcinogen exposure

The Department of Mineral Resources (DMR) considers an occupational hygiene database, which includes medical and exposure monitoring data, as essential to determine the relationship between worker exposure and the development of occupational related diseases (DME, 2002).

A medical surveillance system must be implemented and well maintained by the employer and periodic medical examinations should be performed as seen fit. All medical examination reports must be recorded which will allow the employer to prevent, detect and treat occupational diseases (MHSA, 1996).

3.2.6 Importance and general aim of study

Due to the thousands of people employed by South African coal mines, it is crucial to focus on the risk associated with occupational carcinogen exposure. Protecting the workers from unnecessary occupational carcinogen exposure will reduce the risk of the development of cancer later in life. This study aimed to provide an improved understanding about the various occupational carcinogens as well as the carcinogenic risk present in the South African coal mining environment through the appraisal of historical medical and exposure monitoring data. This study also aimed to establish if a relationship exists between occupational exposure to carcinogens and the development of cancer among coal mine workers. Cancer incidence, in this study, refers to the proportion of coal mine workers who developed cancer during a particular time period (i.e. 2009-2015) and not to the number of new cancer cases occurring in the coal mine worker population during a specific time period (CDC, 2012).

3.3 Methodology

3.3.1 Literature review

A comprehensive literature review was undertaken to identify occupational carcinogens potentially present in a coal mine as well as the cancer types linked to the occupational exposure thereto (refer to Table 3-1).

3.3.2 Characteristics of thermal coal mines

Historical medical data from ten thermal coal mines from a mining company in South Africa was used for this research study. The thermal coal mines had different characteristics as shown in Table 3-2 below.

Table 3-2: Thermal coal mine characteristics

	Mine type
Mine 1[b]	Underground mine
Mine 2	Opencast and underground mine
Mine 3	Opencast mine
Mine 4	Opencast and underground mine
Mine 5	Opencast mine
Mine 6	Underground mine
Mine 7	Opencast and underground mine
Mine 8	Opencast mine
Mine 9	Opencast mine
Mine 10	Opencast mine

[b] High risk underground coal mine from which exposure monitoring data was available

3.3.2.1 Characteristics of high risk underground coal mine (Mine 1)

Mine 1 is the high risk underground coal mine that was focused on and is unique in the sense that it is one of the deepest underground coal mines in South Africa. This mine is also one of the few underground coal mines which uses the longwall mining method. The methane concentration in the mine is the highest of all coal mines in South Africa and in view of the 7 000 tonnes being produced annually, immediately increases the risk of spontaneous combustion and explosions during the mining operations (Colman, 2015).

Mine 1 was chosen as the high risk underground coal mine for the reasons mentioned above, as well as for the fact that coal workers employed at and working underground in a coal mine have a higher health and safety risk than workers employed at an opencast coal mine (WCI, 2009). Thus, Mine 1 was used to determine the potential exposure risk to carcinogenic substances that may exist in a coal mine.

3.3.3 Historical medical data

Various medical examinations are performed on coal mine workers at different time periods and for numerous reasons. The mining company evaluated during this research study developed an

electronic occupational health and hygiene record database for workers in the mining industry in 2009. This database is managed by theHealthSource (tHS), an independent business providing various healthcare providers with access to an EMRS (Electronic Medical Record System), which prevents unnecessary duplication of medical assessments, tests and records. The database operates with a single central database allowing for real-time healthcare transactions from numerous occupational health and hygiene providers in the mining industry (Pienaar, 2014; tHS, 2016). The number of individuals registered on the tHS database exceeds 350 000 and this total quantity was used for the extraction of the historical medical data. More than 500 records were extracted from the tHS database, which included cancer incidences, pneumoconiosis and dermatitis cases. Pneumoconiosis and dermatitis were included due to the relationship between these conditions, the exposure to certain carcinogens (such as beryllium that can lead to allergic contact dermatitis), and the development of cancer (CWP that can lead to lung cancer) (ATSDR, 2002; Lundberg *et al.*, 2005; Kaplan *et al.*, 2013).

3.3.3.1 All medical data versus data only referring to cancer incidences

When referring to the use of all medical data, it means the total number of medical records extracted from tHS as mentioned above, and includes the cancer incidences, pneumoconiosis and dermatitis cases. When referring to the use of only cancer incidences, it means the 32 cancer incidences that were extracted from the historical medical data.

3.3.3.2 Limitation(s) to historical medical data

The historical medical data was extracted and filtered from tHS by the competent medical personnel working at the mining company's hospital. Unfortunately, the historical medical data from the ten thermal coal mines was limited to the years 2009 to 2015 as the database was only developed as from 2009.

3.3.3.3 Collection of relevant historical medical data

In order to filter and extract the data according to the specific needs of the study, a list of ICD-10 diagnosis codes (International Classification of Diseases, Tenth Revision) was compiled using a reference list (ICD10Data.com, 2016) to assist the medical personnel with this process. The ICD-10 diagnosis codes listed, included the cancer types associated with the carcinogens identified in the literature study.

3.3.4 Historical exposure monitoring data

Exposure monitoring at a coal mine is done to determine the occupational exposure to various hazardous chemical substances experienced by the workforce and to ensure that the mining

company complies with the regulations set out in the MHSA. Personal coal and crystalline silica dust exposure is monitored to ensure that the concentrations workers are exposed to do not exceed the recommended OELs (Occupational Exposure Limits). Baseline risk assessments are assessments conducted in order to determine the initial occupational health risks present in a working environment, which is then used as a guideline for further risk assessments (Badenhorst, 2006; EPA, 2010). The data used as part of this research study was historical data from occupational hygiene measurements done at the high risk underground mine (Mine 1) and a baseline risk assessment performed at nine of the thermal coal mines and a DPM baseline risk assessment performed at ten of the thermal coal mines. The number of workers at the ten individual coal mines, at any given time from 2009 to 2015, varied from a minimum of 645 workers to a maximum of 4 361 workers per mine. Mine 1 had an average workforce of 1 808 workers between 2009 and 2015.

3.3.4.1 Limitation(s) to and collection of historical exposure monitoring data

The historical exposure monitoring data was limited to the years 2006 to 2015 due to the lack of readily available data. Included was information regarding occupational exposure of mine workers to dust – coal and crystalline silica dust at Mine 1– as well as a summary of the site-specific findings and recommendations at the ten thermal coal mines encompassed in the baseline risk assessment.

3.3.4.2 Important note concerning occupation descriptions

Occupation descriptions were not identical in the historical medical data and exposure monitoring data, and a reliable comparison between the different occupation descriptions needed to be generated in order to equate the individual data sets. The comparison can be seen in the Supplementary material (Table 3-11).

3.3.5 Statistical analysis

3.3.5.1 Basic descriptive statistics

Statistical analysis of the historical data involved descriptive statistics (mean, minimum and maximum values, frequencies, percentages) using Statistica 13 (Statsoft Inc.). Graphs, such as histograms, were used to portray the data graphically. Ratios were calculated to determine the number of workers developing cancer in each mine type, for example 1 in 1 000 workers in an underground coal mine developed cancer.

3.3.5.1.1 Frequency tables

Frequency tables were obtained from the historical medical data to determine the total number of cancer incidences recorded as well as the number of each cancer type identified. Frequency tables were also used for the historical exposure monitoring data to categorise the different classes of activity and occupation descriptions in order to determine the number of mine workers in each of these classes. Frequency tables were also used to determine the various frequencies of factors involved in the exposure.

3.3.5.1.2 Cross-tabulation analysis

Cross-tabulation analysis was applied in order to record the various frequencies retrieved from the historical data. For example, cancer types (retrieved from the historical medical data) were matched in a two-directional table to the corresponding occupation description (retrieved from the historical exposure monitoring data).

3.3.5.2 Effect sizes – Odds ratio (OR) and Relative risk (RR)

Effect sizes (Steyn and Ellis, 2009) were used to describe the correlation as well as the strength of this relationship between the various factors retrieved from the historical data. Odds ratios (OR) indicated the odds of a person developing a disease, such as cancer, if exposure to a factor of interest, such as smoking, was compared to the odds if a person not exposed. For example, if an OR were to be calculated as 2, it would refer to the odds of a worker developing cancer would be twice as high as the odds in a non-exposed worker (Machin *et al.*, 2007; Harris and Taylor, 2008). The OR was interpreted as an effect size by reducing the OR value analogously to a standardised difference (δ_{OR}) and it was compared to a guideline value that showed either a small, medium or large effect (Steyn, 2012). Relative risk (RR) was used to indicate the increased risk of a worker developing a disease if they were to be exposed to a certain factor. For example, if a RR were to be calculated as 2, it would refer to the prevalence of the outcome in an exposed group may be twice as high as the prevalence in an unexposed group (Harris and Taylor, 2008; Dancey *et al.*, 2012).

3.3.6 Ethics

Ethical approval from the Health Research Ethics Committee (HREC) of the North-West University was received (NWU-00069-16-A1). All historical medical data, as well as historical exposure monitoring data, was received already anonymised by the relevant parties. Thus, no personal information was available to the researchers during the study.

The historical medical data gathered serves the purpose of monitoring the health of the workers at the mine and is not specifically allocated for research purposes. Only the relevant data was sent electronically and already anonymised via email to the researcher, and prevented the privacy of the workers being compromised. Therefore, this was a study with minimal ethical risk.

3.4 Results

3.4.1 Historical medical data

3.4.1.1 Cancer incidences

In Table 3-3, the cancer incidences retrieved from the historical medical data are shown, together with additional information including smoking status, age category, gender, nationality, years service (if available), ICD-10 code and the corresponding cancer type, the worker's job title (occupation) when diagnosed, the mine at which the worker was employed as well as the mine type. Cells indicated in grey indicate information that was unknown. Only one of the cancer incidences were diagnosed in a female worker. Shared services indicate the departments that offer centralised services, including training, consultant services, human resources, and emergency rescue services. Workers who are part of the shared services of the mining company are not subjected to any high risk or high exposure areas for long periods of time. A total of 32 cancer incidences were retrieved from the historical medical data. Mine 1 that was identified as the high risk underground coal mine (shown in red) had one cancer incidence.

Table 3-3: Summary of the cancer incidences extracted from the historical medical data with additional supporting information

Smoking	Age	Gender	Nationality	Years service	ICD-10	Cancer type	Job title	Mine name	Type
No	20-29	F	South Africa		C85.1	B-cell lymphoma (unspec)	Mining Assistant (Cheesa)	Mine 5	OC
Yes	50-59	M	South Africa		C85.1	B-cell lymphoma (unspec)	Multi-Task Worker	Mine 9	OC
No	50-59	M	South Africa		C67.9	Bladder (malignant neoplasm, unspec)	Stockyard Worker	Mine 4	OC + UG
	65+	M	South Africa		C15.5	Oesophagus (malignant neoplasm, lower 1/3)			
No	50-59	M	South Africa		C15.9	Oesophagus (malignant neoplasm, unspec)	Multi-Task Worker	Mine 9	OC
Yes	30-39	M	South Africa		C31.1	Ethmoidal sinus (malignant neoplasm)	Mining Assistant (Cheesa)	Mine 7	OC + UG
No	40-49	M	South Africa	21	C39.9	Lower respiratory tract (malignant neoplasm, unspec part)	Engineering Foreman	Mine 4	OC + UG
No	60-64	M	South Africa		C34.9	Lung (malignant neoplasm, unspec)	Engineer (Underground)	Mine 4	OC + UG
	50-59	M	Other		C34.9	Lung (malignant neoplasm, unspec)			
No	60-64	M	South Africa		C78.0	Lung (secondary malignant neoplasm)	Engineering Technician	Mine 4	OC + UG
Yes	60-64	M	Lesotho		C78.0	Lung (secondary malignant neoplasm)	Stockyard Worker	Mine 9	OC
No	**30-39**	**M**	**South Africa**	**12**	**C31.0**	**Maxillary sinus (malignant neoplasm)**	**Multi-Task Worker**	**Mine 1**	**UG**
No	40-49	M	South Africa		C45.9	Mesothelioma (unspec)	Auto Electrician	Mine 3	OC
Yes	50-59	M	South Africa		C11.9	Nasopharynx (malignant neoplasm, unspec)	Miner (General)	Mine 4	OC + UG
Yes	50-59	M	South Africa	9	C11.9	Nasopharynx (malignant neoplasm, unspec)	Multi-Task Worker	Mine 10	OC
No	60-64	M	Lesotho		C85.9	Non-Hodgkin Lymphoma (unspec)	Section Miner	Mine 9	OC
No	60-64	M	South Africa		C85.9	Non-Hodgkin Lymphoma (unspec)	Multi-Task Worker	Mine 6	UG
Yes	50-59	M	South Africa		D07.5	Prostate (Carcinoma in situ)	Multi-Task Worker	Mine 2	OC + UG
No	50-59	M	South Africa	9	D07.5	Prostate (Carcinoma in situ)	Boilermaker	Mine 5	OC
No	50-59	M	Lesotho	34	D07.5	Prostate (Carcinoma in situ)	Boilermaker/Fitter Assistant	Mine 6	UG
No	60-64	M	South Africa		C61	Prostate (malignant neoplasm)	Fitter	Shared services	
Yes	50-59	M	South Africa		C61	Prostate (malignant neoplasm)	Stockyard Worker	Mine 4	OC + UG
No	60-64	M	South Africa		C61	Prostate (malignant neoplasm)	Multi-Task Worker	Mine 4	OC + UG
No	60-64	M	Lesotho		C61	Prostate (malignant neoplasm)	Section Manager	Mine 9	OC
Yes	50-59	M	South Africa		C61	Prostate (malignant neoplasm)	Multi-Task Worker		
No	60-64	M	South Africa	8	C61	Prostate (malignant neoplasm)	Mine Transport Worker	Mine 5	OC
Yes	50-59	M	South Africa	10	C61	Prostate (malignant neoplasm)	Nurse (registered)	Shared services	
No	60-64	M	South Africa	9	C61	Prostate (malignant neoplasm)	Mine Transport Worker	Mine 6	UG
No	50-59	M	Lesotho		C61	Prostate (malignant neoplasm)	Boilermaker/Fitter Assistant	Mine 9	OC
Yes	50-59	M	South Africa	8	C61	Prostate (malignant neoplasm)	Foreman	Mine 4	OC + UG
Yes	30-39	M	South Africa		D04.7	Skin of lower limb (carcinoma in situ)	Fitter	Mine 9	OC
Yes	30-39	M	South Africa	13	C73	Thyroid (malignant neoplasm)	Security Officer	Shared services	

