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KUMASI, GHANA

Assessing the Risk of Exposure of Underground Mine Workers to Respirable Mine Dust and Diesel Particulate Matter Hazards, a Case Study of Chirano Gold Mines Company Limited, Ghana

by

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A Thesis submitted to the Department of Materials Engineering, College of Engineering

In partial fulfillment of the requirements for the degree of

MASTER OF PHILOSOPHY IN

ENVIRONMENTAL RESOURCE MANAGEMENT

NOVEMBER, 2016

DECLARATION

I hereby declare that this submission is my own work towards the MPhil and that, to the best of my knowledge, it contains no material previously published by another person, nor material which has been accepted for the award of any other degree of the university, except where due acknowledgement has been made in text.

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ACKNOWLEDGMENT

I thank the almighty God for his divine YES unto my life and seeing me through the entire academic work .I am highly indebted to my family and friends most especially my father Mr. Stephen Kofi Mensah for all the financial and moral supports given me throughout my academic life.

My sincere thanks go to the management of Health Safety and Environment (HSE) for the funding of this research. To Dr. Koduah Dapaah (HSE manager) and entire staff of the department, most especially the occupational hygiene team (Dr. Alex Djan, Mrs. Sylvia Djan and Miss Benedicta Cobbah), I say a very big thank you all. I very much enjoyed my stay during the research all because of the love and care you genuinely offered me.

To my wonderful supervisor; Dr. Kwadwo Mensah-Darkwa, I highly appreciate your efforts. Been at my beck and call really energized me to accomplish this research smoothly. To all who prayed, encouraged and supported me in diverse ways, I say we achieved it all together and may the good lord bless you all for I am very grateful.

DEDICATION

This work is dedicated specially to the Kofi Mensah family of Sefwi Wiawso and all her allies as an appreciation of their love, care, support and encouragements they gave me during my education.

ABSTRACT

Particulate matter is a significant health hazard to many industrial workers, most especially those in the mining industry. Many underground workers globally suffer from silicosis, cancer and other health related effects due to prolonged exposure to respirable crystalline silica dust and diesel particulate matter (DPM). In order to determine the possible potential outbreak of these diseases at Chirano Gold Mines Limited (CGML), an assessment of the levels of exposure of underground mine workers to occupational respirable mine dust and DPM hazards were undertaken. The study could not take into consideration the use of respirators as a control measure thereby considering all the experimental findings as potential exposures.

Gravimetric air sampling pumps were used in collecting dust and DPM samples for analysis. The respirable dust fraction were determined by the differences in weight between the empty cassette filters and the used filters whereas their crystalline silica content were determined by X-ray diffraction using National Institute for Occupational Safety and Health's (NIOSH) analytical method 5040 as a guide. The

DPM fraction of the samples was also determined using NIOSH analytical method 7500. After analysis, the results showed that the respirable dust exposures to the

SEGs where far below American Conference of Governmental Industrial Hygienist's (ACGIH) PEL of $3.0mg/m^3$ over a Time Weighted Average (TWA) of 8 hours. However, high crystalline silica contents were observed in some of the samples. The order of exposure to silica is presented in a descending order as follows; Jumbo operators> Cubex operators>Shotcretes operators>Solo operators>Blast men>Service men>Diamond drillers>Bogger operators>Supervisors>Truck operators. The results indicated that about 40.58% of the Sampled Exposure Groups

(SEGs) recorded levels higher than ACGIH's recommended Permissible Exposure Limit (PEL) of 0.05 mg/m^3. DPM results also revealed a higher level of exposure to SEGs as 48.68%, 11.84% and 39.47% of the SEGs fell within class A, B and C respectively. Shotcrete operators recorded the maximum mean exposure level of 287.99 µg/m^3 whereas truck operators recorded the minimum mean levels of 70.07 µg/m^3. In a survey of 98 respondents majority of them were aware of the presence of the particulate matter hazards and its related effects. Nevertheless, a significant portion of the respondents had very little knowledge of these. The research further ascertained that well about 79.59% of the workers generally feel uncomfortable when using the FFp2 respirators during operational activities. This had a negative effect on the use of their respirators during work. High silica values in little respirable dust sampled suggests the presence of high silica bearing rocks underground thereby putting workers at risk to contracting silicosis. High DPM levels also suggest a high DPM generation by machines and equipment underground. Inefficiency of available mitigation measures other than respirators is also a factor of the high DPM exposure underground. From the study, if the current underground PM generation levels remain unchanged, then an increased risk to respiratory diseases silicosis, lung cancer as well as other related disease would occur.

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ACRONYMS

ACGIH	American Conference of Governmental Industrial Hygienists
ALR	Air-line Respirators
ANOVA	Analysis of Variance
APR	Air purifying Respirator
CALR	Combination Air-lines Respirators
CDC	Centre for Disease Control
CGML	Chirano Gold Mining Limited
COPD	Chronic Pulmonary Diseases
CSR	Corporate Social Responsibility
DPM	Diesel Particulate Matter
EC	Elemental Carbon
EPA	Environmental Protection Agency
EV	Exposure Value
FFP	Filtering Face Piece
HSE	Health, Safety and Environment
IARC	International Agency for Research on Cancer
IDLH	Immediately Dangerous to Life or Health
IDMC	Inspectorate Division of Mineral Commission
LEVs	Local Exhaust Ventilation system
MAK	Maximum Workplace Concentration
MEL	Maximum Exposure Limit

Mg	Milli-gram
Mppcf	Million Particles per Cubic Foot
MSHA	Mine Safety and Health Administration
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
PEL	Permissible Exposure Limit
PM	Particulate Matter
PPE	Personal Protection Equipment
PVC	Polyvinyl Chloride
SABA	Supplied Air-Breathing Apparatus
SCBA	Self-contained breathing apparatus
SEGs	Sampled Exposure Group(s)
TB	Tuberculosis
TC	Total Carbon
TSP	Total Suspended Particles
TWA	Time Weighted Average
USA	United States of America

CHAPTER ONE

INTRODUCTION

1.1 Overview of Mining Practices

Mining, a highly intensive operation that employs the use of several intensive technologies with sophisticated machines is generally regarded as among the most dangerous operations in the world (Grayson, 1999). The generation of varying levels of particulate matter, noise, heat, vibrations amongst others is very conspicuous in a mine environment. They result from the mining cycle which involves excavation, drilling, blasting, bogging, hauling and crushing. Over the past decades, mining industries in Ghana had little and weak measures towards health and safety of their employees (Armah, 2015). Safety was seen as expensive and a measure to reduce company's revenue but instead, complied more on industrial regulations to prevent legal suit against their operations (Staley, 1992). Nevertheless, environmental and health impacts associated with mining are well noted in the world.

Particulate matter exposures have long been known to be a serious health threat to workers in mines. Exceeding the exposure limits to respirable silica dust and diesel fumes in the work environment can lead to the development of varying health complications such as lung cancer, silicosis and other pulmonary infections (Churchyard *et al*., 2004, NIOSH, 1992). Poor vision, irritating smells in the work area are notable effects of Diesel Particulate Matter (DPM) emissions. Crystalline silica, a common component of dust generated by mining activity mostly as alpha quartz can have devastating health impact when over exposed to higher level.

According to the International Agency for Research on Cancer (IARC), crystalline silica was identified as a suspected probable cancer causing particles to humans (Grayson, 1999).

The degree of health implications associated with the exposure to respirable mine dust and diesel particulate matter is mostly dependent on the following significant factors; the chemical and mineralogical content of the particulate matter inhaled, its quantity, particle size distribution, structure and average duration of exposure (Yassin et al., 2005). It has also been reported that freshly fractured silica containing rock or soil is very toxic and highly reactive than stale dust (Wang and Banks, 1998). Once silicosis which develops after exposure to high silica dust is contracted, they become incurable. As a result, the ultimate aim of all industrial managers must be geared towards its prevention by limiting workers exposure to the hazards at work. This can be achieved by employing both engineering and administrative measure to eliminate or reduce the emission of high Particulate Matter to recommended exposure levels (REL). Silicosis may be acute, accelerated or chronic depending on the average exposure levels and exposure duration of the victim (NIOSH, 1992).

The Mine Safety and Health Administration (MSHA) collaborated with NIOSH in notifying general industry on silicosis in 1996 due to the high incidence of silicosis in Pennsylvania among drill operators at surface mines (Rosenstock and Stout, 1998). With the current worldwide concern and campaigns by varying stakeholders such as Ghana's IDMC, ACGIH, MSHA, EPA, OSHA, and NIOSH for the need for stringent measures towards health and safety of all industrial workers and the environment without compromising on costs, various control mechanisms have been instituted. The establishment of health and safety standards, monitoring of effluence and particulate matter generation for compliance purpose in most industries are well recognized.

These are to help address the general health and safety concerns facing mine workers in order to ensure their well-being. In Ghana, the Environmental

Protection Agency (EPA) and Inspectorate Division of Minerals Commission (IDMC) are among the key bodies that ensure compliance to Environment, health and safety regulations in all industries. Their activities involve monitoring the operations of all industries by checking the level of effluence into the atmosphere, assessing their pollution control measures, use of appropriate management practice, enforcing compliance to environmental management plan among others.

At Chirano Gold Mining limited (CGML) many control measures involving administrative and engineering controls are in place. Underground workers are first inducted before working. Several dust control measures are used to limit particulate matter exposures in the occupational work place. Workers of CGML are further subjected to scheduled health screening and monitoring exercise against potential health disorders. Such exercise involves; lung function test, tuberculosis test as well as others medical studies in relation to the possible health disorders that may arise from their work types. Despite all the PM mitigation plans instituted, the presence of the hazard is very conspicuous thereby requiring in-depth investigations into how to tackle the hazard appropriately.

1.2 Problem Statement

Underground mining operations in CGML evolve large volumes of dust and diesel fumes to the work area exposing workers to potential health hazards through engine exhaust and rock breaking. Bio *et al.* (2007) Has stated that for every quantity of respirable gold mine dust collected, about 30% of free silica exists and their inhalation could trigger the formation of the Chronic Obstructive Pulmonary Disease (COPD).

He further reported that, the development of chronic silicosis could be associated with continuous respiration of crystalline silica at moderate to high levels of 0.05-0.1 mg/m^3 over a long period of years (Armah, 2015). Nearly 200-300 deaths were reported each year during the period 1992–1995 from silicosis in the USA (Sherson, 2002). High exposure to DPM can result in cancer in humans and other

fatalities.

1.3 Justification

Even though CGML works assiduously in mitigating PM generation throughout the mine, dust and DPM hazards still exist in underground occupational areas. There have been reported cases of silicosis and other PM related health effects in some other mines which could occur at CGML if exposure levels are high above the recommended PEL. Silica (quartz) is a common constituent of some soils accounting for about 28.5 % weight of the earth crust and occurs widely in goldmines. CGML is committed to providing all the necessary supports to help successfully conduct the research so that safe mining which is a priority of all stakeholders will be achieved. Considering the aforementioned challenges in the mining industry, this study is vital to provide CGML with vivid underground occupational conditions to efficiently protect its workers from PM hazards.

1.4 Aim and Objectives

This study aims to ascertain the levels of exposure of underground mine workers to respirable mine dust and diesel particulate matter hazards.

The specific objectives are;

- To determine the potential exposure levels of workers to respirable dust and DPM.

- To determine the sources of dust and DPM generation underground.
- To identify the category of workers with high risk to contracting silicosis, lung cancer and other pulmonary diseases due to silica and DPM exposures.
- To identify the available mitigation measures to dust pollution at Chirano Mines.
- To determine workers awareness to the presence and adverse effect of particulate matter pollution to their health.
- To establish workers attitude in relation to the use of respirators during work.

CHAPTER TWO

LITERATURE REVIEW

2.1 Evolution of Dust and DPM in Underground Mines

Underground mining involves the excavation of earth materials from below the surface of the earth for economic purposes. The activity generally involves drilling, blasting, bogging and hauling of ores and waste from underground to the surface for further processing and/or disposal. All the machines used for the above activities are powered by either diesel and /or electricity. During such operations, large volumes of dust and diesel fumes are generated, exposing underground workers to great danger. Where silica occurs in the rock, workers risk the development of silicosis and/or other dust related pulmonary infections and lung cancer. Even though various control measures are in operation, the hazard exists at significant levels (Armah, 2015).

2.2 Classifications of Dust

2.1.1 Respirable Dust

Dusts that have the potential to invade the respiratory system and move deep into the lungs are mostly referred to as respirable dust. Such particles due to their minute aerodynamic diameter sizes of less than or equal to 10 μm generally envade the body's natural clearance mechanisms of cilia and mucous and get retained in the lungs and alveoli region of the body. They are the class of dust that may be responsible for airborne respiratory illness like silicosis and lung cancers (Lumens and Spee, 2001).

2.1.2 Inhalable Dust

The inhalable dust fraction of dust includes that fraction of dust which enters the body during breathing but are been entrapped by the body's metabolism. They are mostly available for deposition in the mouth or nose. The aerodynamic diameter of these dusts is above 10 µm.

