ASSESSMENT OF THE EFFECTS OF GEOTHERMAL WELL DRILLING OCCUPATION ON THE SAFETY AND HEALTH STATUS OF WORKERS IN KENYA - A CASE STUDY OF MENENGAI GEOTHERMAL PROSPECT

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JOMO KENYATTA UNIVERSITY OF

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2019

Assessment of the Effects Of Geothermal Well Drilling Occupation on the Safety and Health Status Of Workers in Kenya: A Case Study of Menengai Geothermal Prospect

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A thesis submitted in partial fulfilment of the degree of Master of Science in Occupational Safety and Health in the Jomo Kenyatta University of Agriculture and Technology

2019

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This thesis is my original work and has not been submitted for a degree in any other University.

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This thesis has been submitted for examination with our approval as University supervisors

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I dedicate this study to Hilton Kachila, my father who urged me to press on in the face of many challenges and to Mercy Kachila, my lovely and virtuous wife, the mother of my four wonderful children (Hilton, Benjamin, Lemuel and Alicia), and my number one supporter in my academic pursuits. Thank you all.

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I would like to thank my supervisors, Dr. Paul Njogu and Mr. Pius Makhonge for their technical advice, academic guidance and professional counsel in the preparation of this thesis. I also deeply appreciate the management of Geothermal Development Company (GDC) for allowing me to carry out the research in their workplace. I also salute the staff of GDC who participated in this study. I also acknowledge the Institute for Energy and Environmental Technology of the Jomo Kenyatta University of Agriculture and Technology for their invaluable input throughout the entire study. Finally, I would like to thank my family for their prayers and moral support throughout the study period. Well done!

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API RP : American Petroleum Institute Recommended Practice

CCOHS : Canadian Center for Occupational Health and Safety

CDC : Centre for Disease Control

CFR : Code of Federal Republic

CTDs : Cumulative Trauma Disorders

DOSHS : Directorate of Occupational Safety and Health Services

EARS : East African Rift System

EMCA of 1999: Environmental Management Coordination Act of 1999

ESAW : Europe Safety at Work

EUROSTAT : Statistics Directorate-General of the European Commission

EU-OSHA : European Agency for Safety and Health at Work

GDC : Geothermal Development Company

GOK : Government of Kenya

HCP : Hearing Control Programme

HSE : Health and Safety Executive, of United Kingdom

ILO : International Labour Organisation

IMIS	: Integrated Management Information System
IPP	: Independent Power Producer
JSA	: Job Safety Analysis
KenGen	: Kenya Generating Company Ltd.
KPLC	: Kenya Power and Lighting Company
LOTO	: Lock Out Tag Out
MOEP	: Ministry of Energy and Petroleum
MSDs	: Musculoskeletal disorders
MSDS	: Material Safety Data Sheets
MWe	: Megawatt of Electricity
OEL	: Occupational Exposure Limit
OOS	: Occupational Overexertion Syndrome
OSHA 2007	: Occupational Safety and Health Act of 2007
OSHMS	: Occupational Safety and Health Management System
pH	: negative logarithm of concentration of hydrogen
PPC	: Personal Protective Clothing
PPE	: Personal Protective Equipment

ppm	: parts per million
PSPs	: Plant Safety Programmes
PTW	:Permit to Work
RPM	: Revolutions per Minute
RSIs	: Repetitive Stress Injuries
RT	: Repeated Trauma
SAGAs	: State and Government Agencies
SCRs	:Silicon Controlled Rectifiers
SPSS	: Statistical Package for the Social Sciences
US OSHA	: United States Occupational Safety and Health Administration
VDT	: Video Terminal
VFDs	: Variable Frequency Drives
WIBA 2007	: Work Injuries Benefit Act of 2007

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The global trend today is towards generation of clean, green and renewable energy. Geothermal well drilling is the process of sinking a hole into the earth to tap the energy stored in form of steam or hot water reservoirs using a facility called a drilling rig. In Kenya, the government has prioritized geothermal power generation and specially formed the Geothermal Development Company (GDC) in 2008 to drive this agenda. The geothermal drilling industry is highly specialised and concentrates safety critical static rig systems and vehicular plant within a relatively small footprint. Furthermore, the operating parameters are safety critical and the environmental setting is also prone to risks and hazards such as blowouts, excessive noise, severe manual handling, working at heights and occupational stress. The purpose of this study was to assess the effects of geothermal well drilling occupation on the safety and health and status of workers in GDC. To assess the adequacy and effectiveness of the onsite plant safety programmes, the study employed a survey study design. The study infers instances of inadequacies and ineffective on the onsite plant safety programme as regards six out of the nine elements assessed. The study also graphically illustrated the noise distribution at the well site during a drilling ahead activity without air drilling. The results indicated that the workers are exposed well beyond the permissible noise levels on the 3 dB (A) exchange rate. Finally, the study employed an observation checklist and interviews to assess the eight main components of the OSH management system in place at GDC and the scores in descending order were as follows: organising co-operation (75%); policy (71%); organising communication (71%); measuring performance (64%); auditing and reviewing (63%); planning and implementation (54%); organising control (50%); and organising competence (50%). The overall score of the evaluation of the OSH management system was 60%. The results showed that the effectiveness and efficacy of the OSH Management System is moderate.

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1.1 Background to the study

Geothermal well drilling is the process of sinking a hole into the Earth to tap the energy stored in a steam or hot water reservoir for electricity generation or other direct uses. Drilling activities also include the casing and cementing operations that are used to case off and seal unproductive sections of the well while making a conduit through which the steam flows to the surface. The deep productive zones are cased off using slotted liners that permit the steam to flow into the tubulars and to the surface. The drilling technology used, has to a great extent, been borrowed from the oil and gas industry (Njee, 1987). Since the workplace setting and environment are similar, the occupational and safety parameters largely match.

A drilling rig is used in the drilling operations. This is the equipment that provides the motive power to rotate the drilling bit, allowing the weight exerted on the bit to break the rock underneath while circulating the drilling fluid. The drill bit hence penetrates the rock as fast as the rock cuttings can be evacuated to the surface through the annulus space between the walls of the hole and the outside of the drill-string. The successful product of the drilling operation is a well that is discharging high pressure steam, hot water or a combination of both.

The drill rig is an aggregate of individual systems that work together to accomplish the drilling mission. This facility is assembled on a flattened and competent ground called the drilling pad. In drilling operations, the drilling rig and all associated equipment for use that is situated within the drilling pad constitutes the workplace (Appendix 5 gives the plan layout of the drilling pad)

Historically, in Kenya, deep geothermal drilling has been going on in Olkaria field since 1957 by the former Kenya Power and Lighting Company (KPLC), and later on by Kenya Electricity Generating Company (KenGen). The initial Olkaria I geothermal power plant with a capacity of 45MWe was supported by 24 production wells and 2 re-injection wells. When Olkaria II power plant was generating 105MWe, it was gathering steam from steam from 22 production wells and 4 re-injection wells. Presently an Independent Power Producer (IPP), Orpower 4 inc., is feeding 92.4 MWe into the National Grid from Olkaria III geothermal power plant.

The Ministry of Energy and Petroleum (MOEP) of the Government of Kenya (GOK) in its first medium term Strategic Plan 2008 – 2013targeted to drill 80 geothermal wells to power additional units of Olkaria I power plant and new units of Olkaria IV power plant(Government of Kenya, 2008). To drive this agenda, a fully government-owned company, the Geothermal Development Company (GDC) was formed in 2008 as a Special Purpose Vehicle. GDC is tasked with developing steam fields and selling geothermal steam for electricity generation to KenGen and to private investors. In it's second medium term Strategic Plan 2013 – 2017 (Government of Kenya, 2013), MOEP targeted to develop 1,691 MWe from geothermal wells.

Kenya is endowed with 10,000 MWe of geothermal resource spread in 14 potential prospects along the Rift Valley (GOK, 2013). The fields that are currently generating electric power are Olkaria and Eburu. Olkaria volcanic complex is the one that is best known (Lagat, 2004). Other geothermal sites are at various stages of development (Omenda, 2010). The figure 1.1 below illustrates the geothermal prospects in Kenya.

The deep seated geothermal reservoirs can only be accessed through a process of deep well drilling. Typical drilling depths for the East African Rift System (EARS) are between 2,000 to 3,200 m below the ground surface. The entire geothermal project cycle has been conceptualised into four major phases and nine key steps as shown in the figure 1.2 below (Coopers, 2007). Figure 1.2 also shows that drilling operations feature in three of the four stages as exploration drilling, appraisal drilling and production drilling. It should also be noted that reservoir management may also entail drilling of re-injection wells as directed by scientific studies done during steam abstraction for power production.

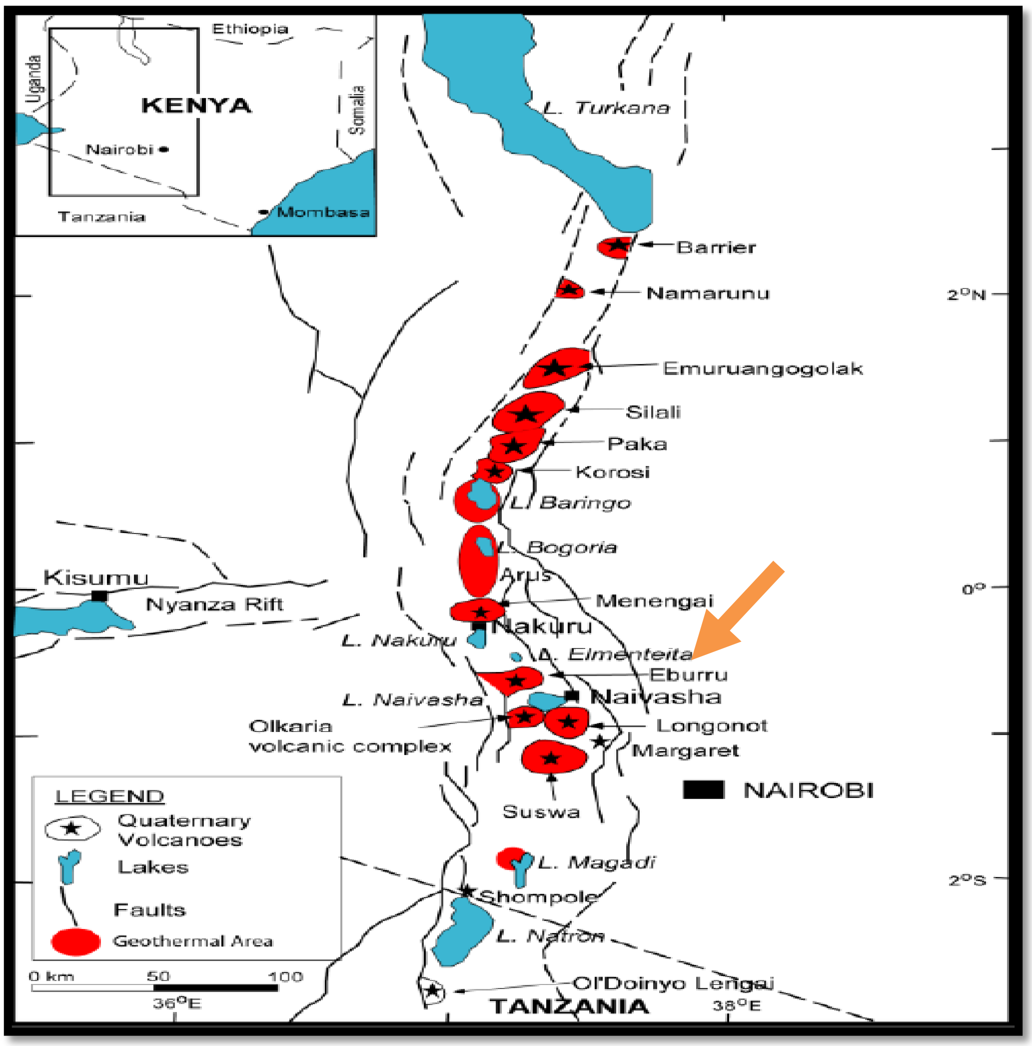


Figure 1.1: Geothermal prospects in Kenya

Source: (Omenda, 2010)

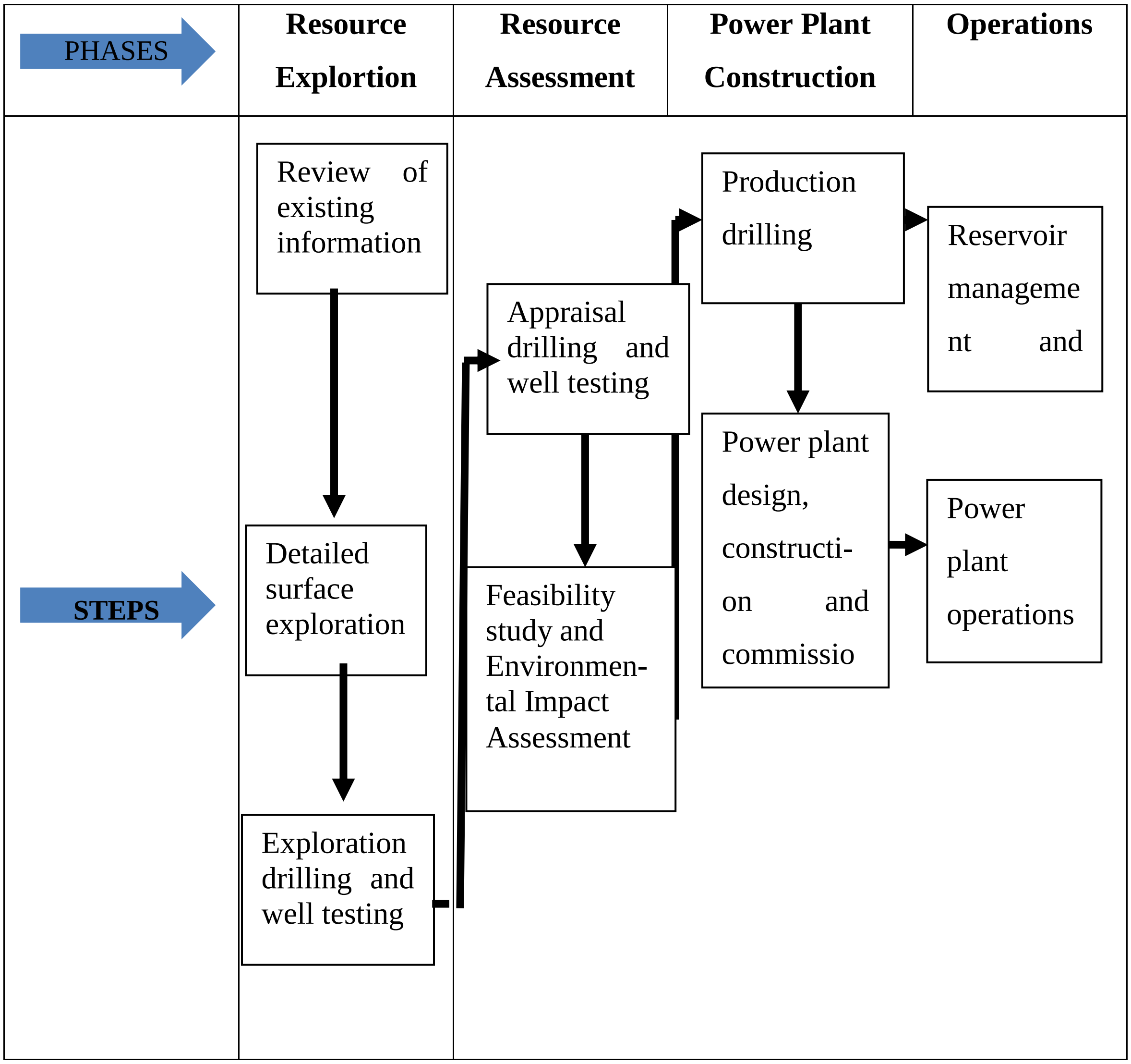


Figure 1.2: Geothermal development phases

Source: (Coopers, 2007)

The geothermal drill rig is an aggregate of individual systems that work together to accomplish the drilling mission. Operational and economic requirements dictate the sophistication of the rig (Ngugi, 2010), however a typical geothermal drilling rig consist of the following systems:

i. The power system comprise the diesel generators, start-up compressor, variable frequency drives (VFDs), Silicon Controlled Rectifiers (SCRs) and means of transmission and distribution of electric power to the loads.
ii. The hoisting system is used to support the rig, lift or lower the rotating drill-string. It consists of the draw-works, the crown block, the travelling block, the hook, the links and elevators, the winches, the substructure, the rig floor and the derrick.
iii. The circulation system is used to circulate the drilling fluid and ensure that cuttings are lifted to the surface while at the same time cooling the bit and maintaining well bore stability. It consists of mud pumps, standpipe, rotary hose, swivel/Kelly system or top-drive system, shale shakers, the cyclonic cleaners, mud tanks, mud pits, mixing hoppers or tanks, and associated hoses or pipes. For aerated drilling the system includes set of high pressure compressors, set of air boosters and air dryers.
iv. The rotary system is responsible for creating rotation torque on the entire drill-string and the bit. It may be a Kelly system including the rotary table and Kelly bushing or the Top-drive system, consisting of an integrated rotary, rod handling and swivel system. The drill stem transmits the rotation torque and drilling fluid to the bit.
v. The well control system consists of the Blow-out protector stacks, choke manifold system, kill manifold system, accumulator system and the associated controls.
vi. The rig auxiliary equipment includes the other components that supplement the other systems so as to enable the rig to function more efficiently. They include such components as drill-string handling tools, rig instrumentation, the driller's console, cement silos, air drilling package, diesel tanks, slings, pipe racks, drilling offices, canteen, workshops , warehouses, cranes, forklifts and trucks.
vii. The rig also includes the camp which houses the staff.

viii. The rig includes facilities for specialized services such as cementing plant and laboratories.

The Figure 1.3 below shows the main components of the drilling rig on the well pad.

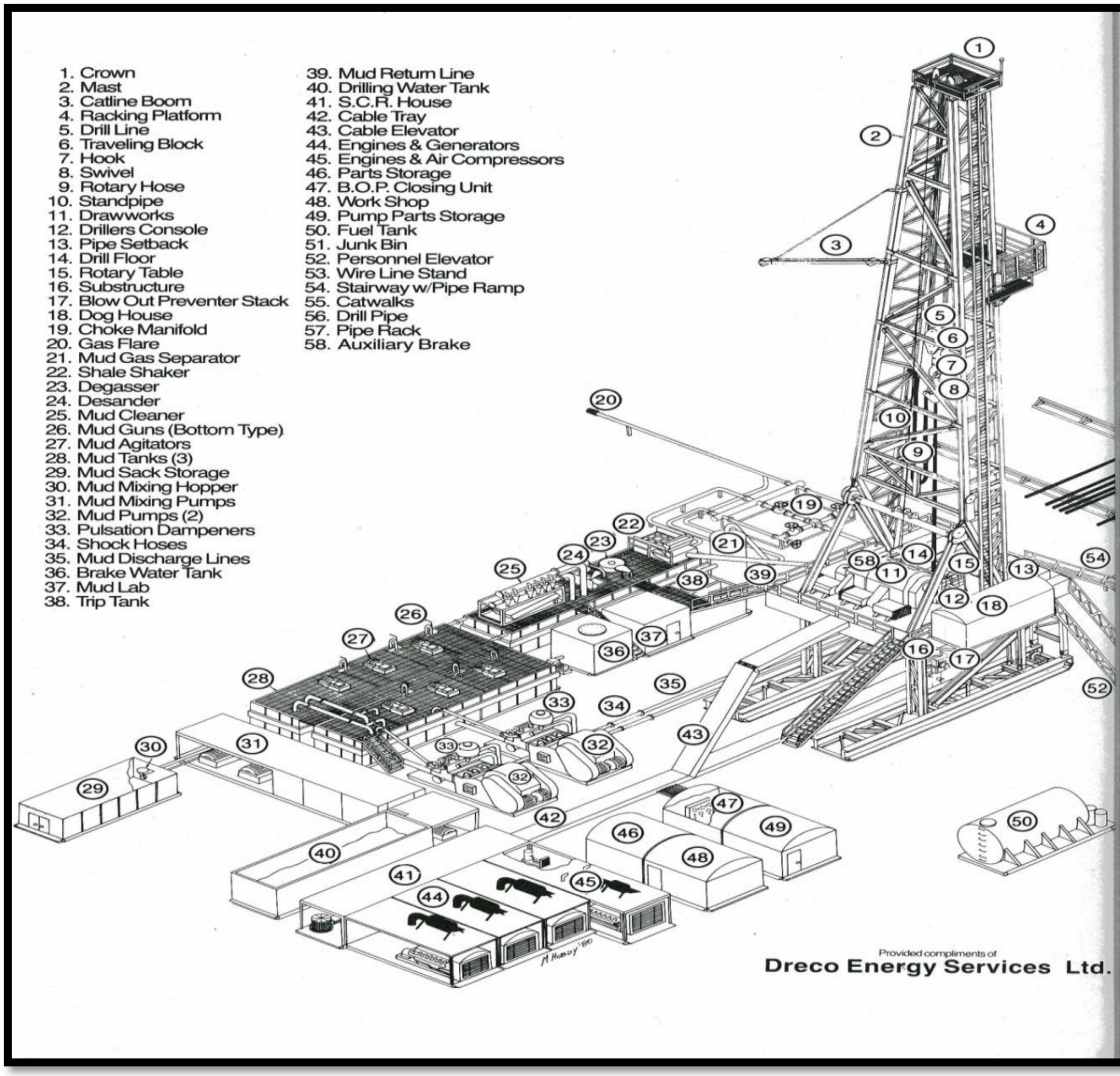


Figure1.3: A pictorial of the main components of the drill rig

Source: (Eustes, 2016)

Geothermal drilling is similar to on-shore oil and gas drilling but is more expensive (in cost/depth) for three principal reasons (Blankenship, 2010):

i. Technical challenges because the igneous and metamorphic geothermal formations are hot, hard, abrasive, highly fractured and under-pressured compared to sedimentary formations for most oil and gas reservoirs. They also contain formation fluids that are corrosive and with very high solids content. These conditions mean that drilling is usually difficult—rate of penetration and bit life are typically low, corrosion is often a problem, lost circulation is frequent and severe, and most of these problems are aggravated by high temperature.
ii. Large diameters: because the produced fluid (hot water or steam) is of intrinsically low value, large flow rates and thus, large holes and casing, are required. In many cases, it would require more casing strings to achieve a given depth in a geothermal well than in an oil well to the same depth.
iii. Uniqueness: geothermal wells, even in the same field, are more different than oil and gas wells in the same field, so the learning curve from experience is less useful.