ICD-10: International Classification of Diseases, 10th edition Information unknown
OC: Opencast coal mine UG: Underground coal mine OC+UG: Combination of opencast and underground coal mines
M: Male F: Female

3.4.1.2 Respiratory and prostate cancers

The frequency of each cancer incidence is shown in Table 3-4 including the ICD-10 code of each cancer type as well as the total number of cancer incidences. The percentage column indicates the percent of the total number of cancer incidences for each cancer type. Respiratory cancers (including: oesophagus (C15.5 and C15.9), ethmoidal sinus (C31.1), lower respiratory tract (C39.9), lung (C34.9 and C78.0), maxillary sinus (C31.0), nasopharynx (C11.9) and mesothelioma (C45.9)) represented a percentage of 37.5% of the 32 total cancer incidences and a ratio of 0.18 in 1 000 workers. The occupations with the highest respiratory cancer incidence rate was shown to be multi-task workers (25%) and the engineering occupation (25%), where engineering showed the highest lung cancer incidence.

Prostate cancer (D07.5 and C61) was the cancer type with the highest incidence rate (shown in grey), with a percentage of 40.7% [D07.5 (9.4%) and C61 (31.3%)] of the 32 total cancer incidences and a ratio of 0.6 in 1 000 workers. Of the 32 total cancer incidences only one incidence was female. Unfortunately, no data was available on the total number of male and female workers employed at each mine, but it is known that only a small percentage of the workers employed at the coal mines are female. Therefore, the ratio of workers developing prostate cancer was calculated using the total number of workers (male and female). The highest prostate cancer incidence rates are shown within the maintenance job title (12.5% of cancer incidences) (which included fitters, boilermakers and electricians (auto and general)). The prostate cancer incidences reported in the age category of 50-59 years was the highest in the maintenance category and the incidences in the age category 60-64 years was the highest in the multi-task worker category. A multi-task worker is responsible for performing various activities including operation of the continuous and/or long wall mining equipment, roof bolting equipment as well as the operation of stone dusters – collectively known as production activities. Odds ratio (OR) was used as a measure to determine the relationship between the two age categories and the prostate cancer incidence. The OR was interpreted as an effect size by reducing the OR value (OR = 1.3) analogously to a standardised difference (δ_{OR}) and it was compared to a guideline value that showed a large effect.

3.4.1.3 Other factors that may play a role in cancer development

3.4.1.3.1 Age

A comparison was drawn of the percentage of cancer incidences in each age category. The cancer incidences are the highest in the 50-59 years age category and the lowest in the 65+ year age category.

3.4.1.3.2 Years service

The mean of the years service of the workers diagnosed with cancer was indicated as 13.3 years. A comparison between the years service of each different age group was drawn between the cancer incidences and all the historical medical data. The results indicated that in the age category 50-59 years the mean years' service was 14 years (cancer incidences) and in the same age category (all historical medical data), the mean years service was 23 years.

Table 3-4: Cancer type frequencies indicating the number of each cancer type and the percentage of the total number of cancer incidences

ICD-10	Cancer type	Number of cancer incidences	Percent of total incidences (%)
C85.1	B-cell lymphoma (unspec[a])	2	6.3
C67.9	Bladder (malignant neoplasm, unspec[a])	1	3.1
C15.5	**Oesophagus (malignant neoplasm, lower 1/3)**	**1**	**3.1**
C15.9	**Oesophagus (malignant neoplasm, unspec[a])**	**1**	**3.1**
C31.1	**Ethmoidal sinus (malignant neoplasm)**	**1**	**3.1**
C39.9	**Lower respiratory tract (malignant neoplasm, unspec[a] part)**	**1**	**3.1**
C34.9	**Lung (malignant neoplasm, unspec[a])**	**2**	**6.3**
C78.0	**Lung (secondary malignant neoplasm)**	**2**	**6.3**
C31.0	**Maxillary sinus (malignant neoplasm)**	**1**	**3.1**
C45.9	**Mesothelioma (unspec[a])**	**1**	**3.1**
C11.9	**Nasopharynx (malignant neoplasm, unspec[a])**	**2**	**6.3**
C85.9	Non-Hodgkin Lymphoma (unspec[a])	2	6.3
D07.5	**Prostate (Carcinoma in situ)**	**3**	**9.4**
C61	**Prostate (malignant neoplasm)**	**10**	**31.3**
D04.7	Skin of lower limb (carcinoma in situ)	1	3.1
C73	Thyroid (malignant neoplasm)	1	3.1
	TOTAL	**32**	**100.0**

Prostate cancers Respiratory cancers

[a] Unspec: unspecified; coding used when important details of a patient's condition are not known

3.4.1.3.3 Job title

The percentage of each cancer incidence per job title is presented in Table 3-5. Job titles with the highest cancer incidences were the multi-task worker (25%) and maintenance (18.8%) job titles (shown in bold in Table 3-5).

Table 3-5: Comparison between job titles (occupation) and cancer incidence (number and percentage) of coal mine workers

Job title	Number of cancer incidences	Percentage of total cancer incidence (%)
Maintenance	**6**	**18.8**
Stockyard Worker	3	9.4
Multi-Task Worker	**8**	**25.0**
Section Manager	1	3.1
Mine Transport Worker	2	6.3
Nurse (registered)	1	3.1
Foreman	1	3.1
Security Officer	1	3.1
Miner (General)	1	3.1
Unknown	2	6.3
Mining Assistant (Cheesa)	2	6.3
Engineering	3	9.4
Section Miner	1	3.1
TOTAL	**32**	**100.0**

3.4.1.3.4 Average number of workers per mine

Table 3-6 presents a summary of the average number of workers (from 2009 to 2015) at each of the ten coal mines used for this study, as well as the number and the average percentage of cancer incidences at each mine. The average workers were calculated by determining the mean over the 6 year time period from 2009 to 2015. The mine type, as well as the number of cancer incidences reported from shared services and the unknown mines, is also shown in Table 3-6, but not included in the calculation of the percentage cancer incidences. Mine 1 (indicated in red) represents the high risk underground coal mine identified for this study and has had an average of 1 808 workers. Mine 4, a coal mine incorporating both opencast and underground coal mining processes, had the highest average number of workers (3 691 workers) as well as the highest number of cancer incidences (8 cancer incidences), but only

the second highest percentage cancer incidences compared to the average number of workers (0.22%). Mine 9, which is an opencast coal mine, had the highest percentage cancer incidences compared to the average number of workers (0.25%). Mine 4 and Mine 9 are both highlighted grey in Table 3-6.

Table 3-6: Summary of the average number of workers for the ten coal mines as well as the number and percentage cancer incidences per mine

	Average workers (2009-2015)	Number of cancer incidences per mine	Percentage cancer incidences per average workers per mine (%)	Mine type
Mine 1	**1808**	**1**	**0.06**	**UG**
Mine 2	2752	1	0.04	OC + UG
Mine 3	2586	1	0.04	OC
Mine 4	**3691**	**8**	**0.22**	**OC + UG**
Mine 5	1999	3	0.15	OC
Mine 6	2132	3	0.14	UG
Mine 7	1610	1	0.06	OC + UG
Mine 8	1046	0	0.00	OC
Mine 9	**2768**	**7**	**0.25**	**OC**
Mine 10	1235	1	0.08	OC
Shared services[a]		3		
Unknown[b]		3		
TOTAL	**21 627**	**32**	**0.15**	

[a] Refers to the departments that offer centralised services, including training, consultant services, human resources, and emergency rescue services. Not dedicated to only one mine at a time.

[b] Name of the mine was not known at the time of diagnosis

OC: Opencast coal mine; UG: Underground coal mine; OC+UG: Combination of opencast and underground mines

3.4.1.3.5 Mine type

In Table 3-7 the number of each mine type is shown as well as the average number of workers per mine type (underground (UG), opencast (OC), combination mine (OC + UG)). Cancer incidences per mine type (number and percentage) are also shown. The ratio of the number of workers per 1 000 workers that developed cancer is shown in the last column. The ratio calculated for all the individual mine types ranged from 1.02 in 1 000 workers (UG) to 1.25 in 1 000 workers (OC).

Table 3-7: Summary of cancer incidence (percentage and ratio) per mine type

Mine type	Number of each mine type	Total workers per mine type	Cancer incidences per mine type	Cancer incidence percentage per mine type (%)	Ratio (Number of workers per mine type with cancer)
Underground (UG)	2	3 940	4	0.102	1.02 in 1000
Opencast (OC)	5	9 634	12	0.125	1.25 in 1000
Combination mine (OC + UG)	3	8 053	10	0.124	1.24 in 1000
TOTAL	**10**	**21 627**	**26**	**0.120**	**1.20 in 1000**

3.4.1.4 Pneumoconiosis and dermatitis

Pneumoconiosis and dermatitis incidences were also extracted as part of the historical medical data and the frequencies of each, together with the cancer incidences, are shown in Figure 3-1. The percentages indicate the percent of the total number of historical medical data records received by the researcher – i.e. 10.8% of the historical medical data records were pneumoconiosis incidences and 33.7% were dermatitis incidences The pneumoconiosis incidences related to exposure to asbestos and other mineral fibres (J61), crystalline silica (J62) and unspecified exposures (J64). Pneumoconiosis was mostly present in the multi-task worker occupation (57.6% of pneumoconiosis incidences). Dermatitis incidences include various types of allergic contact dermatitis related to exposure to different metals (L23.0), chemicals (L23.5) and other agents (L23.8) as well as unspecified exposures (L23.9). The occupation with the highest incidence rate for dermatitis was the multi-task worker (16.9% of the total dermatitis cases).

3.4.1.4.1 Lung cancer and pneumoconiosis

A comparison between the lung cancer and pneumoconiosis incidences according to the corresponding job titles was compiled and the highest incidence of pneumoconiosis was seen in the multi-task worker job title. The highest lung cancer incidence was seen in the engineering job title (included engineer (underground), engineering foreman, engineering technician and engineering assistants).