2.1.3 Total Dust

Regardless of the aerodynamic diameter, total dust includes all the type of dust. It is therefore the sum total of both respirable and inhalable dust in an area over a given period of time (Tsai *et al.*, 1996). The description of the various dust particle sizes are presented in Table 2.1.

Table 2.1: Description of various dust particle size

Particle Size	Description
TSP	Total suspended particle matter (TSP) generally refers to all particles that are suspended in air. It is therefore embodies all the superfine particles to the coarser particle size.
$>PM_{10}$	Describe those particles with size greater than 10microns in diameter.
$<PM_{10}$	Particulate matters of aerodynamic diameter between 2.5-10 microns are classified in this category. They are also referred to as coarse particles
$PM_{2.5}$	Also called fine particles, they represent all particles less than 2.5micron in diameter. They have the tendency to travel deep into the respiratory tract as compared to the others due to their aerodynamic diameter.

2.2 Silica

Silica refers to the chemical compound silicon dioxide (SiO_2). It is the second most abundant earth material to oxygen. It accounts for about 28.5 % of the earth's weight with 90 % of the earth crust been composed of silicate minerals. Silicon can be utilized commercially with or without processing from nature. This may include the use of clay, stones, sands and other earth materials in construction. Polymorphism exists in

the formation of silica and may include alpha quartz (crystalline silica), beta quartz, tridymite, cristobalite, keatite, coesite, stishovite and moganite (Mao *et al*., 2001). Quartz, a common component of soil and rocks predisposes several workers to quartz dust effects in many occupations and industries (Colinet *et al*., 2010). Cristobalite and tridymite are also found in rocks and soils, however, they are produced mostly by industrial operations when alpha quartz or amorphous silica is heated over high temperatures as found in foundry, brick and ceramics
manufacturing and silicon carbide production (Jones *et al*., 2006).

2.3 Legislation and Measurements of DPM

According to Grenier *et al*. (2001), the Mine Safety and Health Administration (MSHA) in January 2001 made a declaration and ordered all metal and non-metal industries in the US to operate in a manner not to exceed an exposure limit 0.40 mg/m^3 to DPM. This limit was to be reduced further to 0.16 mg/m^3 in five (5) years from the day of declaration. For example, NIOSH analytical method 5040 was the procedure employed in measuring total carbon (TC) when establishing exposure levels. For ACGIH, their recommended PEL for respirable dust and crystalline silica concentrations are 3.0mg/m^3 and 0.05 mg/m^3 respectively (ACGIH, 2015). Various countries use varying limits of exposure depending on the reasons for the measurements. Typical references could be made to Germany and Switzerland. For example in Germany, elemental carbon is used in measuring workers exposure to DPM at a limit of 0.10 mg/m^3 whilst TC is used in calculating workers exposure to DPM in Switzerland at a limit of 0.2 mg/m^{3}respectively.

2.4 Classification of Exposure Levels

According to Armah (2015) exposure levels to particulate matter can be divided into the classes of A, B and C. Where class A, B and C denote the levels above the permissible exposure threshold limit, closer or slightly below the limit and values far below the limit, respectively. Workers in class A zone will be at high risk of developing PM associated impacts. These could be silicosis, lung cancers, COPD and/ or other related respiratory infections. Such workers require proper medical surveillance and examinations to help establish the development of these associated effects. The improvement of PM control measures in their work areas is vital to avoiding PM health hazards. Class C exposures are always far below the threshold limit of the type of PM exposed to. This suggests that, workers in this zone are not at risk of developing the health related effects to excessive PM exposure. This also indicates that safe working procedures are adhered to which needs to be encouraged at all times. Even though class B exposure groups are not exposed to high PM concentrations, they can be potentially at risk when little deviation occurs in the available PM mitigation plan. The best management plan therefore is to keep workers exposure levels within class C of a designated threshold limit when the hazard cannot be avoided.

2.5 Reasons for Sampling DPM and Dust at work place

Sampling in the mine is mostly done by the occupational hygiene team or by eligible consultants. Reasons for sampling in the mining industry may vary. Key among them is for compliance purposes for industries to prove that their workers operate within the allowable levels to occupational DPM and dust exposures. Some other reasons could be to sample engine exhaust for DPM concentration. This helps to determine the state of fitness and maintenance of diesel powered engines or to measure the efficiency of exhaust treatment devices and monitor the efficiency of a local exhaust ventilation system (Grenier *et al*., 2001).

2.6 Health and Environmental Concerns

Even though environmental exposures to DPM are of concern, occupational exposures are greater due to higher emissions at the workplace (Birch, 2003). Studies into the health effect of DPM using animals produced a range of cancerous and noncancerous effects like obstructive and restrictive lung function pattern and chronic inflammations when subjected to very high concentration of DPM (Rogers and Davies, 2001). Furthermore, other epidemiologic studies in animals have also revealed that excessive DPM exposures can have mutagenic and carcinogenic effects on organisms. Out of 4 animal inhalation studies conducted, 50 % recorded extreme negative effects of high DPM inhalation, while the other halve showed no health implications (Steenland *et al*., 1998). According to Faiz (1990) irritation of the eyes and throat are characteristic problems noted with diesel contaminations in the occupational area. In addition, large amounts of diesel fumes can affect the good vision of truck and machine operators underground. These can lead to accidents in the mine since good visibility is already a challenge due to equipment size and relatively dark environment. Way back in 1988 the National Institute for Occupational Safety and Health (NIOSH) released a report on a suspected probable occupational carcinogenicity of diesel fumes. Again, the U.S Environmental Protection Agency (EPA) has also classified diesel exhaust as a ―likely human carcinogen‖(Grenier et al., 2001).

2.7 Generation and Composition of Diesel Exhaust

Assessment of underground mining work condition shows that, the DPM concentrations are usually over 100 more times higher than the ambient environmental level of 2 mg/m^3. NIOSH considers diesel exhaust as a potential occupational carcinogen and recommends that employers reduce workers exposure to permissible levels (Sheesley *et al.*, 2008). The exhaust gas from diesel engines during combustion is a complex mixture of air pollutants, mainly from complete or incomplete combustion, type of fuel and lubricants used and small amount of products resulting from the oxidation of Sulphur and nitrogen (Elliott *et al*., 1955).

The component of diesel fume is presented in Table 2.2.

Table 2.2: Major and minor components of diesel fume

Major Constituents (> 1%)	**Minor constituents (< 1%)**
Water (H_2O)	Oxides of sulfur (SO_2, SO_3)
Carbon dioxide (CO_2)	Oxides of nitrogen (NO, NO_2)
Nitrogen (N)	Alcohols (CH_nOH)
Oxygen (O)	Hydrocarbons (C_nH_n)
Hydrogen (H)	
Carbon monoxide (CO)	

It has being reported by Grenier *et al* (2001) that incomplete combustion by diesel engines results in the formation of solid and liquid particulate matter in the exhaust. This black soot often discharged from diesel combustion is mostly a composite of many individual compounds, several of which are known carcinogens. The basic building blocks are very small solid carbon particles that could be lower than 0.1 micron in diameter. These particles can further attract and adsorb several types of other hydrocarbons. They also serve as carriers for the condensed liquid hydrocarbons. Depending on the composition of the fuel burnt, sulphates can also be found. An important physical characteristic of DPM is its size. Due to its submicron aerosol diameter, it has a higher likelihood of penetrating into deeper part of the lung, where oxygen enters the blood stream. This makes the body's metabolism unable to exclude them. Another consequence of their small size is that DPM is not easily removed from the air stream since it does not settle to the ground easily by gravity. Once it is airborne, it stays in the mine until it finds its way out through the mine exhausts.

2.7.1 Carbon Monoxide (CO)

In well industrialized countries vehicular emissions from transportation accounts for about 95% of carbon monoxide pollutions whereas, developing countries produces about 9%. However, the growing trend in industrialization and improved transport systems is expected to accelerate the level of vehicular emissions in developing countries. According to Riedl and Diaz-Sanchez (2005) the respiration of CO into the blood stream impairs the oxygen carrying capacity of the blood. The availability of oxygenated blood to the body's organ and tissues are reduced. Exposure groups with cardiovascular diseases also suffer accelerated effects. High CO exposure is recognized to reduce; work efficiencies of workers, manual dexterity and performance of complex tasks as well as reduces alertness of workers. At extremely high concentrations, exposure to CO can result in fatalities (Elliott et al., 1955).

2.7.2 Oxides of Nitrogen (NO_2)

Acute respiratory illness in children and young adults are reported to be strongly associated with elevated levels of nitrogen oxide respiration. It has an irritating effect on individuals that have been exposed to it. NO_2 can impair good visibility by absorbing light in areas where they occur at high concentrations. This is particularly dangerous in underground situations where visibility has already been compromised. Nitrate aerosol particles resulting from the reaction of nitrites with the atmosphere can also cause cancer. Acidic conditions (oxidation of NO_3 to HNO_3) can result especially in underground conditions where moisture is mostly in abundance (Elliott et al., 1955).

2.7.3 Sulphur Oxides

Sulphur is an inherent constituent of crude oil from nature. When burnt, near 100% of the sulphur in the diesel fuel will be released as SO_2. Asthmatic patients suffer short term breathing challenges when exposed to air polluted by SO_2. Accelerated heart related illness and respiratory diseases are known effects of SO_2 gas and particulate exposures. As sulphur levels in diesel fuel increases, a direct proportionality of emitted PM, its carcinogenicity and toxicity also occur.

Three categories of exhaust gases exist in relation to air pollution. They are;

a) Objectionable; these are mostly irritating or odorous and results from aldehydes and reactions from fuel or compounds of incomplete combustion.
b) Harmful to health; such gases are lethal and must be avoided
c) Potentially objectionable; such gases have the potential to react directly or indirectly to form irritating pollutants. Hydrocarbons are typical gases of this category because they have the tendency to react with oxides of nitrogen to form nose and eye irritants (Elliott *et al.*, 1955).

2.8 DPM Control Systems

Low-emission engines, low sulphur fuel, Diesel Oxidation Catalysts (DOCs) and catalyzed filtration devices are commonly employed to reduce underground miners' exposure to DPM. The right use of the above strategies in combination with other engineering control plan is a measure of the holistic approach to reduced DPM emissions underground. These strategies are described below;

2.8.1 Low-Emission Engines

Even though emission reductions from engines have not been quantified in underground mines, most machines already conform to United State of America's EPA non road emission requirement (Haney and Saseen, 2000). However it is envisaged that MSHA will develop a guideline that will compel mine operators to design and use new and improved strategies to reduce DPM emission. Such engines operate at high fuel injection pressures that ensure a more efficient and complete combustion of fuel. It has further been reported that a survey by MSHA established the influx of low emission engines into underground mining market (Bagley *et al*., 2001). Emission control systems mostly target reducing carbon monoxide and other hydrocarbons by using diesel oxidation catalyst and diesel particulate filter technologies. MSHA enforces underground gas concentration threshold limits value in metal mines to the following levels; CO- 50 ppm, CO_2 – 500 ppm, NO – 25 ppm and NO_2 – 5 ppm (Bugarski *et al*., 2012).

2.8.2 Maintenance

No matter the kind of technology used, within a time frame of its application they will require verification of their performance and maintenance where applicable. DPM underground can be reduced by regular monitoring and maintenance of diesel engines in other to continually perform its task. Where engines exhaust their lifespan, they get replaced in other to ensure that optimal outputs are obtained from the use of the machine.

2.8.3 Use of low-Sulphur diesels

Diesel fuels of less than 5% sulphur have the tendency of reducing the sulphate fraction in DPM. This helps in reducing the objectionable irritating characteristics that Sulphur rich fuels presents. It further maximizes the performance of oxidation catalyst during combustion. Reduced wearing and maintenance cost of engines is also achieved with the use of fuels low in sulphur (Bagley et al., 2001).

2.8.4 Diesel Oxidation Catalysts (DOCs)

The quantity of hydrocarbons, carbon monoxide and aldehydes in diesel fumes can be drastically reduced with the use of DOCs even though they increase nitrogen dioxide emission (Addy, 2012). Gas phase hydrocarbon and soluble organic fraction of DPM can be curtailed up to about 50% leading to reduced carcinogenic compounds and their related effects (Voss *et al.*, 2006). Three (3) main stages are involved in the catalytic oxidation reaction. They are;

- Oxygen bond formation occurs at the catalytic site,
- Reactants, like carbon monoxides and hydrocarbons diffuse to the surface and react with the bonded oxygen and
- Reaction products, like CO_2 and water vapour, desorb from the catalytic site and diffuse to the bulk of the exhaust gas.

2.9 Dust and DPM control Measures

Dusts and DPM generated in underground mines could be prevented from reaching injury levels in the workplace by employing the hierarchy of PM control methods. This involves; PM elimination strategies, administrative and engineering control methods.