The workers that are directly involved in geothermal drilling operations at the well-site include the following: drillers, the rig floor men, the derrick men, the roustabouts, the drilling supervisors or superintendents, drilling engineers, the maintenance team (technicians and engineers), cementing team, well logging team, crane and folk-lift operators and the rig manager. The other support staffs at the well-site include drivers, safety, environment and quality assurance officers.GDC has purchased seven deep drilling rigs that are operated and maintained by a Kenyan crew for drilling geothemal wells (GDC, 2016), and has employed about 150 workers in its drilling department (Fankey, Githiri, & Mburu, 2013).

Geothermal drilling operations normally run round the clock in shifts. The typical shift durations before breaking for off duty are fourteen days, twenty one days, twenty eight days and thirty five days. However the shift cycle is an administrative issue and depends on such factors as the remoteness of the site, security and employee contractual terms.

1.2 Statement of the Problem

The geothermal drilling industry is highly specialised and concentrates safety critical static rig systems and vehicular plant within a relatively small footprint (a typical well pad is about 150m x 85m and the drilling rig occupies about 50% of the area). The drilling operating parameters such as air pressure, hydraulic pressures, and voltages rated safety critical. The environmental setting is also prone to risks and hazards such as blowouts, excessive noise, severe manual handling, working at heights and occupational stress. There is need therefore to assess the effects of geothermal well drilling occupation on the safety and health status of the engaged workers.

1.3 Justification of the study

The fleet of geothermal drill rigs mobilised to the geothermal prospects in Kenya has been rising since 2008 due to good political will towards clean and green power generation. The number of workers involved in geothermal drilling production, maintenance and related support functions has also followed a similar trajectory. Whereas the drilling rig concentrates workers and plant in a relatively small area, there has been little, if any research on the occupational safety and health effects of workers involved in geothermal drilling activities in GDC. This is the thrust of this study.

It was therefore envisaged that the findings of this study would find practical use by OSH policy makers, OSH regulators, Occupiers or Management, Practicing Engineers (Process, Maintenance and Safety) and Employees involved in geothermal drilling activities.

1.4Main Objectives of the Study

The main objective of the study was to assess the effects of geothermal well drilling occupation on the safety and health of workers of Geothermal Development Company in Menengai Geothermal Project.

1.4.1 Specific Objectives

i. To evaluate the adequacy and effectiveness of the onsite plant safety programmes (PSPs) in enhancing the safety and health of geothermal drilling workers in Menengai.
ii. To determine the noise exposure and distribution at the drill site during drilling ahead operations.
iii. To evaluate the efficacy of the occupational safety and health management systems (OSHMS) of GDC.

1.5 Research questions

This study attempted to answer the following research questions;

i. How adequate and effective are the onsite plant safety programmes (PSPs) in enhancing the safety and health of geothermal well drilling workers in Menengai?
ii. How is the noise distributed and exposed to the workers at the drill site?
iii. How effective is the OSH management system(OSHMS) of Menengai?

1.6 Study Scope

The study was carried out atthe Menengai geothermal prospect in Nakuru County andwithin the greater East African Rift System (EARS). Specifically, the study was carried out on geothermal drilling rigs publicly owned by MOEP through its State and

Government Agency(SAGA) called Geothermal Development Company (GDC). The study population were the personnel working at the well sites.

1.7 Study Limitations

The study was constrained by the time allocation given to the researcher at the well site. The researcher was given only four days at the site. This meant that the personnel who were on off-duty at that time did not participate. However the staff present gave a satisfactory sample size because it coincided with the shift change and therefore only one of the four shifts per rig could not be reached.

2.1 Theoretical Principles

2.1.1 Hazards in geothermal drilling process

A hazard is generally defined as risky, perilous, or dangerous condition or situation that could result in the exposure of individuals to unnecessary physical or health risks. Hazards can be biological, chemical, physical, mechanical, human-made or naturally occurring (Vincoli, 2000). It further defines a hazard as dangerous condition, potential or inherent, that can interrupt or interfere with the expected orderly progress of an activity. It is any real or potential condition which either has previously caused or could reasonably be expected to cause personal injury or property damage.

Geothermal well drilling and servicing activities involve many different types of equipment and materials. The United States Occupational Safety and Health Administration (US OSHA) postulates that the recognition and controlling hazards is critical to preventing injuries and deaths (United States Department of Labour, 2016). This department further highlights the following as the most prevalent hazards in typical drilling rigs: vehicular accidents; Struck-by or Caught-in or Caught-between; Blow-outs; Slips, Trips and Falls; Confined spaces; Ergonomic hazards; High pressure lines and equipment; Electrical and other hazardous energy and Machine or plant hazards(United States Department of Labour, 2016).

It has been reported that most of the rigging injuries occur due to varied reasons such as carelessness and recklessness; misuse of equipment; not using proper PPE; failure to provide training and delaying in repair or replacement of rigging equipment (Chamberland, 2016).

2.1.1.1 Vehicular Accidents during Rig down, Rig Move and Rig up Operations

Geothermal drilling operations require workers and workplace (drilling rig and auxiliary equipment) be transported from one well site to another. The drilling rig is a movable workplace because it moves from one drill pad to another, often located in remote areas and long distances apart. The entire process of rigging down, transportation of rig components and equipment to new site and rigging up at the new site is an elaborate and highly mechanised process that is hazardous. Rigging up is placing and assembling the various parts of equipment that make up the rig, and preparing the rig for drilling. During assembly of the rig, some equipment may be handled and set with crane, rig up trucks, or forklift, depending on the size of the rig. It should be noted that overhead hazards such as high voltage power lines may be present. There may be two or more crews (teams) working together in the rigging up process. The rigging up process includes the following steps, some of which are done simultaneously:

i. Setting up the Substructure
ii. Setting up the rig floor and mast or derrick
iii. Installing handrails, guardrails, stairs, walkways, and ladders
iv. Installing the power system
v. Rigging up the circulating system
vi. Installing the auxiliary equipment
vii. Inspecting the rig before start up
viii. Rigging down to move it to the next site after completing the well

The US OSHA indicates that roughly 4 of every 10 workers killed on the job in this industry are killed as a result of a highway vehicle incident during rig move (United States Department of Labor, 2013). The United Kingdom, HSE reported that people are knocked down, run over, or crushed against fixed parts by vehicles, plant and trailers. It further asserts that people also fall from vehicles – whether getting on or off, working at heights, or when loading and unloading (Health and Safety Executive, 2014).

The following safety instructions should be adhered to as regards vehicular safety (Bierlein, 1977):

i. Materials should be packed into trailers in such a way as to avoid the shifting of loads during travel. They can be loaded with little or no space between containers or between containers and walls.
ii. Containers should be secured with ropes, straps, chains or cargo nets to prevent movement.
iii. Containers having valves or fittings must be loaded to minimise the likelihood of damage in transit.

The areas that employers should consider while designing programmes on workplace transport safety are the following(Health and Safety Executive, 2014):

i. safe site (design and activity)
    a. Safe site – design - covers the layout of the workplace, for example traffic routes and their maintenance, the positioning and design of pedestrian crossing points, lighting and signage. The main aim of any design should be the segregation of vehicles from pedestrians.
    b. Safe site – activity - covers activities on a site such as reversing operations, coupling and uncoupling, loading and unloading, tipping and sheeting.
ii. safe vehicle - covers identifying and choosing the most appropriate vehicle for the tasks and environment and the people who will use it, as well as how it will be maintained.
iii. safe driver - covers the competence and behaviour of those who operate vehicles.

2.1.1.2 Blow out hazard

Plate 2.1: A blow out on a geothermal drill rig

Source: Puna Pona Alliance of Hawaii (Petricci, 2013)

A blow out is an uncontrolled flow of fluids from a wellhead or wellbore. If the hole advances into a fractured or permeable stratum where the pore pressure is higher than the static head of the drilling fluid, the formation fluid will flow into the wellbore—this is called a “kick”—and that flow must be controlled. If control of that flow is lost, then the resulting disaster is a “blowout” which, at the least will be very expensive and, at worst, can result in loss of life, equipment, and the drill rig, as well as damage to the environment (Blankenship, 2010).

The essence of well control programmes is to prevent a blowout which ejects superheated steam, hot corrosive or acidic fluids and toxic gases into the rig floor where there are workers. The plate 2.1 above shows a typical blowout.

2.1.1.3 Slips, Trips and Falls

The most common causes of serious injury at work are slips and trips and falls from height (Health and Safety Executive, 2014). On average, slips and trips cause 40 per cent of all reported major injuries and can also lead to other types of serious accidents, for example falls from height. Slips and trips are also the most reported injury to members of the public (Health and Safety Executive, 2012). Workers might be required to access platforms and equipment located high above the ground. The US OSHA requires fall protection to prevent falls from the mast, drilling platform, and other elevated equipment (United States Occupational Safety and Health Administration, 2016). A company's overall safety and health programme should include a slip and fall prevention component. Effective strategies for preventing slips and falls provided in(Goetsch, 2011) include the following:

i. Review and analyze accident statistics to determine where slip and fall accidents are happening and why; then take the appropriate corrective measures.
ii. Monitor the condition of walking surfaces continually and make appropriate preventive corrections immediately.
iii. Make sure that ramps and sloped floors have high-friction surfaces.
iv. Use safety mats, nonslip flooring, and slip-resistant safety shoes.
v. Make sure that stairs have handrails.
vi. Make sure that visibility is good in potentially hazardous areas. Add extra lighting if necessary. Also make sure that the colour of paint in these areas is bright and helpful in calling attention to potential hazards.
vii. Make sure that spills are cleaned up immediately and that the underlying cause of the spill is corrected.

viii. Make sure that employees who work in potentially hazardous areas select and wear the right slip-resistant footwear.
ix. Use appropriate technologies such as vertical incidence tribometers to measure the slip resistance of floors and take appropriate action based on the results.
x. Conduct periodic audits of walking surfaces throughout the facilities in question, document carefully the findings, and take appropriate action in a systematic way.

2.1.1.4 Confined spaces

A confined space is one that meets any or all of the following criteria:

i. Large enough and so configured that a person can enter it and perform assigned work tasks therein but limited entry and exit
ii. Continuous employee occupancy is not intended (Goetsch, 2011).

Geothermal drilling workers are often required to enter confined spaces such as diesel storage tanks, mud pits, reserve pits and other excavated areas, well-site cellar and other confined spaces around a wellhead. Safety hazards associated with confined space include ignition of flammable vapours or gases or inhalation of toxic gases such as hydrogen sulphide. Health hazards include asphyxiation and exposure to hazardous chemicals. Confined spaces that contain or have the potential to contain a serious atmospheric hazard must be classified as permit-required confined spaces, tested prior to entry, and continuously monitored.

Organizations that expose workers to confined spaces in the course of doing their jobs should adopt a comprehensive confined space management policy and enforce it carefully and consistently. The policy should cover at least the following areas of concern (Goetsch, 2011): administrative controls, training for all applicable personnel, permitting procedures, and work-team requirements.

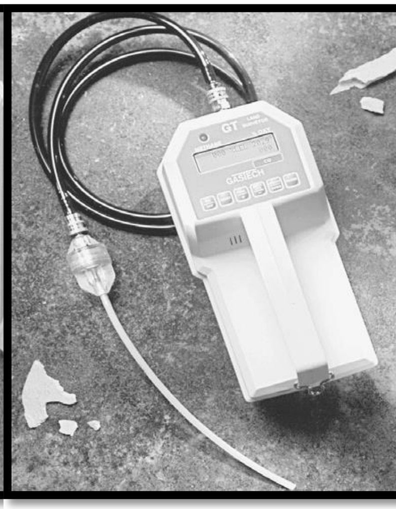
The US OSHA standard mandates that entry permits be required before employees are allowed to enter a potentially hazardous confined space. Before the permit is issued, a supervisor, a safety or health professional, or some other designated individual should do the following:

i. *Shut down equipment/power.* Any equipment, steam, gas, power, or water in the confined space should be shut off and locked or tagged to prevent its accidental activation.
ii. *Test the atmosphere.* Test for the presence of airborne contaminants and to determine the oxygen level in the confined space. Fresh, normal air contains 20.8% oxygen. OSHA specifies the minimum and maximum safe levels of oxygen as 19.5% and 23.5%, respectively. Atmospheric tests indicate whether a respirator is required and, if so, what type, classification, and level.
iii. *Ventilate the space.* Spaces containing airborne contaminants should be purged to remove them. Such areas should also be ventilated to keep contaminants from building up again while an employee is working in the space.
iv. *Have rescue personnel stand by.* Never allow an employee to enter a confined space without having rescue personnel standing by in the immediate vicinity. These personnel should be fully trained and properly equipped. It is not uncommon for an untrained, improperly equipped employee to be injured or killed trying to rescue a colleague who gets into trouble in a confined space.
v. *Maintain communication.* An employee outside the confined space should stay in constant communication with the employee inside. Communication can be visual, verbal, or electronic (radio, telephone) depending on the distance between the employee inside and the entry point.

Plate 2.2 below shows various types of gas detectors.

SAFE T NET 2000 detection device.

Courtesy of Gas Tech, Inc.



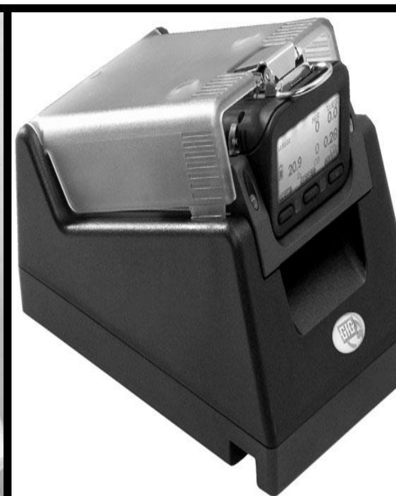
GT Land Surveyor detection device.

Courtesy of Gas Tech, Inc.

STM 2100 detection device.

Courtesy of Gas Tech, Inc.

SAFE T NET 150 detection device.



DS 400 gas detector.

Courtesy of GFG

G640 handheld gas detector. Courtesy of GFG Instrumentation, Inc.

Courtesy of Gas Tech, Inc. Instrumentation, Inc.

2.1.1.5 Ergonomic Hazards

Oil and gas workers might be exposed to ergonomics-related injury risks, such as lifting heavy items, bending, reaching overhead, pushing and pulling heavy loads, working in awkward body postures, and performing the same or similar tasks repetitively (United States Occupational Safety and Health Administration, 2016). According to (Reese, 2009) the ergonomic risk factors that should be looked for include:

i. Force—the amount of physical effort required to perform a task (such as heavy lifting) or to maintain control of equipment or tools
ii. Repetition—performing the same motion or series of motions continually or frequently for an extended period of time
iii. Awkward or static postures—include repeated or prolonged reaching, twisting, bending, kneeling, squatting, or working overhead, or holding fixed positions (see Plate 2.3)
iv. Contact stress—pressing the body or part of the body against a hard or sharp edge, or using the hand as a hammer

Plate 2.2: Devices used for checking the atmosphere courtesy of (Goetsch, 2011)

The plate 2.3 below shows rig floormen manually setting back strands of drill pipes during a tripping out operation. The derrick man is at the top at the monkey board also safety securing the strands.

Plate 2.3: Drilling rig floormen setting back drill strands and exposed to ergonomic risk factors

courtesy of US OSHA (United States Department of Labour, 2016)

Musculoskeletal disorders (MSDs) are injuries and disorders of the soft tissues, muscles, tendons, ligaments, joints, and cartilage and nervous system. They can affect nearly all tissues, including the nerves and tendon sheaths, and most frequently involve the arms and back. The specific types of MSDs include such disorders as cumulative trauma disorders (CTDs),repeated trauma (RT), repetitive stress injuries (RSIs),and occupational overexertion syndrome (OOS).These painful and often disabling injuries generally develop gradually over weeks, months, and years. MSDs usually result from exposure to multiple risk factors that can cause or exacerbate the disorders, not from a single event or trauma such as a fall, collision, or entanglement (US Occupational Safety and Health Administration, 2000).

Manual handling causes over a third of all workplace injuries including MSDs. The term manual handling covers a wide variety of activities including lifting, lowering, pushing, pulling and carrying. If any of these tasks are not carried out appropriately there is a risk of injury (Health and Safety Executive, 2014).

To reduce the chance of injury, work tasks should be designed to limit exposure to ergonomic risk factors. Engineering controls are the most desirable, where possible. Administrative or work practice controls may be appropriate in some cases where engineering controls cannot be implemented or when different procedures are needed after implementation of the new engineering controls. Personal protection solutions have only limited effectiveness when dealing with ergonomic hazards (Center for Disease Control and Prevention (CDC), 2016).

Table 2.2 indicates the various types of MSD, the body parts affected symptoms, possible causes, predisposed workers and disease name and Table 2.3 gives the intervention to limit exposure to MSDs.