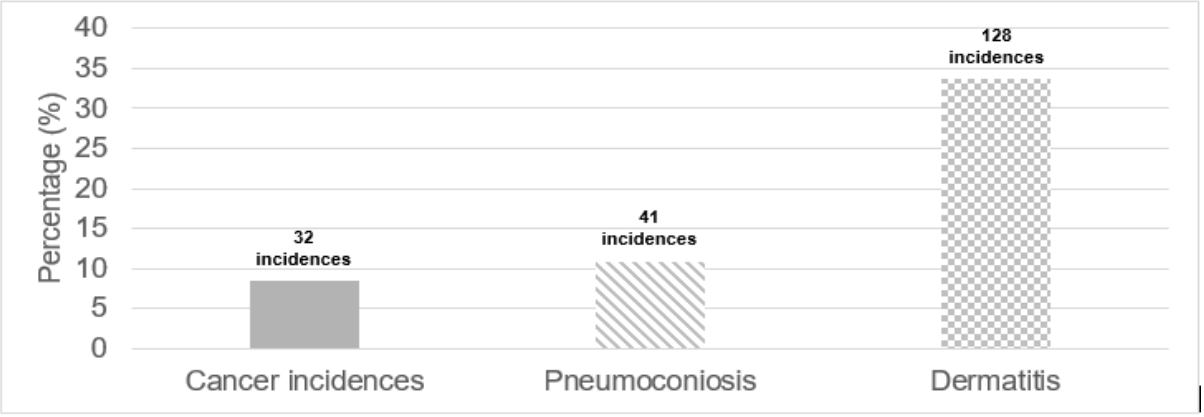


Figure 3-1: Summary of all historical medical data indicating frequencies and percentages of cancer, pneumoconiosis and dermatitis incidences

3.4.1.5 Influence of smoking status on cancer development

From the historical medical data a comparison between smoking and non-smoking coal mine workers were drawn to determine if smoking status had an influence on the number of cancer incidences diagnosed. The presence of cancer among non-smoking workers were higher (56.3%) than in workers who smoked (37.5%). Respiratory cancers made up 33.3% of the cancer types diagnosed from the non-smokers. The smoking workers showed the same percentage of diagnosed respiratory cancers (33.3%).

3.4.2 Historical exposure monitoring data

3.4.2.1 Occupational exposure of coal mine workers

Table 3-8 gives an indication of the occupation types exposed to coal mine dust exposures above the OEL of 2 mg/m^3. As indicated in grey, the multi-task worker occupation had the highest number of workers overexposed to coal mine dust, with a maximum exposure of 19.8 mg/m^3. It was also indicated that 32.9% of multi-task workers were overexposed to coal mine dust. Multi-task workers was the only occupation overexposed to crystalline silica dust as well as coal mine dust, with a minimum crystalline silica dust exposure of 0.14 mg/m^3 and maximum of 1.5 mg/m^3 and 9.1% of multi-task workers were exposed above the OEL for crystalline silica dust (0.1 mg/m^3). Table 3-9 compares the amounts of workers' occupations and their activity descriptions. Multi-task workers are mostly involved in continues mining operations (76.1%) and maintenance workers in moving around underground (77.8%).

3.4.2.2 Baseline risk assessments

In Table 3-10 a summary is given of the observations shown in the baseline risk assessment done at nine out of the ten coal mines during an 8 month period in 2012-2013. One of the potential health risks observed at all of the mines is the lack of available Material Safety Data Sheets (MSDS) at storage areas of Hazardous Chemical Substances (HCS). Excessive exposure to respirable dust (usually containing crystalline silica) was found to be a concern at 6 of the 9 mines. The exposure to dust posed a problem during underground and opencast production activities.

Another baseline risk assessment performed to evaluate the exposure of workers to diesel particulate matter (DPM) revealed that the DPM exposure of underground coal mine workers is a larger concern than in opencast coal mine workers. Underground exposure occurs mostly during diesel intensive operations such as production activities, belt extension and belt moves, section moves, long wall moves, transport of coal via load haul dumper (LHD), and maintenance activities. Another concern was the idling of diesel engines for long periods of time in the underground environment. Personal exposure monitoring was performed at the ten coal mines and the MSHA (Mine Health and Safety Administration (USA)) benchmark of 123 µg/m^3 EC (environmental carbon) was used as an exposure surrogate for DPM. Personal exposure results that did not comply with the benchmark were Mine 1 (3 out of 6 samples), Mine 4 (4 out of 9 samples), and Mine 6 (3 out of 6 samples). Mine 1 and Mine 6 are both underground coal mines, and Mine 4 is a combination mine implementing both opencast and underground mining processes.

Table 3-8: Basic descriptive statistics depicting occupational exposures exceeding the OEL of coal mine dust (OEL = 2 mg/m^3) and crystalline silica (OEL = 0.1 mg/m^3)

Occupation	Mean exposure	Minimum exposure	Maximum exposure	Number of samples over OEL	Percentage (%) of samples over OEL[a]	Percentage (%) per occupation over OEL[b]
Coal mine dust						
Beltsman	4.22	4.22	4.22	1	0.6	-
Maintenance	3.1	2.8	3.5	3	1.7	-
Miner (General)	2.5	2.5	2.5	1	0.6	-
Mining assistant (cheesa)	2.3	2.3	2.3	1	0.6	-
Multi-task worker	**5.5**	**2.1**	**19.8**	**29**	**16.3**	**32.9**
Section miner	2.4	2.4	2.4	1	0.6	-
Crystalline silica						
Beltsman	0.01	0.01	0.01	0	0	-
Maintenance	0.008	0.0006	0.04	0	0	-
Miner (General)	0.02	0.005	0.08	0	0	-
Mining assistant (cheesa)	0.006	0.005	0.007	0	0	-
Multi-task worker	**0.5**	**0.14**	**1.5**	**8**	**4.9**	**9.1**
Section miner	0.03	0.03	0.03	0	0	-
Total values for all exposures						
Coal mine dust	**1.5**	**0.03**	**19.8**	**36**	**20.2**	-
Crystalline silica	**0.04**	**0.0005**	**1.5**	**8**	**4.9**	-

[a] Percentage calculated from the number of workers monitored for coal mine dust (178 workers sampled) and crystalline silica dust (163 workers sampled), thus percentage refers to the % of the number of samples collected that had occupational exposure over the recommended OEL.

[b] Percentage calculated from the number of samples collected per occupation (eg. multi-task worker), thus percentage refers to the % of samples in a specific occupation that had occupational exposure over the recommended OEL. Only the occupation(s) with the highest number of overexposed samples are shown.

Table 3-9: Comparison of amounts and percentages of workers' occupations and their activity descriptions

Occupation	Activity descriptions									
	Continuous miner	**Longwall Mining**	**Rock Mining (coal)**	**Roving underground**	**Shafts and services**	**Roving surface**	**Ground handling (conveyor/loco's)**	**Underground workshops**	**Surface workshops**	**Total number of each occupation**
Multi-task Worker	**67 (76.1%)**	9 (10.2%)	3 (3.4%)	8 (9.1%)	1 (1.1%)					**88**
Senior Technician				1 (100%)						**1**
Miner (General)	1 (10%)		1 (10%)	8 (80%)						**10**
Maintenance	1 (2.8%)			**28 (77.8%)**		4 (11.1%)	1 (2.8%)		2 (5.6%)	**36**
Security Officer						2 (100%)				**2**
Safety Officer				1 (100%)						**1**
Clerk (mining)					1 (100%)					**1**
Engineering				5 (83.3%)		1 (16.7%)				**6**
Mining Assistant (cheesa)	1 (10%)		1 (10%)	7 (70%)			1 (10%)			**10**
Beltsman							1 (100%)			**1**
Diesel Mechanic								3 (75%)	1 (25%)	**4**
Stockyard Worker							2 (100%)			**2**
Training Instructor						2 (100%)				**2**
Geologist				2 (100%)						**2**
Planning Management (mining)				1 (100%)						**1**
Mine Transport Worker					8 (100%)					**8**
Shift Boss			1 (33.3%)	2 (66.7%)						**3**
Section Miner				1 (100%)						**1**
Total number of workers in each activity description	**70**	**9**	**6**	**64**	**10**	**9**	**5**	**3**	**3**	**179**
Occupation number as percentage of total	**39.1%**	**5.0%**	**3.4%**	**35.8%**	**5.6%**	**5.0%**	**2.8%**	**1.7%**	**1.7%**	**100%**

(%) indicates percentage of each activity description per total number of each occupation

Numbers indicated in bold: highest numbers (and percentages) of activity descriptions per occupation

Table 3-10: Summary of observations retrieved from baseline risk assessment (2012-2013) done at nine out of the ten coal mines

Name of mine	Mine type	Observations
Mine 1	UG	• Incorrect and mixed storage of PPE with HCSs • Contractors bypassing prescribed protocols • Presence of asbestos in older buildings on surface • Respirable dust exposure (including crystalline silica) of roof bolters and dyke crews • MSDSs not readily available or displayed at storage areas
Mine 2	OC + UG	• Engineering and production workers experienced high levels of airborne respirable dust exposure and included activities such as continuous mining, overburden drilling, loading and tipping of mined coal. • Incorrect storage and usage of PPE. • Removal of contaminated PPE (overalls) from site. • MSDSs not readily available or displayed at storage areas
Mine 3	OC	• Engineering and production workers experienced high levels of airborne respirable dust (coal mine dust and crystalline silica dust) exposure and included activities such as overburden and seam drilling, loading and tipping of mined coal. • Incorrect storage and usage of PPE (dust masks) • Removal of contaminated PPE (overalls) from site • High exposure levels of welding fumes in Bucket Repair Shop • Use of trichloroethylene by tire contractors • Possible asbestos panelling in ceilings of change houses • MSDSs not readily available or displayed at storage areas
Mine 4	OC + UG	• Incorrect storage and usage of PPE (dust masks) • Removal of contaminated PPE (overalls) from site • Incorrect PPE for specific tasks leads to leather gloves becoming impregnated with HCS • MSDSs not readily available or displayed at storage areas
Mine 5	OC	• Incorrect storage of PPE • Food and HCS stored together • Removal of contaminated PPE (overalls) from site • Fallout dust occurring continuously through whole of operation • MSDS's not readily available or displayed at storage areas
Mine 6	UG	• Incorrect storage of PPE • Mixed storage of PPE with HCSs • Food and HCS stored together • Fallout dust occurring continuously through whole of operation • Presence of Asbestos ceiling boards in surface workshop area • MSDSs not readily available or displayed at storage areas
Mine 7	UG + OC	• Incorrect storage of PPE • Mixed storage of PPE with HCSs • MSDSs not readily available or displayed at storage areas • No specifically designated areas for storing chemicals (some areas) • Contractors by-passing prescribed protocols
Mine 8	OC	• MSDSs not readily available or displayed at storage areas • Availability of PPE for sun/UV protection • Contractors bypassing prescribed protocols • Poor dust suppression on roadways in Pit and Plant
Mine 9	OC	• MSDSs not readily available or displayed at storage areas • Availability of PPE for sun/UV protection • Contractors bypassing prescribed protocols

3.5 Discussion

Interpretations from the historical medical data as well as the historical exposure monitoring data will be discussed concurrently.

3.5.1 Cancer incidences with the highest prevalence

From the historical medical data two groups of cancers with the highest incidences will be discussed. Included in this discussion is the possible exposures leading to the development of the cancer types as well as the comparison of the cancer risk with the cancer risk of the general population.

3.5.1.1 Prostate and respiratory cancers

The development of prostate cancer can be influenced by a male worker's age as well as other lifestyle factors such as smoking (Clapp *et al.*, 2008). Prostate cancer was the cancer type with the highest incidence rate (40.7%) of the 32 total cancer incidences (of which only one cancer incidence was female). Odds ratios (OR) was used as a measure to determine the effect of the age of the workers' who developed prostate cancer. The standardised difference OR (δ_{OR}) was found to be 1.14, which indicated a large difference between the prostate cancer incidence in the one age category (50-59 years) compared to the other category (60-64 years). Ultimately, this emphasises that a coal mine worker has a 1.14 larger risk of developing prostate cancer in the age category of 50-59 years, than developing prostate cancer between the ages of 60-64 years. There were no prostate cancer incidences reported in workers under the age of 50 years. Even though female worker numbers were included in the ratio calculation, which is an underestimation of the true ratio if only males would have been included (0.6 in 1 000 workers), the ratio calculated was still higher than that of the general population (0.26 in 1 000 individuals) (NIOH, 2011).

Respiratory cancers were the cancer type with the second highest incidence rate (37.5%) and is a concern where the exposure to high concentrations of dust (coal mine dust and crystalline silica dust) is present, such as at production activities (Maiti and Bhattacherjee, 1999; Schneider, 2014). The comparison of the development of respiratory cancer among coal mine workers and the general public is further discussed in paragraph 3.5.1.1.2.

3.5.1.1.1 Occupational exposure(s) to carcinogens in a coal mining environment

Occupational exposure to carcinogens that may be responsible for the development of prostate cancer include PAHs and diesel engine exhaust seen in mine transport workers, coal mine dust exposure in multi-task workers, stockyard workers, section managers as well as

maintenance workers. Cadmium exposure can occur through welding processes, mainly performed during maintenance procedures, and may lead to the development of prostate cancer (IARC, 2010; IARC, 2012a).