2.9.1 Elimination

This form of method involves avoiding activities and/or operations that can result in the generation of dust or DPM. It is generally hard to achieve as this will mean a complete halt of operations. Nevertheless, controlled procedures are employed during work to achieve a reduction level in the generation of PM.

2.9.2 Administrative Controls

These are non-engineering control measures employed to prevent or reduce the generation of PM and its related health implication in the occupational workplace.

They involve systematic and structurally laid down procedures that are used with the ultimate aim of either reducing PM emissions or preventing its related effects. Some administrative control methods commonly employed are;

- Induction and training of workers in good working procedures
- Mine re-entry plans after blasting
- Enforcing the use of prescribed PPEs
- Routine dust and DPM monitoring in the work environment
- Enforcing proper work procedures and routine machine maintenance.
- Speed limits enforcement

2.9.3 Engineering controls

During a personal communication with underground mine Captain on 25th -26th of September, 2015, E. Alutu, stated that Engineering control system involves the use of mechanically designed devices and tools in the elimination and control of particulate matter. They have the benefit of eradicating or controlling PM hazards that administrative measures are unable to exclude. Some engineering control measures mostly employed in industry may include;

- The use of Local Exhaust Ventilation systems (LEVs)
- Water blast at production slots
- Sprinkling of water
- Use of respirators
- Use of well-furnished cabins in machines
- Wet drilling and cutting of dust generating materials.

2.10 Key Respirable dust and DPM Control Measures

2.10.1 Use of Respirators

Respirators, although are not the most preferred means of PM control according to industrial hygiene practices, are commonly used PPE as secondary control measures. These occur when various engineering measures employed are unable to efficiently exclude occupational PM hazards. However, in cases of emergencies where engineering and work practice controls cannot be used to reduce airborne contaminants below their occupational exposure levels, they can serve as primary control measures.

It is estimated that about 5 million workers wear respirators either regularly or occasionally. For high respirator protection efficiency to be achieved, the following factors must be ensured; selection of the right respirator for the desired task and proper fitting of the respirator on the worker. Consistencies in the use of the respirator during work, as well as proper maintenance are also required. These variables can only be controlled if a comprehensive respiratory protection program is developed and implemented in each workplace where respirators are used.

2.11 Types of Respirators

The Air purifying Respirator (APR) and Supplied Air-Breathing Apparatus (SABA) are the two major common types of respirators mainly used in industry. The type of respirator used for a particular task is dependent the nature of the work to be done. Thus weather it is used for the purposes of controlling dust, fumes, or for entering an unknown confined environment. Occasional fit testing is essential for workers in the use of respirators. This could be done at least once in a year.

2.11.1 Air Purifying Respirator (APR)

Examples of APRs (plate 2.1) include the dust mask and combination cartridge.

A-full face respirator **B**- Half Face Respirator **C**-FFp 2

Plate 2.1: Air purifying respirator types (source; Google images)

Other subtypes depending on the level of face protection may include; full-face or half face respirators. N, R and P series category of respirators exist depending on their resistibility or tolerance to some substances that may be present in the contaminated air. Tight or loose fitting respirator types also exist when considering the —fit‖ type. APRs only filter the existing atmosphere and do not supply extra oxygen to the wearer. The following should therefore be well noted when using

APRs at the work place;

- They should not be used when entering O_2 deficient areas.
- Should not be used when poor warning sign exists or where the concentration of the pollutant is unknown.
- Not suitable for work in an unconfirmed confined workspace or where IDLH environments exist.

The type of respirator selected for a particular task has capacity to provide workers protection to a range of up to 95% or higher when fitted well by the worker. The three commonly used dust masks; FFp 1, FFp 2 and FFp 3 masks are described below:

Filtering Face piece 1 (FFp 1): it has a lowest efficiency ranging from 85%-100% when compared with the other types. It is good in protecting workers from dusts which are non-toxic. Such dusts when inhaled have the potential of irritating the respiratory system or posing unpleasant smell to the worker. It is commonly used by workers in the food or construction industry. They may be worn as long as the maximum workplace concentration transgression measures no more than the fourfold industry-specific value.

Filtering Face piece 2 (FFp 2): workers are better protected from deleterious kinds of dust, smoke, and aerosols at the work place when FFp 2 masks are well fitted. These particles have the tendency to irritate the respiratory system in the short term and can result in reduction of elasticity of pulmonary tissue in the long run. These types filter particles measuring up to 0.6μm and may be used in environments transgressing the MAK up to a maximum of the tenfold concentration such as the metal and mining industries. Workers in these industries are frequently in contact with aerosols, fog and smoke that result in conditions of the respiratory system such as lung cancer in the long term. Its efficiency may range from 89%-100 % (UVEX SAFETY Personal Protective Equipment - Uvex Safety Group).

Filtering Face piece 3 (FFp 3); this type offers the best protection for workers against poisonous and deleterious kinds of dust, smoke, and aerosols. Oncogenic, radioactive substances and pathogens such as viruses, bacteria and fungal spores are filtered by this protective class of respirator masks. Its efficiency may range from 95%-100 %

when well fitted. They are mostly used in the chemical industry where the working environment can transgress the MAK values by the thirtyfold industryspecific value (UVEX SAFETY Personal Protective Equipment - Uvex Safety Group).

2.11.2 Supplied Air-Breathing Apparatus (SABA)

The design of these types of respirator was to augment the limitations of the APRs stated above. They have the potential of providing better protection to the wearer when well fitted by supplying fresh air directly. This means the wearer does not have to depend on the immediate contaminated air purified for respiration. Its design and use requires specialized training which makes them uncommon as compared to the APRs. Typical examples of the Supplied Air Breathing Apparatus may include; Airline Respirators (ALR), Self-contained breathing apparatus (SCBA), Combination Air-lines Respirators (Plate 2.2) amongst others. The under listed factors must be taken into account when using these respirators.

- They should be used by only trained workers.
- Its air intake valves must be farther away from the contaminated air or source of pollution.
- Emergency oxygen supply system must be fitted to the worker when using it.

(A) Supplied Air-Breathing Apparatus (B) Self-Contained Breathing Apparatus.

Plate 2.2: Examples of breathing apparatus

2.11.3 Local Exhaust Ventilation System (LEVs)

The rate at which particulate matter is generated as well as the airflow field that transmits the contaminated air to the breathing zone are the main factors that determine the exposure level of underground workers to airborne contaminate. The use of LEV is the major and common engineering technique employed in many mineral processing plants and other enclosed workplaces for controlling airborne particles. Also the use of LEVs in the construction industry appears to be the most preferred means of controlling dust exposures. Their use resulted in the reduction of mean respirable dust and respirable crystalline silica exposures from 0.91 to 0.03 times and from 3.41 to 0.37 times the respective OSHA PELs in a construction firm at Seattle, Washington D.C. (Croteau *et al.*, 2004).The basic purpose of LEVs is to get rid of contaminated air from the mine atmosphere, most especially at their generation points and/or around the breathing zone of the worker. They have the potential to remove very fine PM that may be very difficult for other control measures like water suppression to exclude (Colinet *et al.*, 2010).

LEVs have the added benefit of enhancing the introduction of fresh air into the work area thereby making work environments more conducive as contaminated air is removed. Even though a well-designed LEV has the potential of eliminating high PM exposure at the workplace, it is also dependent on factors such as; the right orientation of it exhaust hood, the flow rate of air, fume generation rate, level of enclosure, other available control measures, distance between the point of contaminant generation and the breathing zone as well as work practice (Flynn and Susi, 2012). Studies by Croteau *et al*. (2004) showed that, using LEVs (Plate 2.3) can help reduce respirable dust exposures by 95% in a controlled field study.

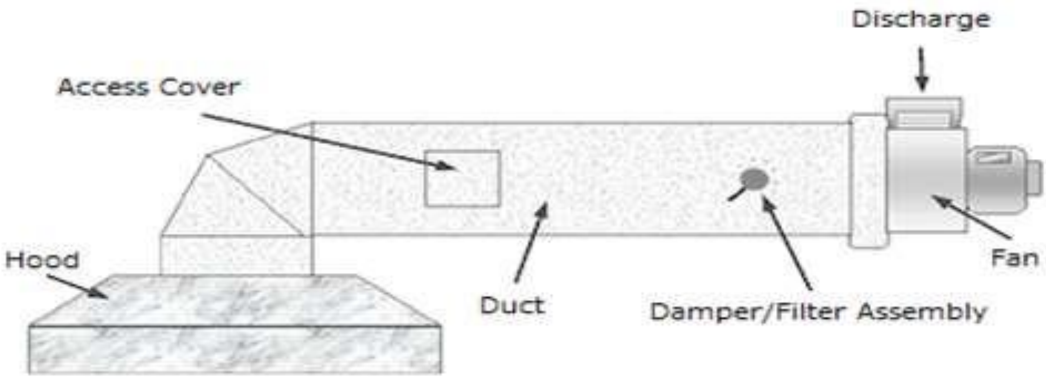


Plate 2.3: Simplified design of LEV

A controlled field study environment is therefore a recommended approach for assessing the efficacy of LEVs as conditions continually change at various workplaces with time and work practices. The efficiency of LEVs can also be influenced by its size, distance from dust and DPM generation point to the hood. Workers can further enhance their protection by repositioning portable exhaust hoods or themselves so that they do not block the suction direction of the hood. Air velocity drops off very rapidly in front of local exhaust hoods, especially with small LEV types(Flynn and Susi, 2003).For better performance, they must be located close to the arc. Furthermore, Brandt reported that, large exhaust hoods are more powerful and efficient. Their performances are not significantly distorted by an absolute change in distance as they have the capacity to exert strong flow field over a greater distance than the smaller ones can do (Flynn and Susi, 2012).

2.11.4 Water Suppression and Water blast

Wetting of dust generating pathways is another most commonly used technique in controlling dust in the workplace. Water pipes are laid underground to routinely supply water for suppressing dusts in operational areas as well as access routes. In developing headings of underground mines, water blast is also employed to control dust generation during blasting. It has an added benefit of dissolving gas particles thereby reducing their presence in the mine. Even though water can effectively control dust emissions, their excessive use can result in difficulties in material handling, slippery access routes, weakening of structures and waste water disposal challenges in underground work place. This therefore limits the potential of water to efficiently control particulate matter (Captain E. Alutu Personal communication on 25th September, 2015).

2.11.5 Use of Enclosed Cabins

Studies have shown that the use of well fitted air-conditioned cabins by diesel equipment operators is a cost effective way of reducing their exposure levels. Nevertheless, mechanical deviations in air-condition system, door seals and habits of operators driving with window rolled down negates these benefits. Inside and outside comparisons of DPM exposures are presented in the Table 2.3 (Rogers and Davies, 2001).

Table 2.3: DPM measurements in and out a cabin

Location	DPM exposures (mg/m^3)
Inside a cabin	0.11
outside a cabin	0.79

2.12 Silica Exposure and Potential Health Impacts

According to Yassin et al. (2005) between the years 1987 to 1996, about 3600-7300 silicosis cases were estimated annually in the United States. It was further estimated by OSHA that in the U.S, over 1.8 million employees involved in construction related activities were exposed to silica. Out of these, 216,000 of them were exposed to higher concentrations of 250 μg/m^3 or more. Also general industry occupational exposures were estimated to be 2.1 million with 265,000 employees being exposed to high concentrations of 250 μg/m^3 or more. In 1936 "America's worst industrial disaster" occurred when about 1,500 men died near the town of Gauley Bridge, West Virginia, due to silicosis. The victims were tunneling through a mountain of almost pure silica without precautionary measures taken, even though the health effects of silica exposure had been documented for decades. Furthermore, in November1992, NIOSH issued an emergency alert to all workers involved in rock drilling and related activities of the high tendency of them developing silicosis. The alert titled

―Preventing Silicosis and Deaths in Rock Drillers" also stated that silicosis was the cause of over several hundreds of death in America annually with many other disabling effects. It has been estimated that about two million American workers remain at risk for developing silicosis several decades after 1936 "America's worst industrial disaster had occur (NIOSH, 1992). Nevertheless, NIOSH (2004) reported

CDC data which revealed a decline in silicosis cases in the United States by 84% between 1968 and 1999.Only 187 deaths in 1999 were related to silicosis. It further reported that many silicosis victims die yearly undiagnosed or unreported making the actual number of silicosis related issues inaccurate. It is important to note that the degree of health hazard and their harmfulness varies depending of the following factors (Jones et al., 2006);

- Dust composition describes chemical and mineralogical content of the dust exposed.
- Dust concentration describes the weight as expressed in milligrams of dust per cubic meter of air (mg/m^3) or quantity as expressed as million particles per cubic foot of air (mppcf) of dust in air over an area at a particular time.