Table 2.1: Examples of Muskuloskeletal Disorders

Source: (Reese, 2009)

Body Parts Affected	Symptoms	Possible Causes	Workers Affected	Disease Name
thumbs	pain at the base of the thumbs	twisting and gripping	butchers, house keepers, packers seam stressers, cutters	De Quervain's disease
fingers	difficulty moving finger; snapping and jerking movements	repeatedly using the index fingers	Meat packers; poultry workers, carpenters, electronic assemblers	trigger finger
shoulders	pain, stiffness	working with hands above the head	power press operators, welders, painters, assembly line workers	rotator cuff tendinitis
hands, wrists	pain, swelling	repetitive or forceful hand and wrist motions	core making, poultry processing, meat packing	tenosynovitis
fingers, hands	Numbness, tingling, ashen skin, loss of feeling and control	Exposure to vibration	Chain saw, pneumatic hammer, and gasoline powered tool operators	Raynaud syndrome (white finger)

fingers, wrists	tingling, numbness, severe pain, loss of strength, sensation in the thumbs, index, or middle or half of the ring fingers	repetitive and forceful manual tasks without time to recover	meat and poultry and garment workers, upholsterers, assembly, VDT operators, cashiers	carpal tunnel syndrome
back	low back pain, shooting pain or numbness in the upper legs	whole body vibrations	truck and bus drivers, tractor operators, warehouse workers, nurses aides, bag handlers	back disability

Table 2.2: Interventions to limit exposure to ergonomic risks

Source: (Reese, 2009)

Type of Control	Workplace Example
Engineering Controls (implement physical change to the workplace, which eliminates or reduces the hazard on the job/task)	Use a device to lift and reposition heavy objects to limit force exertion Reduce the weight of a load to limit force exertion Reposition a work table to eliminate a long/excessive reach and enable working

	in neutral postures Use diverging conveyors off a main line so that tasks are less repetitive Install diverters on conveyors to direct materials toward the worker to eliminate excessive leaning or reaching Redesign tools to enable neutral postures
Administrative and Work Practice Controls (establish efficient processes or procedures)	Require that heavy loads are only lifted by two people to limit force exertion Establish systems so workers are rotated away from tasks to minimize the duration of continual exertion, repetitive motions, and awkward postures. Design a job rotation system in which employees rotate between jobs that use different muscle groups Staff "floaters" to provide periodic breaks between scheduled breaks Properly use and maintain pneumatic and power tools
Personal Protective Equipment (use protection to reduce exposure to ergonomics-related risk factors)	Use padding to reduce direct contact with hard, sharp, or vibrating surfaces Wear good fitting thermal gloves to help with cold conditions while maintaining

	the ability to grasp items easily

2.1.1.6 Psych-social Hazards

Maintenance workers may experience stress caused by the very nature of the maintenance work. According to (European Agency for Safety and Health at Work, 2010) stress might be caused by any or the combination of the following factors:

i. Time pressure – during maintenance work, the productivity of an organisation is frequently hindered and maintenance workers have to cope not only with the demands of the task in hand, but also with a sense of responsibility for the swift resumption of production and for workers waiting to resume their tasks. This problem is compounded when staff cut-backs have led to a decrease in number of maintenance workers available to deal with emergencies.
ii. Complex technology combined with non-routine situations.
    a. Communication problems – for example, working with contractors, or several contractors at the same site
    b. Working alone and in isolation.
    c. Irregular working hours such as shifts, weekend work, night work, or being on call
    d. Insufficient knowledge – as, for instance, when workers are not familiar with the building lay-out or the machines they have to use or to maintain.
    e. Insufficient training – when workers may not know how to perform certain maintenance tasks

2.1.1.7 High Pressure Lines and Equipment

Workers might be exposed to hazards from compressed gases or from high-pressure lines. Internal erosion of lines might result in leaks or line bursts, exposing workers to high-pressure hazards from compressed gases or from high-pressure lines. If connections securing high-pressure lines fail, struck-by hazards might be created (United States Occupational Safety and Health Administration, 2016). The equipment that generate high pressures at the well-site include air compressors, booster compressors, mud pumps and the hydraulic pump unit (HPU). When things go wrong, these types of equipment can cause serious injuries and even fatalities (Health and Safety Executive, 2012).

The API Recommended Practice for OSH for Onshore Operations (API RP 74) defines critical equipment is as equipment and other systems determined to be essential in preventing the occurrence of, or mitigating the consequences of an uncontrolled event. Such equipment may include pressure vessels, pressure relief devices, compressors, alarms, interlocks, and emergency shutdown systems. Critical equipment should be periodically inspected and tested as recommended by the manufacturer or in accordance with recognized engineering practices.

Confirming the point of pressurized gas leakage can be difficult. After a gas has leaked out to a level of equilibrium with its surrounding air, the symptoms of the leak may disappear. There are several methods of detecting pressure hazards (Goetsch, 2011):

i. *Sounds* can be used to signal a pressurized gas leak. Gas discharge may be indicated by a whistling noise, particularly with highly pressurized gases escaping through small openings. Workers should not use their fingers to probe for gas leaks as highly pressurized gases may cut through tissue, including bone.
ii. *Cloth streamers* may be tied to the gas vessel to help indicate leaks. Soap solutions may be smeared over the vessel surface so that bubbles are formed when gas escapes. A stream of bubbles indicates gas release.
iii. *Scents* may be added to gases that do not naturally have an odour. The odour sometimes smelled in homes that cook or heat with natural gas is not the gas but a scent added to it.

iv. *Leak detectors* that measure pressure, current flow, or radioactivity may be useful for some types of gases.

v. *Corrosion* may be the long-term effect of escaping gases. Metal cracking, surface roughening and general weakening of materials may result from corrosion.

2.1.1.8 Electrical and Other Hazardous Energy

Workers might be exposed to uncontrolled electrical, mechanical, hydraulic, or other sources of hazardous energy if equipment is not designed, installed, and maintained properly. Further, administrative controls such as operating procedures must be developed and implemented to ensure safe operations (United States Occupational Safety and Health Administration, 2016).

The power system of the geothermal drilling rig comprise the diesel generators, start-up compressor, variable frequency drives (VFDs), Silicon Controlled Rectifiers (SCRs) and means of transmission and distribution of electric power to the loads. The loads convert this electric energy into other forms of energy such as mechanical, hydraulic or optical energy. The plate 2.4 below shows diesel generators and the SCR room of one of the publicly owned geothermal drilling rigs.

Good practices in the operation of electrically powered equipment include keeping the equipment in a good technical condition and following the schedules for periodic measurement of its protection against electric shock.

Plate 2.4: Inside the Generator Sets Room (left) and SCR Room (right) in a GDC Rig in Menengai (note the ear defenders)

The following aspects of work organization should also be emphasized (Dz'wiarek, 2010):

i. Periodic training of employees
ii. Appointing only the persons with relevant permissions to perform all operations of electrical installations and devices
iii. Ensuring that the equipment is used for what it was intended
iv. Displaying tables and warning signs about the hazards of electric shock
v. Performing periodic inspection of non-mobile electrical devices at least once a month and in the following cases:
    a. Before starting the device after changes have been made to its electrical and mechanical parts or after any repairs have been done
    b. Before starting the device after a one-month (or longer) break in its operation
    c. Before starting the device after it has been transferred

d. While reporting all the repairs and inspections in the device maintenance book.

2.1.1.9 Machine Hazards

Oil and gas extraction workers may be exposed to a wide variety of rotating wellhead equipment, including Top drives and Kelly drives, drawworks, pumps, compressors, catheads, hoist blocks, belt wheels, and conveyors, and might be injured if they are struck by or caught between unguarded machines (United States Occupational Safety and Health Administration, 2016).

Risk is assessed based on the analysis of the hazardous situation for each mechanical hazard based on a method developed by (Myrcha & Gierasimiuk, 2010). It is estimated in terms of the probability of harm (injury or other health damage) and its severity. The probability of occurrence of harm depends on the following factors:

i. Frequency and/or duration of exposure to the hazard
ii. Possibility of hazardous events occurring
iii. Possibility of avoidance or reducing the harm; this depends on how rapidly the hazardous event could lead to harm (suddenly, quickly, or slowly)
iv. Practical experience and knowledge of workers, especially their awareness of risk and ability to avoid or limit harm (e.g. reflexes, agility)

The following characteristics can be used to estimate and categorize the probability of occurrence of harm originating from mechanical hazards:

i. Low Probability
   a. when frequency and exposure duration is low (occurrence less often than once in 6 months)
   b. the probability of the hazardous event occurring is low, that is, less than once a year

c. when the harm can be easily avoided

ii. High

a. when exposure occurs daily and the duration exceeds 2 hours
b. when the probability of the hazardous event occurring is very high, for example, a daily event
c. when the ability of harm avoidance is limited or the harm cannot be avoided at all

iii. Medium (all cases between high and low)

The following characteristics can be used to estimate and categorize the severity of harm:

i. *Minor*: When the consequences do not involve any sick leave, for example, slight injuries requiring no more than first aid
ii. *Moderate*: A significant injury or illness requiring more than first aid, but the worker is able to return to the same job
iii. *Serious*: Death or permanent disabling injury or illness (e.g. amputation)

Based on the aforementioned factors and using the three-level scale given in Table 2.4, one can determine the level of risk associated with a given mechanical hazard. The basic criterion for acceptable risk is conformity to the requirements specified in the corresponding regulations and standards. According to Polish OSH standard PN-N-18002 (2000), occupational risk is evaluated as follows:

i. High risk is considered unacceptable; that is, for current work, immediate action should be taken to reduce the risk, while planned works should be started only after the reduction of occupational risk.
ii. Medium and low risks are considered acceptable, but medium risk still leaves room for improvement.

The results of risk assessment can be used to determine the actions necessary to eliminate mechanical hazards or reduce associated occupational risk.

Table 2.3: Risk Matrix for Risk Assessment of Mechanical Hazards

Source: (Myrcha & Gierasimiuk, 2010)

Severity of Harm	Probability of Occurrence of Harm		
	High	Medium	Low
Serious	High risk	High risk	Medium risk
Moderate	High risk	Medium risk	Low risk
Minor	Medium risk	Low risk	Low risk

Measures to eliminate or reduce risks related to mechanical hazards include the following:

i. Suitable design (inherently safe design)
ii. Safeguards to protect persons from mechanical hazards that cannot be eliminated
iii. Additional measures to decrease the risks related to mechanical hazards (PPE)

2.1.1.10Occupational Noise Hazard

The principal subsidiary legislation used is the Noise Prevention and Control Rules of 2005 which provides the under permissible noise levels:

i. that no worker shall be exposed to noise in excess of the continuous equivalent of 90dB(A) in eight hours within any 24 hours duration
ii. that no worker shall be exposed to noise in excess of 140dB(A) peak sound level at any given time
iii. noise transmitted outside the workplace shall not exceed 55dB(A) during the day and 45dB(A) during the night

iv. where noise exceeds 85dB(A), the occupier must develop noise control and hearing conservation programme as specified in the regulations and which shall be reviewed annually to determine its effectiveness

For environmental noise the principal legislation is the Noise and Excessive Vibration Pollution Control Regulations of 2009 under EMCA, 1999 (GOK, 1999). In a high noise installation such as a drilling rig, (Health and Safety Executive, 2012) recommends carrying out a risk assessment to decide what action is needed, and develop a plan. A noise risk assessment transcends more than just taking measurements of noise. Specifically, it should:

i. identify where there may be a risk from noise and who is likely to be affected;
ii. contain an estimate of your employees' exposures to noise (see 'Noise exposure levels');
iii. identify what you need to do to comply with the law, e.g. whether noise-control measures and/or personal hearing protection are needed, or whether working practices are safe; and
iv. identify any employees who need to be provided with health surveillance and whether any are at particular risk.

When the hearing organ is exposed to excessive noise, the hearing threshold is raised. This effect may be *reversible*, a temporary threshold shift, or *permanent*, after many years of dangerous exposure, and may occur in different frequency ranges. In both cases, the symptom is difficulty in hearing. A temporary threshold shift diminishes after the noise ceases; a permanent threshold shift is irreversible and does not show any recovery over time. A permanent threshold shift is an irreversible damage to the hearing organ. The risk of permanent hearing damage begins when the sound level exceeds 80–85 dB (A). Moreover, continuous exposure to noise is more harmful than interrupted exposure, because hearing regeneration can begin even during short interruptions (Taylor & Francis Group, 2010).

Non-auditory noise effects are not yet fully recognized. Examples of non-auditory physiological responses include motor reflexes, such as muscle contractions, which change the body posture after an unexpected signal such as an explosion or a shot, and the reactions of other systems, such as the reduction of the respiratory rate, contraction of the peripheral blood vessels, and decreased intensity of intestinal peristalsis (Taylor & Francis Group, 2010).

The methods for preventing, eliminating, or limiting noise exposure are based upon the simultaneous application of technical, administrative, and organizational solutions, which are selected based on a detailed analysis of the acoustic conditions at workstations with excessive noise. The most significant technical solutions that limit noise include the following (Taylor & Francis Group, 2010):

i. Use of low-noise technological processes.
ii. Mechanization and automation of technological processes including remote and automatic control devices for noisy machines.
iii. Construction and application of low-noise or noiseless machines, devices, and tools.
iv. Proper layout of the plant and adaptation of rooms, taking into account the acoustic aspects.
v. Use of noise control devices such as silencers, enclosures, screens, and sound-absorbing materials and systems as illustrated in Figure 2.1.
vi. Use of structure-related sound insulation (vibration isolators and vibroisolated foundations of machines and devices).

Noise reduction after the construction of the plant and the installation of machines and devices or during the full-scale operation stage is not only much more difficult, but also much less efficient, leading to only a slight reduction of noise at a relatively high cost. Moreover, the necessary alterations or adaptations are not always favourable to the technological process applied (Taylor & Francis Group, 2010).

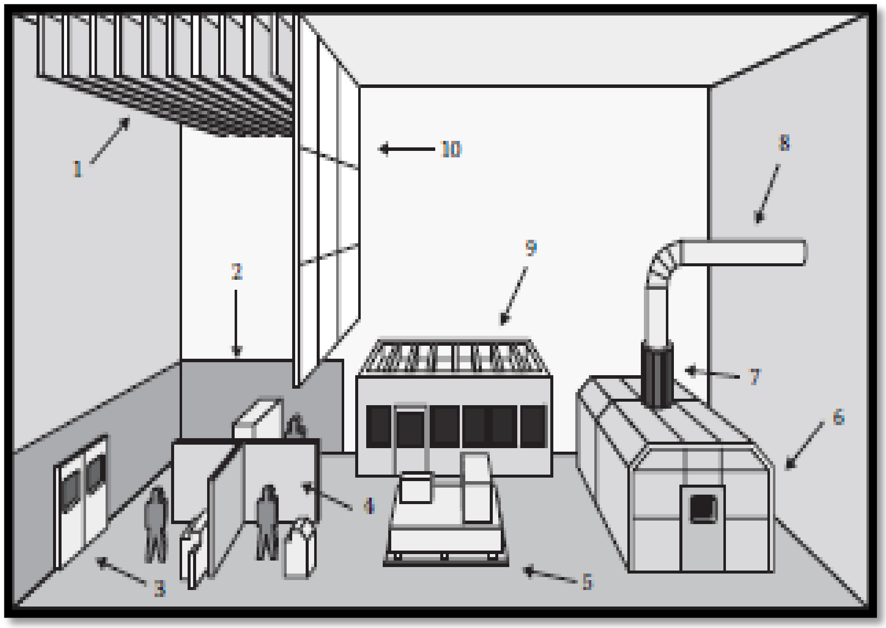


Figure 2.1: Noise control measures at work stations

Source: (Taylor & Francis Group, 2010)

From fig. 2.1: (1) absorbers, (2) sound-absorbing materials, (3) soundproof doors, (4) screens, (5) vibration isolation, (6) enclosure, (7) silencer, (8) sound isolated pipeline, (9) sound-insulating cabin and (10) sound-absorbing system.

2.1.2 Plant Safety Programmes

In order to ensure safety of the process plant, a comprehensive maintenance programme should be in place to certify, inspect, and where necessary, calibrate equipment and instruments. This programme should include (American Institute of Chemical Engineers, 1995):

i. Testing and inspection -The Equipment and materials control programme should be able to verify that :
    a. Equipment, spare parts, components, tools and materials as received meet purchase specifications
    b. Equipment, spare parts, components, tools and materials in storage still satisfy requirements
ii. Calibration - Faulty calibration of equipment may allow a plant to operate in a hazardous manner. The control programme should therefore include the proper facilities and schedule for periodic inspection and calibration.
iii. Preventive maintenance – The preventive maintenance programme should include preventive measures that recognise the limited life of plant equipment and recommend service or decommission before it fails and create a hazard.

There are certain types of inspection and maintenance work in a geothermal drilling site that is hazardous and therefore requires special precautions. Some of these activities include:

i. Plant modifications– requires a Change Control Programme
ii. Working in confined spaces – requires a Permit-To-Work Programme
iii. Working on equipment that can be inadvertent started by unauthorised or malicious personnel – requires an Equipment Lockout System
iv. Opening of closed vessels and pipelines – requires Work Authorization System
v. Working with hazardous materials – requires extra measures to prevent workers involved in installation, renovation or maintenance work.
vi. Welding – as the most common ignition source in many plants, it requires extra precautions to ensure safety of workers.

The plant safety programme should also include a robust Contractor Safety Programme so that the gains made by the in-house team are further consolidated and not compromised by the outside contractors.

According to European Standard EN 13306, maintenance concerns ‘the combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function’. A maintenance function is critical to:

i. ensure continuous productivity
ii. produce products of high quality
iii. Maintain a company’s competitiveness.

Maintenance also contributes significantly to occupational safety and health. Maintenance influences the safety and health of workers in two ways. First, regular maintenance that is correctly planned and carried out is essential to keep both machines and the work environment safe and reliable. Second, maintenance itself has to be performed in a safe way, with appropriate protection of maintenance workers and others present in the workplace (European Agency for Safety and Health at Work, 2010).

Three different types of maintenance can be distinguished:

i. Corrective maintenance, i.e. maintenance carried out after fault recognition and intended to put an item into a state in which it can perform a required function. In this case, maintenance actions are intended to restore a system from a failed state to a working state, i.e. to restore the functional capabilities of failed or malfunctioned systems. This involves, for example, repair or replacement of failed components. This type of maintenance is also known as ‘reactive maintenance’ because the action is initiated when there is an unscheduled event of equipment failure
ii. Preventive maintenance, i.e. maintenance carried out at predetermined intervals or according to prescribed criteria intended to reduce the probability of failure or the degradation of the functioning of an item. In this case, actions are scheduled, proactive and intended to control the deterioration process leading to failure of a

system. They are carried out to either reduce the likelihood of a failure or prolong the life of the component by, for example, performing replacement, lubrication, cleaning or housekeeping and inspection.

iii. Change/ Modification maintenance, i.e. it concerns large-scale maintenance carried out to allow an item to accomplish new or additional functions, or the same function in better conditions. It is frequently carried out during shutdown (an outage scheduled in advance) of the item. The actions performed concern, for example, modification, rebuilding, modernisation or renovation of the equipment or system.

While maintenance of the drill rig equipment is absolutely essential to ensure safe and healthy working conditions, the maintenance work itself can pose serious health and safety risks if not properly managed. Maintenance work may cause additional hazards, e.g. fire, machine guards removed, slips trips and falls, which need to be assessed to eliminate or reduce the risk of injury or ill health (Health and Safety Authority, 2016). Occupational accidents during maintenance work are numerous. Based on the data from several European countries, it is estimated that 10-15% of fatal accidents at work, and 15-20% of all accidents, are connected with maintenance. In Germany, where more than 15% of the workforce is employed in maintenance, about 20% of all fatalities occurred during maintenance work in 2001. Approximately 50% more accidents happen during maintenance work than during normal production. These accidents often result in severe injuries and prolonged time off work. Maintenance workers are not only at risk of being involved in a work-related accident, but also of developing occupational diseases. (European Agency for Safety and Health at Work, 2010). Further, lack of maintenance or inadequate maintenance can also lead to dangerous situations, accidents and health problems (European Agency for Safety and Health at Work, 2010).

According to (European Agency for Safety and Health at Work, 2010), maintenance is one of the most subcontracted functions in industry. In a bid to free themselves so as to focus on their core mandates, many companies have decided to outsource some functions or departments that were hitherto integrated into their structure. The main thrust for this strategy is to allow for specialisation while cutting down on the maintenance costs.

According to (European Agency for Safety and Health at Work, 2010), maintenance operations involve some specific risks over and above those associated with any working environment. These include working alongside a running process and in close contact with machinery. During normal operation, automation typically diminishes the likelihood of human error that can lead to accidents. In maintenance activities, contrary to normal operation, direct contact between the worker and machine cannot be reduced substantially - maintenance is an activity where workers need to be in close contact with processes. Maintenance often involves unusual work, non-routine tasks and it is often performed in exceptional conditions, such as working in confined spaces. Maintenance operations typically include both disassembly and reassembly, often involving complicated machinery. This can be associated with a greater risk of human error, increasing the accident risk. Maintenance involves changing tasks and working environment. This is especially true in case of contract workers. Subcontracting is an aggravating factor in terms of safety and health – numerous accidents and incidents relate to subcontracting maintenance. Working under time-pressure is also typical for maintenance operations, especially when shutdowns or high-priority repairs are involved. Thus it is vital for maintenance workers to be well informed about occupational risks. They should be provided with the appropriate work equipment, protection equipment, and work procedures (European Agency for Safety and Health at Work, 2010).

2.1.2.1 Testing and Inspection Techniques

Plant equipment and materials must be inspected in order to reveal defects that would prevent safe operation. Where this inspection is a function of the safety department or production department, close liaison must be maintained with maintenance for the immediate correction of deficiencies (Dabbs, 2008). Table 2.5 lists the various types of defects and their origins (Factory Mutual Engineering Corp., 1967). Table 2.6 describes the frequently used non-destructive testing (NDT) techniques and lists their advantages and disadvantage (Sandier & E. T. Luckiewicz, 1988).

2.1.2.2 Equipment Calibration

If a process plant is to operate safely, the instruments used to control and inspect process systems must be periodically calibrated. Even equipment purchased to a detailed specification may not operate as specified for one reason or another and must therefore be monitored in the early stages of operation to determine whether recalibration is necessary.