Occupational exposures that may lead to the development of lung cancer include crystalline silica, diesel engine exhaust and PAHs (Claxton, 2014; IARC, 2014a). Occupational exposures to coal mine dust and crystalline silica are the most commonly monitored substances in a coal mine. Table 3-8 showed the maximum concentrations workers were exposed to and since these exposures were much higher than the recommended OELs, it poses a tremendous risk for the development of various health related complications such as respiratory cancer. The occupation most at risk for high dust exposure is the multi-task worker due to the production activities performed by these workers directly at the coal face – known for generating high volumes of dust. Multi-task and maintenance workers showed the highest cancer incidence of all occupations in Table 3-5. Multi-task workers had the highest exposure to respirable dust (coal mine dust and crystalline silica dust) as well as the highest incidence of respiratory cancers (25%) and pneumoconiosis (57.6%). This could yet again be an indication of the high exposure of these occupational roles to carcinogenic substances during production activities in a coal mining environment.

As seen in Table 3-9, work activities in a coal mine vary tremendously. The most common activities that include the largest number of workers are mostly production activities as well as underground roving, which refers to walking around and performing various activities in the underground environment. High exposure during these activities may increase the workers' risk of developing health related problems, such as cancer or pneumoconiosis. Occupations most at risk of exposure, such as the multi-task worker, correlates with the findings from Table 3-9. Maintenance workers' dust exposure is also a concern due to the activities they perform, which may include roving underground and maintenance of contaminated machinery. Thus, multi-task workers performing production activities (i.e. continuous mining) and maintenance workers performing underground roving activities and maintenance of contaminated machinery are most at risk of high dust exposure in an underground mining environment which could possibly contribute to the development of occupational cancer.

3.5.1.1.2 Cancer risk compared to the general population

South African cancer statistics, provided in the NCR (National Cancer Registry) reports are currently not up to date. The most up-to-date cancer statistics available for the South African population is from the 2011 NCR report and was used for the comparison of the historical medical data with the general population data (CANSA, 2012).

When compared to South African statistics of cancer incidences diagnosed under the general population (NIOH, 2011) prostate cancer occurs in 25.93 out of 100 000 men (0.26 in 1 000). Whereas in the coal mining environment, when the prostate cancer incidences from the historical medical data were taken into consideration, 0.6 out of 1 000 all workers developed prostate cancer. Thus, the risk for developing prostate cancer is twice as high for a coal mine worker than someone from the general population.

For lung cancer – one of the respiratory cancers – when compared to South African statistics (NIOH, 2011), lung cancer occurs in 6.49 out of 100 000 people (0.06 in 1 000). Whereas in the coal mining environment, when the lung cancer incidences from the historical medical data are taken into consideration, 0.18 out of 1 000 workers developed lung cancer. Thus, the risk for developing lung cancer is three times more for a coal mine worker than a person from the general population.

Thus, for both prostate and lung cancer, the risk of developing these cancer types is higher for coal mine workers, than for the general population.

3.5.1.2 Pneumoconiosis and dermatitis

The high incidence of pneumoconiosis and dermatitis represents a concern as to the inhalation as well as the dermal exposure of the coal mine workers to various hazardous chemical substances. Pneumoconiosis – more specifically coal workers' pneumoconiosis (CWP) – can increase the risk of the development of lung, gastric, liver and oesophageal cancers, especially in older males (Hung *et al.*, 2014).

3.5.1.2.1 Occupations with the highest prevalence for pneumoconiosis (and lung cancer)

The highest incidence of pneumoconiosis shown in the multi-task worker raises a concern in terms of the occupational exposure of these workers. These workers are categorised under a high risk group for exposure to coal mine dust which lead to the development of CWP and ultimately lung cancer. The highest lung cancer incidence shown with the engineering occupation can refer to poor administrative – for example incorrect usage of PPE – as well as poor engineering control mechanisms – improper ventilation with clean air – where these workers perform their duties.

3.5.1.2.2 Occupations with highest prevalence for dermatitis

Dermatitis – largely allergic contact dermatitis – can be caused by various occupational exposures, including carcinogenic substances such as trichloroethylene and beryllium mostly used during maintenance processes (Lundberg *et al.*, 2005; Kaplan *et al.*, 2013; Kretsinger *et*

al., 2013). Multi-task workers showed the highest incidence of dermatitis (16.9%) and the occurrence thereof can be largely due to the poor administrative controls (incorrect use of PPE, insufficient training on occupational hazards, lack of supervision, poor personal hygiene) seen at some of the coal mines. One skin cancer incidence was shown in a maintenance occupation in an opencast mine (refer to Table 3-3), and may indicate possible dermal exposure to occupational carcinogens such as UVR (from welding or sun exposure) or PAHs. Poor administrative controls could include the absence of MSDSs at HCS storage areas and the improper use of PPE, as stated in the baseline risk assessment. Thus, the cause of dermatitis developing among coal mine workers may be due to the daily exposure to occupational carcinogens and skin irritants.

3.5.2 Other factors that may play a role in cancer development

3.5.2.1 Smoking status

The development of occupational cancer can also be influenced by the smoking status of a worker and can potentially increase the risk thereof (Tulchinsky and Varavikova, 2014; Takala, 2015). The risk of developing respiratory cancers was shown to be equal (33.3%) among smoking and non-smoking workers. Thus, the risk presented by occupational carcinogen exposure to each respective worker remained the same during the study, independent of the smoking status.

3.5.2.2 Age and years of service

The duration a worker's exposure to a certain carcinogenic substance depends largely on the number of hours per day worked as well as the number of years a worker has been employed in a certain occupation. According to literature (Schoen, 2012; Eaton and Gilbert, 2013), cancer risk increases proportionally with an increase in exposure to an occupational carcinogen. Although no dose occurs with absolutely zero risk, the risk decreases proportionally with a decrease in dose. The most common age of cancer diagnosis in the general population was shown to be 60-64 years (NIOH, 2011) and another study indicated the age to be between 75 and 84 years of age (ACS, 2011). As seen with the prostate cancer incidences, the highest incidence rate was shown in male workers over the age of 50 years and no younger workers showed any signs of prostate cancer. Respiratory cancers showed the highest incidence rate in workers over the age of 50 years.

3.5.2.3 Mine type

According to the World Coal Institute, an underground coal mine poses a higher health risk than an opencast coal mine (WCI, 2009). As seen in Table 3-7, the results showed that the risk was similar across all mine types with the cancer development ratios indicated as 1.02 in 1 000 workers (underground (UG)), 1.25 in 1 000 workers (opencast (OC)), and 1.24 in 1 000 workers (combination mine (OC + UG)). This may indicate that the risk of developing occupational cancer when employed in a coal mine are equivalent irrespective of the type of mine, but may be slightly more in an opencast (OC) and combination mine (OC + UG) due to the mining processes employed or the control mechanisms in place.

Workers employed in an opencast mine, as well as combination mines (OC + UG), has the added disadvantage of being exposed to environmental elements such as sunlight or UVR, that underground coal mine workers are not exposed to. Opencast coal mining operations increase the risk for exposure to high levels of respirable coal dust and drill operators run the risk of being exposed to crystalline silica dust (Petsonk and Attfield, 2005). Ventilation, which relies on natural air movement in an opencast mine, is a bigger concern in underground mining due to the risk of spontaneous combustion and is necessary for the sufficient removal of dust particles and other hazardous substances (WCI, 2009; WCA, 2016).

3.5.2.4 Exposure monitoring of occupational carcinogens

In order for a mining company to comply with the recommended legislation set forward by the DMR only a few of the abovementioned carcinogens is monitored, including crystalline silica and coal mine dust. However, exposure to diesel engine exhaust and DPM and other carcinogenic metals, for example, is not monitored on a regular basis. This may indicate that the occupational monitoring programmes of the South African mining companies are not up to standard due to the exclusion of important occupational carcinogen exposures.

3.5.3 Observations retrieved from baseline risk assessments

Observations made during the baseline risk assessment (refer to Table 3-10 confirmed most of the abovementioned findings, especially the high dust exposure experienced by maintenance as well as production workers (i.e. multi-task workers). Other concerns raised during the assessment included exposure to carcinogenic substances such as trichloroethylene, which was used as a degreaser of metal parts. Trichloroethylene, a well-known HCS and Group 1 carcinogen, can increase the risk of the development of various cancers including brain, liver, and non-Hodgkin lymphoma, as well as bring about contact dermatitis through dermal exposure (Shen, 2013; IARC, 2014b; European Commission,

2015). Due to the absence of MSDSs at storage areas of HCSs, the proper use and disposal of these substances are not known by the workers and can increase their risk of developing adverse effects such as dermatitis and cancer because they are not adequately informed of the risks associated with the use of and exposure to hazardous substances.

PPE plays an important role in the protection of the health of the workers, and if stored, used and cleaned incorrectly can lead to cross-contamination as well as exposure to various substances present in the coal mining environment. Cross-contamination can occur when PPE is stored with HCSs, especially when PPE is not cleaned properly before the next use. Another concern is when PPE (i.e. overalls) are removed from site to be cleaned at home. Removal of contaminated PPE may lead to the exposure of family members to possible carcinogenic substances. The risk of unwanted exposure to carcinogenic substances can also be increased when a mining company's prescribed protocols are bypassed. Protocols are set in place to ensure the workers' health is protected against unwanted exposure, and when these protocols are bypassed, a worker will increase his/her risk of developing occupational illnesses such as cancer, dermatitis and pneumoconiosis.

The DPM baseline risk assessment indicated a concern in underground coal mines for an increased risk of DPM exposure, particularly in diesel intensive operations. Due to the absence of any OEL (Occupational Exposure Limit) for DPM in South Africa, the MSHA was used as a benchmark for compliance assessments in the ten mines. The reasons for the high DPM exposure can be attributed to the increased number of diesel operating engines during the various diesel intensive activities performed, such as belt moves and production activities. This increases the risk of workers – especially those in production activities – of being exposed to high levels of DPM.

3.5.4 Relationship between historical medical and exposure monitoring data

A statistical significant relationship could not be drawn between the historical medical and exposure monitoring data due to the data not being sourced from the same workers. However, the results revealed that the occupations who experienced the highest exposures to coal mine dust and crystalline silica also had the highest occurrence of respiratory cancers and pneumoconiosis.

3.6 Conclusion

The aim of this study was to establish if a risk of occupational carcinogenic exposure exists in South African coal mines and to determine if the development of occupational cancer in coal mine workers can be linked to this occupational exposure. The literature study confirmed the presence of and exposure to various occupational carcinogens in the coal mining environment. This study was performed in order to determine the type and frequency of cancer incidences among coal mine workers as well as to ascertain which workers can be classified as the groups that have the highest risk for exposure as well as occupational cancer development. The findings confirmed that coal mine workers of various occupational roles (eg. multi-task workers) have the risk of developing occupational cancer. The risk was indicated in the historical medical data retrieved from ten South African coal mines. It was indicated that cancer is diagnosed among coal mine workers in South Africa and the highest exposed occupation can be classified as the multi-task worker and the highest exposed activity can be classified as continuous mining. The highest cancer incidence rate was shown among the multi-task and maintenance workers.

The presence of carcinogens was confirmed in various exposure concentrations in a coal mining environment. This was indicated by the historical exposure monitoring data as well as the baseline risk assessments that were performed. The occupational carcinogen exposure in a coal mining environment may lead to the development of various types of cancer, such as prostate and lung cancer, due to the daily exposure of workers to particularly dust (coal mine dust and crystalline silica) during production activities (Schoen, 2012; Eaton and Gilbert, 2013). Other external factors and exposures may also play a role in the development of cancer in coal mine workers and should always be taken into consideration. When compared to the general population (as seen with prostate and lung cancer) the results indicate that the risk for developing occupational cancer is higher among coal mine workers than for the general population.

The development of occupational cancer is largely preventable and should be considered a high priority in the protection of the coal mine workers' health. Mining companies should include exposure monitoring of other occupational carcinogens, such as DPMs, into their occupational monitoring programmes to ensure the optimal protection of worker health.

3.7 References

ACS (American Cancer Society). (2011) Cancer in Africa. Available from: URL: https://www.cancer.org/acs/groups/content/@epidemiologysurveilance/documents/document/acspc-031574.pdf (accessed 24 October 2016)

ATSDR (Agency for Toxic Substances and Disease Registry). (2002) Toxicological profile for Beryllium. Available from: URL: http://www.denix.osd.mil/cmrmd/upload/ATSDRTOXICOLOGICALPROFILEFORBERYLLIUM.PDF (accessed 3 February 2015)

Badenhorst CJ. (2006) Occupational health risk assessment: overview, model and guide for the South African mining industry towards a holistic solution. Potchefstroom: NWU

Baxter PJ, Waldron HA. (1989) The introduction and monitoring of occupational diseases. *In* Waldon HA, editor. Occupational Health Practice. London, UK: Butterworths. p. 41-72. ISBN 0 407 33702 4.