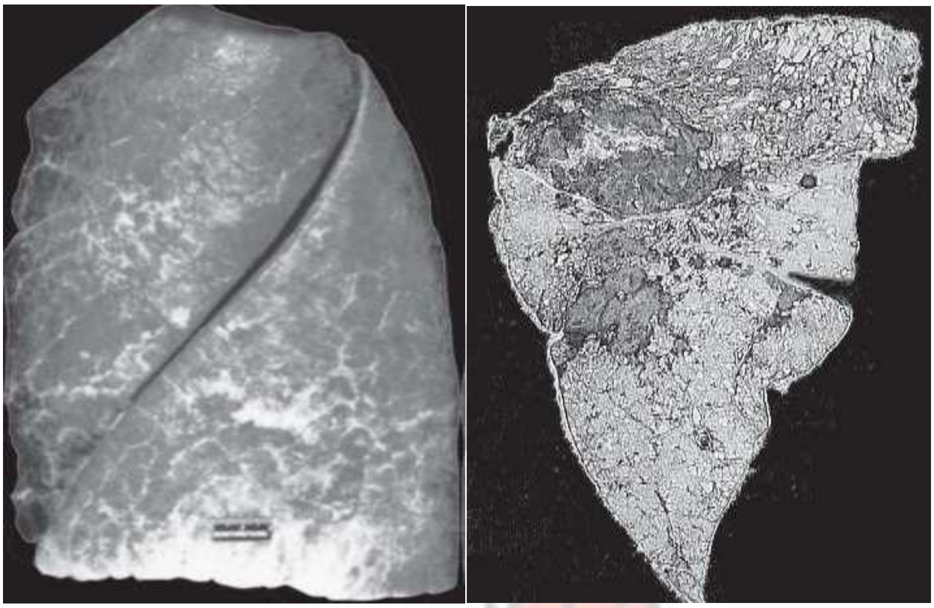
- The particulate size distribution within the respirable range and whether they are spherical or fibrosis.
- Long-term exposure to harmful respirable dusts has a higher devastating effect as compared to short term exposures. Long term exposures to high dust concentrations may result in a respiratory disease called pneumoconiosis.

2.13 Silicosis

The predisposing factors to silicosis and its related effects were well identified and documented several centuries ago as reported by Agricola in his treaties of mining way back 1556 (Ziskind *et al.*, 1976). Crystalline silica particles that deposit in the alveolar region of the lungs can stimulate an inflammatory and toxic process that can ultimately develop into clinically recognizable silicosis. NIOSH has reported in its hazard review; ―Health Effects of Occupational Exposure to Respirable Crystalline Silica," that occupational exposure to respirable crystalline silica dust can have several adverse health implications including silicosis, tuberculosis, chronic bronchitis, emphysema, and chronic renal disease. People affected by silicosis risk contracting tuberculosis and /or other mycobacterial diseases (Greaves, 2000).

2.14 Formation of Silicosis

The process of silicosis formation occurs when fine crystalline silica particles is respired by humans mostly at their occupational work place through dust inhalation. Once the silica particles are deposited in the alveoli region of the lung, they become entrapped. Scaring and nodulation formation occur around them. Plate 2.4 compares a healthy lung tissue (A) and a diseased lung tissue (B) (CDC, 2004).



(A) Healthy lung tissue **(B) Diseased lung tissue**

Plate 2.4: Lung tissue conditions

As the condition worsens, the nodules become progressively larger and breathing becomes increasingly difficult. Eventually the worker may die of respiratory failure. Because of the ambiguity of the symptoms; cough and shortness of breath, silicosis is frequently misdiagnosed as bronchitis, emphysema, or tuberculosis(NIOSH, 1992).

Once silicosis develops it become incurable even though life support programs to slow its deterioration rate are available.

2.15 Forms of Silicosis

2.15.1 Acute Silicosis

Development of symptoms occurs when very high concentrations of crystalline silica are respired. Its development occurs from few weeks to 4–5 years of exposure. This form of silicosis rarely occurs in modern day industry since PM generation levels are mostly monitored and mitigated to alleviate very high concentration of PM exposure.

Symptoms of acute silicosis include severe disabling shortness of breath, weakness and weight loss, which often leads to death.

2.15.2 Accelerated Silicosis

Industrial workers may develop accelerated silicosis after 5 to 10 years of initial exposure to crystalline silica at high concentrations. It is a less common form of silicosis. The onset of symptoms takes longer than in acute silicosis. Symptoms may include severe shortness of breath, weakness and weight loss.

2.15.3 Chronic Silicosis

This is the commonest form of silicosis. When workers are exposed to relatively low concentrations of silica for a period of 10 or more years, chronic silicosis would develop. Symptoms associated with this type of silicosis may not be readily observed until chest X-ray is conducted to ascertain the lung damage of the worker. Progressive form of the disease may cause shortness of breath upon an active moment and have clinical signs of poor oxygen/carbon dioxide exchange. In the later stages, the worker may experience fatigue, extreme shortness of breath, chest pain and/or respiratory failure (Leung *et al.*, 2012).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Site Selection and Access

Chirano Gold Mining Limited was selected for the study because it had favourable operational conditions to facilitate a successful study. Other reasons include but not limited to the following; willingness of the company to collaborate and provide funding for the research, the company is among the few gold mining companies that actively operate underground explorations in Ghana. Again its consistent successes in the ―Akoben‖ Green rating by the EPA of Ghana for being the best improved mine in environmental management in Ghana influenced the study area selection. (CGML, 2014). Prior to the research, an official letter detailing the importance and methodology for the research was sent to the management of the company for consideration. After the necessary formalities and procedures, access to the mine and required facilities were granted for research activities to begin.

3.2 Geography of the Area

The mine is located mostly in the Bibiani-Anhwiaso –Bekwai district and partly in the Sefwi-Wiawso Municipality of the Western Region of Ghana. CGML is about 100 kilometers south-west of Kumasi. It has a mine lease of thirty-six square kilometers (36km^2) lying between latitude 6˚00ˈ00N and 6 ˚24ˈ75ˈˈ N and longitude

2˚21' 33ˈˈ W and 2˚24ˈ 33ˈˈW. (CGML, 2014).There are thirteen communities within CGML mining lease with a population of about 14,987(VC-Consult, 2012). The major occupation of the indigenes is farming. However, the presence of the mine has created a diversified source of income through direct and indirect employments.

Physical infrastructure such as schools, hostels, markets, modern water supply systems, business centres among others are very conspicuous in the catchment areas. These can be linked to the economic empowerment of the inhabitants through job creation, increased income levels and corporate social responsibility (CSR) of the company.

3.3 Geology and Mineralization of CGML Catchment Area

According to CGML (2005), Chirano gold camp is located in southwest Ghana within Paleoproterozoic rocks at the southeast margin of the Sefwi-Bibiani volcanic belt and Kumasi sedimentary basin. The Sefwi-Bibiani volcanic belt is one of several similar volcanic belts in the region, around 20-70 km wide, separated by sedimentary basins.

Both belt and basin comprise rocks of Birimian age, with the belt been dominated by mafic volcanics and the basin typified by fine grained, deep-water sediments. Both are intruded by granites. All the gold deposits contain numerous quartz and ankerite veinlets and there is a broad correlation between intensity of veining and grade of mineralization. The quartz veins vary in style from early veins, which may be recrystallised, folded, boudinaged, corroded by pressure solution, offset by microfaults or truncated at the edge of clasts to late quartz veins which may be straight and show crustification for example with carbonate crystals lining their edges.

The mineralization contains pyrite and it is the primary sulphide mineral and is generally present in low concentrations of between 1% and 2%.The deposits of CGML are hosted near the boundary of Birimian mafic igneous rocks with Tarkwaian sedimentary rocks. Where faulted, this boundary has been intruded by tonalite. Volcano-sedimentary rocks and the tonalites are metamorphosed to greenschist facies assemblages and in least strained regions are generally unfoliated.

It was previously, considered that tonalite intrusions were the main host to gold mineralization. However, recent exposures in open-pits have shown that the volume of tonalite has been over-estimated at several deposits, which are mostly hosted within strongly hydrothermally altered mafic igneous rocks. Plate 3.1 shows the geological map of CGML catchment area (CGML, 2005).

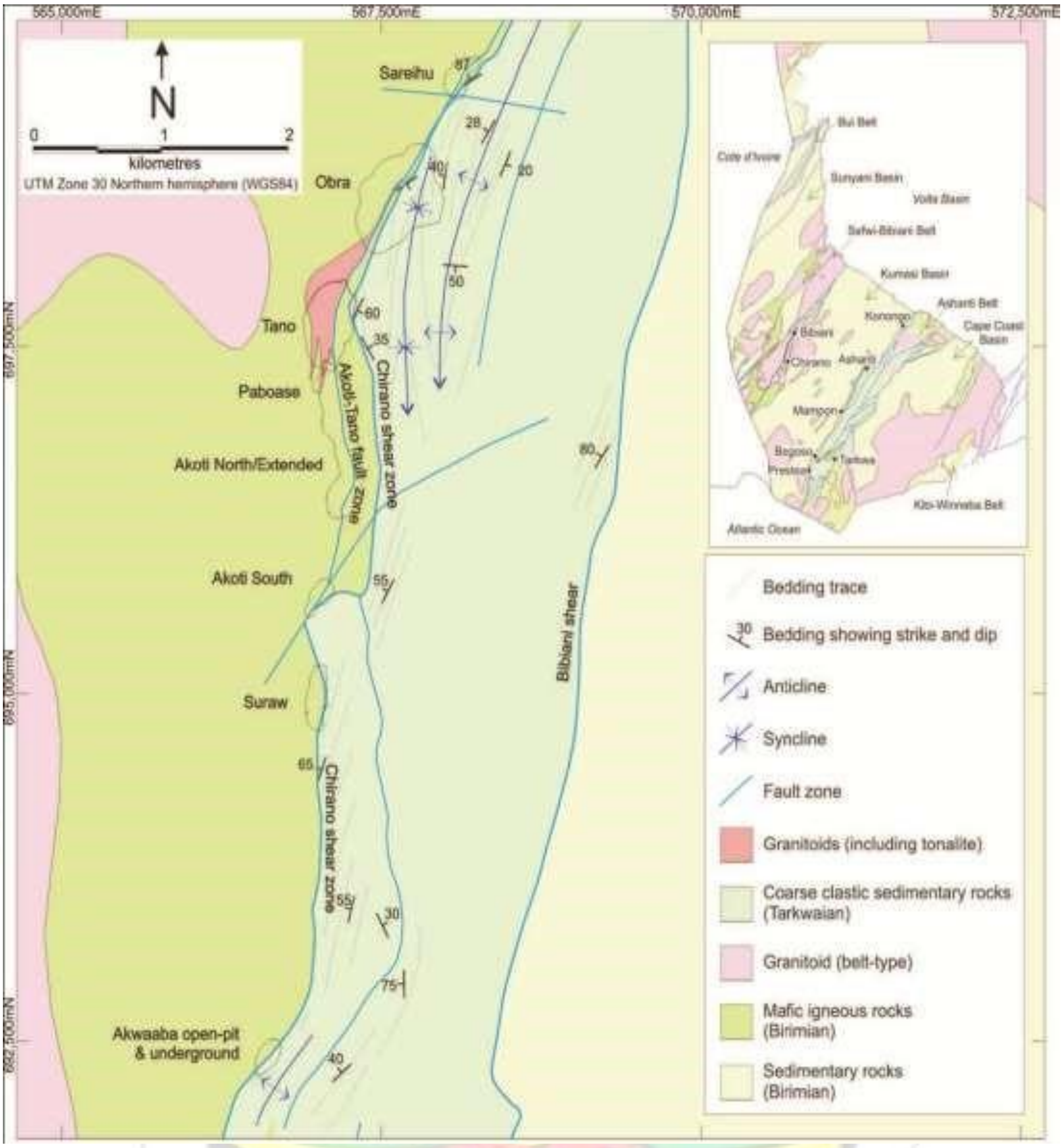


Plate 3.1: Geological map of CGML. (Source; CGML, 2005).

3.4 Methodology

Gravimetric air samplers were used to collect dust and DPM samples from the breathing zones of the SEGs. The samples were then subjected to analysis to determine the potential levels of exposure of respirable mine dust, crystalline silica and DPM to underground mine workers. Structured questionnaires, personal observations and personal interviews were employed to determine workers awareness to dust and DPM exposure effects, to ascertain their work habits in the use of recommended respirators when at work as well the available PM mitigation measures at CGML underground pits.

3.5 Pre-sampling

The prepared sampling train (gravimetric air samplers) made up of10mm nylon cyclone, pre-weighed PVC cassette, clipper and connecting tube. A charged constant flow pump (AirChek XR5000 model 210-5000 from SKC laboratories) calibrated to 1.7 liters per minute was used. The 37mm diameter low-ash polyvinyl chloride (PVC) filter cassette was used for collecting dust samples whiles, quartz-fiber filters were used for collecting DPM samples. Plate 3.2 shows a labeled sampling train for PM sampling.