Failure to calibrate may result in failure to detect unsafe operating conditions. Some devices are especially critical to the safety of an operation. These critical devices fall into three categories (Dabbs, 2008):

i. Equipment designed to warn or to reduce the possibility of unsafe operation e.g. combustible gas analyzers, toxic gas analyzers, oxygen analyzers, vibration analyzers and radiation monitors
ii. Equipment designed to maintain operation within specified conditions e.g. temperature sensors, level sensors, pH and specific ion sensors, dew point/relative humidity sensors, analyzers, such as gas chromatographs, vibration sensors, RPM sensors, pressure/vacuum sensors, flow sensors, conductivity sensors, strain gauges and turbidity/smoke detectors
iii. Equipment used to calibrate items listed above and to inspect piping and process equipment for flaws e.g. electrical test equipment (signal tracers, multi-meters, power supplies, etc.), temperature calibrators, ultrasonic detectors, portable gas detectors, ground resistance testers, pressure/vacuum calibrators, X-ray detectors and sound level monitors

Table 2.4: Origins and types of equipment defects

Source: (Factory Mutual Engineering Corp., 1967)

No	Origin	Type of equipment defect
1	Raw material defects	stress cracking
		gas porosity
		slag inclusion
		shrinkage porosity
2	Defects prodiuced during manufacture	welding defects
		machining defects
		heat treating defects
		residual stress cracking
3	Defects produced during assembly	additional welding defects
		missing parts
		incorrect assembly
		additional stress cracking
4	Defects produced during service	wear
		thermal degradation
		creep
		fatigue
		corrosion

Table 2.5: Non-destructive testing techniques

Source: (Sandier & E. T. Luckiewicz, 1988)

Technique	Advantages	Disadvantages
Radiographic: Used to examine the internal soundness of weldments and metals by bombarding the piece with x-rays or gamma rays.	Sharp picture of defects. Film provides a permanent record	Special personnel protection and training required. Both sides of the piece must be accessible.
Ultrasonic: Uses high-frequency sound waves to locate defects.	Very sensitive; can detect very fine surface and subsurface cracks. Equipment is portable Only one side need be accessible.	Personnel must be trained to interpret equipment response. Not effective on rough surfaces or welds with backing rings.
Magnetic particle: Used to find surface defects by applying a liquid suspension of fine particles that flow into fine cracks. A strong magnetic field concentrates the particles in the area of the defect, highlighting its size and shape.	Shows fine cracks that are not noticeable in radiographic examination. Shows where and what material must be removed for weld repair.	Cannot be used on nonmagnetic material. Detects surface cracks only. Cannot detect defects parallel to the magnetic field.
Dye-penetrant: Used for surface defects. A liquid dye is applied to a clean, dry surface and allowed to penetrate surface cracks and dry. A developer put over the surface causes the dye to outline the defect clearly.	Useful for nonmagnetic materials. Can be used on nozzles and surfaces difficult to inspect radiographically.	Detects surface defects only. Not practical on rough surfaces.

2.1.2.3 Preventive Maintenance Programme

A comprehensive preventive maintenance program will include predictive maintenance, time-driven maintenance tasks, and corrective maintenance to provide comprehensive support for all plant production or manufacturing systems (Mobley, 2008). Work performed on a routine rather than emergency basis will usually be safer, cheaper, more effective and of higher quality. Predictive maintenance techniques use evaluation of the actual operating condition of equipment to determine the need for maintenance. Periodic analysis of lubricating oil, for example, can be used to forecast the time at which it should be changed. Examination of the metallic particles found in the oil can reveal the type of wear which is occurring in machinery and help skilled maintenance technicians to identify a developing problem before it becomes critical.

The size of the plant and the nature of its organization will determine whether it is better to gather all maintenance information into a central comprehensive set of dedicated maintenance manuals or to file it by equipment item as part of the operating manuals. The maintenance information should cover the following(Health and Safety Executive, 2013):

i. maintenance procedures
ii. troubleshooting guide
iii. spare part requirements and specifications
iv. use of special tools and equipment
v. preventive maintenance schedule for lubrication, cleaning, testing, calibration and replacement
vi. safety precautions such as personal protective equipment (PPE), Material Safety data Sheets (MSDS) for lubricants, chemical, solvents, etc. and special procedures

The assigned custodian of the maintenance manuals should see that they are:

i. available for all equipment. All relevant information for a particular piece of equipment should be in the appropriate file. This often requires cross-filing.
ii. kept in a secure location. Copies may be used locally, but a master file should be kept in a designated spot, away from the production area, available to all personnel who may be involved in maintenance work.
iii. up to date. Changes made in the plant should be reflected in the maintenance manuals. Information on new items or changes in procedure should be added,

and obsolete information should be purged. These changes should be communicated specifically to maintenance personnel; simply adding them to a maintenance manual is not enough.

Operating safety is enhanced by the maintenance of a well organized and adequately stocked inventory of equipment, spare parts, and tools. The proper volume of spares is a function of plant size and complexity and of the availability of parts from equipment vendors. Maintaining a quality inventory of spare parts, tools, and equipment requires careful scrutiny of all materials received into stores. Downtime not only reduces production but also can create hazards. Since maintenance work cannot always be planned, some minimum inventory of spare parts should be available for disbursement and routing to the trouble spot in the plant. All returns should be inspected for damage and defects before replacement in stores. Damaged items should be repaired or scrapped (American Institute of Chemical Engineers, 1995).

2.1.2.4 Change/ Modification Control Programme

"Change" as opposed to “Replacement” refers to a new or fundamentally different system or procedure. All true modifications must be well documented. No modifications should be permitted without prior authorization and follow-up documentation. Extensive or higher levels of change should require higher levels of authorization. A carefully planned and executed Change Control Program must be instituted to prevent the hazards that often arise from quick responses or reflex action. Plant personnel should immediately be made aware that a plant modification has been made. Its effects on operating and maintenance practices must be clear. Personnel should be trained before actually working with the modified equipment or procedure(American Institute of Chemical Engineers, 1995).

2.1.2.5 Equipment Lock Out/ Tag Out (LOTO) System

Whenever the inadvertent or unauthorized starting of a piece of driven equipment will create a hazard for inspection or maintenance personnel, it is important to disable that equipment while work is being performed. LOTO is used for controlling hazardous energies such as electrical, mechanical, hydraulic, pneumatic, chemical, thermal, and other energy sources. If its driver is a motor, the equipment is taken off line by opening a switch or breaker and locking it to prevent closure. The switch should be individually locked or tagged by each person or department involved with the work. At a minimum, this would include the direct operator of the equipment and the inspecting or maintenance group. The first lock applied, and the last removed, should be that of the organization responsible for the equipment. When the switch or breaker is first locked out, the production supervisor or operator should attempt to start the piece of equipment in question. This will verify that the correct switch has been disabled. The maintenance or inspection group should check with production before beginning work and should add their tags to the switch as appropriate. Each tag should be signed and dated. None should be removed except by the person who affixed it (or a delegate). Tags should be removed only when the responsible party is convinced that all work has been performed properly (American Institute of Chemical Engineers, 1995).

According to (Poseidon Maritime UK Ltd, 2004) LOTO isolations may be subject to risk assessment, Permit-To-Work (PTW) and to Job Safety Analysis (JSA). Further, methods of electrical and process/mechanical isolations should be implemented, understood, practiced, reviewed and updated as required at regular intervals. All personnel involved in maintenance and repair should be familiar with the systems and should adhere to the instructions pertaining to isolation of equipment undergoing tests, maintenance, repair or replacement. Figure 2.2 below shows examples of tags proposed by US OSHA standard for the Control of Hazardous Energy (Lockout/Tagout), Title 29 Code of Federal Regulations (CFR) Part 1910.147.

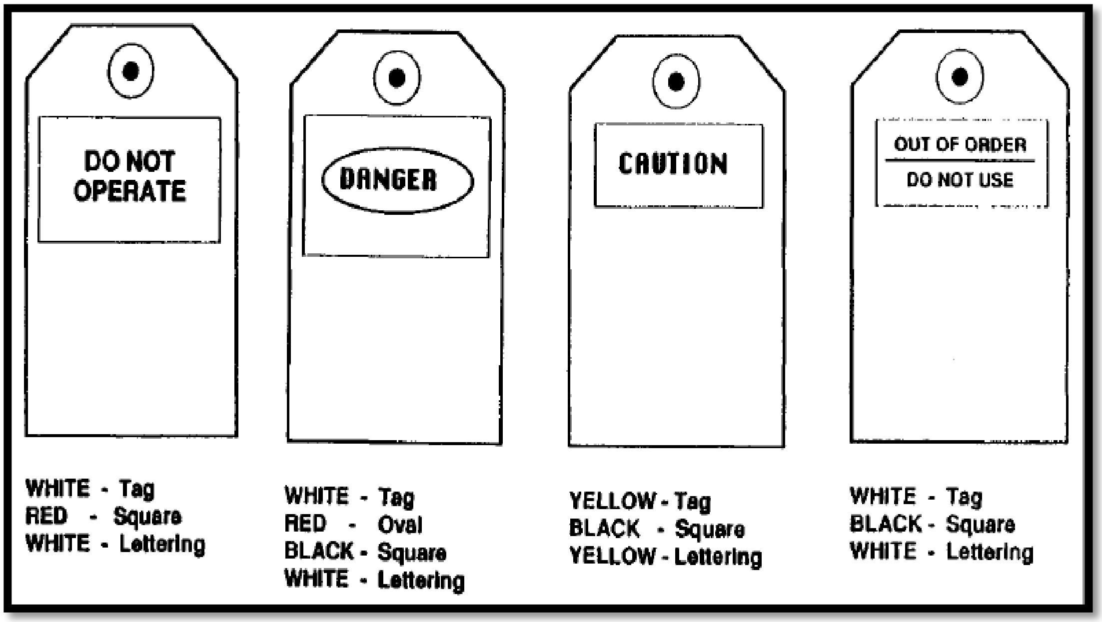


Figure 2.2: Accident Prevention Tags (US OSHA)

2.1.2.6 Permit to Work (PTW) System

A PTW system is a formal written system used to control certain types of work which are identified as potentially hazardous. It is also a means of communicating safety requirements between site/installation management, plant supervisors, contractors and operators and those who carry out the work. A PTW system should ensure that proper planning and consideration is given to the risks of a particular task. The permit is a written document which authorizes certain people to carry out specific work, at a certain time and place, and which sets out the main precautions needed to complete the task safely. An organization should assess the risks involved in activities and define specific operations and types of work which should be subject to PTW systems. PTW should be considered wherever it is intended to carry out any work which may adversely affect the safety of personnel, the environment or the plant. It is also advisable to use a PTW system when two or more individuals or groups of people, from different trades or different contractors, need to co-ordinate their activities to ensure that their work is completed safely(Poseidon Maritime UK Ltd, 2004).

Examples of work that should be performed only with a specific permit include the following(Fawcett & Wood, 1965): entry into a vessel or a confined space; work on rotating machinery; breaking into lines or removing components – pipelines, pumps or other line apparatus; opening of vessels or other equipment; hot work (welding, cutting, open flame); work with especially hazardous materials (handling procedures, material control, and personnel qualification); whenever electrical maintenance work is done in a hot (operating process) location.; bypassing of interlocks or other safety devices and instruments; specialized vehicle operation such as fork lift trucks, pay loaders, graders, excavators, cranes, bulldozers and transporters; disposal of hazardous waste; special excavation (contaminated soil; unstable soil conditions; underground power lines, pipelines or obstructions); unusual operations outside of normal working hours; unattended operation; fire sprinkler valve closing; and high work on scaffolds, platforms, pipe racks, or elevated equipment.

2.1.2.7. Emergency Response Management Plan

Emergency planning is part of an overall strategy for preventing and minimising the effects of major accidents to people and the environment. There are three basic parts of this major accident strategy, proposed by the Advisory Committee on Major Hazards of United Kingdom. This Committee was appointed by the Health and Safety Commission (subsequently merged with the Health and Safety Executive) to consider the problems of major accident hazards and to make recommendations, following the Flixborough accident of 1974. The three parts are (Health and Safety Executive, 1999):

(a) **Identification** - establishments holding more than specified quantities of dangerous substances should notify their presence to the enforcing authority;

(b) **Prevention and control -** by applying appropriate controls based on an assessment of the hazards, risks and possible consequences, the likelihood of a major accident can be minimised; and

(c) **Mitigation -** even with the best controls, major accidents would never be totally eliminated so the effects of any that do occur should be kept as small as possible. Emergency planning is one of the principal steps to achieving this.

An emergency response plan would be effective only if it is clearly understood by all participants. This happens if the plan is well-conceived, clearly written, made available to the interested parties, and then practiced. The benefit of drills cannot be overemphasized. The written plan should address (American Institute of Chemical Engineers, 1995):

i. company policy, purposes, authority, principal control measures, and emergency organization chart showing positions and functions
ii. description of potential emergencies with risk factors
iii. maps of plant and offices showing equipment, medical and first aid centers, fire control apparatus, shelters, command center, evacuation routes, and assembly areas
iv. central communications center, with information regarding cooperating agencies and emergency contacts
v. plant warning system
vi. visitor and customer handling
vii. emergency equipment and resource listings and locations specific procedures for response to defined events, including shutdown procedures for operation and support functions
viii. training plans and schedules

2.1.2.8Personal Protective Equipment (PPE) Programme

Personal protective equipment (PPE) belongs to the group of protective devices that directly protect a worker against hazards in the work environment. Before deciding to use PPE, all possible technical and organizational measures to eliminate the risk at the source must be undertaken. When efforts to completely eliminate hazards to life and health or to reduce their admissible values do not succeed, that is, the concentration or intensity values of harmful factors present at workstations are still higher than is permissible, the use of PPE is the final barrier for the worker (Taylor and Francis Group, LLC, 2010).

PPE can be categorized as follows, based on the scope of protection:

i. Protective clothing
ii. Hand and foot protection
iii. Head protection
iv. Hearing protection
v. Eye and face protection
vi. Respiratory protection
vii. Equipment protecting against falls from a height

The need to use PPE in the work environment means the employer must implement an appropriate system for PPE selection with regard to the hazards, the correct use of the PPE and the level of protection it provides. According to (Taylor and Francis Group, LLC, 2010), a suitable PPE programme should include at least the following areas:

i. Risk assessment that would enable selection of the appropriate type of equipment and protection level (i.e. hazards identification, influence on the body, excess of exposure limits)

ii. Workstation characteristics, including the occupational activity of the worker, microclimate, space limitation, need for movement and communication, evacuation speed from the hazard zone, and additional hazards such as fire or explosion
iii. Participation of PPE users in the process of selecting technical solutions
iv. Continuous training for workers, with special attention to increasing awareness of the effects of not using PPE, understanding the instructions for use, practical adjustments in use, time limits, and problems that may occur during use
v. Marking areas where PPE must be used
vi. Ensuring the correct method of storage, maintenance, and necessary servicing
vii. Constant monitoring by audits of the PPE to ensure correct use, storage, technical conditions, and updating training

Ear Protection Equipment

There are two main types of hearing protection (Health and Safety Executive, 2015):

i. Earplugs: These fit into or cover the ear canal, to form a seal. They sometimes have a cord or neckband to prevent them being lost. They can be permanent (indefinite use), reusable (use only a few times) or disposable (use once);
ii. Earmuffs: These are normally hard plastic cups, which fit over and surround the ears. They are sealed to the head by cushion seals (filled with plastic foam or a viscous liquid). The inner surfaces of the cups are covered with a sound absorbing material, usually soft plastic foam. They can be headband or helmet mounted and some can have communication equipment built into them.

2.1.3 Noise Mapping

The National Institute for Occupational Safety and Health (NIOSH) estimates that 84% of carpenters, 77% of operating engineers, and 73% of construction workers are exposed to noise levels over the recommended limit (Berndt, 2018). Sudden or gradual hearing loss is not just a risk to workers health but to the employer too. Business productivity, reputation and legal standing can be eroded if proper mitigation measures are not put in place to protect workers from excessive noise. This implies that occupational noise should be part of the risk analysis and planning process for every employer.

According to (Berndt, 2018), accurate mapping using noise-mapping softwares can ensure that everything possible is done to mitigate excessive exposure in a cost-effective manner. Noise maps can depict noise levels in a straightforward way using coloured contour lines and facade dots according to user set scale, so that the best option is clear. This allows for simulations to be done for various other rig activities and diverse combinations of machinery at the rig site. The noise maps show all the sources of noise and how it is dispersed, making it easier to establish key areas for mitigation measures. Other more sophisticated mapping and simulation softwares which give the option of developing "what-if scenarios" can also be deployed so that the noise impacts of developments or activities can be assessed in advance.

2.1.4 Occupational Safety and Health Management Systems (OSH MS)

The establishment of the occupational safety and health management system is the duty and responsibility of the employer and should therefore maintain the right tone at the top.

The International Labour Organisation defines OSH management system as a set of interrelated or interacting elements to establish OSH policy and objectives, and to achieve those objectives (International Labour Organization, 2001). These ILO OSH 2001 guidelines further report that the OSH management system should contain elements of policy, organizing, planning and implementation, evaluation and action for improvement.

The lack of ISO standards to certify OSH management systems had prompted a group of international private certification and consulting bodies to develop the documents

OHSAS 18001:1999 and OHSAS 18002: 2000. Prior to these standards, there was mixed and varied opinions about the effectiveness of formal OSH management systems(Pawlowska, 2004). However,(Podgorski, 2010) showed that systematic OSH management systems, if correctly understood and implemented, can have considerable benefits for the enterprise. A report by(Robson, et al., 2007), which was based on an analysis performed on nine different types of OSH management interventions, as described in scientific publications, clearly indicated that OSH management systems, if properly implemented, bring a number of benefits to enterprises, e.g.:

i. Reduced numbers of accidents at work and sickness absence days
ii. Reduced accident insurance premiums
iii. Better understanding of occupational risks among managers and employees
iv. Better safety climate and employee involvement in activities towards improvement of OSH
v. Improved productivity in the entire company

ISO has developed ISO 45001:2018, *Occupational health and safety management systems – Requirements with guidance for use.* This standard is based on earlier international standards such as OHSAS 18001, ILO-OSH Guidelines 2001, various national standards and the ILO's international labour standards and conventions. ISO has also published the complementary technical specification – ISO/IEC TS 17021-10, *Conformity assessment – Requirements for bodies providing audit and certification of management systems – Part 10: Competence requirements for auditing and certification of occupational health and safety management systems*, which define the required skills and knowledge of those bodies auditing organizations that have implemented the health and safety standard.

2.2 Legal, Regulatory and Institutional Framework on Occupational Safety and Health

2.2.1 Kenyan framework

The principal OSH legislation in Kenya is the Occupational Health and Safety Act (OSHA) of 2007 and it is supported by the Work Injury Benefits Acts (WIBA) of 2007. The OSHA 2007 replaced the Factories and Other Places of Work Act (Cap. 514) which was legislated and found to be inadequate in provision for safety and health of workers in all workplaces. The WIBA 2007 repealed the Workman's Compensation Act thereby introducing a legal framework which is compliant with the International Labour Organisation (ILO) conventions with regard to the compensation of employees, ensuring adequate compensation for employees who are injured at work or who contract work-related diseases and to extend insurance cover to all employees.

The OSHA 2007 is applicable to all workplaces where any person is at work, whether temporarily or permanently. Section 3(2) of OSHA 2007 gives the purpose of the Act to include the following:

i. Secure the safety, health and welfare of persons at work: and
ii. Protect persons other than persons at work against the risks to safety and health arising out of, or in connection with, the activities of persons at work.

The OSHA 2007 (GOK, 2007) gives provisions relating to general duties of occupiers, registration of workplaces; general and specific provisions relating to occupational safety, health and welfare; machinery safety provisions; chemical safety provisions; provisions for special applications and other pertinent miscellaneous provisions. Further it describes the offences under the Act and prescribes penalties for them.

Part VII of OSHA 2007 is dedicated to machinery safety. Section 55 provides that "All plant, machinery and equipment whether fixed or mobile for use at the workplace or as a workplace, shall only be used for work which they are designed for and be operated only by a competent person.” The drilling rig being a mobile workplace is therefore legally mandated to be operated by competent personnel only. This underscores the important of continuous training. Specific provisions are provided for safe maintenance and operation of equipment such as prime movers, transmission machinery, handheld power tools and equipment, self acting machines, hoists, cranes and other lifting equipment, steam boilers, steam receivers/ containers, compressed air receivers, cylinders for compressed liquefied and dissolved gases and refrigeration plants.

The administration of the Act is the mandate of the Director of the Directorate of Occupational Safety and Health Services (DOSHS), a state department under the Ministry of Labour. The Act also creates the National Council for Occupational Safety and Health whose mandate is to advise the Cabinet Secretary on, among other duties:

i. the formulation and development of national occupational safety and health, policy framework;
ii. legislative proposals on occupational safety and health, including ways and means to give effect to International Labour Organization Conventions (ILO), and other international conventions and instruments relating to occupational safety, health, compensation and rehabilitation services;

The OSHA 2007 is enforced by Safety Officers from the Directorate of Occupational Safety and Health Services (DOSHS).