Belle BK. (2008) Use of baseline personal DPM exposure data for mine ventilation planning – A South African Journey. 12th US/North American Mine Ventilation Symposium 2008. p. 481-485. ISBN 978 0 615 20009 5.

Borm PJA, Tran L. (2001) From quartz hazard to quartz risk: the coal mines revisited. *Ann Occup Hyg*; **46**: 25-32.

Brown AM, Christie D, Taylor R, *et al*. (1997) The occurrence of cancer in a cohort of New South Wales coal miners. *Aust NZ J Publ Heal*; **21**: 29-32.

CANSA (The Cancer Association of South Africa). (2012) Statistics – South African cancer statistics. Available from: URL: http://www.cansa.org.za/south-african-cancer-statistics/ (accessed 7 November 2016)

CCOHS (Canadian Centre for Occupational Health and Safety). (2016) Skin cancer and sunlight. Available from: URL: https://www.ccohs.ca/oshanswers/diseases/skin_cancer.html (accessed 14 March 2016)

CDC (Centers for Disease Control and Prevention). (2012) Section 2: Morbidity frequency measures. Available from: URL: https://www.cdc.gov/ophss/csels/dsepd/ss1978/lesson3/section2.html (accessed 12 April 2017)

Chamber of Mines of South Africa. (2015) Facts and figures 2013/2014. Available from: URL: http://www.chamberofmines.org.za/media-room/facts-and-figures (accessed 28 April 2015)

Clapp RW, Jacobs MM, Loechler EL. (2008) Environmental and occupational causes of cancer: New evidence, 2005-2007. *Rev Environ Health*; **23**: 1-37.

Claxton LD. (2014) The history, genotoxicity, and carcinogenicity of carbon-based fuels and their emissions. Part 3: Diesel and gasoline. *Mutat Res*; **763**: 30-85.

Colman, T. (2015) Anglo American New Denmark Colliery: The power of collaboration. Available from: URL: http://thesa-mag.com/features/mining/anglo-american-new-denmark-colliery-the-power-of-collaboration/ (accessed 4 January 2016)

Dancey CP, Reidy JG, Rowe R. (2012) Statistics for the health sciences: A non-mathematical introduction. London, UK: Sage Publications. ISBN 978 1 84920 335 7.

DME (Department of Minerals and Energy). (2002) SAMOHP (South African Mines Occupational Hygiene Programme): Codebook. Available from: URL: http://www.mhsc.org.za/sites/default/files/Guide%20line%20SAMHOP%20_codebook.pdf (accessed 12 June 2015)

Donbak L, Rencuzogullari E, Yavuz A, Topaktas M. (2005) The genotoxic risk of underground coal miners from Turkey. *Mutat Res*; **588**: 82-87.

Driscoll T, Steenland K, Prüss-Üstün A, *et al*. (2004) Occupational carcinogens: assessing the environmental burden of disease at national and local levels. Environmental burden of disease series, no. 6. Available from: URL: http://www.who.int/quantifying_ehimpacts/publications/en/ebd6.pdf?ua=1 (accessed 21 April 2015)

Eaton DL, Gilbert SG. (2013) Principles of toxicology. *In* Klaassen CD. editor. Casarett and Doull's Toxicology: The basic science of poisons. 8th ed. China: McGraw-Hill Education. p. 13-48. ISBN 978 0 07 176925 9.

Environ. (1986) Elements of toxicology and chemical risk assessment: a handbook for non-scientists, attorneys and decision makers. Washington, DC: Environ Corporation. ISBN 0 89116 468 5.

EPA (United States Environmental Protection Agency). (2010) Vocabulary catalog: waste and cleanup risk assessment glossary. Available from: URL: https://ofmpub.epa.gov/sor_internet/registry/termreg/searchandretrieve/glossariesandkeywordlists/search.do?details=&glossaryName=Waste%20and%20Cleanup%20Risk%20Assess (accessed 5 April 2016)

European Commission. (2015) Chemical Safety Report: Trichloroethylene. Available from: URL: http://ec.europa.eu/DocsRoom/documents/10925/attachments/1/translations/en/renditions/native. (accessed 3 February 2016)

Falk HL, Jurgelski W. (1979) Health effects of coal mining and combustion: carcinogens and cofactors. *Environ Health Persp*; **3**: 203-226.

Feychting M, Forssen U, Floderus B. (1997) Occupational and residential magnetic field exposure and leukemia and central nervous system tumors. *Epidemiology*; **8**: 384-389.

Gilman P, Ames RG, McCawley MA. (1985) Leukemia risk among U.S. white male coal miners: A case-control study. *J Occup Environ Med*; **27**.

Graber JMA. (2012) Morbidity and mortality among underground coal miners. Dissertation: University of Illinois.

Harris M, Taylor G. (2008) Medical statistics made easy 2. Banbury, UK: Scion Publishing. ISBN 978 1 9048425 5 2.

Hung YP, Teng CJ, Liu CJ, *et al*. (2014) Cancer risk among patients with coal workers' pneumoconiosis in Taiwan: A nationwide population-based study. *Int J Cancer*; **134**: 2910-2916.

IARC (International Agency for Research on Cancer). (1988) Monographs on the evaluation of carcinogenic risks to humans (Volume 43): Man-made mineral fibres and radon. Available from: URL: http://monographs.iarc.fr/ENG/Monographs/vol43/mono43.pdf (accessed 28 April 2015)

IARC (International Agency for Research on Cancer). (1990) Monographs on the evaluation of carcinogenic risks to humans (Volume 49): Chromium, nickel and welding. Available from: http://monographs.iarc.fr/ENG/Monographs/vol49/mono49.pdf (accessed 1 February 2016)

IARC (International Agency for Research on Cancer). (1992) Monographs on the evaluation of carcinogenic risks to humans (Volume 55): Solar and ultraviolet radiation. Available from: URL: http://monographs.iarc.fr/ENG/Monographs/vol55/mono55.pdf (accessed 3 February 2016)

IARC (International Agency for Research on Cancer). (1997) Monographs on the evaluation of carcinogenic risks to humans (Volume 68): Silica, some silicates, coal dust and para-amid fibrils. Available from: URL: http://monographs.iarc.fr/ENG/Monographs/vol68/mono68.pdf (accessed 16 June 2018)

IARC (International Agency for Research on Cancer). (2002) Monographs on the evaluation of carcinogenic risks to humans (Volume 80): Non-ionizing radiation, Part 1: Static and extremely low-frequency (ELF) electric and magnetic fields. Available from: URL: http://monographs.iarc.fr/ENG/Monographs/vol80/mono80.pdf (accessed 7 January 2016)

IARC (International Agency for Research on Cancer). (2010) Monographs on the evaluation of carcinogenic risks to humans (Volume 92): Some non-heterocyclic polycyclic aromatic hydrocarbons and some related exposures. Available from: URL: http://monographs.iarc.fr/ENG/Monographs/vol92/mono92.pdf (accessed 22 April 2015)

IARC (International Agency for Research on Cancer). (2012a) Monographs on the evaluation of carcinogenic risks to humans (Volume 100C): Arsenic, metals, fibres, and dusts. Available from: URL: http://monographs.iarc.fr/ENG/Monographs/vol100C/mono100C.pdf (accessed 28 April 2015)

IARC (International Agency for Research on Cancer). (2012b) Monographs on the evaluation of carcinogenic risks to humans (Volume 100D): Radiation. Available from: URL: http://monographs.iarc.fr/ENG/Monographs/vol100D/index.php (accessed 14 March 2016)

IARC (International Agency for Research on Cancer). (2014a) Monographs on the evaluation of carcinogenic risks to humans (Volume 105): Diesel and gasoline engine exhausts and some nitroarenes. Available from: URL: http://monographs.iarc.fr/ENG/Monographs/vol105/mono105.pdf (accessed 22 April 2015)

IARC (International Agency for Research on Cancer). (2014b) Monographs on the evaluation of carcinogenic risks to humans (Volume 106): Trichloroethylene, tetrachloroethylene, and some other chlorinated agents. Available from: URL: http://monographs.iarc.fr/ENG/Monographs/vol106/index.php (accessed 6 January 2016)

ICD10Data.com. (2016) 2016 ICD-10-CM Codes. Available from: URL: http://www.icd10data.com/ICD10CM/Codes (accessed 12 October 2015)

Jamasmie C. (2016) South Africa allows biggest ever class action against gold giants to go ahead. Available from: URL: http://www.mining.com/south-africa-allows-biggest-ever-class-action-lawsuit-against-gold-giants-to-go-ahead/ (accessed 5 September 2016)

Jenkins WD, Christian WJ, Mueller G, Robbins KT. (2013) Population cancer risks associated with coal mining: a systematic review. *Plos One*; **8**: 1-12.

Kammer R, Tinnerberg H, Eriksson K. (2011) Evaluation of a tape-stripping technique for measuring dermal exposure to pyrene and benzo(a)pyrene. *J Environ Monitor*; **13**: 2165-2175.

Kaplan BLF, Sulentic CEW, Holsapple MP, Kaminski NE. (2013) Toxic responses of the immune system. *In* Klaassen CD, editor. Casarett and Doull's Toxicology: The basic science of poisons. 8th ed. China: McGraw-Hill Education. p. 559-638. ISBN 978 0 07 176925 9.

Kohler JL. (2005) Mining. *In* Rosenstock R, Cullen MR, Brodkin CA, Redlich CA, editors. Textbook of clinical occupational and environmental medicine. London: Elsevier, Inc. p.201-214. ISBN 0 7216 8974 4.

Kretsinger RH, Uversky VN, Permyakov EA. (2013) Encyclopedia of Metalloproteins. NY:Springer. eISBN 978 1 4614 1533 6.

León-Mejía G, Quintana M, Debastiani R, *et al*. (2014) Genetic damage in coal miners evaluated by buccal micronucleus cytome assay. *Ecotox Environ Safe*; **107**: 133-139.

Lundberg I, Hogstedt C, Lidén C, Nise G. (2005) Organic solvents and related compounds. *In* Rosenstock R, Cullen MR, Brodkin CA, Redlich CA, editors. Textbook of clinical occupational and environmental medicine. London: Elsevier, Inc. p. 991-1009. ISBN 0 7216 8974 4.

Machin D, Campbell MJ, Walter SJ. (2007) Medical statistics: A textbook for the health sciences. San Francisco, CA: John Wiley & Sons. ISBN 978 0 470 02519 2.

Maiti J, Bhattacherjee A. (1999) Evaluation of risk of occupational injuries among underground coal mine workers through multinomial logit analysis. *J Safety Res*; **30**: 93-101.

Majzlan J, Drahota P, Filippi M. (2014) Parageneses and crystal chemistry of arsenic minerals. *In* Bowell RJ, Alpers CN, Jamieson HE, Nordstrom DK, Majzlan J, editors. Reviews in mineralogy and geochemistry (volume 79): Arsenic – environmental geochemistry, mineralogy, and microbiology. p. 17-184. ISBN 9 780 939950 94 2.

Masters GM. (1998) Introduction to environmental engineering and science. Englewood, NJ: Prentice Hall. p. 117-157. ISBN 9 780 131553 84 2.

McCormack VA, Schüz J. (2012) Africa's growing cancer burden: environmental and occupational contributions. *Cancer Epidem*; **36**: 1-7.

Mengeot MA. (2007) Occupational cancer: The Cinderella disease. Belgium: European Union Trade Institute for Research and Education. ISBN 978 2 87452 074 7.

MHSA (Mine Health and Safety Act and Regulations). (1996) Act 29 of 1996. Lexis Nexis. ISBN 978 0 409 12279 4.

Muzyka V, Bogovski S, Scheepers P, *et al*. (2003) Effects of occupational exposure to diesel exhaust on porphyrin metabolism in lymphocytes of workers employed at black coal and oil-shale mines. *Am J Ind Med*; **44**: 70-74.

Naghadehi MZ, Sereshki F, Mohammadi F. (2014) Pathological study of the prevalence of silicosis among coal miners in Iran: A case history. *Atmos Environ*; **83**: 1-5.

Nazaroff WW, Alvarex-Cohen L. (2001) Environmental engineering science. NY: John Wiley and Sons. p. 396-397, 569-573. ISBN 9 78 0471144 9 46.