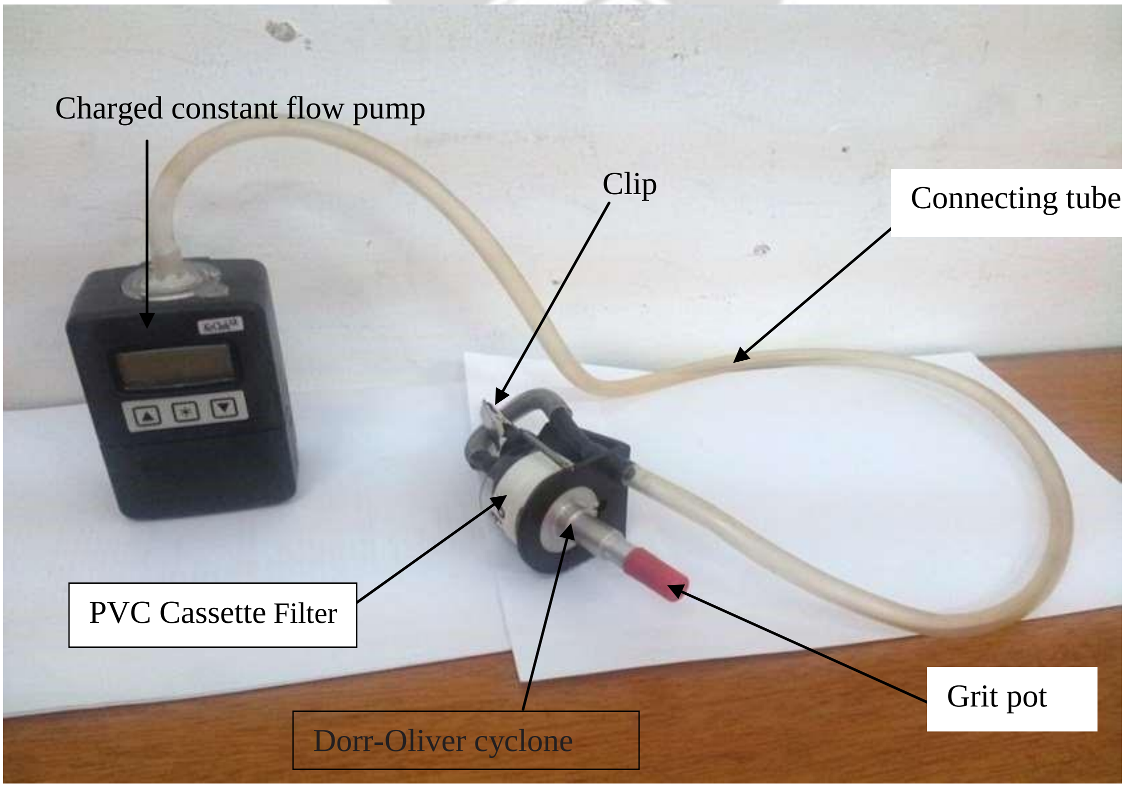


Plate 3.2: Labelled sampling train for personal dust and DPM collection.

The target groups for the study were underground miners of CGML's Paboase pit. Prior to sampling, information on the various exposure groups underground were obtained from the mining department. This helped in selecting 10 Sampled Exposure Groups (SEG), their responsibilities (table 3.1), shift schedules and their total numbers.

Table 3.1: Sampled Exposure Groups (SEGs) and their job description

SEGs	JOB DESCRIPTION

Blast men	Charging of development phase, re-entry, carrying explosives.
Shotcrete operators	Spraying of development and production headings with cementing materials.
Service men	Hanging ventilation fans, extension of water and air lines, Carrying of bolts and mesh underground.
Truck operators	Haulage of waste and ore from underground.
Jumbo operators and offsiders	Sealing, meshing and drilling of development phase.
Diamond drillers	General drilling.
Solo operators and offsiders	Drilling of production and service holes.
Bogger operators	Cleaning of development and production headings of ore and/or waste by loading them into trucks.
Cubex operators	Drilling of service holes and production slots.
Supervisors	General monitoring and supervision of underground activities.

3.6 Sampling

After the selection of the target groups, some members were randomly selected for monitoring. Sampling was done to take into consideration the mining cycle and work shifts of workers. The workers were briefed on the importance of the exercise and the precautionary measures that were to be taken in handling the device for efficient sampling. The pump kept in an SKC bag was fitted to the waist of the workers. The filter cassette and cyclone components were fitted at the breathing zone of the worker (Plate 3.3).

Plate 3.3: Air samplers fitted for dust and DPM sampling

The pump and cyclone were connected by a tube. Sampling time was throughout the 8-12 hour work shift of the workers. Regular monitoring was done to make sure workers were doing their normal routine works as recorded and the devices were operating as required. The total number of workers in each target group and the numbers sampled for the dust and DPM monitoring are presented in the table 3.2.

Table 3.2: Total number of exposure groups and numbers sampled for dust and DPM sampling.

SEGs (target groups)	Total number	DPM	Dust

Blast men	12	8	8
Service crew	21	13	11
Truck operators	18	10	11
Jumbo operators and offsiders	12	10	9
Solo operators and offsiders	7	7	4
Diamond drill operator	8	5	6
Bogger operators	9	8	6
Shotcrete operators	4	4	4
Cubex operators	6	6	6
Supervisors	7	5	4
TOTAL	**104**	**76**	**69**

After closure of daily work activities, the sampling trains were collected. Care was taken not to turn the cyclone upside down to prevent the inhalable dust fraction from settling on the filter cassette. Sampling time and post calibrated values were recorded. The sampling trains were kept in the laboratory until the next day. Post sampling weight values were recorded and cassettes sealed (Plate 3.4) for analysis.

Plate 3.4: Researcher holding bagged filter cassettes for analysis

3.7 Analysis

For compliance and authenticity purposes, the bagged dust and DPM samples were transported to an accredited laboratory (Gijima Holdings (Proprietary) limited) in South Africa for analysis. NIOSH's guideline 5040 (Thermal-optical method) was used in the analysis of the DPM samples whiles NIOSH dust analytical method 7500 was used for the analysis of the respirable dust fraction for its crystalline silica content. Excel data analysis was used to run a one-way analysis of variance to test for the level of significance among exposure groups. The NIOSH analytical method 7500 and 5040 are summarized below;

3.7.1 NIOSH Analytical Method 7500

- Ashing of sample filters was done in a 50 ml beaker at a low temperature.
- Filters were carefully remove from cassettes, folded three times, placed in the bottom of a 50 ml centrifuge tube and 10 ml of THF added to dissolve
- Care was taken to avoid contamination.
- Sample solution was agitated and filtered into beaker.
- Beaker was covered with watch glass and agitated in an ultrasonic bath for about 3minutes to ensure agglomerated particles were dissociated completely.
- Silver filter was place in a filtration apparatus. Funnel was securely attached to the entire filter circumference and 2-3 ml of propanol poured onto it.
- All sample suspension was transferred from the beaker into the attached funnel.
- The vacuum was left on after filtration to produce a dry filter and when thoroughly dried, the silver filter was mounted on the XRD sample holder.
- Calibration and quality control measures in operating X-ray were followed.

- Standard X-ray diffraction procedures were used to obtain a qualitative X-ray diffraction scan of the area air sample to determine the presence of free silica polymorphs and interferences.
- Calculation of the concentration of crystalline silica, C (mg/), in the air volume sampled, V (L) was done using the formula below;

$$C = \frac{\hat{I}_x f(t) - b}{mV} \text{ mg/m}^3.$$

Where; $\hat{I}_x$ = normalized intensity or sample peak, b = intercept of calibration graph, m = slope of calibration graph and f(t) = absorption correction factor.

3.7.2 NIOSH Analytical Method 5040

- An aluminium foil surface was cleaned with acetone and sample filter placed on it.
- By avoiding hand contact and disturbance to filter sample, a representative portion of the filter was punched out and place in a holder with the aid of a needle.
- Calibration and quality control procedures were followed in handling the analyzer.
- Adjustment of the analyzer settings according to manufacturer's recommendation was also followed.
- Sample portion was placed in an oven and temperature set as recommended. Where other forms of carbon difficult to oxidize such as graphite existed, higher temperatures and longer time were required.
- Elemental carbon (EC) and organic carbon (OC) results were reported by the analyzer in units g/cm^2 of C

- Since the reported area represented the standard punch used, actual figure was determined multiplying the result of the analyzer by 1.5cm^2 and divided by the portion area.
- The EC concentration was calculated using the formula:

$$C_{EC} = \frac{W_{EC} - W_b}{V} (mg/m^3)$$

- Where W_{EC} = total mass of EC on each filter sample, W_b = the mass found in the average field blank and V = the air volume sampled in litres (NIOSH, 2003).

3.8 Questionnaire Use and Personal Observations

Structured questionnaires (Appendix 2) were employed in assessing workers awareness to particulate matter hazards and their willingness to use respirators for the control of dust and DPM exposure. Identification of dust and DPM control measures were also established by personal interaction and observations. Ninetyeight (98) workers were randomly selected for this survey.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Dust Exposure Measurements

The American Congress of Governmental Industrial Hygienists (ACGIH) recommended PEL for both respirable dust and crystalline silica are 3.00 mg/m^3 and 0.05 mg/m^3 respectively (ACGIH, 2015). This is calculated over an eight-hour time weighted average (TWA).

4.2 Potential Respirable Dust Exposures

The average values for the potential exposure levels of SEGs to respirable dusts are expressed in a descending order (highest exposure value to the lowest) as follows; Shotcrete operators> Solo operators> Cubex operators>Jumbo operators>Diamond drillers>Bogger operators>Blast men> Supervisors> Service men>Truck operators. From the order above, shotcrete operators recoded the highest average exposure level of 0.883 mg/m^3. This exposure level is about 70.57 % below ACGIH's nominal PEL. This relatively high exposure level when compared to other SEG values is as a result of the ambient air at the work place. After sampling of the shotcrete operators, cement dusts were observed to have soiled the sampling train and the pump bags. This suggests a possible inhalation of the cementing materials used for spraying contributing to the relatively high levels amongst other SEGs. The relatively low exposure levels by the other SEGs can be attributed to the very low dust contents in the ambient air at the individual work areas. The analysed results indicate that 100% of all the SEGs were not potentially at risk to respirable dust hazards. All the results were far below ACGIH's recommended limit of 3.00 mg/m^3 for respirable dust exposures as shown in Figure 4.1.

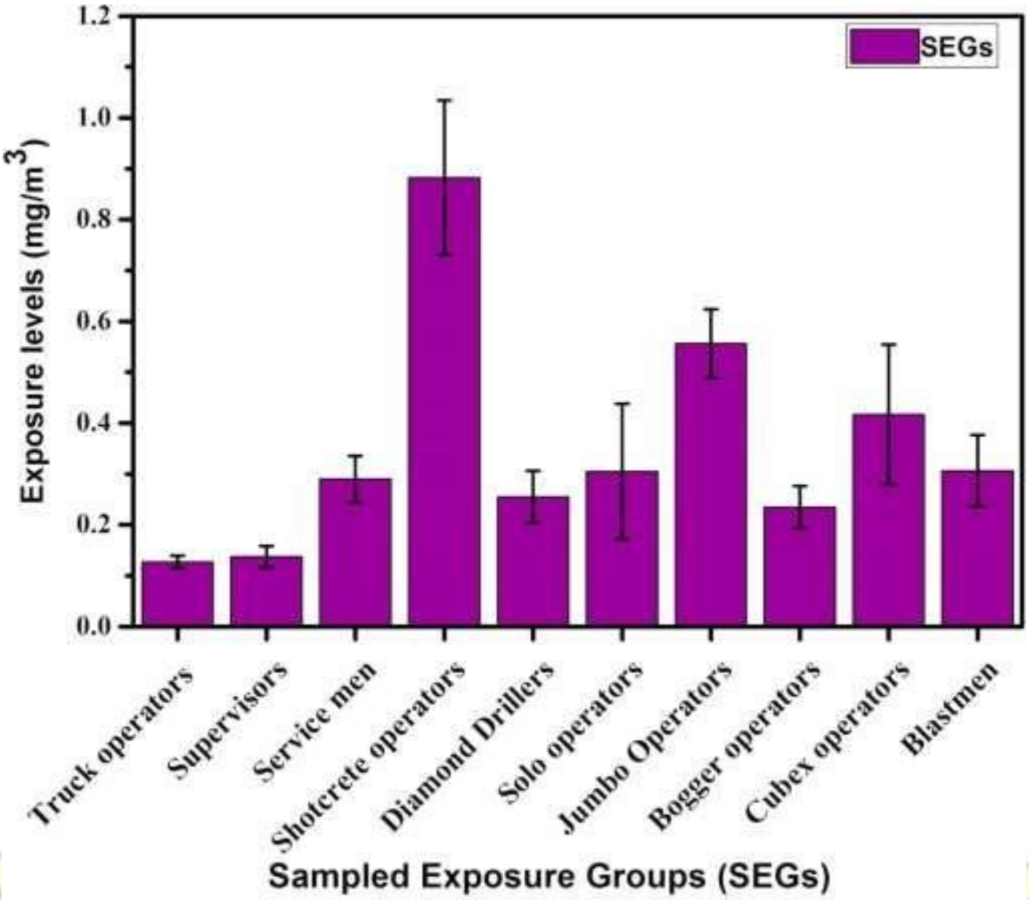


Figure 4.1 Potential respirable dust exposures to the SEGs

This further suggests that, should the workplace conditions at the time of the data collection remain unchanged then the workers will not be at potential risk to respirable dust disorders. Nevertheless, as reported by Croteau *et al*. (2004), underground workplace conditions change with time and work practice making a constant workplace conditions impossible. There was a significant difference ($p < 0.05$) among the exposure levels of SEGs (Appendix 1A). With references to respirable dust exposures only, the use of respirator protection by subjects will serve as a healthy protection.