Section 127 of OSHA 2007 empowers the sitting Cabinet Secretary of Labour, in consultation with the National Council for Occupational Safety and Health to make regulations which are necessary or expedient in the advancement of the purposes of the Act. This is the legal basis for the existence of the body of subsidiary legislation that addresses specific requirements for occupational safety and health. Table 2.1 below highlights the subsidiary legislation supporting the OSHA 2007.

The WIBA 2007 (GOK, 2007) is applicable to all employees, including employees employed by the Government, other than the armed forces,in the same way and to the same extent as if the Government were a private employer.

The Article 41 (2b) of the bill of rights of the Constitution of Kenya that was promulgated in 2010, grants every worker the right to reasonable working conditions (GOK, 2010).

Article 2 (5) provides that, "*The general rules of international law shall form part of the law of Kenya."*

Article 2 (6) provides that, "*Any treaty or convention ratified by Kenya shall form part of the law of Kenya under this Constitution."*

The fact that Kenya is a member of the ILO and has ratified all the OSH instruments, implies that by all the OSH conventions, protocols and recommendations are therefore part and parcel of the laws of Kenya. It is therefore mandatory for the government, employers and workers to comply with them.

2.2.2 International OSH Standards

The International Labour Organisation (ILO) standards on OSH provide tools for governments, employers and workers to establish such practises and provide for maximum safety at work (International Labour Organisation, 2016).

The types of instruments that ILO uses include international conventions, international protocols and codes of practices. ILO websites lists the following as the OSH instruments that ILO has issued so far:

i. C155 - Occupational Safety and Health Convention, 1981 (No. 155)
ii. P155 - Protocol of 2002 to the Occupational Safety and Health Convention, 1981

iii. R164 - Occupational Safety and Health Recommendation, 1981 (No. 164)
iv. C161 - Occupational Health Services Convention, 1985 (No. 161)
v. R171 - Occupational Health Services Recommendation, 1985 (No. 171)
vi. C187 - Promotional Framework for Occupational Safety and Health Convention, 2006 (No. 187)
vii. R197 - Promotional Framework for Occupational Safety and Health Recommendation, 2006 (No. 197)
viii. R097 - Protection of Workers' Health Recommendation, 1953 (No. 97)
ix. R102 - Welfare Facilities Recommendation, 1956 (No. 102)
x. R194 - List of Occupational Diseases Recommendation, 2002 (No. 194)

Table 2.6: Subsidiary legislation under Occupational Safety and Health Act, 2007

Item	Subsidiary Legislation	Purpose
1	First Aid Rules, L.N. 666 (1963)	Specifies the required contents of First-Aid box or Cupboard
2	Factories (Form of Abstract) Order	Requires workplaces to display the abstract of the Act conspicuously
3	Factories (General Register) Order	Enforces subsection (1) of section 62. Register "L.D. Form 206" from the Government Printer
4	Safety and Health Committee Rules, 2004	Enforces participation of employees in occupational safety and health
5	Medical Examination Rules, 2005	Enforces occupational health of workers in high exposure occupations
6	Noise Prevention and Control Rules, 2005	Enforces hearing protection at the workplace
7	Fire Risk Reduction Rules,	Enforces occupiers to take proactive measures to detect and prevent fires and

	2007	reduce loss due to fire outbreaks
8	Hazardous Substances Rules, 2007	Ensures that exposure of hazardous substances does not exceed the exposure limits set Schedule 1
9	Examination of Plant Order, L.N. 666/1963	Regulations for enforcing part VII: Machinery Safety

2.3Previous works related to the study

The Health and Safety Executive, Offshore Safety Division that is concerned with influencing the duty holder to identify and reduce the risk to personnel on offshore installations and certain other vessels and pipeline operations carried out a study aimed at identifying reportable offshore incidents which have occurred during maintenance activities and may be related to maintenance having not been done, or done incorrectly. The study involved analysis of1,971 accidents and incidents on off-shore drilling activities over a period a three year period from 1989 to 1991. The findings showed that around 15% of incidents occur during maintenance, and a further 30% occur following maintenance. These kinds of accidents involved over 100 people per year (i.e. 326 fatal accidents in total or two fatal accidents per week(Health and Safety Executive, 1996).

The European Agency for Safety and Health at Work (EU OSHA), carried out a literature review on exposure of maintenance workers to different risks using information from the National Spanish Survey of Working Conditions. It reported that although based only on data from Spain, the analysis is unique and can be assume to infer the situation in other European countries. This report, (European Agency for Safety and Health at Work, 2010), further details unique data on occupational accidents from

EUROSTAT, which are not published elsewhere and are based on the European Statistics on Accidents at Work (ESAW) methodology. These data, although covering only a few European countries, demonstrate the high level of accident statistics for maintenance workers.

The EU OSHA in their report on "Safe maintenance in practice", (European Agency for Safety and Health at Work, 2010), presented a selection of good practice case studies focusing on the safety and health and protection of the maintenance workers themselves. It is reported that many companies, insurers and authorities have successfully developed solutions to improve safety and health during maintenance. The new approaches presented in this report demonstrate clearly that good occupational safety and health (OSH) management practices are at the heart of reliable and safe maintenance.

A recent study on occupation and safety on construction sites in Nairobi (Kemei, Kaluli, & Kabubo, 2019), found out that the lack of investment in health and safety by management, lack of training and failure to enforce laws on health and safety are the three leading causes of accidents.

In (Gikunju, Njogu, & Makhonge, 2017), the results demonstrated that levels of exposure to ambient hydrogen sulphide (H_2S) were below OEL of10 ppm for a shift of 8 hrs set by the World Health Organisation (WHO). This study however did not consider the acute and fatal exposure of H_2S as it relates to working in enclosed spaces.

In a study that evaluated the noise pollution levels in the manufacturing sector in Thika District in Kenya (Mithaga, Gatebe, & Gichuhi, 2013), it was reported that magnitude of noise exposure to the workers in generator and production units of manufacturing industries was high and recommended strict enforcement of noise control regulations supported by necessary trainings, policies and personal protective equipments.

The review of literature did not reveal any studies relating to geothermal drilling activities in Kenya and Africa as a whole. Further, the studies are available only for offshore drilling installations and not onshore geothermal drilling.

3.1 Study design

This was a cross-sectional study that utilized a mix of survey study design, observational study design and field measurements to assess the effects of geothermal well drilling occupation on the safety and health status of workers in Geothermal Development Company. This mix design was selected as it presents an optimal opportunity to collect standardised and accurate qualitative data.

3.2 Study area and population

The study was carried out in GDC's Menengai geothermal site that lies within the East African Rift System (EARS)in Nakuru County in Kenya, located about 180 km Northwest of Nairobi, Kenya (highlighted by arrow in fig. 1.1).The study population was 150 workers involved in geothermal drilling operations categorised as drilling operations, drilling maintenance and drilling support services.

3.3 Sampling Method

Simple random sampling method was used to draw the study respondents from among the well site workers who were on duty during the data collection period. Each drilling rig operated a four-way shift rota and had its own assigned engineers, technicians, craftsmen and technicians.

3.4 Sample Size Determination

The Krejcie and Morgan equation for a finite population (Krejcie & Morgan, 1970)was used to estimate the critical sample size.

$$S = \frac{X^2NP\ (1-P)}{d^2(N-1) + X^2P\ (1-P)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .1$$

Where:

S = *Required Sample size*

X = *Z value (e.g. 1.96 for 95% confidence level)*

N = *Population Size*

P = *Population proportion (expressed as decimal) (assumed to be 0.5 (50%)*

d = *Degree of accuracy (5%), expressed as a proportion (.05); It is margin of error*

Therefore, $S = (3.8416 * 150 * 0.5(1-0.5))/\{[0.05 * 0.05(150-1)] + [3.8416 * \ 0.5(1-0.5)$

S = 108 (The number of respondents)

The required sample size was therefore 108.

3.5Research instruments

To determine the effectiveness and adequacy of the onsite plant safety programmes, data was collected using 108 structured questionnaires as in appendix 1 to provide information on demographics and further nine areas of operational safety: Lost Time Accidents; Inspection and Testing of Plant Equipment; Equipment calibration; Permit to Work (PTWs) system; Maintenance Safety; Equipment Lockout Tagout (LOTO) system; Emergency Response Plan; Personal Protective Equipment (PPE) programme; and Ergonomic and Psychosocial Factors. The data collection period covered the shift change period and therefore three out of the four shifts in each rig participated in the study. The distribution and collection of the questionnaires was strictly controlled to ensure that all the 108 issued questionnaires were received back. This was made possible by appointing volunteers in each rig to ensure accountability of every issued questionnaire.Where practically possible, the respondents were encouraged to complete the questionnaires in the presence of the researcher, mostly during operational breaks or shift change-over toolbox meetings, so that the researcher could be able to offer clarification when needed.

To measure the noise levels at the drill sites and map out the noise levels, a properly calibrated sound level noise meter (Model NL-42 and Serial No. 01161047) was employed to carry out general noise mapping of the entire workplace (Plate 3.1 and appendix V). With regard to averaging time value, noise was recorded using the Short-term averaging method (of 1 second) of particular significance for the assessment of unsteady and short-term noise, lasting several seconds (maximum A-weighted sound level). The well pad was divided into arbitrarily into equal 5 by 8 sectors and the researcher took noise measurement taken for each sector.

Plate 3.1: The noise meter used in the study

Source: Author

To determine the efficacy of the occupational safety and health management systems, a self appraisal checklist originally designed by the UK HSE (see Appendix 2) wasmodified to suit this research and utilized to audit and score the rig safety management system on eight auditable areas: policy, control, communication, co-operation, competence, performance measurement and review processes. This checklist had 70 check points covering all the 8 auditable areas. There were six checklists were used in the exercise; five were independently filled by the officers of the Quality and Safety Department and one by the Researcher. Thereafter the final scores were negotiated, agreed and owned based on evidence provided. The audit working papers were safely kept for subsequent verification should a need arise.

All the research instruments were applied after seeking consent from the management of GDC, guaranteeing anonymity and confidentiality of the data collected for the study. It was emphasized that this research was purely for academic interest and without economic or financial interests. The letter requesting GDC Management for permission to carry out the research is in Appendix 4. The letter approving the research is in Appendix 5.

3.6 Data processing, analysis and validation

After collection of the filled questionnaires from the respondents, they were sorted and serialized to allow for systematic analysis. Preliminary data editing was done by reading through the filled questionnaires with a view to spot any inconsistencies or errors which could have occurred during data collection. The primary data was then be coded and analyzed in IBM SPSS statistical software version 24 and MS Excel 2007 to derive differential statistics such as frequencies and Pearson’s rank order correlations. This information was presented in form of charts (figures) and tables.

The data from the noise level measurements was keyed in MS Excel 2007 and a contour plot of the noise distribution was generated and thereafter superimposed on the rig layout plan to generate the noise map.To assure reliability of the measurements, the tests were taken twice separately by the researcher and the assistant and the final reading was the average of the two measurements. This information was evaluated for compliance to the permissible levels given by the Noise Prevention and Control Rules of 2005. The results were used to identify and map out hazardous work-stations so as to advise on the noise control and hearing conservation programme.

The score of the audit or observation of the OSHMS collected using the self assessment checklist were tallied to give the total score for each of the eight (8) elements as well as the overall total score. This score was used give an indication of the efficacy of the OSH management system.

[illegible]

[illegible]

4.1 Participants Response Rate and Demographic Information

The distribution and collection of the questionnaires was strictly controlled to ensure that all the issued questionnaires were received back. This was made possible by appointing volunteers in each rig to account for every issued questionnaire. The analysis of the questionnaires is provided in section 4.2. In addition, six checklists were used in the exercise; five were independently filled by the officers of the Quality and Safety Department and one by the Researcher

4.1.1 Response Rate of the Questionnaires

A total of 108 employees from GDC participated in this study. All the questionnaires that were issued were received back giving a response rate was 100%. This is an indication that the respondents were willing to participate in the study. According to (Babbie, 2007), a response rate of at least 50% is considered adequate for analysis and reporting; a response of 60% is good; a response of 70% is very good; a response of 80% and above is excellent. Therefore this response was considered excellent.

4.1.2 Demographic Information of Respondents

Table 4.1 gives the demographic data of the study respondents in tabular format. Among the participants, majority were male, 91.7% and 8.3% were female. This indicates that geothermal drilling activities are a male dominated sector. This can be attributed to the manual nature of the work, remote workplace, and shift nature of work. All these are occupational risk factors. Manual work with high occupational risk exhibits similar demographics according to (Jeanne, 2007).

Table 4.1: Demographic data of study respondents

Source: Author

	Variable	Frequency	Percent	Cumulative Percent
1	**What is your sex?**			
	Male	99	91.7	91.7
	Female	9	8.3	100.0
	Total	108	100.0	
2	**What is your marital status?**			
	Single	16	14.8	14.8
	Married	91	84.3	99.1
	Divorced	1	.9	100.0
	Total	108	100.0	
3	**What is your age bracket?**			
	18 - 25 yrs	5	4.6	4.6
	>25 - 35 yrs	74	68.5	73.1
	>35 - 45 yrs	26	24.1	97.2
	>45 yrs	3	2.8	100.0
4	**What is your highest level of education?**			
	High school	24	22.2	22.2
	Diploma	57	52.8	75.0
	Degree	19	17.6	92.6
	Post graduate degree	8	7.4	100.0
	Total	108	100.0	
5	**Do you work in a shift?**			
	Yes	100	92.6	92.6
	No	8	7.4	100.0

	Total	108	100.0	
6	**Which title best describes your work?**			
	Engineer	22	20.4	20.4
	Technician	57	52.8	73.1
	Craftsman	17	15.7	88.9
	Artisan	12	11.1	100.0
	Total	108	100.0	
7	**How many years of experience do you have in maintenance work?**			
	< 3 yrs	28	25.9	25.9
	3 - 7 yrs	56	51.9	77.8
	> 7 - 10 yrs	15	13.9	91.7
	> 10 yrs	9	8.3	100.0
	Total	108	100.0	

As regards marital status of the respondents, 14.8% were single, 84.3% were married and 0.9% was divorced. Majority of the respondents were therefore married.

The study showed that 4.6% of respondents were between 18 and 25 years of age, 68.5% were between 25 and 35 years, 24.1% were between the ages of 35 to 45 years and a minority, 2.8% was over 45 years.

The study also sought to find out the highest level of education of the respondents. Out of the respondents 22.2% had attained High School; 52.8% had attained Diploma; 17.6% had degrees and 7.4% had Post-graduate qualifications.

The work designations or equivalents, showed that Artisans and Craftsmen were 26.8% of the participants, while Technicians were 52.8% and Engineers were 20.4%. This information closely matches the information on education level and indicates very strong correlation between education levels and work designations.

In this study, majority of the respondents were working in shifts, 92.6% and minority were not shift worker, 7.4%.

4.2 Adequacy and Effectiveness of onsite plant safety programmes (PSPs) at GDC

4.2.1 Lost Time Accidents (LTAs)

The study showed that most of the respondents, 82.4% have not been absent from work because of an occupational accident or disease. Only 17.6% have missed work because of occupational accidents or diseases. Table 4.2 illustrates the relationship between LTAs and years of working experience.

Table 4.2: Relationship between Lost Time Accidents and Years of Experience

		How many years of experience do you have in maintenance work?				Pearson Correlation
		< 3 yrs	3 - 7 yrs	> 7 - 10 yrs	> 10 yrs	N = 108
Have you ever been absent from work because of an occupational accident?	Yes	7	11	0	1	0.167*
	No	21	45	15	8	
Category Totals		28	56	15	9	N = 108

* Correlation is significant at 0.05 level (1-tailed)

The results of Table 4.2 show that LTA and Years of working experience have no statistically linear relationship ($p < .001$). The categories of respondents under three years experience have the greatest percentage of those who have been absent from work because of an occupational accident. This result does not affirm what was postulated by (Myrcha & Gierasimiuk, 2010) that the probability of occurrence of harm is affected by practical experience and knowledge of workers, especially their awareness of risk and ability to avoid or limit harm through reflexes and agility. This could be attributed to the fact that the geothermal drilling activities had been on-going for only 6 years which is not sufficient enough to support correlationships. However, the study found out that the category with the second highest years of experience (7 to 10 years of experience) had zero casualties. The 11% of respondents in the most experienced category also encountered LTA could be attributed to other factors such as the frequency and/or duration of exposure to the hazards that comes naturally with one becoming a veteran at the work place.

Table 4.3: Relationship between Lost Time Accidents and Section

		Which section best describes your work at the well site?			Pearson Correlation
		Drilling Production	Drilling Maintenance	Drilling Support Services	N = 108
Have you ever been absent from work because of an occupational accident?	Yes	14	0	5	.101
	No	45	21	23	
Categories Totals		59	21	28	N = 108

The results of Table 4.3 show that LTA and Work Sections have a no statistically linear relationship ($p < .001$). According to (European Agency for Safety and Health at Work, 2010), maintenance workers are not only at risk of being involved in a work-related accident, but also of developing occupational diseases. However in this study Maintenance section was found to have zero lost time accidents. The section that was most affected was drilling production (24%) followed by drilling support services section (18%). This can be attributed to the fact that the drilling equipment is still relatively new and there are not many corrective maintenance and shutdown jobs. Most of the jobs are the scheduled preventive maintenance jobs.

This finding is converse to the findings of (European Agency for Safety and Health at Work, 2010) that reported that maintenance accidents often result in severe injuries and prolonged time off work. The same study indicated that maintenance workers are not only at risk of being involved in a work-related accident, but also of developing occupational diseases.

4.2.2 Inspection and Testing of Plant Equipment and Materials

In this study 82% of the respondents agreed that the reliability of the well control system is always assured by regular inspection and testing. There were 9% who disagreed and a further 9% were unsure. The well control system is the one used to prevent a blowout hazard which ejects superheated steam, hot corrosive or acidic fluids and toxic gases into the rig floor which is the main working platform. A blow out is always fatal and may result to loss of lives and the rig. It is therefore critical that the reliability of this system is assured. This finding is indicative of an adequate and effective onsite plant safety intervention.

Is the reliability of well control system is always assured by regular inspection and testing?

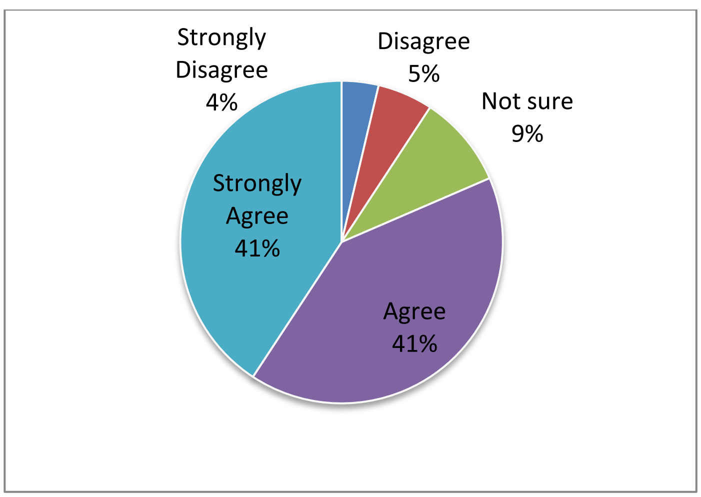


Figure 4.1: Inspection of Well Control System

Are high pressure systems (compressors, boosters etc) are periodically inspected and maintained as recommended by the OEM?

The results showed that 64% of the study participants agreed that high pressure systems such as compressors, boosters and hydraulic lines are periodically inspected and maintained as recommended by the Original Equipment Manufacturers. The remainder 36% is significant and is composed of 24% who are unsure and 12% who disagreed. Given that these systems are safety critical, the awareness towards this end needs improvement

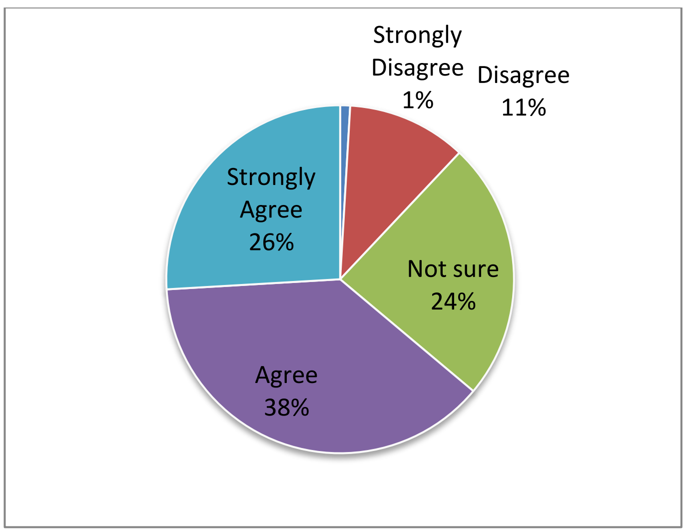


Figure 4.2: Inspection of high pressure systems

A risk assessment of the rig is done to determine the rig site hazards

The results of risk assessment empower the occupier with the necessary information on how to handle occupational risks and hazards. This study showed that 66% of the respondents agreed that indeed risk assessments are done at the rig site to identify potential hazards. The remainder 34% is made up of 18% who are unsure and 16% who disagreed. This statistic is indicative of moderate adequacy and more awareness is required.