NIOH (National Institute for Occupational Health). (2011) Cancer in South Africa – 2011 Full report (National Cancer Registry). Available from: URL: http://www.nioh.ac.za/?page=national_cancer_registry&id=41 (accessed 19 October 2016)

NIOSH (National Institute for Occupational Safety and Health). (2011) Current Intelligence Bulletin 64: Coal mine dust exposures and associated health outcomes. Available from: URL: http://www.cdc.gov/niosh/docs/2011-172/pdfs/2011-172.pdf (accessed 2 March 2015)

NTP (National Toxicology Program). (2014) Report on carcinogens, thirteenth edition. Available from: URL: http://ntp.niehs.nih.gov/ntp/roc/content/profiles/polycyclicaromatichydrocarbons.pdf (accessed 14 May 2015)

Petsonk EL, Attfield MD. (2005) Respiratory diseases of coal mines. *In* Rosenstock R, Cullen MR, Brodkin CA, Redlich CA, editors. Textbook of clinical occupational and environmental medicine. London: Elsevier, Inc. p. 393-407. ISBN 0 7216 8974 4.

Petsonk EL, Rose C, Cohen R. (2013) Coal mine dust lung disease: new lessons from an old exposure. *Am J Respir Crit Care Med*; **187**: 1178-1185.

Pienaar J. 2014. Sharing one electronic health record database/system: this is a futuristic article. *Occup Health*; **20**: 23.

Povtak T. (2016) Class action lawsuits. Available from: URL: https://www.asbestos.com/mesothelioma-lawyer/class-action-lawsuit.php (accessed 5 September 2016)

Sangani RG, Ghio AJ. (2011) Lung injury after cigarette smoking is particle related. *Int J Chron Obstruct Pulmon Dis*; **6**: 191-198.

Schneider MJ. (2014) Introduction to public health. Burlington, MA: Jones and Bartlett Learning. ISBN 978 1 4496 8887 5.

Schoen D. (2012) Threshold vs. non-threshold carcinogens. Available from: URL: http://standards.nsf.org/apps/group_public/download.php/18366/threshold%20carcinogens%20vs%20non-threshold%20carcinogens.pdf (accessed 5 March 2016)

Shen DD. (2013) Toxicokinetics. *In* Klaassen CD, editor. Casarett and Doull's Toxicology: The basic science of poisons. 8th ed. China: McGraw-Hill Education. p. 367-390. ISBN 978 0 07 176925 9.

Siemiatycki J, Richardson L, Straif K, *et al*. (2004) Listing occupational carcinogens. *Environ Health Persp*; **112**: 1447-1459.

Stats SA (Statistics South Africa). (2012) National Accounts: Mineral accounts for South Africa (1980-2009). Available from: URL: http://www.statssa.gov.za/publications/D04052/D040522009.pdf (accessed 1 February 2016)

Stats SA (Statistics South Africa). (2015) The importance of coal. Available from: URL: http://www.statssa.gov.za/?p=4820 (accessed 7 January 2016)

Steyn HS, Ellis SM. (2009) Estimating an Effect Size in One-Way Multivariate Analysis of Variance (MANOVA). *Multivar Behav Res*; **44**: 106-129.

Steyn HS. (2012) Manual for the determination of effect size indices and practical significance. Available from: URL: http://www.nwu.ac.za/content/statcs-manual (accessed 3 October 2016)

Swaen GMH, Aerdts CWHM, Sturmans F, *et al*. (1985) Gastric cancer in coal miners: a case-control study in a coal mining area. *Brit J Ind Med*; **42**:627-630.

Swaen GMH, Meijers JMM, Slangen JJM. (1995) Risk of gastric cancer in pneumoconiotic coal miners and the effect of respiratory impairment. *Occup Environ Med*; **52**: 606-610.

Takala J. (2015) Eliminating occupational cancer. *Ind Health*; **53**: 307-309.

tHS (theHealthSource). (2016) The Health Source: innovation, efficiency and health. Available from: URL: http://thehealthsource.co.za/about/ (accessed 8 January 2016)

Tulchinsky TH, Varavikova EA. (2014) The new public health. London, UK: Elsevier, Inc. ISBN 9780 12 415766 8.

Unsted AD. (2001) Airborne pollutants. *In* Guild R, Ehrlich RI, Johnston JR, Ross MH, editors. A handbook on occupational health practice in the South African mining industry. Braamfontein(SA): SIMRAC. p. 85-118. ISBN 1 919853 02 2.

Velga LHS, Amaral ECS, Colin D, Koifman S. (2006) A retrospective mortality study of workers exposed to radon in a Brazilian underground coal mine. *Radiat Environ Biophys*; **45**: 125-134.

Wagner GR, Hearl FJ. (2005) Mineral dusts: Asbestos, silica, coal, manufactured fibres. *In* Rosenstock R, Cullen MR, Brodkin CA, Redlich CA, editors. Textbook of clinical occupational and environmental medicine. London: Elsevier, Inc. p. 1073-1086. ISBN 0 7216 8974 4.

WCA (World Coal Association). (2013) Coal mining. Available from: URL: http://www.worldcoal.org/coal/coal-mining/ (accessed 15 March 2015)

WCA (World Coal Association). (2016) Mining safety. Available from: URL: http://www.worldcoal.org/coal/coal-mining/mining-safety (accessed 4 July 2016)

WCI (World Coal Institute). (2009) The coal resource: a comprehensive overview of coal. Available from: URL: http://www.worldcoal.org/bin/pdf/original_pdf_file/coal_resource_overview_of_coal_report%2803-06-2009%.pdf (accessed 1 May 2015)

3.8 Supplementary material

Table 3-11: Comparison of occupation descriptions retrieved from historical data

Occupation description used for research study	Occupation description (Medical data)	Occupation description (Exposure monitoring data)	SAMOHP code
Multi-task worker	Mining operator	Multi-task worker (underground production)	20704
		Continuous miner operator	20602
		Mine production worker	29999
		Roof bolt machine operator	20806
		Roof bolt worker	20807
Miner (General)	Faceboss	Miner (General)	20305
Engineering	Engineering operator	Engineering technician (n.e.c)	40203
	Eng Foreman: Mechanical	Engineering foreman (n.e.c)	40004
	Section Engineer (UG)	Engineer (n.e.c)	40201
	Engineering senior assistant	Engineering assistant	40205
	Engineering clerk	Clerk (engineering)	49995
	Engineering Planning Assistant	Clerk (engineering planning)	40195
	Technical assistant	Technical assistant engineering (n.e.c)	40204
		Technical assistant mining (n.e.c)	20211
	Principal engineer mining	Mining engineer (n.e.c)	20201
Maintenance	Artisan's aide	Boilermaker assistant/attendant	40803
		Fitter assistant/attendant	40803
	Boilermaker assistant	Boilermaker assistant/attendant	40803
	Boilermaker	Boilermaker (Gr 1)	40450
		Boilermaker (aide) (Gr 2)	40451
	Fitter	Fitter (operative) (Gr 1)	40434
		Fitter (operative aide) (Gr 2)	40435
	Auto electrician	Auto electrician	40319
	Electrician	Electrician	40314
		Electrician: Underground section	40316
		Electrician: Worker (n.e.c)	40318
	Electrician chargehand	Electrician: chargehand	40313
Stockyard worker	Plant operator	Stockyard worker/Yard worker	10321
	Plant assistant		
	Washing plant operator		
	Stockyard worker w.o. Coal prep cert.		

Table 3-11 (cont.): Comparison of occupation descriptions retrieved from historical data

Occupation description used for research study	Occupation description (Medical data)	Occupation description (Exposure monitoring data)	SAMOHP code
Mine transport worker	Driver	Haulage/UG rail transport	21099
	Mine Transport worker P5	Mine transport worker	21499
	Mine Transport worker P6	Load haul dump driver	21106
	Operator Dump Truck	Haulage/UG rail transport	21099
Mining assisant (cheesa)	Mining Senior Assistant	Mining assistant (cheesa)	20504
	Mining Assistant		
Blasting worker	Blasting assistant	Blasting worker (n.e.c)	20599
Lampsman	Lampsman	Lampsman	40345
Beltsman	Beltsman	Beltsman	30205
Millwright	Millwright	Electro mechanic/ millwright/ minewright	40437
	Electromechanic		
Dragline operator	Dragline operator	Dragline operator	21102
	Trainee Dragline operator		
Training instructor	Senior training instructor	Training management	60300
	Trainer	Training officer (n.e.c)	60301
	Training facilitator	Training assistant	60302
		Training worker (n.e.c)	60399

CHAPTER 4: CONCLUDING CHAPTER

In this chapter conclusions will be made with reference to the aims, objectives and research question of this study. Recommendations related to the observations from the historical data (medical and exposure monitoring data) and baseline risk assessments will be given in an attempt to improve the present control measures in place to prevent and/or reduce exposure to occupational carcinogens in a coal mining environment. The limitations of the study and the possibility of future studies will also be discussed.

4.1 Further discussion and conclusion

The main aim of this study was to appraise the historical medical data of ten thermal coal mines as well as the historical exposure data of one high risk underground thermal coal mine in South Africa in order to evaluate the occupational carcinogenic risk in coal mines.

This study was requested by a mining company in South Africa where a concern about occupational carcinogen exposure in a coal mining environment existed. The risk of exposure to occupational carcinogens as well as the development of cancer under coal mine workers, raised a concern and therefore, was deemed the general aim of this study. With extended knowledge about the risks involved due to occupational carcinogen exposure, informed decisions can be made with regard to the monitoring (area or personal exposure monitoring) as well as the control of these exposures.

A comprehensive literature study as well as historical exposure monitoring data was utilised in order to determine the extent of the coal mine workers' occupational exposure to various carcinogens. Various occupations were evaluated in order to determine the extent of exposure risk present in each, as well as to determine which of these occupations were considered the highest exposed occupations. Historical medical data was extracted and appraised to determine if workers employed in certain occupations had an increased risk of developing cancer types related to their occupational exposures. Statistical analysis of the historical data, comprising descriptive statistics, was utilised in order to determine the frequencies of cancer types diagnosed and effect sizes were used to portray the relationship of various factors involved in the development of occupational cancer.

Discerning occupational carcinogen exposure in a coal mining environment is of great importance since the risk of developing cancer may increase later in life as the exposure to carcinogens continues (Schoen, 2012; Eaton and Gilbert, 2013). Due to the delay between exposure to a carcinogen and the first sign of an adverse effect – referred to as the latent

period – it is difficult to establish the initial cause of certain occupational cancers (Schneider, 2014). It remains crucial to consider these occupational carcinogen exposures since no threshold for carcinogens exists in the body. All recurring exposures which the body does not recover from and any exposure, even at a very low dose, will increase the risk of developing cancer (Masters, 1998; Nazaroff and Alvarex-Cohen, 2001). A concern that was raised was that mining companies did not monitor the exposure to all occupational carcinogens and mostly included coal mine dust and crystalline silica in the occupational hygiene monitoring programmes to comply with legislation. The IARC classifies diesel engine exhaust, of which DPM is a component, as a Group 1 carcinogen and occupational exposure occurs mostly through inhalation (Claxton, 2014, IARC, 2014a). Currently, there are no South African OELs for DPM exposure, and the mining company should consider improving exposure monitoring, as well as control measures, to protect workers during diesel intensive operations (mostly production activities and the exposure to carcinogenic metals).

Another contributing factor to cancer development is the exposure to carcinogens outside the working environment such as tobacco smoking or environmental pollution. Occupational cancer is a leading cause of death worldwide even though exposures to occupational carcinogens are largely preventable (Tulchinsky and Varavikova, 2014; Takala, 2015).

Exposure to some of the occupational carcinogens may also lead to other adverse health effects comprising pneumoconiosis – such as coal workers' pneumoconiosis (CWP) and silicosis – and dermatitis due to inhalation and/or dermal exposure to specific carcinogenic substances (Kaplan *et al.*, 2013; Kretsinger *et al.*, 2013; Hung *et al.*, 2014).