4.3 Potential Silica Exposure

Percentages in potentially high silica exposure levels were calculated for each SEG as shown in Table 4.1. The representation of the results is presented in a descending order (highest mean exposure level to the lowest) as follows; Jumbo operators>

Cubex operators= Solo operators= Diamond drillers= Short craters> Service crew> Blast men> Bogger operators> Supervisors=Truck operators.

Table 4.1: Percentage of workers over exposed to silica in each SEG

SEG	Number sampled	Number overexposed	% Over – exposure
Truck Operators	11	0	0
Shotcrete operators	4	2	50
Diamond Drillers	6	3	50
Solo Operators	4	2	50
Jumbo Operators	9	9	100
Bogger Operators	6	1	16.67
Cubex Operators	6	3	50
Blast men	8	3	37.5
Service men	11	5	45.45
Supervisors	4	0	0
Total	69	28	40.58

From the results above, a total of 40.58% of the individual workers in all SEGs recorded levels above ACGIH's PEL of 0.05mg/m^3.All the jumbo operators were over exposed, recording a mean concentration of 0.111 mg/m^3 (Figure 4.2). This represents about 122 % over-exposure when compared with ACGIH's nominal PEL of 0.05

mg/m^3. Other SEG over-exposure percentages in relation to the nominal limit of 0.05 mg/m^{3}are; 90 %, 30 % and 26 % for cubex operators, shotcrete operators and solo operators respectively. The results (Table 4.1) indicate that 40.58 % of sampled workers are at potential risk of contracting silicosis and other pulmonary infections in their work environment. According to Churchyard *et al*. (2004) 313 cases of silicosis were recorded in a studies to determine the prevalence of silicosis among 520 black African gold miners in South African mines. This occurred after 90 % of them were exposed to an average of 0.051-0.075 mg/m^3 of silica for an average working period of 21.8 years. On the basis of class (Table 4.2), 4 out of the 10 SEGs were considered to be in class A whilst the remaining SEGs were evenly spread in both class B and class C respectively.

Table 4.2: Classes of SEGs in relations to silica exposure

Class A	Class B	Class C
Jumbo operators	Blast men	Supervisors
Cubex operators	Service men	Truck operators
Solo operators	Diamond drillers	Bogger operators
Shotcrete operators		

The information in the table above indicate that, SEGs in class C are generally not exposed to high silica concentration underground. Their exposure levels were; 54 %, 74 % and 30 % lower for supervisors, truck operators and bogger operators respectively when compared to ACGIH's nominal PEL of 0.05 mg/m^3. Since class B groups are considered to be in a fragile zone a little deviation from normal could increase their exposure levels above the acceptable threshold. An analysis of variance among the various groups and their exposure levels revealed a significant difference of $p<0.05$ as shown in appendix 1B. According to Croteau *et al*. (2004), the use of LEVs in a construction industry could not prevent workers exposure to high personal respirable crystalline silica. About 25.9 % of study subjects exceeded

ACGIH's threshold limit value (TLV) even though sampled respirable dust exposures were very low.

Again, from the study, at an average respirable dust exposure of 0.36 mg/m^3, high average silica exposure of 0.051 mg/m^3 were recorded. The high silica levels led to the development of silicosis within 21.8 years of occupational exposure (Churchyard *et al.*, 2004). The work of Jumbo operators underground involves the drilling and meshing of rocks in the development headings of the mine; and during such operation respirable dusts are generated. Even though water is used in the drilling process, the presence of dust suggests inadequacy of this control method. Again, cleaning and loading at the development heading is done by bogger operators. The operation is recognized as the single activity that contributes significantly to the dust contents in underground mines. However, after their operations jumbo operators immediately re-enter the phase for onwards drilling thereby compounding their exposure risks. The high silica exposures to class A therefore suggests the presence of high silica bearing rocks underground even though very low respirable dust levels were recorded.

The result agrees with the findings of Hnizdo (1992) which stated that for every fraction of respirable gold mine dust collected, about 30% free silica can be found. Also, since jumbos have cabins, the presences of lower levels of dust suggest either a leakage into the cabin or exposure to the ambient air. 3 out of the 4 class A exposure groups are all involved in drilling of rocks; this therefore agrees with the publication of NIOSH (1992), which stated that all silica bearing rock drillers are at risk of contracting silicosis as their working conditions favours its formation.

The zero percent (0 %) over-exposure level recorded for supervisors and truck operators could be attributed to the limited work hours they spend underground as compared to the other working groups. Also, truck and supervisors always move in well fitted and furnished vehicles and trucks as per regulation to help prevents the entry of particulate matter even though occasional poor fitting of cabins and faulty air conditions do exist in industries. The relatively small respirable dust concentrations recorded by supervisors could be attributed to the dust in the ambient air of the mine encountered during occasional walking and supervision works. The mean silica concentration of 0.013mg/m^3 recorded amongst truck operators (Figure 4.2) suggests the presence of high silica in the dust particles.

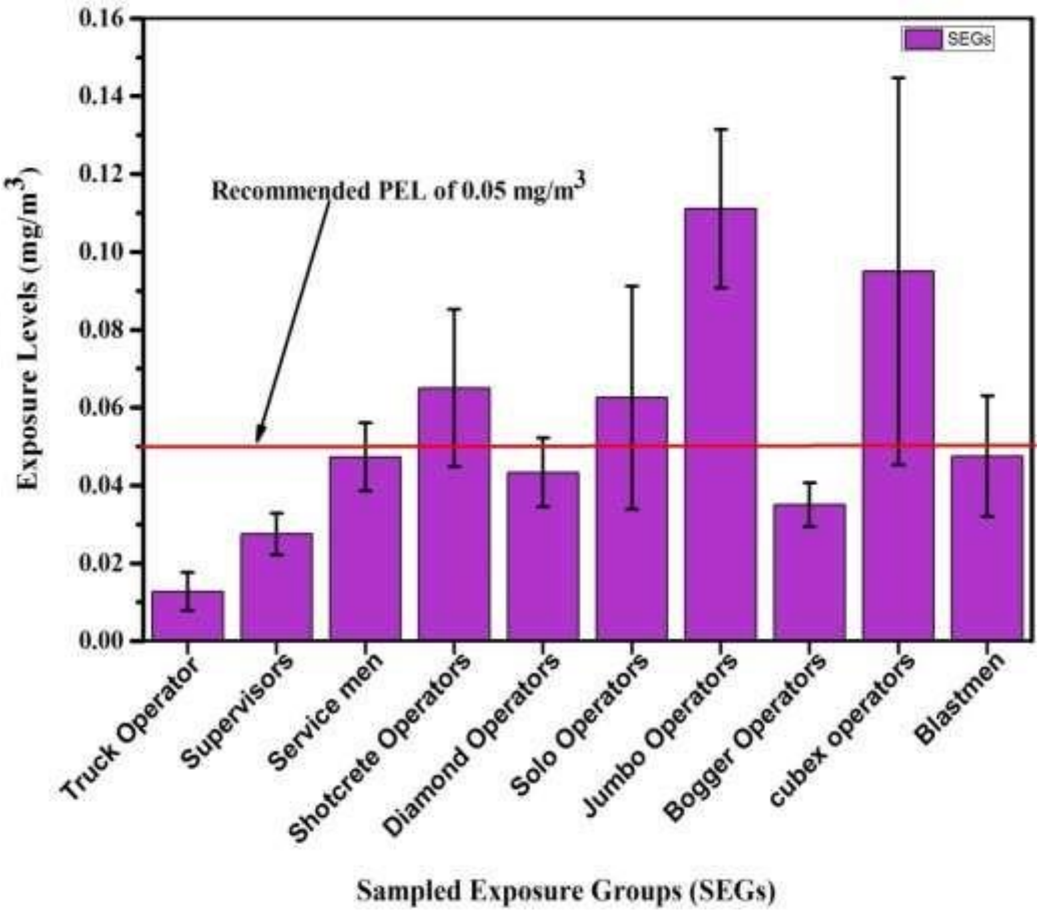


Figure 4.2: Potential silica exposures to SEGs

Dust mitigation measures around the work area of class B workers (Table 4.2) require improvement in order to minimize risk. Since this class works in a fragile zone where little deviations in dust control can easily put them in class A. Low mean values for SEGs in class C suggest low exposure levels. It also indicates good industrial practices which need to be encouraged at all places in the mine.

4.4 Diesel Particulate Matter exposures

The ACGIH's recommended PEL for DPM using its elemental carbon (EC) content over an eight hour TWA is 160.00 µg/m^3.The analysed DPM samples showed that, 48.68%, 11.84% and 39.47% of the total sample fell within class A, B and C respectively. Shotcrete operators recorded the highest mean value of 287.99 µg/m^3 which is 80 % more than the exposure threshold limit of 160.00 µg/m^3. Truck operators also recorded the minimum exposure level of 70.07 µg/m^3 representing 43.79 % of the PEL. The order of representation (Figure 4.3) in a descending order (highest exposure value to the lowest) in relation to the computed means is presented as; Shotcrete operators> Bogger operators> Diamond Drill operators> Jumbo operators> Blast men> Cubex operators> Service men> Supervisors> Solo operators> Truck operators.

Only four of the SEGs (truck operators, solo operators, supervisors and service men) recorded mean DPM exposure levels lower than the recommended PEL. The remaining groups exceeded the threshold limit by a range of 11.5-80.0 %. Apart from cubex operators, blast men, shotcrete operators and service men, all the other groups studied work mostly in closed cabins. However, with the exception of truck and solo operators some members (bogger operators and diamond operators) within the remaining groups recorded class A exposure levels.

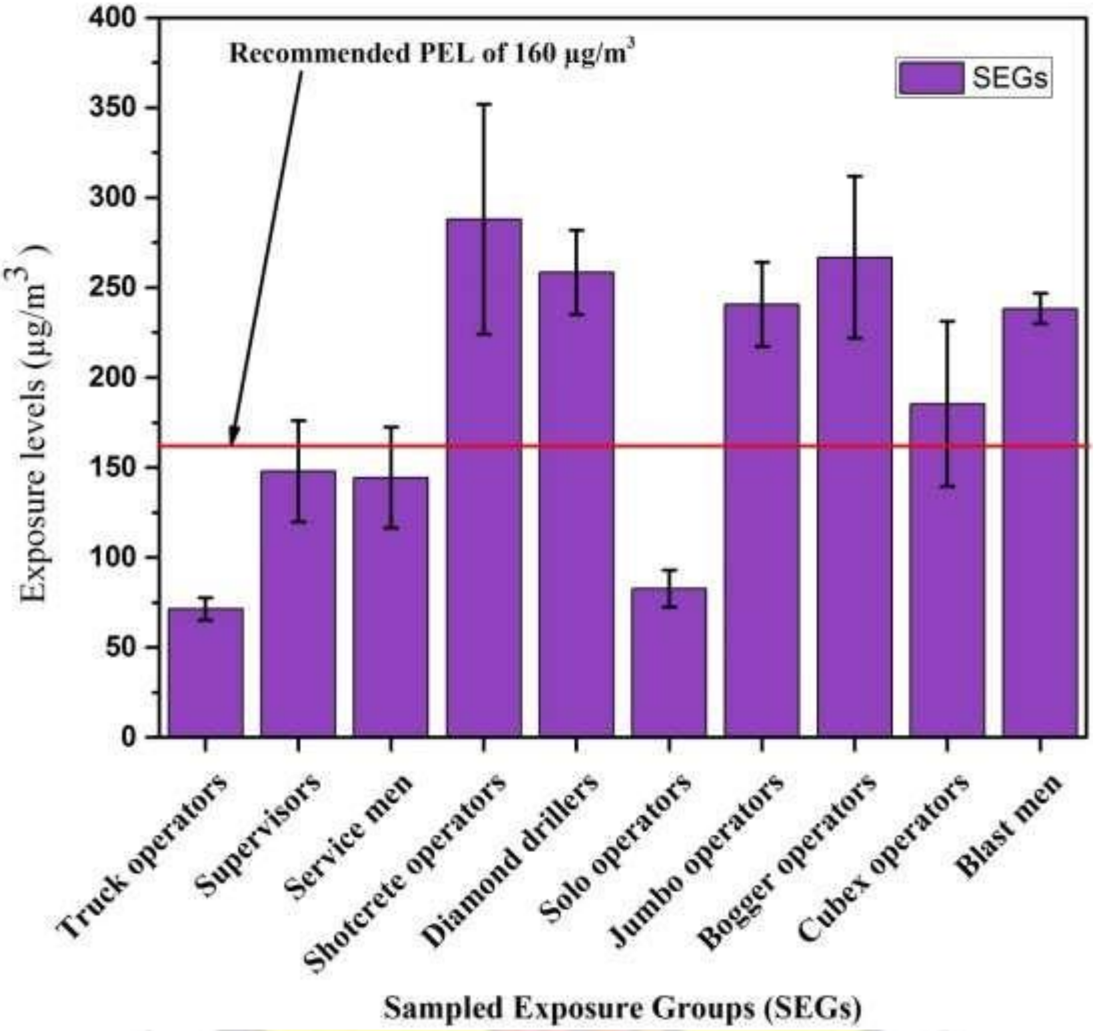


Figure 4.3Potential Mean DPM exposure levels of SEGs.