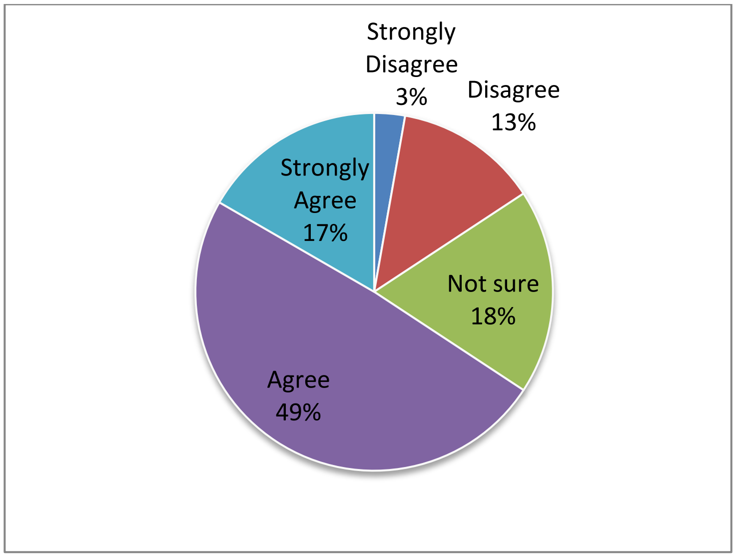


Figure 4.3: Risk assessments to determine work place hazards

4.2.3 Equipment Calibration

Figure 4.4 shows that most study respondents (59%) agreed that there is a schedule of calibration of critical measuring instruments. These instruments are used for plant parameters measurements and protection of workers against exposure to excessive energy and toxic gases. 25 % of the respondents indicated that they are not sure while 15% responded in the negative. These measuring instruments are critical in reducing the possibility of unsafe operation byindicating or warning. They include monitors, temperature sensors, level sensors, pH and specific ion sensors, dew point/ relative humidity sensors,analyzers, such as gas chromatographs, vibration sensors, RPM sensors, pressure/vacuum sensors, flow sensors, conductivity sensors, strain gauges and turbidity/smoke detectors. Another category of equipment is used to calibrate items listed above and to inspect piping and process equipment for flaws e.g. electrical test equipment (signal tracers, multi-meters, power supplies, etc.), temperature calibrators, ultrasonic detectors, portable gas detectors, ground resistance testers, pressure/vacuum calibrators, X-ray detectors and sound level monitors. combustible gas analyzers, toxic gas analyzers, oxygen analyzers, vibration analyzers and radiation

There is a properly enforced schedule for calibration of critical measuring instruments and dials?

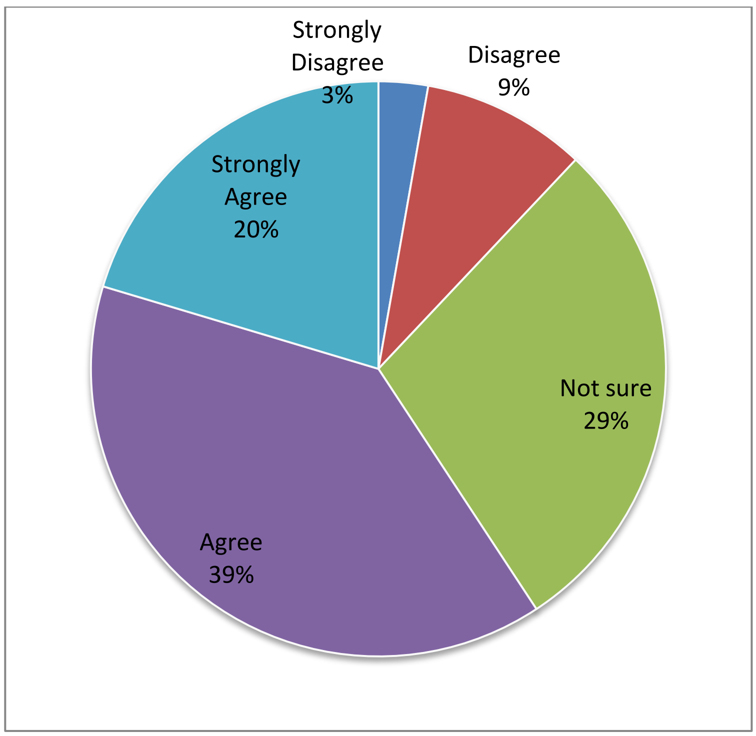


Figure 4.4: Equipment calibration

4.2.4 Permit to Work (PWT) System

Figure 4.5 shows that 51% of the study respondents agreed that there is a PTW system in place to control certain types of work which are classified as hazardous. This leaves a 49% of respondents who are collectively unsure (22%) or disagree (27%). A PTW is a written document which authorizes certain people to carry out specific work, at a certain time and place, and which sets out the main precautions needed to complete the task safely. This system is advised by proper planning and a prior risk assessment of the operation in question. PTW should be considered wherever it is intended to carry out any work which may adversely affect the safety of personnel, the environment or the plant. The PTW system is also advisable in workplace that has multiple vendors or contractors and therefore need for proper coordination of their activities to ensure that work is completed safely (Poseidon Maritime UK Ltd, 2004). The result indicates that this system needs to be enhanced to increase operational safety at the rig site.

There is a Permit to Work (PTW) System in place that is used to control certain type of work which are identified as potentially hazardous

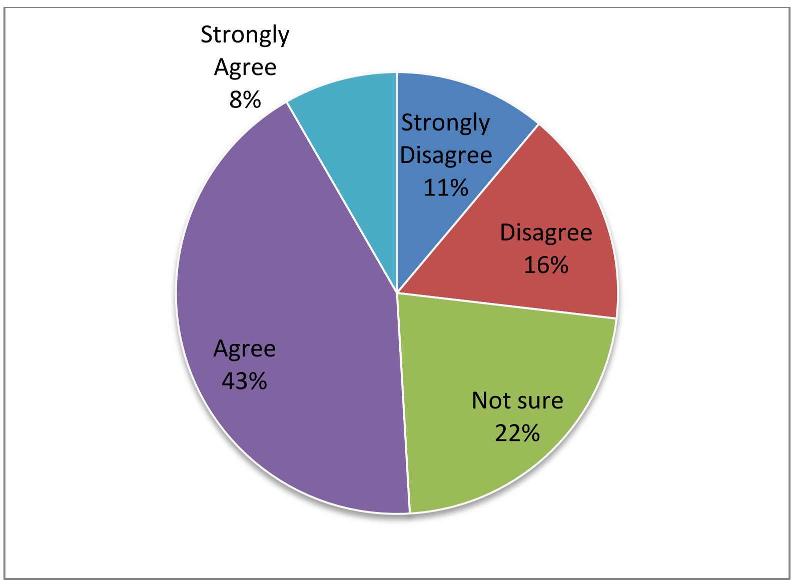


Figure 4.5: Permit to Work (PTW) system

4.2.5 Plant Maintenance Safety Programme

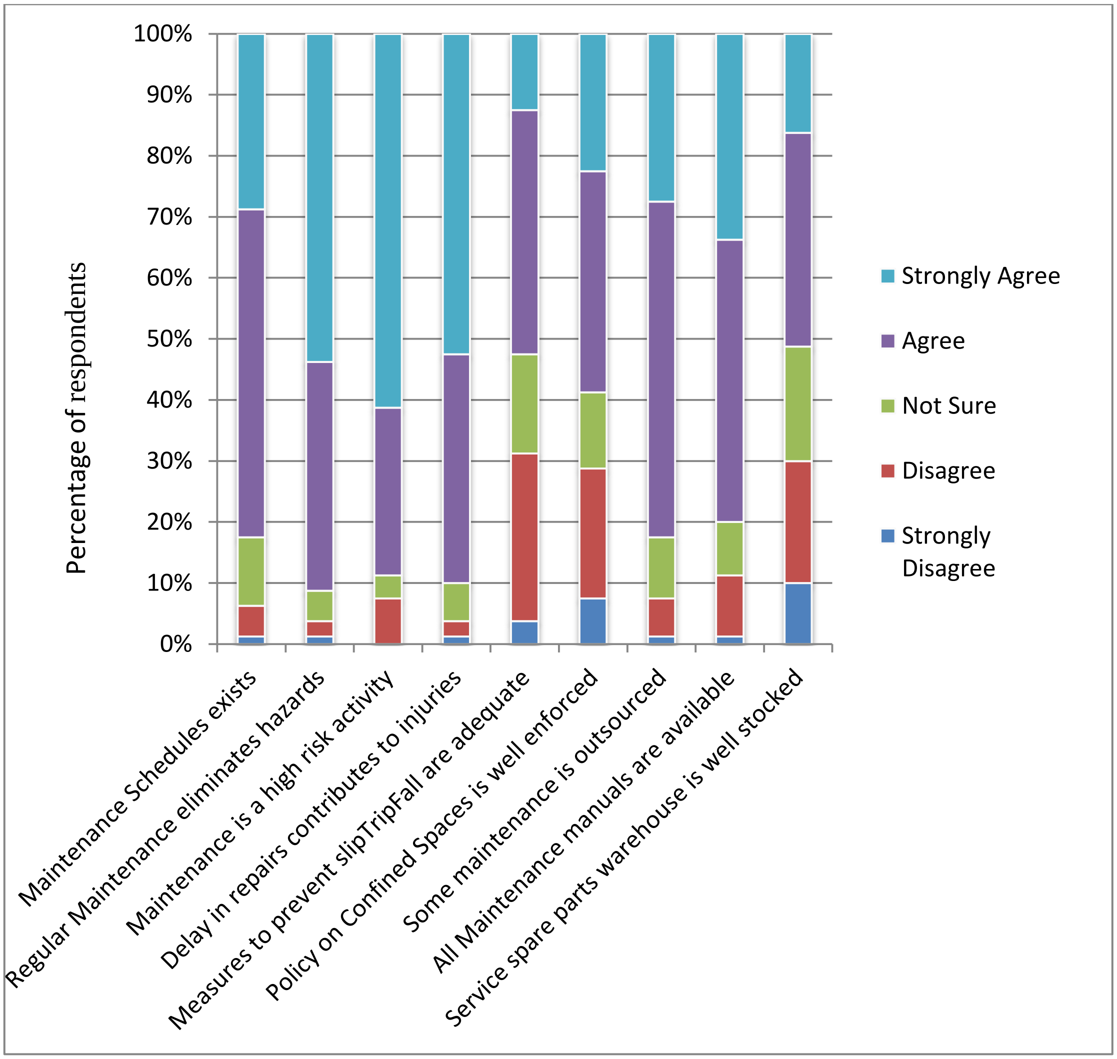


Figure 4.6: Maintenance Safety Considerations

Figure 4.6shows that majority of the respondents (83%) agreed that maintenance schedules exist for all major rig systems e.g. hoisting system, power system, mud pumps, instrumentation, hydraulic power unit (HPU), compressed air system etc. Only 6% of them disagreed. This alludes that the plant safety programme on equipment maintenance is adequate on that criteria.

The study also revealed that majority of the respondents (91%) agreed that regular maintenance eliminates work place hazards. This finding supports what (European Agency for Safety and Health at Work, 2010) reported that the lack of maintenance or inadequate maintenance may lead to dangerous situations, accidents and health problems.

Most of the study respondents (89%) also agreed that maintenance is a high risk activity and has to be performed in a safe way. There were only 8% who disagreed and the rest (4%) were not sure. Based from data from several European countries, (European Agency for Safety and Health at Work, 2010) estimated that 10-15% of fatal accidents at work, and 15-20% of all accidents, are connected with maintenance. Further, in Germany, where more than 15% of the workforce is employed in maintenance, about 20% of all fatalities occurred during maintenance work in 2001 and approximately 50% more accidents happen during maintenance work than during normal production.

In this study, most responded (90%) agreed that delay in repair or replacement of rigging equipments during scheduled breakdowns and service times contributes to injuries whereas only 4 % disagreed. This is indicative of the readiness of the workers for continuous improvement in safety performance, culture and systems.

The study also checked the level of satisfaction of workers on the measures and strategies put in place to prevent slipping, tripping and falling from heights. 53% of the respondents agreed to the adequacy and effectiveness of these safety interventions. It was noted that a substantial 31% of the workers were dissatisfied with the onsite safety measures whereas 16% were not sure. This is indicative of the fact that more efforts need to be directed towards this area.

The study also enquired from the respondents on the existence of a well enforced policy dealing with work in confined spaces such as cellars, inside mud tanks etc. 59 % of the respondents agreed that such a policy exists whereas a significant 29% disagreed and

12% were not sure. Working in confined spaces in a geothermal site is considered hazardous because of the danger of sulphur dioxide. The US OSHA documents an average of 92 deaths and nearly 11,000 injuries per year and despite their spotlight on confined spaces, the number of deaths have remained relatively the same as 23 years ago (Kennedy, 2016)The results allude to the fact that the awareness of this policy needs to be enhanced to the rig site workers.

The majority of the study participants (83%) agreed that they are aware that some of the rig site operations are contracted out to service providers when such skills are locally available. A significant proportion, (10%) are not sure whereas 7 % disagreed. The relatively small footprint of the rig site demands the diverse teams are aware of the roles and existence of other players to assure coordinated safety effort. These findings therefore present an opportunity for joint safety toolbox meetings.

The study shows that majority of the study sample (80%) agreed that the maintenance manuals are available for all equipment, are kept in a secure location and are up to date and readily accessible to the maintenance team. There were 11% who disagreed and 9% who were not sure.

The results showed that 51% of the study participants agreed that there is a well organised and adequately stocked warehouse inventory of service spare parts, wear parts and consumables. A significant proportion (30%) disagreed and a further 19% was not sure.

The majority of the respondents (90%) agreed that whereas maintenance is a safety critical activity at the rig site, when done regularly as per maintenance schedules, it eliminates workplace hazards and reduces injuries. The majority (over 80%) also concurred that the foundational requirements for a sound maintenance system - maintenance schedules and manuals for all equipment- are available and easily accessible. In the other parameters assessed: measures to prevent slips, trips and fall;

measures on working in confined spaces and availability of service parts, a significant proportion of respondents (40% -50%) indicated that they are not adequate or effective.

4.2.6 Equipment Lock Out/ Tag Out (LOTO)

Table 4.4 shows that 67% of the participants are familiar with the Lock Out/ Tag Out (LOTO) system and all other methods of electrical or mechanical isolation of equipment that is -undergoing maintenance. 14% were unsure whereas 19% are not familiar.

Table 4.4: LOTO frequency table

I am familiar with the Lock Out/ Tag Out (LOTO) system for quipment under maintenance	**Frequency**	**Percent (%)**
Strongly Disagree	4	3.7
Disagree	17	15.7
Not sure	15	13.9
Agree	47	43.5
Strongly Agree	25	23.1
Total	**108**	**100.0**

Table 4.5 categorised the data into the sections,20 out of 21 respondents in maintenance section (representing 95%) are aware of LOTO while 40 out of 59 respondents in the drilling section (representing 68%) are familiar and for drilling support services 12 out of 28 (representing 43%) are aware.

Whereas it is the maintenance and inspection workers that utilise LOTO to prevent the inadvertent or unauthorized starting of a piece of driven equipment while work is being performed on it, it is very critical that the workers from drilling section (production) are familiar with these procedures so that the gains are not eroded.

Table 4.5: Relationship between LOTO and Section

I am familiar with the Lock Out/ Tag Out (LOTO) system		*Which section best describes your work at the well site?*				
		Drilling Production	Drilling Maintenance	Drilling Support Services	**Total No.**	**Total %**
	Strongly Disagree	2	0	2	**4**	**3.7%**
	Disagree	7	1	9	**17**	**15.7%**
	Not sure	10	0	5	**15**	**14.0%**
	Agree	25	16	6	**47**	**43.5%**
	Strongly Agree	15	4	6	**25**	**23.1%**
	Total	**59**	**21**	**28**	**108**	**100.0%**

The statistic given by (Grover, Controlling Hazardous Energy with Lockout/ Tagout - common challenges and best practices, 2017) indicate that only about 10% of companies in the USA run effective LOTO programmes - defined as meeting or exceeding compliance requirements with lockout being practiced routinely each time it is indicated by the hazards of the task being performed. In fact, it was observed that up to 30% of the employers have no lockout programme at all.

This study therefore finds the awareness levels of respondents to be adequate. However, employers need to go beyond awareness to ensure a well-documented policy on LOTO is in place and is being implemented because occupational safety and health is substantially beneficial to the bottom line and sustained productivity. According to (Grover, 2017), the sporadic nature of when LOTO needs to be applied can cause logistical challenges and create a belief that it impedes productivity. (Grover, 2018)indicates that since the rules, engineering methods, lockout devices, and various training programmes already exist but are falling short of effectively solving the problems, enhancing engagements at all levels of employment is a viable solution to drive better practices going forward.

4.2.7 Emergency Response Management Plan

Table 4.6 shows that 55 study respondents (representing 51%) agreed that there is a documented emergency response plan for preventing and minimising the effects of major accidents to people and environment at the rig site. That leaves out 53 (representing 49%) who are either unsure or altogether disagree. Out of these 53, 30 were from Drilling Production, 16 were from Drilling Support Services and only 7 were from Drilling Maintenance.

The study further revealed that out of the 21 maintenance workers surveyed,14 (representing 67% of them) agreed that there is an Emergency Response Plan. For drilling production 29 out of 59 (representing 49 % of them) were aware of the Emergency Response plan and for drilling support services 12 out of 28 (representing 43% of them) were aware of the Emergency Response Plan.

An Emergency may arise in any section at the rig site. The first moments of an emergency are known to be chaotic, disorienting and scary and therefore human nature alone is not a reliable safety system. Everyone responds during an emergency depending on their varying experience levels and physical abilities. If an employee responds in some given way, he or she could become ill, be injured, or lose his or her life (Marks, 2017). Therefore there is need to train the rig site workers on the content of the Emergency Response Plan and other hands-on, scenario-based trainings to not only enhance awareness but also adequately prepare the workers to effectively handle emergencies.

Table 4.6: Relationship between Emergency Response Plan and Section

		Which section best describes your work at the well site?				
		Drilling Production	Drilling Maintenance	Drilling Support Services	**Total No.**	**Total %**
There is a documented emergency response management plan	Strongly Disagree	3	0	2	**5**	**4.6%**
	Disagree	12	3	9	**24**	**22.2%**
	Not sure	15	4	5	**24**	**22.2%**
	Agree	24	7	6	**37**	**34.3%**
	Strongly Agree	5	7	6	**18**	**16.7%**
	Total	**59**	**21**	**28**	**108**	**100%**

4.2.8 Personal Protective Equipment (PPE) Programme

Figure 4.7 shows that a significant proportion of the respondents, 46% were not satisfied that the PPE provided is adequate in providing appropriate protection against workplace hazards. Only 36% agreed that the PPE was satisfactory whereas 18% was not sure.

The study showed that 62% of the respondents agreed that there are instances when they have to share PPE because of inadequate supply to the workers. This is comparable to 33% who did not have to share and 5% who were unsure.