In Chapter 3 the historical exposure monitoring data and baseline risk assessments indicated the presence of various occupational carcinogens (including coal mine dust and crystalline silica dust) liberated during the day-to-day coal mining processes. The results retrieved from the historical medical data showed the presence of various cancer types diagnosed under coal mine workers employed in numerous occupations in a coal mine. Prostate cancer had the highest incidence rate (40.7%) of the 32 total cancer incidences retrieved and respiratory cancers had the second highest incidence rate (37.5%). Respiratory cancers encompassed all cancer types related to the respiratory system – including oesophagus, ethmoidal and maxillary sinus, respiratory tract, and lung, to name a few. The occupation shown to be most at risk of the development of all cancer types was the multi-task worker (25% of total cancer incidences). Multi-task workers also had the highest exposure to respirable dust (coal mine dust and crystalline silica dust) as well as the highest incidence rate of respiratory cancers (25%) and pneumoconiosis (57.6%). A multi-task worker is responsible for performing various activities, including operation of the continuous and/or long wall mining equipment, roof bolting

equipment as well as the operation of stone dusters – collectively known as production activities in a coal mine.

According to the World Coal Institute, underground coal mining processes pose the highest health risk of workers, due to difficulties associated with the ventilation of clean air, the removal of airborne carcinogenic substances and dust particles as well as the mining activities performed by the workers (WCI, 2009). However, the cancer incidence results retrieved from the historical medical data revealed a different picture in relation to the abovementioned literature, in that it showed that workers employed in any type of coal mine had an increased risk of developing cancer. Although the ratios were not identical (1.02 in 1 000 workers (underground (UG)), 1.25 in 1 000 workers (opencast (OC)), and 1.24 in 1 000 workers (combination mine (OC + UG)) the ratio indicated in the opencast (OC) coal mine was slightly higher than the other mine types. When compared to the general population (NIOH, 2011) – 0.26 in 1 000 individuals (prostate) and 0.06 in 1 000 individuals (lung) – the ratios indicated an increased risk of developing these cancers among coal mine workers – 0.6 in 1 000 workers (prostate) and 0.18 in 1 000 workers (lung). This indicates that employment at a coal mine will increase the risk of developing cancer when compared to the general population. Another concern raised from the historical medical data results showed a very high incidence of pneumoconiosis in the multi-task worker occupation that may be due to the exposure of these workers to respirable dust (coal mine dust and crystalline silica dust) during production activities. Hung *et al.* (2014) showed an increased risk of the development of lung cancer in especially workers who were diagnosed with coal workers' pneumoconiosis.

Results retrieved from the historical exposure monitoring data showed the exposure to occupational carcinogens in different concentrations, and the exposures which exceeded the recommended OELs (coal mine dust and crystalline silica exposures) was focused on further. The most common occupational carcinogens monitored for in an underground coal mine were coal mine dust ($\bar{x}$=1.5 mg/m^3; minimum = 0.03 mg/m^3; maximum = 19.8 mg/m^3) as well as crystalline silica dust ($\bar{x}$=0.04 mg/m^3; minimum = 0.0005 mg/m^3; maximum = 1.5 mg/m^3). The occupation most at risk of exposure to coal mine dust was shown to be the multi-task worker ($\bar{x}$=5.5 mg/m^3; minimum = 2.1 mg/m^3; maximum = 19.8 mg/m^3), with all the statistical values exceeding the recommended OEL for coal mine dust (2 mg/m^3). Crystalline silica dust exposure was also a concern with the multi-task workers where all the measured concentrations exceeded the recommended OEL ($\bar{x}$=0.5 mg/m^3; minimum = 0.14 mg/m^3; maximum = 1.5 mg/m^3) for crystalline silica dust (0.1 mg/m^3).

Baseline risk assessments performed at the coal mines confirmed the concern raised during the appraisal of the historical medical and exposure monitoring data. Exposure to respirable

dust (coal mine dust and crystalline silica dust) was a concern at most of the coal mines and posed a problem mostly during production activities. DPM exposure during production activities, especially where diesel intensive operations were performed, showed to be a concern at especially underground coal mines.

To summarise the results retrieved from Chapter 3: occupational carcinogen exposure as well as the number of multi-task workers – mostly responsible for production activities in a coal mine – diagnosed with cancer, showed that the exposure to carcinogens should be afforded a higher priority where this occupation is concerned. Occupational carcinogens raising the biggest concern with this occupation is the exposure to respirable dust (coal mine dust and crystalline silica dust).

Various studies have linked carcinogen exposure in an occupational environment, such as a coal mine, to the development of several types of cancer (Driscoll *et al.*, 2004; Graber, 2012; Rushton *et al.*, 2012; IACR, 2014). This raised the research question: Does a correlation exist between the occupational carcinogen exposure and the development of occupational cancer in the South African coal mines used for this study? Although no statistically significant relationship could be determined between the occupational carcinogen exposure and the development of occupational cancer in a coal mining environment due to the nature of the historical data sets, this study successfully indicated that a relationship does indeed exist. This study also indicated the highest exposed occupation could be identified as the multi-task worker involved in the production activities of a coal mine, due to the number of cancer incidences retrieved from the medical data as well as the high exposure to respirable dusts (coal mine dust and crystalline silica dust) in the exposure data. To answer this research question: a relationship between the exposure to occupational carcinogens and the development of occupational cancer in the South African coal mining environment does exist. The highest exposed occupation group (i.e. multi-task worker) showed the highest incidence rate for cancer. In all the mine types a similar risk of cancer development was indicated, but when cancer development was compared with the general population – using prostate and lung cancer as examples – it was shown that the cancer risk of these respective cancers were increased in coal mine workers.

Reflecting on the results that were yielded by the comparison between the historical medical data and historical exposure monitoring data it is possible to make a conclusion regarding the relationship between the cancer incidences reported and occupational carcinogens coal mine workers are exposed to. Cancer development due to occupational exposure should become a higher priority in the coal mining industry, not only in South Africa, but the rest of the world

as well. Thus, protection of coal mine workers should be improved regarding exposure to various carcinogenic substances to reduce or prevent the development of cancer later in life.

4.2 Limitations of the study

In retrospect, there were a number of limitations that occurred whilst conducting the study.

- Availability of historical medical data was one of the major limitations to this study and therefore created a limiting factor relating to the number of cancer incidences that could be retrieved from the historical medical data. Historical medical data was only available from 2009 to 2015 due to tHS only starting in 2009.
- Availability of historical exposure monitoring data was also a major limitation to this study and created a limiting factor relating to the number of workers monitored for exposure to occupational carcinogens. Exposure monitoring data from only one mine (Mine 1) was available and used for this study. Exposure monitoring in Mine 1 is performed only for coal mine dust and silica dust and no other occupational carcinogen.
- Exposure monitoring done for legislative purposes was limited to mostly respirable dust exposures (including coal mine dust and crystalline silica dust) and therefore created a limiting factor relating to the occupational carcinogens identified during the comprehensive literature review done for this study.
- Historical medical data could not be compared statistically to the historical exposure monitoring data due to the nature thereof – cancer incidences identified in the historical medical data could not be compared to the exposures of workers in the historical exposure monitoring data because the individual instances were not identical. For example, a worker diagnosed with lung cancer was not necessarily the same worker monitored for exposure to coal mine dust or crystalline silica dust.
- Occupation descriptions were not identical in both the historical medical data and exposure monitoring data, and the researcher had to generate a reliable comparison between the different occupation descriptions in order to equate the individual data sets (refer to the Supplementary Material in Chapter 3).
- South African cancer related statistics are currently not up to date, and the most recent data available from the NCR (National Cancer Registry) is a full report released by the NIOH (National Institute for Occupational Health) for 2011. Thus, comparison of the cancer incidences retrieved from the historical medical data with data from the general population's cancer incidence was not recent.
- Cancer incidences retrieved from the historical medical data may not have been as complete due to the fact that many cancer incidences only develop later in a worker's life

– i.e. after retirement – and the diagnosis thereof may not have been reported as part of the mining hospital's statistics.

- The development of cancer cannot always be linked to the occupational exposure to carcinogens. External factors such as smoking and environmental pollution may also play a role, and it is therefore difficult to make definite assumptions about the cause of the cancer.
- Coal mine workers not of South African descent (migrant workers) (i.e. worker originally from Swaziland) may have been diagnosed with cancer, due to occupational exposures while employed at a South African coal mine, in his/her country of birth. Thus, cancer incidences not diagnosed at the mining hospital in South Africa would not form part of the cancer statistics.

4.3 Future studies

As mentioned previously, only South African coal mines of a specific mining company were used for this study. For future studies it would be ideal to conduct a more comprehensive study comparing occupational carcinogen exposure of workers at different mining companies in South Africa. To further expand the scope of future studies, occupational carcinogen exposure at coal mines in other countries, such as Australia, can be compared with the occupational carcinogen exposure of workers in South African coal mines, in view of the difference in coal quality mined in different parts of the world. The quality or rank of coal can determine the crystalline silica content and therefore increase the health hazard to coal mine workers (WCI, 2009; Naghadehi *et al.,* 2013).

No personal or area sampling was performed during this research study, but for a future study exposure monitoring can be conducted to confirm the findings on occupational carcinogen exposure communicated in a baseline risk assessment. Exposure monitoring can also be conducted (personal and/or area sampling) and compared to the findings reported in the normal day-to-day exposure monitoring data performed for legislative purposes at a coal mine. The focus should be placed on occupational carcinogens that may lead to the development of prostate and respiratory cancers in a coal mining environment such as PAHs, diesel engine exhaust and DPMs (Muzyka *et al.*, 2003; Clapp *et al.*, 2008; IARC, 2010).

4.4 Recommendations

Observations and the corresponding recommendations (including legislative recommendations) were made to emphasise the various concerns perceived during the research study. These recommendations can be found in Table 4-1. Recommendations focusing on the highest exposed occupation (i.e. multi-task workers) were made separately and can be found in section 4.4.1.

4.4.1 Observations and recommendations for highest exposed occupation

Several observations concerning the exposure, as well as the development of cancer among multi-task workers were made from the historical medical and exposure monitoring data. A summary of the observations and the corresponding recommendations can be found in section 4.4.1.1 to 4.4.1.2.

4.4.1.1 Observations from historical data

The highest cancer incidence rate was seen among the multi-task workers (25% of the total number of cancer incidences) and cancer types ranged from prostate cancer, various respiratory cancers, to Non-Hodgkin Lymphoma. Other occupational diseases that showed the highest incidence rate among these workers were pneumoconiosis (57.6%) and dermatitis (16.9%). The exposure monitoring data and the baseline risk assessments indicated multi-task workers to be most at risk for overexposure to coal mine dust and crystalline silica dust. Cross-contamination of PPE during storage with HCSs and improper cleaning was observed in the baseline risk assessment.

4.4.1.2 Recommendations for minimising exposure of multi-task workers

4.4.1.2.1 Engineering controls

Ventilation during production activities plays a crucial role in the control of dust exposure in an underground coal mine but is only one of the engineering controls that is usually implemented. Face ventilation is used to provide an adequate amount of dilution as well as carry the airborne dust down the face during production to prevent dust migration to other parts of the mine (WCI, 2009; Colinet *et al.*, 2010; WCA, 2016b).

Installation of flooded-bed scrubbers – a component of a continuous miner and some longwall miners – provides an effective means of capturing and removing airborne dust. Dust-laden air is captured from the coal face, carried through ductwork on the continuous miner where it is passed through a filter panel kept wet with water sprays. Dust particles are mixed with water

droplets and removed from the airstream by a mist eliminator. The cleaned air is discharged from the back of the scrubbed into the mine environment (Colinet *et al.*, 2010; Novak and Wedding, 2015). Water-spray systems, located on the cutting drums of longwall miners and continuous miners, play a role in supressing dust generation and migration during production activities (Colinet *et al.*, 2010). It is recommended that continuous miners and longwall miners be equipped, where possible, with flooded-bed scrubbers in order to minimise the dust released from the coal face during production activities and water-spray systems to further supress the generation of dust.