Out of the total numbers studied for each group, 100 %, 80 %, 62.5 %, 80 %, 100 %, 50 %, 23 % and 40 % of diamond drill operators, jumbo operators, boggers, shotcrete operators, blast men, cubex operators, service men and supervisors respectively fell within class A exposures; these are summarized in Table 4.3. The results indicate that majority of the target groups are potentially exposed to DPM pollutions. There were significant differences ($p<0.05$) among SEGs in relation to their DPM exposure levels (Appendix 1C).

Table 4.3: Number of sampled workers exposed to high DPM concentrations

SEGs	Number sampled	Number over exposed	% over exposed
Truck operators	10	0	0.0
Supervisors	5	2	40.0
Service men	13	3	23.0
Shotcrete operators	5	4	80.0
Diamond drillers	5	5	100.0
Solo operators	7	0	0.0
Jumbo operators	10	8	80.0
Bogger operators	8	5	62.5
Cubex operators	6	3	50.0
Blast men	7	7	100.0

High exposure rate suggests a generally high diesel fume generation by underground diesel equipment into the ambient air. Higher mean exposures recorded by shotcrete operators correlates with that of respirable dust recorded earlier. This indicates that shotcrete operators are the working group with higher risk of exposure to PM pollutions. Poorly fitted cabins and faulty air-conditions may have also contributed to the exposure levels of workers who mostly operate in cabins through leakages.A review report by Steenland *et al*. (1998) revealed that operators in cabbed machines where exposed to diesel fumes emitted by their own engines. This was observed in an experiment where 88 trucks were tested for in-cab concentration of DPM, 40 % of the sampled trucks were cited for leakages. The entry points were either through the cab floor where the pedals are located and/or through the windows. This increased the drivers (operators) exposure levels about twice of non-leaking trucks.The high exposure level connotes the inefficiency of the available DPM control plan other than respirator use. From the results, the use of PPEs needs to be well enforced minewide in order to minimise the hazard of inhaling high DPM. This would in the long run help prevent the occurrence of lung cancer and other related effects in the future. The generally high diesel exhaust exposures to underground SEGs is constituent with the findings of Attfield *et al.* (2012) in a cohort studies among 12,315 workers in 8 non-metal mines in the U. S. Their studies revealed high lung cancer mortality risk among underground mine workers after been exposed to high concentration of DPM in their occupational work areas.

4.5 Sources of Dust and DPM at CGML Underground Pit and their Control

4.5.1 Drilling

The drilling process generates varying levels of dusts hence; the operation requires that water is used throughout the entire process. This prevents dry cutting thereby controlling potential dusts that may evolve. This technique is complimented by the use of LEVs and respirators to control personnel exposures. The sophisticated drilling machines are powered by both diesel and electricity. Diesel engines are utilized when the machines are moving in, out or within the mine. In order to control DPM generations and fire hazards during drilling, electric power is used in operating the machine.

4.5.2 Blasting

As the breaking of the rock material occur, dust erupts vehemently thereby contaminating the underground mine environment. Noxious gases (NO_2, SO_2) generation also occur compounding the hazard levels. Blasting has an added disadvantage of weakening the walls of underground tunnels. Control of the PM generated is achieved by the use of water blast, administering mine re-entry plan and control blasting. The resulting solution from the water blast and its interaction with the gases generated may be very hazardous if not properly managed.

4.5.3 Re-sizing and Loading

After blasting, rock cut of sizes greater than the carrying capacity of the loading machine are resized to normal before they are loaded into trucks for haulage. The breaking and carrying into trucks prior to haulage serves as a great source of underground dust. Dust resulting from rock cuttings and loading is mainly mitigated by sprinkling of water during cutting and loading into haulage trucks. The presence of the LEV also excludes significant quantities of dust from the work area. On the other hand, due to material characteristics and handling challenges, not much water is applied making the existence of the hazard very conspicuous(Croteau *et al*., 2004).

4.6 Haulage and Movement of Equipment

Conveying of ores and/or wastes from underground production headings generate varying levels of dust. Movement of other heavy and light vehicles during routine activities also contributes to the total quantities of dust in the underground mine environment. Apart from installed LEVs mine wide, speed limits of 20 km/h have also been instituted. Access routes are routinely watered. The disadvantage of this method is that when too much water is sprinkled on the route, they become slippery for machines and equipment to ply on. Again, the access routes to underground resources involve declining long but gentle slopes. When returning to surface, machines and equipment operators require high accelerations to successfully climb these long and high declines. As a result, high diesel fumes are generated into the ambient air.

4.6.1 Cleaning and Servicing

Routine cleaning and maintenance activities underground also add up to the dust concentrations underground. Even though their contribution to total occupational dust exposures to workers may be minimal with respect to other sources, they are significant sources. Since the entire mine is generally dusty, they easily settle on underground installations. Work in such environment involves the extension of service lines, repair of underground equipment and cleaning as well as general maintenance of underground equipment. During such operations, dislodging of settled dust particles occur making them air-borne. Such suspended air fraction when inhaled and respired into the lungs may cause respiratory related illness. Where residual chemical traces may be contained in the dust, detrimental effects may occur. Control measures include; use of respirators, avoiding dry cleaning and wetting of operational areas.

4.7 Particulate Matter Awareness survey

4.7.1 Dust Awareness

Ninety-eight (98) of the target work forces were randomly sampled to determine workers initial awareness to dust and its related health implications (Appendix 2).The results as shown in Figure 4.4 revealed that 62.24% of the study subjects had good awareness of the presence of dust hazards and its related effects. 28.57% of the workers acknowledge the presence of the hazards but could not expedite more on the major consequences to high dust exposure apart from citing catarrh. The remaining 9.18% of the respondents were below par to the hazard awareness. Respondents only acknowledged the presence of the hazards in their working environment but had poor knowledge of its consequences to their health other than mentioning catarrh and coughing. The scale for grading is briefly described in the Table 4.4.

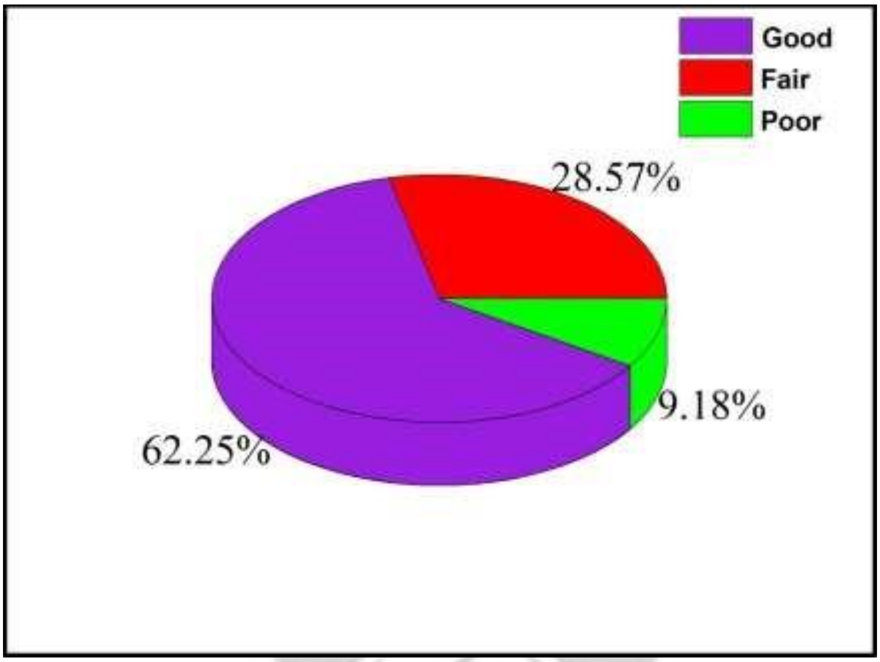


Figure 4.4: Dust awareness survey response

Table 4.4: Grading system for assessing workers initial awareness to dust hazards

GRADE	DESCRIPTION
Good	Ability to recognize the hazard and give/describe some examples of health and other implications to potential exposure to high levels. Stating/describing silicosis, lung cancer, tuberculosis amongst others was a desired option.
Fair	Ability to recognize the hazard and vaguely describe a related health implication to high levels apart from mentioning catarrh and/ or coughing.
Poor	Acknowledges the presence of the hazard but does not give a health related effect to high exposure levels other than catarrh and/or coughing.

4.7.2 Silicosis Awareness

The level of awareness of workers to silicosis which is caused by the crystalline silica fraction of respirable dust revealed a similar trend as in dust awareness report stated above. The results as expressed in Figure 4.5 shows that 60.20% of the respondents were very much aware of silicosis whereas the remaining fraction representing 39.80% were not aware of silicosis. Such individuals exhibited absolute ignorance to the disease including the possible causes.

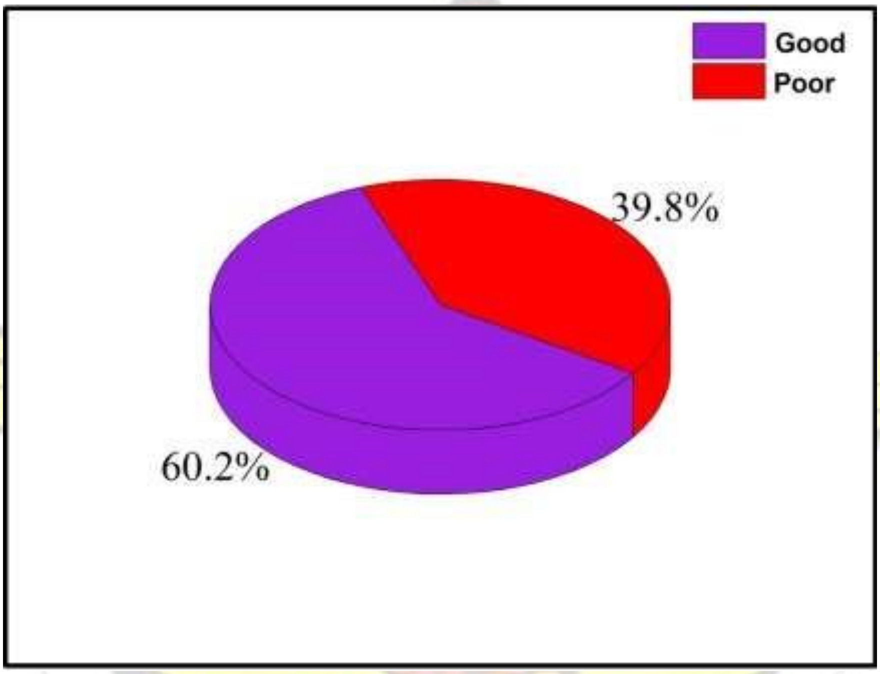


Figure 4.5: Silicosis awareness survey response

4.7.3 DPM Awareness

The results establishing workers initial knowledge to the presence of DPM hazards and its associated workplace and/or health effects revealed a similar trend as recorded in dust hazard awareness. A grading scale similar to that of the dust exposure and effect awareness above was used. However, some occupational work place effects and cancer were much considered.52.04% of the respondents were very much aware of the hazard and its associated occupational work area and health effects. They were able to give examples such as; reducing workplace visibility, air pollution and cancer whilst 31.63% were aware of the presence of the hazard even though they could not mention some major characteristic effects like cancer. The remaining 16.33% of the respondents only acknowledged the presence of the DPM hazard but could not give correct potential health or occupational effect as presented in figure 4.6.