The study also sought to find out whether there are instances when work is done without PPE because of lack of new supplies to replace worn out PPEs. It was found out that 70% of the respondents had at one time or another proceeded to work without PPEs. However the study did not drill down to identify the specific time of PPE in question. This is comparable to 18% who have never worked without PPE and a further 12% who were not sure. The use of PPE is the

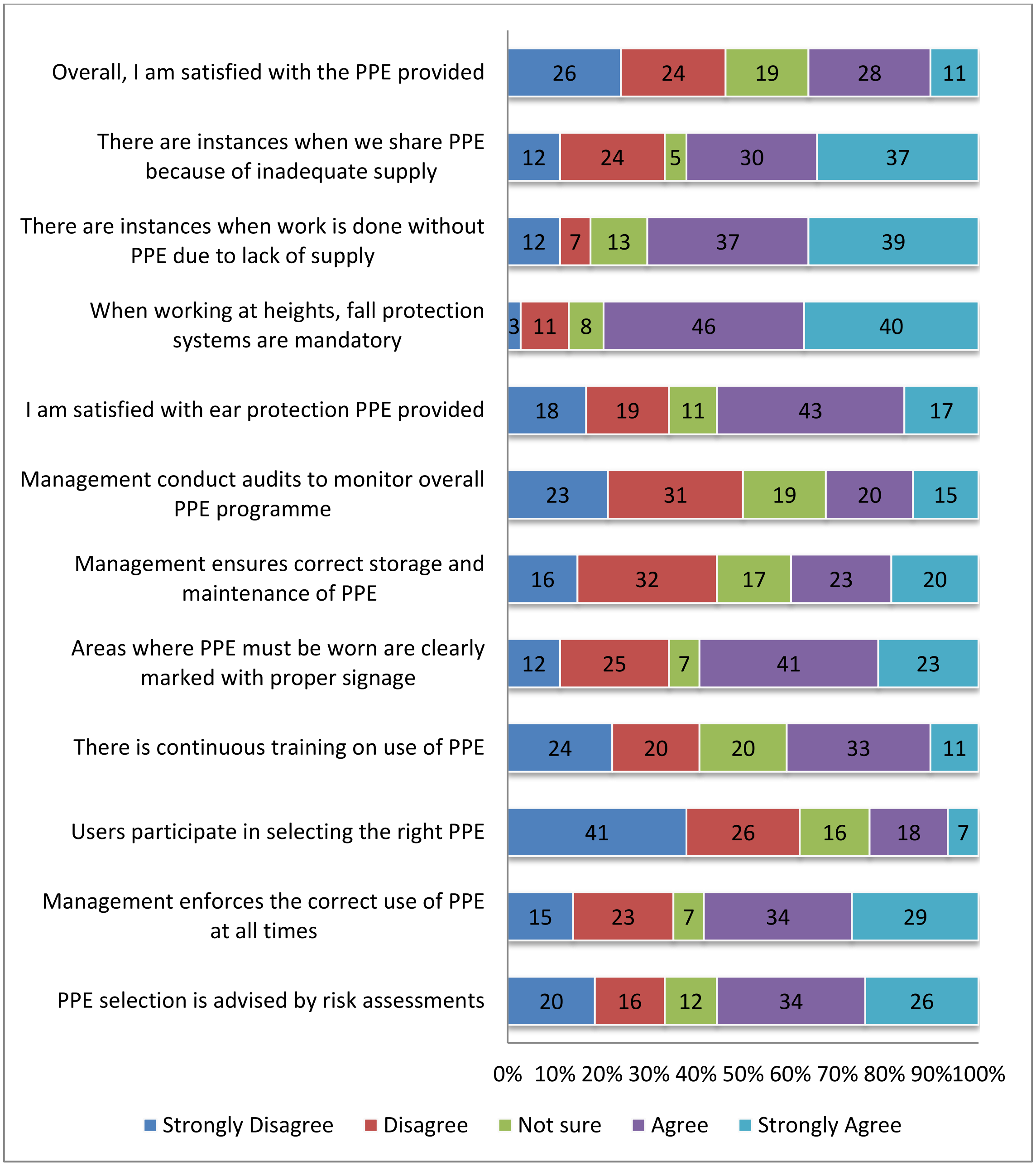


Figure 4.7: PPE Programme

final barrier for the workers to protect them from residual hazards exhausting all engineering and administrative controls (Taylor and Francis Group, LLC, 2010). Therefore the workers should under no circumstances proceed with work without PPE.

This result indicates a weakness on the PPE programme and policy that needs to be reviewed and addressed.

In this study 80% of the participants agreed that it is mandatory to be provided with personal fall protection systems when working at heights. Of the remainder, 12% disagreed and 8% were not certain (Figure 4.7).

As regards ear protection PPE, 56% of the respondents averred that they were satisfied with the PPE provided whereas 34% disagreed. There were 10% of them that were not certain (Figure 4.7). Under Noise Prevention and Control Rules of 2005, where noise exceeds 85dB(A), the occupier must develop noise control and hearing conservation programme as specified in the regulations and which shall be reviewed annually to determine its effectiveness. This programme should be able to address the need of the 46% of the respondents who were not satisfied.

The results showed that only 32% agreed that management conducts audits to monitor the PPE programme so as to assure the correct use, storage, technical condition and training. This is comparable to 50% of the respondents who refuted and 18% who were not sure (Figure 4.7).

The study revealed that out of the respondents, 40% agreed that management ensures the correct method of storage, maintenance and necessary servicing where necessary. This is comparable to 44% who disagree and 16% who were not sure (Figure 4.7).

There were 59% of the respondents who agreed that the areas of the rig where PPE must be worn are clearly marked with the proper safety signage. This is comparable to 34% who disagreed and 7% who were not sure (Figure 4.7). This is a moderately positive statistic but an effective safety plan is that which ensure that all hazardous sections of the rig are marked with proper safety signages.

In this study, 41% of the participants agreed that there is continuous training and instruction on the use of PPE; effects of not using PPE and on problems that occur during use. However, another 41% disagreed and 18% were not sure (Figure 4.7). This metric in indicative of some weakness in the PPE programme.

The study also revealed that only 23% agreed that the users are involved in the process of selecting the right PPE. 62% opined that the users are not involved and a further 15% were not sure (Figure 4.7). This statistic is indicative of some inadequacies and inefficiencies in the entire PPE programme that requires improvement.

The study showed that 48% of the respondents agreed that the management enforces the correct use of PPE at all times. This is comparable to 35% who disagreed and 7% who were not sure (Figure 4.7).

The study finally showed that 56% of the respondents agreed that PPE selection is advised by risk assessment of the workplace characteristics. This is comparable to 33% who disagreed and 11% who were not certain. The results show that a simple majority of the responded is in agreement that best industry standards are being adhered to. However there is still room for improvement.

4.2.9 Ergonomic and Psychosocial Factors

The study showed that majority of the respondents, 59% agreed that management has established systems so that workers can be rotated away from tasks to minimize the duration of continual exertion, repetitive motions and awkward posture. This is compared to 26% who disagreed and 15% who were not sure (Figure 4.8).

This study also revealed that 69% of the respondents agreed that management uses engineering controls to eliminate or reduce exposure to ergonomic hazards during maintenance at the workplace. This is done through use of forklifts, ergonomic work stations etc. A small portion, 10% disagreed whereas 21% were uncertain (Figure 4.8).

In this study, a majority of the participants, 75% agreed to have noticed that maintenance work as affecting their arms, shoulders and back. There were only 13% who disagreed and 12% were not certain. This finding is consisted with (Health and Safety Executive, 2014) that reported that manual handling causes over a third of all workplace injuries including MSDs.

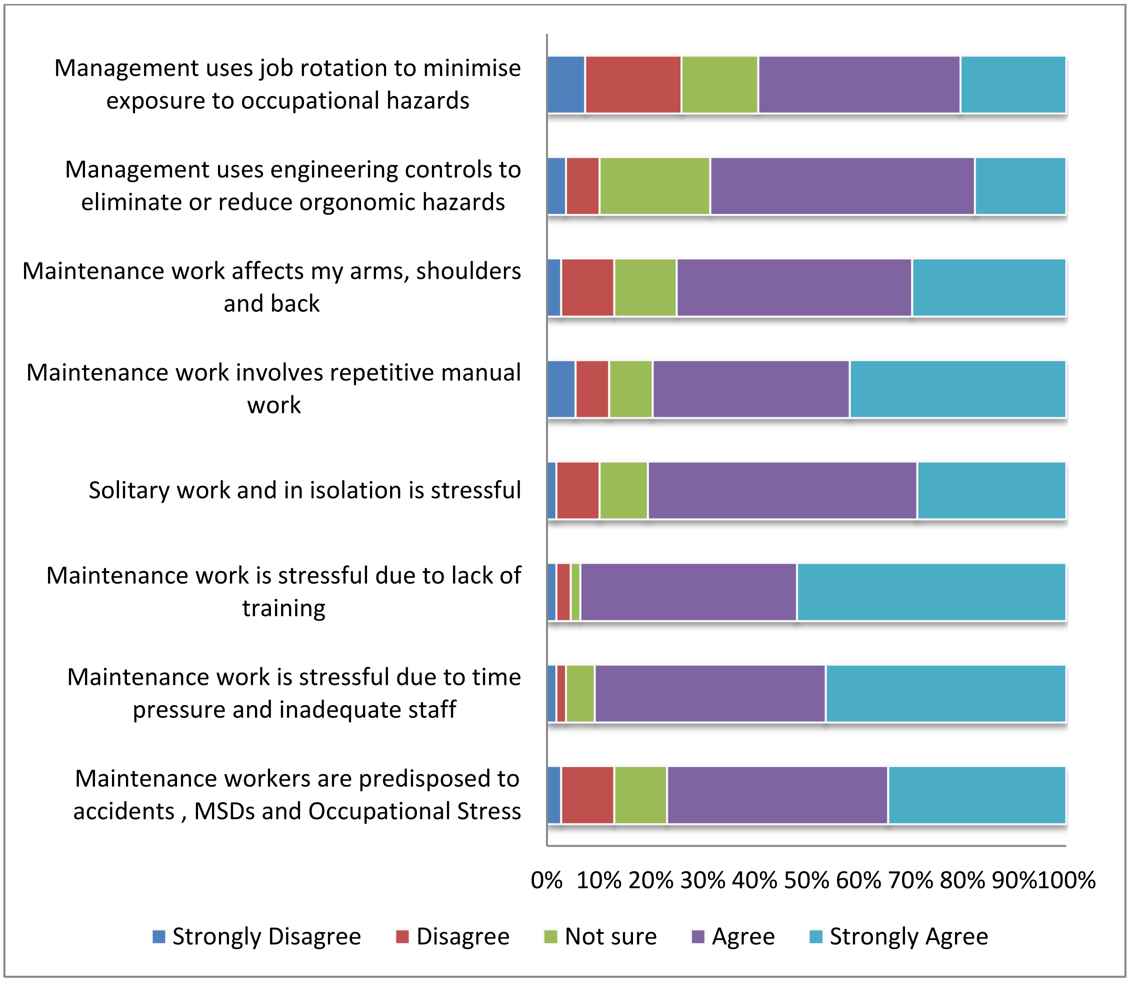


Figure 4.8: Ergonomic and Psychosocial Factor

There were 80% of study respondents who agreed that maintenance work involved bending, lifting heavy items, pushing and pulling loads, working in awkward body postures or performing the same tasks repetitively. This is comparable to 12% who disagreed and 8% who were not sure (Figure 4.8).

The study showed that majority of the respondents, 81% admitted that it is very stressful carrying out maintenance work alone and in isolation. In the same vein, 10% disagreed and 9% were not sure (Figure 4.8).

In this study, a majority of the participants, 94% averred that maintenance work is stressful when you are not familiar and not well trained on the equipment. Only 4% disagreed and 2% were not sure (Figure 4.8).

Majority of the study respondents, 91% agreed that maintenance work is stressful when there are time pressures for swift resumption of drilling production and yet there is inadequate staff. This is comparable to 4% that disagreed and 5% who were not sure (Figure 4.8).

The study further showed that 83% of the respondents agreed that maintenance workers are not only being at risk of being involved in a work related accident but also of developing occupational diseases e.g. MSDs or occupational stress (Figure 4.8).

4.3 Noise Level Measurement at the Well Site During Drilling Ahead Activity

The table 4.7 below shows the final readings of the noise measurements taken at Rig 4 on 5th October 2016 between 1200 hrs to 1300 hrs. The drilling rig was undertaking a drilling -ahead activity in normal overbalanced conditions. This means that only the two of the three mud pumps were engaged while the air drilling package (compressors and boosters) were not running.

Table 4.7: Noise Measurements at Rig 4 during drilling ahead activity

	Noise measurements in dB (A)					
Sectors	**0**	**20**	**40**	**60**	**80**	
0	77.55	76.35	78.9	81.75	76.25	Noise measurements in dB(A)
10	85.65	92.6	112.3	79.1	82	
20	81.2	80.8	83.3	81.35	70.95	
30	80.65	81.2	87.6	87.15	76.15	
40	79.15	77.8	84.9	81.35	75.15	
50	75.9	75.25	76.9	77.75	72.15	
60	67.45	69.9	69.45	71.65	73.9	
70	70.7	66.4	68.95	68.7	74.4	

Source: Author, taken on 5th October 2016 between 1200 hrs to 1300 hrs

The noise measurements in Table 4.7above were input in MS Excel and generated a contour that was superimposed on the rig layout plan to reproduce figure 4.9. The figure illustrates that dangerous noise hazard of above 110 - 120 dB (A) was identified inside the generator rooms. A high noise levels of above 95 - 110 dB (A) was exhibited around the generators and mud pump no.3.Cellar area, at mud pumps no. 2 and 1, and mud mixing area exhibited a noise levels in the range of 80-95dB (A). The aerated drilling area and the rest of the well pad registered the lowest noise levels of between 65 -80 dB (A).

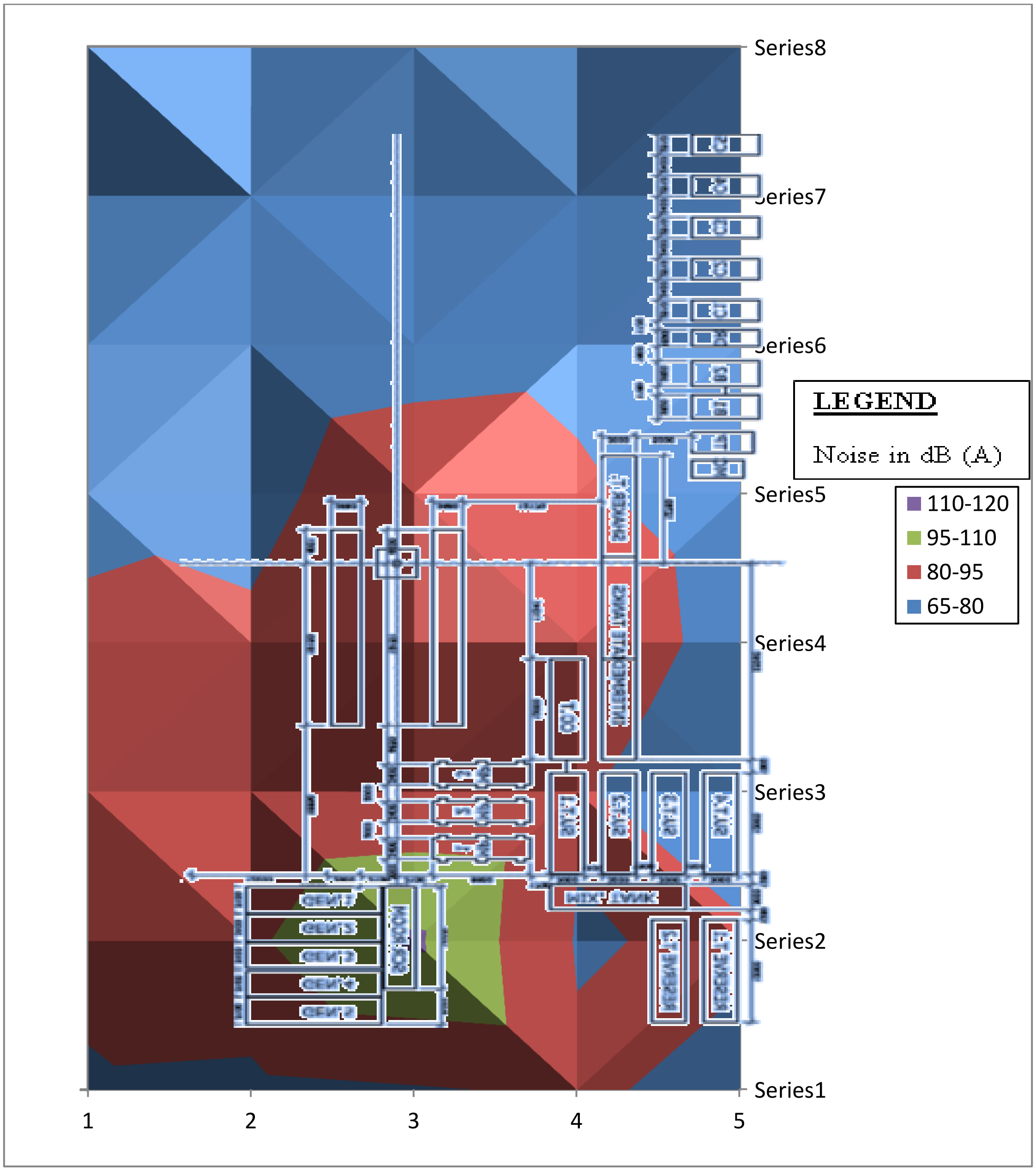


Figure 4.9: Noise Map of Rig 4 on 5th October 2016 (1200 hrs - 1300hrs)

The noise map shows that over 50% of the well pad experienced noise levels of over 80 dB (A) during a drilling ahead activity without aerated drilling (compressors, boosters and dozing pumps all switched off). The map furthers show that within the rig equipment plan, about 80% - 85% of the area registered noise levels of intensity higher than 80 dB (A) without aerated drilling. This scenario indicatives that in under-balanced drilling activity whereby at least two air compressors, one booster compressor and the soap dozing pump all running, this percentage will most likely increase to almost 100%.

The dangerous noise levels of over 110 dB (A) inside the generator room is attributed to the fact that at least two of the five generators are always running during a drilling ahead activity. The generator rooms are kept open to ensure that the heat dissipated by the radiators is distributed away by natural draft to cool the area. This ensures that the noise is also distributed from the source and hence the high noise levels of over 95 dB (A) around the generators and mud pump no. 3.

These noise maps can be done for all combinations of activities and noise generating running equipment at the rig site to show all the sources of noise and how it is dispersed, making it easier to establish key areas for mitigation measures. In this study, the noise measurements were taken during a drilling ahead activity.

The Noise Prevention and Control Rules of 2005 provide the following permissible noise levels:

i. that no worker shall be exposed to noise in excess of the continuous equivalent of 90dB(A) in eight hours within any 24 hours duration
ii. where noise exceeds 85dB(A), the occupier must develop noise control and hearing conservation programme as specified in the regulations and which shall be reviewed annually to determine its effectiveness

The Canadian Center for Occupational Health and Safety (CCOHS) gives the following permissible noise levels using a criterion level of 85 dB (A) and exchange rate of 3 dB (A) and 5 dB (A).

Table 4.8: Noise Exposure Limits when Criterion Level is 85 dB (A)

Source: Canadian Center for Occupational Health and Safety (CCOHS)

Noise Exposure Limits when Criterion Level = 85 dB(A)		
3 dB(A) Exchange Rate	**Maximum Permitted Daily Duration (hours)**	**5 dB(A) Exchange Rate**
Allowable Level dB(A)		Allowable Level dB(A)
85	8	85
88	4	90
91	2	95
94	1	100
97	0.5	105
100	0.25	110
103	0.125	115
106	0.0625	120
109	0.03125	125
112	0.015625	130

In this study, analysis is based on the 3 dB (A) rule as it is the one that most experts recognize as more logical(Canadian Center for Occupational Health and Safety (CCOHS), 2016) proposing the allowable exposure time should be cut in half when the sound level is doubled. It follows, then, that the allowable time should be halved for every 3 dB(A) increase in sound level. Table 4.8 indicates that the maximum permissible exposure period inside the generator rooms that exhibited noise levels of 110 - 120 dB (A) is 0.015625 hrs (less than a minute); around the generators and mud pump no.3., where a high noise levels of above 95 - 110 dB (A) was exhibited, the maximum daily permissible exposure level is 0.125 hours (7.5 minutes); and at the cellar area, mud pumps no. 2 and no.1, and mud mixing area that exhibited a noise levels in the range of 80 -95 dB (A), the maximum daily permissible exposure level is 4 hours. The workers are however engaged at the workplace for 12 hour shifts daily. Whereas the workers are stationed in specified work stations they normally walk around the entire well pad and are therefore exposed for periods well beyond the permissible levels. The occupier should therefore enforce a noise and hearing conservation programme as the entire rig site is hazardous for noise. This noise measurement study validates the survey results in (Fankey, Githiri, & Mburu, 2013), that indicated that 44% of the study respondents had identified high level of noise as an occupational hazard in geothermal development activities in Menegai.

4.4 The Efficacy of OSH Management Systems at GDC

The scores in the checklists were used to evaluate evidence the OSH management system on eight auditable areas: policy, control, communication, co-operation, competence, planning and implementation, performance measurement and review processes are given below. The scores were based on evidence provided by the safety management representatives, negotiated, agreed and owned by all parties. The bulky audit working papers were safely kept for subsequent verification should a need arise.