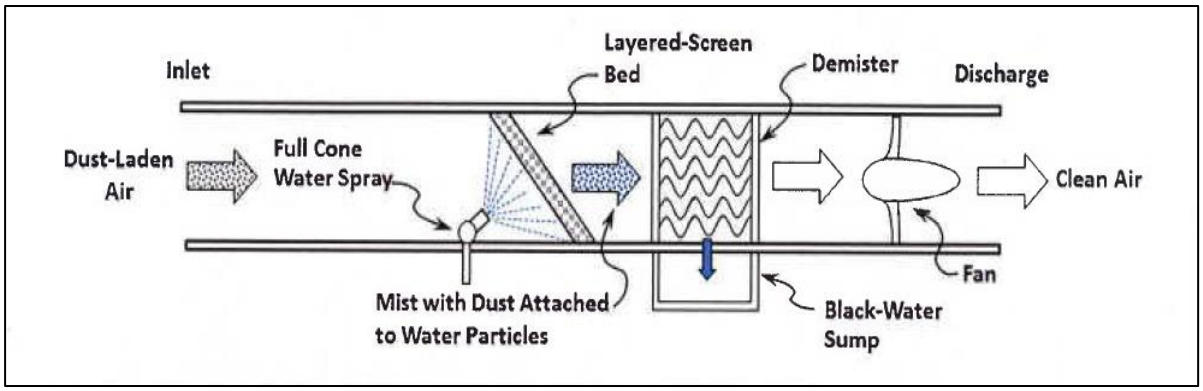


Figure 4-1: General side-view cross-section for a flooded-bed scrubber (Novak and Wedding, 2015)

It is also recommended that all of the abovementioned engineering controls should be maintained on a regular basis– in order to perform optimally. Filters of flooded-bed scrubbers need to be cleaned or replaced to ensure optimal filtration of dust-laden air. Water-spray systems need to be cleaned to prevent clogging of the nozzles with dust. This all will ensure that dust generated during production activities at the coal face is controlled in order to minimise the exposure of multi-task workers. Another important engineering control method is the proper maintenance of the cutting drums by replacing damaged, worn, or missing bits (Colinet *et al.*, 2010). By doing this the amount of dust generated during production will also be decreased.

4.4.1.2.2 Administrative controls

According to the MHSA (Mine Health and Safety Act) it is the responsibility of the employer to ensure that occupational exposure of workers to health hazards (i.e. occupational carcinogens) should be maintained below the OEL. If an employee is experiencing exposure in excess of 50% of the OEL for coal mine dust (OEL = 2 mg/m^3; thus 50% of OEL = 1 mg/m^3) or in excess of 10% of the OEL for crystalline silica dust (OEL = 0.1 mg/m^3; thus 10% of OEL

= 0.01 mg/m^3) a medical surveillance system must be established and maintained. It is also the responsibility of the employer to ensure that occupational hygiene monitoring is maintained at a sufficient level in order to control the risk at the source or minimise the risk as far as possible. If the risk remains, sufficient PPE must be supplied to ensure the safety of the workers.

In order to minimise the number of cancer incidences among multi-task workers it may be required to improve the occupational hygiene monitoring programme to include all hazardous chemical exposures, not only coal mine dust and crystalline silica dust. This will ensure optimal monitoring of the occupational exposure of the multi-task workers. Medical surveillance systems, already in place, may need to be upgraded, reviewed or performed on a more frequent basis to ensure that occupational exposure does not lead to unwanted adverse effects, especially cancer. It is recommended that the scope for occupational monitoring of carcinogens be broadened to include other carcinogenic substances coal mine workers may be exposed to.

Training of multi-task workers is crucial to ensure that they are familiar with work-related health hazards, even at low exposure concentrations, and the measures necessary to minimise and control them. Following the correct work procedures is important to ensure that the work at the coal face is performed in a safe manner. Supervision of these workers may need to be improved to ensure that the correct work procedures are followed. In the event of PPE (respiratory) being issued, supervision of the multi-task workers may be important to ensure that it is used and maintained in the correct way.

Another method of minimising dust exposure of coal mine workers in underground and opencast coal mines, is to limit support activities – such as vehicle movement, delivering or unloading of supplies – and thereby decreasing the amount of workers exposed to dust during production activities, i.e. continuous and long wall mining. Surfactants, such as soaps or detergents, dissolved in water can also be applied to the intake roadways to production areas to control the dust. Surfactants decrease the surface tension of water, which allows the available moisture to wet more dust particles per volume (Rider and Colinet, 2010).

Table 4-1: Observations from historical data and recommendations

Source	Observation	Recommendation	Legislative recommendations
Historical medical data	Occupation descriptions not identical to occupation descriptions in exposure monitoring data.	The mining hospital should ensure that the occupation descriptions used as part of their medical records correlate with the occupation descriptions and codes found in the SAMOHP[a] codebook recommended by the DMR. This will aid the future analysis of historical data.	
	Mine at which worker was employed at time of diagnosis not always available	The mining hospital should ensure that the coal mine at which the worker is employed is included on the worker's medical record. This will aid the future analysis of historical data as well as risk assessments.	According to the MHSA[e] all particulars of the mine where the worker was employed should be included in the medical report.
	Occupation of workers diagnosed with cancer not always available or doesn't correspond with SAMOHP[a] codebook.	The mining hospital should ensure that the occupation of the worker is included on the worker's medical record. This will aid the future analysis of historical data.	
	Years service of workers diagnosed with cancer not always available.	The mining hospital should ensure that the years service of the worker is included on the worker's medical record. This will aid the future analysis of historical data.	

[a] SAMOHP: South African Mines Occupational Hygiene Programme; [b] PPE: Personal Protective Equipment; [c] MSDS: Material Safety Data Sheet

[d] HCS: Hazardous Chemical Substance; [e] MHSA: Mine Health and Safety Act

Table 4-1 (cont.): Observations from historical data and recommendations

Source	Observation	Recommendation	Legislative recommendations
Historical exposure monitoring data	Exposure monitoring of respirable dust (coal mine dust and crystalline silica dust) is the main focus for legislative purposes.	The scope of exposure monitoring in a coal mine should be broadened to include the monitoring of additional occupational carcinogens, such as trichloroethylene, DPMs, and PAHs. This will ensure that health of coal mineworkers is protected.	According to the MHSA[e] it is the responsibility of the employer to ensure that health hazards present in a coal mine should be identified, the risk thereof assessed as well as all measures necessary to eliminate, control and minimise the health risk should be determined.
Baseline risk assessments	Incorrect storage and usage of PPE[b]	Improved control over the storage and usage of PPE[b] by workers should be implemented at the coal mines to ensure the optimal protection of workers during exposure to occupational carcinogens. Workers should also be educated thoroughly in the importance and correct usage of PPE[b].	According to the MHSA[e] it is the responsibility of the employer to ensure that employees are properly trained in the procedures necessary to enable them to perform their work safely and without a risk to their health. This includes the use of PPE[b] which functions in controlling and minimising these hazards. It is also the responsibility of the employer to ensure that an adequate supply of health and safety equipment (i.e. PPE[b]) is available, as far as reasonably practicable.
	Lack of availability of MSDSs[c] at storage areas of HCS[d]	Improved administrative control measures should be implemented regarding the availability of MSDS's[c]. Availability of a comprehensive MSDS[c] is important to ensure that any worker who comes into contact with a HCS[d] is aware of the hazards involved when exposure occurs.	According to the MHSA[e] it is the responsibility of the employer to ensure that employees are properly trained in the procedures necessary to enable them to perform their work safely and without a risk to their health. This includes training the workers in the correct use of HCS[d] with a comprehensive MSDS[c] as an informational training aid.

[a] SAMOHP: South African Mines Occupational Hygiene Programme; [b] PPE: Personal Protective Equipment; [c] MSDS: Material Safety Data Sheet

[d] HCS: Hazardous Chemical Substance; [e] MHSA: Mine Health and Safety Act

4.5 References

Clapp RW, Jacobs MM, Loechler EL. (2008) Environmental and occupational causes of cancer: New evidence, 2005-2007. Rev Environ Health; 23: 1-37.

Claxton LD. (2014) The history, genotoxicity, and carcinogenicity of carbon-based fuels and their emissions. Part 3: Diesel and gasoline. Mutat Res; 763: 30-85.

Colinet JF, Rider JP, Listak JM, et al. (2010) IC9517 (Information circular/2010): Best practices for dust control in coal mining. Available from: URL: https://www.cdc.gov/niosh/mining/UserFiles/works/pdfs/2010-110.pdf (accessed 23 November 2016)

Driscoll T, Steenland K, Prüss-Üstün A, *et al*. (2004) Occupational carcinogens: assessing the environmental burden of disease at national and local levels. Environmental burden of disease series, no. 6. Available from: URL: http://www.who.int/quantifying_ehimpacts/publications/en/ebd6.pdf?ua=1 (accessed 21 April 2015)

Eaton DL, Gilbert SG. (2013) Principles of toxicology. In Klaassen CD. editor. Casarett and Doull's Toxicology: The basic science of poisons. 8th ed. China: McGraw-Hill Education. p. 13-48. ISBN 978 0 07 176925 9.

Hung YP, Teng CJ, Liu CJ, et al. (2014) Cancer risk among patients with coal workers' pneumoconiosis in Taiwan: A nationwide population-based study. Int J Cancer; 134: 2910-2916.

IACR (International Association of Cancer Registries). (2014) Cancer incidence in five continents (Volume X): IARC Scientific Publications No. 164. Available from: URL: https://www.iarc.fr/en/publications/pdfs-online/epi/sp164/CI5volX_Full.pdf (accessed 14 May 2015)

IARC (International Agency for Research on Cancer). (2010) Monographs on the evaluation of carcinogenic risks to humans (Volume 92): Some non-heterocyclic polycyclic aromatic hydrocarbons and some related exposures. Available from: URL: http://monographs.iarc.fr/ENG/Monographs/vol92/mono92.pdf (accessed 22 April 2015)

IARC (International Agency for Research on Cancer). (2014a) Monographs on the evaluation of carcinogenic risks to humans (Volume 105): Diesel and gasoline engine exhausts and some nitroarenes. Available from: URL: http://monographs.iarc.fr/ENG/Monographs/vol105/mono105.pdf (accessed 22 April 2015)

Graber JMA. (2012) Morbidity and mortality among underground coal miners. Available from: URL: http://pqdtopen.proquest.com/doc/1286732006.html?FMT=ABS&pubnum=3551418 (accessed 17 November 2015)

Kaplan BLF, Sulentic CEW, Holsapple MP, Kaminski NE. (2013) Toxic responses of the immune system. In Klaassen CD, editor. Casarett and Doull's Toxicology: The basic science of poisons. 8th ed. China: McGraw-Hill Education. p. 559-638. ISBN 978 0 07 176925 9.

Kretsinger RH, Uversky VN, Permyakov EA. (2013) Encyclopedia of Metalloproteins. NY:Springer. eISBN 978 1 4614 1533 6.

Masters GM. (1998) Introduction to environmental engineering and science. Englewood, NJ: Prentice Hall. p. 117-157. ISBN 9 780 131553 84 2.

Muzyka V, Bogovski S, Scheepers P, et al. (2003) Effects of occupational exposure to diesel exhaust on porphyrin metabolism in lymphocytes of workers employed at black coal and oil-shale mines. Am J Ind Med; 44: 70-74.

Naghadehi MZ, Sereshki F, Mohammadi F. (2014) Pathological study of the prevalence of silicosis among coal miners in Iran: A case history. Atmos Environ; 83: 1-5.

Nazaroff WW, Alvarex-Cohen L. (2001) Environmental engineering science. NY: John Wiley and Sons. p. 396-397, 569-573. ISBN 9 78 0471144 9 46.

Novak T, Wedding WC. (2015) World Coal (Jan. 2015) – Scrubbed clean. Available from: URL: quakerchem.com/wp-content/uploads/.../World_Coal_Jan_2015_Scrubbed_Clean.pdf (accessed 24 November 2016)

Rider JP, Colinet JF. (2010) Chapter 3 – Controlling respirable dust on longwall mining operations. *In* Colinet JF, Rider JP, Listak JM, Organiscak JA, Wolfe AL, editors. Information circular (IC9517) – Best practices for dust control in coal mining. Pittsburgh, PA: Office of Mine Safety and Health Research. p. 17-40.

Rushton L, Hutchings SJ, Fortunato L, *et al*. (2012) Occupational cancer burden in Great Britain. *Brit J Cancer*; **107**: S3-S7.

Schneider MJ. (2014) Introduction to public health. Burlington, MA: Jones and Bartlett Learning. ISBN 978 1 4496 8887 5.

Schoen D. (2012) Threshold vs. non-threshold carcinogens. Available from: URL: http://standards.nsf.org/apps/group_public/download.php/18366/threshold%20carcinogens%20vs%20non-threshold%20carcinogens.pdf (accessed 5 March 2016)

Takala J. (2015) Eliminating occupational cancer. Ind Health; 53: 307-309.

Tulchinsky TH, Varavikova EA. (2014) The new public health. London, UK: Elsevier, Inc. ISBN 9780 12 415766 8.

WCI (World Coal Institute). (2009) The coal resource: a comprehensive overview of coal. Available from: URL: http://www.worldcoal.org/bin/pdf/original_pdf_file/coal_resource_overview_of_coal_report%2803-06-2009%.pdf (accessed 1 May 2015)

4.6 Annexures

Annexure A: Language editing certificate

To whom it may concern

I hereby certify that I have language edited the Mini-Dissertation

"Appraisal of medical and exposure data to estimate the occupational carcinogenic risk in coal mines: a pilot study"

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