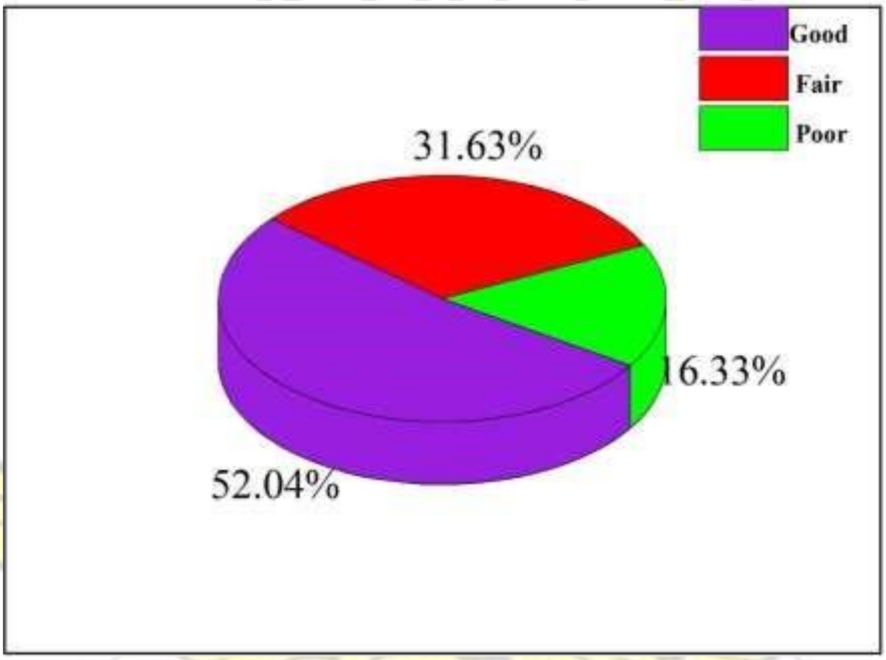


Figure 4.6: DPM awareness survey response

4.7.4 Respirator Use Habit and Comfort Response

It is generally appreciated that, even though the benefits of using appropriate PPE to control air-borne contaminants cannot be over emphasized, their use mostly bring discomfort to users. Out of the 98 respondents considered in the study, only 20 of them representing 20.41% said they felt comfortable always when using the available respirators given them by their employers. The remaining 78 representing 79.59% said they always felt uneasy when using their respirators for long hours. Varied reasons including, but not limited to the following were cited;

- Difficulty in breathing especially when wet,
- Some operations conventionally require that respirators be changed frequently due to clogging of filter pore spaces.
- Presence of cabins in their equipment
- Prefer using wet cloths and bandana due to larger pores in them and higher comfort in breathing. However, their use provides no protection to wearers (CDC, 2004).
- Perceived absence of PM hazards.

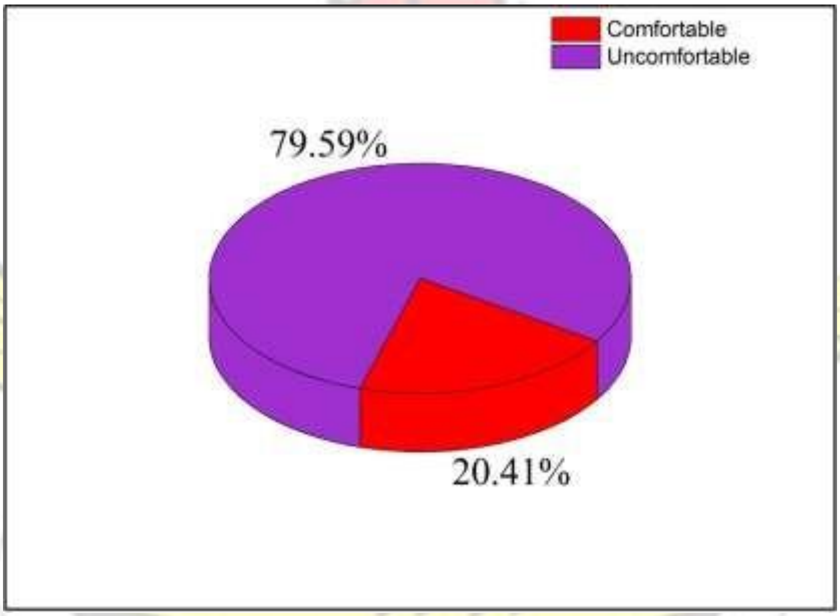


Figure 4.7: Respirator use comfortability response

4.7.5 Respirator Use Scale Index

At CGML, the recommended practice to ensure regularity in the use of a respirator is measured by the workers ability to use a respirator through-out work activity. Further investigations into how regular or irregular workers use their respirators at the work place was conducted. The following as presented in figure 4.8 were revealed; 68 of the respondents representing 69.39% regularly used their respirators amidst the associated discomfort that characterizes their usage. The remaining 30 representing 30.61%

revealed an irregularity in the use of their respirators through-out their working period. The reasons to this deviations where mainly attributed to discomforts in the use of the respirators and the perceived absence of PM hazards during some periods. Most workers underground use the sense of sight in judging the presence or absence of particulate matter in a workplace. Nevertheless, particulate matter most especially the respirable fraction cannot be seen with the naked eyes making their visual judgments incorrect. Their microscopic sizes when combined with the generally dark underground conditions compound workers danger to particulate matter pollution when visual assessments are employed before the use of respirators.

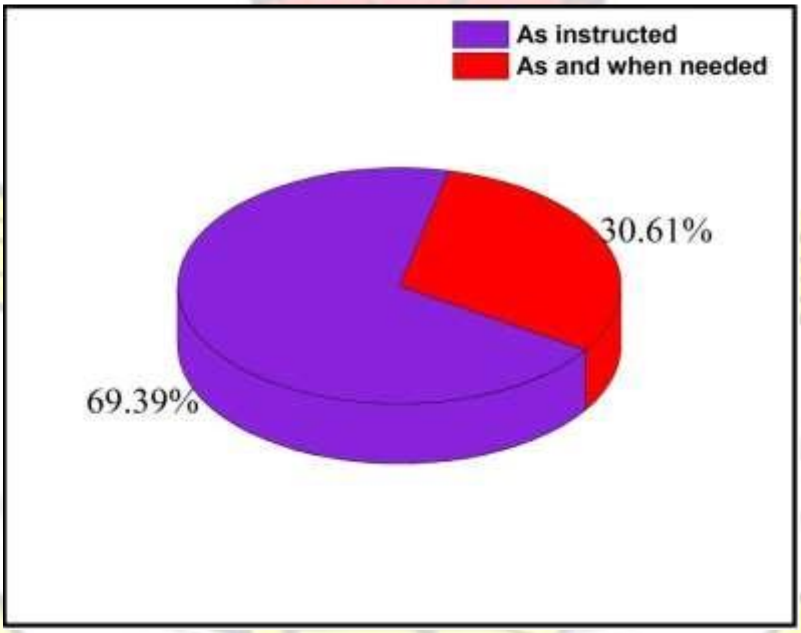


Figure 4.8: Respirator use habits

When the respondents were further asked of their willingly to use or not use respirators if they were not been enforced, 59 of them representing 60.2% emphatically said they would willingly use them since not using could endanger their lives. The remaining 39 representing 39.8% said they would not use them if they were not obliged by their employers to use them. They cited reasons of obstruction of free breathing and general discomfort in the use of the available respirators.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusions

Without giving credence to respirator use, it can be concluded from the study that;

- CGML's dust mitigation measures are very commendable as it helped to reduce workers respirable dust exposures. Workers were observed to be in a safe zone to occupational respirable dust exposures of less than ACGIH's TLV of 3.00 mg/m^3.Nevertheless, continuous improvement is required to advance underground dust situations or eradicate the hazard completely. The use of respirators to control dust serves as a healthy protection
- With the exception of diamond drill operators, all rock drillers and shotcrete operators are potentially exposed to high silica levels. About 40.58 % of sampled workers were exposed to high silica in their work environment. Considering their current exposure levels of 0.063 mg/m^3-0.111 mg/m^3 silicosis and other related pulmonary infections have the potential to occur in the future if conditions does not improve significantly.
- 60.00 % of the SEGs were exposed to high level of DPM. This connotes the inefficiency of the available DPM control plan. Most workers who usually operate in cabins were also exposed. Hence, if the use of respirators is not well enforced mine-wide at all times to include workers in cabins, there would be increased risk of related respiratory diseases such as lung cancer and chronic inflammations. Other occupational effects such as poor visibilities can also cause accident in the mine.

- Minority of the survey respondents ranging from 9.18 % -16.33 % were not well abreast with the health effects of high dust and DPM exposures. Also,

  39.80 % respondents were unfamiliar with issues pertaining to silicosis. Since employees are occasionally re-oriented on PM hazards and effects, the results suggests that, either they were absent during such exercises or could not comprehend what they were taught.
- Majority of workers constituting 79.59 % do not feel comfortable when using the FFp 2 respirators given them by their employers. This has led to an improper use of respirators by about 30.69% of workers.
- Regular health monitoring of all workers is done by the occupational health department of the CGML. There have been no reported cases of silicosis, cancer and/or other pulmonary infection among the workers attributed to silica or DPM exposure.
- The use of respirators by employees was observed to be a part of the minimum PPE requirement by subjects during work. Nevertheless, these requirements are weakly enforced. Some workers preferred other improvised materials such as wet rags; however their use provides no protection for the wearers. The most of the workers considered for the study could not give a clear cut conditions as to when they are required to use their respirators except when the hazard is very conspicuous. This has resulted in working owning the right to judge when to use them.
- Some workers risk contracting particulate matter related health disorders such as lung cancer and pneumoconiosis in the future if current control measures are not improved and adhered to.

5.2 Recommendations

- There should be a clear cut guide of when respirators should be used at work place and well communicated to employees. More stringent measures should be instituted to ensure that PPE use by underground workers is well adhered to at all times during work.
- The use of improvised materials like cloths and bandana should be abolished since they provide no protection to wearers.
- Due to the suspected leakage of PM into cabs, all machine operators except truck operators should be made to use respirators even when in cabins. These suspected deviations should be verified and fixed as early as possible.
- DPM generating equipment should be well audited to better establish their generation levels. More appropriate control measures such as reducing the number of DPM generating equipment underground or enhancing the capacities of the available engineering controls should be adopted to halt their high fume generation levels.
- Re-orientation and sensitization programs should be organized for the general work force to deepen their knowledge in PM hazards and associated effects.
- Since APR provides minimum protect against PM as compared to SABA, SEGs with higher risks to PM pollutions such as shotcrete and cubex operators should be given SABAs during work.
- Further research should be extended to other occupational groups. Studies to determine in-cab exposure to PM should also be focused to either confirm or disprove suspected cabin leakages as reported in this study.

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.

APPENDICES

1A: ANOVA for respirable dust exposures

Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	2.4413052	9	0.2712561	7.855592	1.65E-07	2.0429
Within Groups	2.037289	59	0.0345303			

Total	4.4785942	68				

1B: ANOVA for silica exposures

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.065436	9	0.007271	3.051872	0.004584	2.0429
Within Groups	0.140559	59	0.002382			
Total	0.205994	68				

1C: ANOVA for DPM exposures

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	405185.4	9	45020.6	6.50529	1.42E-06	2.025121
Within Groups	456760.5	66	6920.614			
Total	861945.9	75				

2.0: Questionnaire

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY,

KUMASI

This questionnaire is to enable Mr. Martin K. Mensah a student of KNUST to successfully conduct his research work on the topic **―Assessing the risk of exposure of underground mine workers to respirable dust and diesel particulate matter hazards, a case study of CGML‖**.

Please kindly fill / tick in the appropriate box/ space provided.

1. Age………**A**. 20 - 30 years **B**. 30 – 40 years **C**. 40 – 50 years **D.** Above 50 years
2. Job title……………………………………………
3. How long have you worked underground? **A**. 0 – 2years **B**. 2 – 4years **C**. 4-6 years **D** above 6 years.
4. When do you use your nose masks? **A** when dust or DPM is seen **B** when i enter the mine **C** Never
5. How often do you use your nose mask (respirators) when at work?

A. As instructed **B**. As and when needed **C**. Never

6. Reason for answers in question **5** above? ………
7. Do you feel comfortable when using your nose mask? **A.** Yes **B** No.
8. If no, Why?

   ……………………………………………………………………………………

   …………………………………………………………………………………...
9. Would you use your nose mask if supervisors were not enforcing you? **A.** Yes **B** No **C.** Maybe.
10. Is dust present underground? **A.** Yes **B** No. **C** No idea
11. Do you know/ heard of any possible effect of respirable mine dust on your health? **A.** Yes **B** No.
12. If yes, please kindly state (describe) them

    ……………………………………………………………………………………

    ……………………………………………………………………………………

13. Is diesel fume present underground? **A.** Yes **B** No. **C** No idea

14. Do you know of any possible effect of diesel fumes on your health? **A.** Yes **B** No.

15. If yes, please kindly state (describe)them

…………………………………………………………………………………………

…………………………………………………………………………………………

16. Have you ever been screened for any air-borne related diseases since you started working here? **A.**

Yes **B** No.

17. If yes, please specify

…………………………………………………………………………………………

……………………………..……………..

18. What do you know about **silicosis**?

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………