4.4.1 Evaluation of GDC OSH Policy

Table 4.9: Results of evaluation of OSH Policy

	Fully met	Partially met	Not met at all
1. The company understands its responsibilities for H&S towards employees, customers, visitors and members of the public and has a clear, written policy for health and safety at work, signed, dated and communicated to all employees.		1	
2. The Management regards health and safety of employees as an important business objective.		1	
3. The Management is committed to continuous improvement in health and safety (reducing the number of injuries, cases of work-related ill health, and absences from work and accidental loss).	2		
4. A named Manager or Senior Manager has been given overall responsibility for implementing our health and safety policy.	2		
5. Our policy commits the Management to preparing regular health and safety improvement plans and regularly reviewing the operation of our health and safety policy.		1	
6. Our policy includes a commitment to ensuring that all employees are competent to do their jobs safely and without risks to health.		1	
7. Our policy encourages the involvement of employees and safety representatives in the health and safety effort.	2		
POLICY SCORES	6	4	0
TOTAL SCORE (Maximum = 14)	**10**		

4.4.2 Evaluation of OSH Organizational Control System

Table 4.10: Results of Evaluation of OSH Control System

	Fully met	Partially met	Not met at all
1. We have identified the people responsible for particular health and safety jobs including those requiring special expertise (e.g. our health and safety advisor).		1	
2. Our company responsibilities for all aspects of health and safety have been defined and allocated to our managers, supervisors and team leaders.		1	
3. Our managers, supervisors and team leaders accept their responsibilities for health and safety and have the time and resources to fulfil them.		1	
4. Our managers, supervisors and team leaders know what they have to do to fulfil their responsibilities and how they will be held accountable.		1	
ORGANISING CONTROL SCORES	0	4	0
TOTAL SCORE (Maximum = 8)	**4**		

4.4.3 Evaluation of OSH Communication System

Table 4.11: Results of Evaluation of OSH Communication System

	Fully met	**Partially met**	**Not met at all**
1. We provide clear information to people working on our site about the hazards and risks and about the risk control measures and safe systems of work (which is easily accessible in the relevant work area).		1	

2. We discuss health and safety regularly and health and safety is on the agenda of management meetings and briefings.		1	
3. Our Management, managers and supervisors are open and approachable on health and safety issues and encourage their staff to discuss health and safety matters.		1	
4. Our Management, Managers and Team Leaders communicate their commitment to health and safety through their behaviour and by always setting a good example.		1	
5. We provide clear information to persons working on behalf of the organisation (i.e contractors, visiting drivers) regarding site hazards and risks and about the control measures in place to protect them.	2		
6. We provide clear information to casual and irregular visitors to the site (i.e customers, school visits, auditors) regarding site hazards and risks and about the control measures in place to protect them.	2		
7. We have established clear feedback systems to customers on safety issues, such as drivers breaching traffic rules, climbing on loads, not wearing PPE etc.	2		
ORGANISING COMMUNICATION SCORES	6	4	0
TOTAL SCORE (Maximum = 14)	10		

4.4.4 Evaluation of OSH Co-operation System

Table 4.12: Results of Evaluation of OSH Co-operation System

	Fully met	**Partially met**	**Not met at all**
1. We involve the workforce in preparing health and safety improvement plans, reviewing our health and		1	

safety performance, undertaking risk assessments, preparing safety-related rules and procedures, investigating incidents and problem solving.			
2.We consult our employees and employee safety representatives on all issues that affect health and safety at work		1	
3. We have an active health and safety committee that is chaired by the appropriate Manager or Senior Manager and on which employees from all departments are represented.	2		
4. For contractors and employment agencies whose employees work on our site, we have arrangements for cooperating and coordinating on health and safety matters.	2		
ORGANISING CO-OPERATION SCORES	4	2	0

4.4.5 Evaluation of OSH Competence Processes

Table 4.13: Results of Evaluation of OSH Competence Processes

	Fully met	**Partially met**	**Not met at all**
1. We have a system for ensuring that all our employees, including managers, supervisors and temporary staff, are adequately instructed and trained.		1	
2. We have assessed the experience, knowledge and skills needed to carry out all tasks safely.		1	
3. We have a system for ensuring that people doing particularly hazardous work or exposed to hazardous situations have the necessary training, experience and		1	

other qualities to carry out the work safely.			
4. We have arrangements for gaining access to specialist advice and help when we need it.		1	
5. We have systems for ensuring that competence needs are identified and met whenever we take on new employees, promote or transfer people or when people take on new health and safety responsibilities e.g. when we restructure or reorganise.		1	
6. We have systems for the selection of contractor companies and their personnel entering our organisation. Before contracts are agreed upon we ensure they have the right level of technical and safety competence.		1	
7. We have systems for ensuring that competence needs are identified and met whenever we take on contracted or agency personnel and we have systems to assess the individual can carry out tasks safely.		1	
ORGANISING COMPETENCE SCORES	0	7	0
TOTAL SCORE (Maximum = 14)	7		

4.4.6 Evaluation of OSH Planning and Implementation Processes

Table 4.14: Results of Evaluation of OSH Planning and Implementation Processes

	Fully met	**Partially met**	**Not met at all**
1. We have a system for identifying hazards, assessing risks and deciding how they can be eliminated or controlled.		1	
2. We have a system for planning and scheduling health and safety improvement measures and for prioritising their implementation depending on the	2		

nature and level of risk.	
3. We have arrangements for agreeing measurable health and safety improvement targets with our managers and supervisors.	1
4. Our arrangements for purchasing premises, plant, equipment and raw materials and for supplying our products take health and safety into account at the appropriate stage, before implementation of the plan or activity.	1
5. We take proper account of health and safety issues when we design processes, equipment, procedures, systems of work and tasks.	1
6. We have procedures for dealing with serious and imminent dangers and emergencies.	1
7. We have health and safety rules and procedures covering the significant risks that arise in our day-to-day work activities including normal production, foreseeable abnormal situations and maintenance work.	1
8. We set standards against which we can measure our health and safety performance.	1
9. We have formally stipulated and agreed safety specifications for static plant and equipment used within our organisation, they include requirements to fit certain safety control devices as required i.e. interlock systems, guarding, e-stops etc.	1
10. We have formally stipulated and agreed safety specifications for mobile plant and vehicles (whether owned, contract hired or leased) and they include requirements to fit certain safety devices as required i.e. reversing cameras, autosheeters.	1
12. We have arrangements for dealing with emergency situations, which includes assigning certain roles and responsibilities to persons.	1

13. We have arrangements for managing work which is identified as having a particular high risk and requires stricter controls. The work is carried out against previously agreed safety procedures, a ‘permit-to-work’ system.		1	
14. We have arrangements for ensuring that unauthorised operation of plant and equipment is effectively prevented.			0
15. We have arrangements for performing ‘Pre use’ safety checks on vehicles, plant and equipment assessed as requiring such an inspection.		1	
16. We have procedures and arrangements for dealing with defects / breakdowns which occur during the course of work.			0
17. We have a system for identifying hazards associated with moving, locating and relocating plant / work equipment around site, including skips, containers etc.			0
18. We have arrangements for routinely inspecting plant and equipment in accordance with the OSHA 2007.	2		
19. We have arrangements with competent persons to perform statutory inspections of plant and equipment i.e. in accordance with the OSHA 2007 Examination of Plant Order.	2		
20. We have designed and constructed our site to take into account traffic and pedestrian movements and we have controls in place to ensure each user has a safe route around site.			0
21. We have arrangements for performing routine site inspections which includes traffic management and behavioural safety.		1	
22. We have procedures for maintaining good housekeeping standards to minimise the risk of slips		1	

and trips.			
23. We have controls in place to reduce the risk of falls from height (eg into / from skips) by avoiding at height movements and having a system of work that does not require access at height.		1	
24. We have a system for identifying Manual Handling hazards, assessing risks and deciding how they can be eliminated or controlled, and all relevant employees have been trained accordingly.	2		
25. We have arrangements for ensuring employees are made aware of (and are provided with) the personal protective equipment which has been assessed as being required for a particular work activity.	2		
26. We have ensured that welfare facilities provided are suitable and sufficient to the work environment and those who will be required to use them i.e. staff, visitors, contractors.	2		
PLANNING AND IMPLEMENTING SCORES	12	16	0
TOTAL SCORE (Maximum = 14)	28		

4.4.7 Evaluation of OSH Performance Measuring Systems

Table 4.15: Results of OSH Performance Measuring System

	Fully met	**Partially met**	**Not met at all**
1. We have arrangements for monitoring progress with the implementation of our health and safety improvement plans and for measuring the extent to which the targets and objectives set under those plans have been achieved.		1	

2. We have arrangements for active monitoring (i.e. checking) to ensure that our control measures are working properly, our health and safety rules and procedures are being followed and the health and safety standards we have set for ourselves are being met.		1	
3. We have arrangements for reporting and investigating accidents, incidents, near misses and hazardous situations.	2		
4. Where the arrangements in 2 and 3 above show that controls have not worked properly, our health and safety rules or procedures have not been followed correctly or our safety standards have not been met we have systems to identify the reasons why performance was substandard and where necessary we use disciplinary procedures.		1	
5. We have arrangements for analysing the causes of any potentially serious events so as to identify the underlying root causes including causes arising from shortcomings in our safety management system and safety culture.	2		
6. We have arrangements for measuring customer satisfaction in relation to safety of the products, services and activities we provide.		1	
7. We have arrangements to ensure supervisors continue to check that information, instruction and training has been fully understood by staff and continues to be taken on and used.		1	
MEASURING PERFORMANCE SCORES	4	5	0
TOTAL SCORE (Maximum = 14)	9		

4.4.8 Evaluation of OSH Auditing and Reviewing Processes

Table 4.16: Results of OSH Auditing and Reviewing Processes

	Fully met	**Partially met**	**Not met at all**
1. We have regular audits of our safety management system carried out by competent external auditors or competent auditors employed by our company who are independent of the department they are auditing.	2		
2. We use the information from performance monitoring and audits to review the operation of our safety management system and our safety performance.	2		
3. We regularly review how well we have met the objectives in our health and safety improvement plans and whether we have met them in the agreed timescales.		1	
4. We analyse the information from performance measurement and use it to identify future improvement targets and to identify particular causes of accident, ill health or poor control of risk, to target for future risk reduction effort.	2		
5. We formally review our risk assessments annually and as required by certain events i.e. changes in operation, site layout, new purchases, new developments or following an accident or incident on site.		1	
6. We analyse the information from customer safety breaches and use it to identify future improvement targets and to identify particular causes of accidents, near misses to target for future risk reduction effort.			0
7. We analyse the information from plant and equipment breakdown / maintenance records to		1	

identify patterns of deterioration (cause analysis).			
8. We periodically review the site layout to take account of changes in work activities, traffic type, volume and circulation.		1	
ASSESSMENT METHODS SCORES	6	4	0
TOTAL SCORE (Maximum = 16)	10		

4.4.9 Audit Results Summary

Table 4.17: Overall Results of Evaluation of OSH Management Systems

	SECTION HEADING	Possible points	Actual points	% score	Rank
1	Policy	14	10	71%	2
2	Organising control	8	4	50%	7
3	Organising communication	14	10	71%	3
4	Organising co-operation	8	6	75%	1
5	Organising competence	14	7	50%	7
6	Planning and implementing	52	28	54%	6
7	Measuring performance	14	9	64%	4
8	Auditing and reviewing	16	10	63%	5
	Total points/overall	**140**	**84**	**60%**	
	Date exercise carried out	**6th October 2016**			

Table 4.17 shows that based on the checklist the overall compliance score for the OSH management system is 60%. The order of ranking of the eight sub-components of the OSH management system evaluated is also given on the rank column on the table above. The results indicate that the effectiveness and efficacy of the GDC OSH Management system is moderate.

[redacted]

[redacted]

This chapter gives the conclusion and the recommendation of the research study based on the findings from the collected data.

5.1 Conclusions

The general objective of this study was to assess the effects of geothermal well drilling occupation on the safety and health status of workers in Kenya using GDC as the case study. The following are the specific conclusions based on the study objectives.

5.1.1 Adequacy and Effectiveness of onsite plant safety programmes at GDC

The study statistics infer some inadequacies and ineffectiveness in the onsite plant safety programme as regards six out of the nine elements assessed, namely: the PTW system; plant maintenance system; LOTO system; Emergency Response Planning; PPE programme; and Ergonomic and Psychosocial factors. The elements of the onsite plant safety programme that were found to be adequate and effective were the Lost Time Accidents; inspection and testing of plant equipment and materials; and equipment calibration programme. The adequacy and effectiveness of the onsite plant safety programmes at GDC was therefore found to be operational but moderate.

5.1.2 The Noise Exposure and Distribution at the Drill Site During a Drilling Ahead Activity

The generated noise map for a drilling ahead activity without air drilling showed the following: dangerous noise hazard of above 110 - 120 dB (A) was identified inside the generator rooms; a very high noise level of above 95 - 110 dB (A) was exhibited around the generators and mud pump no.3; a high noise level of80 - 95 dB (A) was exhibited in the Cellar area, at Mud pumps no. 2 and 1, and Mud-mixing area; and the lowest noise level of between 65 - 80 dB (A) was registered at the aerated drilling area and the rest of the well pad.

The noise map shows that over 50% of the well pad experienced noise levels of over 80 dB (A) during a drilling ahead activity without aerated drilling (compressors, boosters and dozing pumps all switched off and therefore not generating noise). The map furthers show that within the rig equipment plan, about 80% - 85% of the area registered noise levels of intensity higher than 80 dB (A) without aerated drilling.

The 3 dB (A) exchange rule issued by the Canadian Center for Occupational Health and Safety, was used to assess the permissible exposure levels for the workers. It was found that the maximum permissible exposure period inside the generator rooms that exhibited noise levels of110 - 120 dB (A) is 0.015625 hrs (less than a minute); around the generators and mud pump no.3, where a high noise levels of above 95 - 110 dB (A) was exhibited, the maximum daily permissible exposure level is 0.125 hours (7.5 minutes); and at Cellar area, mud pumps no. 2 and 1, and mud mixing area that exhibited a noise levels in the range of 80 -95 dB (A), the maximum daily permissible exposure level is 4 hours. The workers are however engaged at the workplace for 12 hour shifts daily and are stationed at specific work stations but move around the entire workplace and are exposed to noise beyond the permissible exposure periods. The entire drilling rig site was found to be hazardous for noise during a 12 hour drilling ahead shift.

5.1.3 The Efficacy of OSH Management System at GDC

The scores for the study of the eight main components of the OSH management system in place at GDC in descending order were as follows: organising co-operation (75%); policy (71%); organising communication (71%); measuring performance (64%); auditing and reviewing (63%); planning and implementation (54%); organising control (50%); and organising competence (50%). The overall score of the evaluation of the

OSH management system was 60%. The results indicate that the effectiveness and efficacy of the OSH Management System is moderate.

5.2 Recommendations

To enhance the occupational safety and health performance, culture and management systems, and therefore mitigate the effects of geothermal drilling operations on the safety and health status of workers, the study makes the following recommendations:

i. The GDC management should independently review its PPE programme to assure itself that it is adequate and meets at least the following criteria:
    a. Risk assessment that will enable selection of the appropriate type of equipment and protection level
    b. Participation of PPE users in the process of selecting technical solutions
    c. Continuous training for workers
    d. Ensuring the correct method of storage, maintenance, and necessary servicing
    e. Constant monitoring by audits of the PPE to ensure correct use, storage, technical conditions, and updating training

ii. Targeting the rig site workers who are predisposed to occupational stress and musculo-skeletal disorders (MSDs), the GDC management should incorporate workplace wellness programmes. These may include, but not limited to stress management and health risk appraisals, including biometric screening for blood pressure and glucose tolerance.

iii. The GDC management should enhance the Hearing Conservation Programme (HCP) based on regulatory standards and best practices and premised on the following 7 elements: Measure, Control, Protect, Check, Train, Record and Evaluate.

iv. From objective three, the GDC management should independently review its current occupational and safety strategy as part of continuous improvement initiative and ensure that it yields sustainable desired results especially on the following important areas in order of decreasing priority: organising control; organising competence; planning and implementation; auditing and reviewing; and measuring performance.

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Appendix I: Questionnaire

See overleaf

MSc THESIS QUESTIONNAIRE

THE ASSESSMENT OF IMPACT OF GEOTHERMAL WELL DRILLING ON OCCUPATIONAL SAFETY AND HEALTH OF WORKERS IN KENYA

Please complete the following questionnaire with by placing a CROSS in the appropriate box [X] on a scale of 1 to 5 (for section A, B and C) and return to the researcher in 24hrs time.

Demographic questions

1	What is your sex?	Male (1) ☐	Female (2) ☐		
2	What is your marital status?	Single (1) ☐	Married (2) ☐	Divorced (3) ☐	Widowed (4) ☐
3	What is your age bracket?	18 – 25yrs (1) ☐	25–35yrs (2) ☐	35– 45yrs (3) ☐	Above 45 yrs (4) ☐
4	What is your highest level of education?	High School (1) ☐	Diploma (2) ☐	Degree (3) ☐	Post Grad. Degree (3) ☐

5	Do you work in a shift?	Yes (1) ☐	No (2) ☐		
6	Where is your work station?	Menengai (1) ☐	Olkaria (2) ☐		
7	Which title best describes your work?	Engineer (1) ☐	Technician (2) ☐	Craftsman (3) ☐	Artisan (4) ☐
8	How many years of experience do you have in maintenance work?	< 3 yrs (1) ☐	3 – 7yrs (2) ☐	>7 – 10 yrs (3) ☐	Over 10 yrs (4) ☐
9	Have you ever been absent from work because of an occupational accident?	Yes (1) ☐	No (2) ☐		
10	Which section best describes your work at the well site?	Drilling Production (1) ☐	Drilling Maintenance (2) ☐	Support Services (3) ☐	

Please proceed to Section A

	SECTION A **Assessing the effectiveness of plant safety programmes in enhancing safety and health of well site workers**	**Strongly Agree (5)**	**Agree (4)**	**Not sure (3)**	**Disagree (2)**	**Strongly Disagree (1)**

11	Maintenance schedules exist for all major systems of the drill rig e.g hoisting system, power system, mud pumps, instrumentation, HPU, cranes, compressors	☐	☐	☐	☐	☐
12	Regular maintenance eliminates workplace hazards	☐	☐	☐	☐	☐
13	Maintenance is a high risk activity and has to be performed in a safe way	☐	☐	☐	☐	☐
14	Delay in repair or replacement of rigging equipment contributes to injuries	☐	☐	☐	☐	☐
15	The reliability of well control system is always assured by regular inspection and testing	☐	☐	☐	☐	☐
16	I am satisfied in the measures and strategies in place to prevent slipping, tripping and falling from heights at the well site.	☐	☐	☐	☐	☐
17	The measures in place to protect workers working in confined spaces (cellars, inside mud tanks) from risk of H_2S There exists a well enforced policy dealing	☐	☐	☐	☐	☐

	SECTION A Assessing the effectiveness of plant safety programmes in enhancing safety and health of well site workers	Strongly Agree (5)	Agree (4)	Not sure (3)	Disagree (2)	Strongly Disagree (1)
	with work in confined places such as cellars, inside mud tanks etc					
18	High pressure systems (compressors, boosters etc) are periodically inspected and maintained as recommended by the Original Equipment Manufacturer	☐	☐	☐	☐	☐
19	A risk assessment of the rig has been done to determine the rig hazards that are present at the work site	☐	☐	☐	☐	☐
20	Some of the maintenance work for which we have no adequate skills is contracted out to service providers	☐	☐	☐	☐	☐
21	There is a properly enforced schedule for calibration of critical measuring instruments and dials e.g. Ammeters, Voltmeters, Flow meters, Barometers etc	☐	☐	☐	☐	☐
22	The maintenance and operation manuals are available for all equipment, kept in	☐	☐	☐	☐	☐

	SECTION A **Assessing the effectiveness of plant safety programmes in enhancing safety and health of well site workers**	**Strongly Agree (5)**	**Agree (4)**	**Not sure (3)**	**Disagree (2)**	**Strongly Disagree (1)**
	a secure location, are up to date and readily accessible to the maintenance team					
23	There is a maintenance of a well organised and adequately stocked in the warehouse inventory of service spare parts, wear parts and consumables	☐	☐	☐	☐	☐
24	I am familiar with the Lock Out/ Tag Out (LOTO) system and all other methods of electrical or mechanical isolation of equipment under maintenance	☐	☐	☐	☐	☐
25	There is a Permit to Work System in place that is used to control certain types of work which are identified as potentially hazardous.	☐	☐	☐	☐	☐
26	There is a documented emergency response management plan for preventing and minimising the effects of major accidents to people and environment	☐	☐	☐	☐	☐
27	Non mobile electrical devices are inspected, tested and reported periodically to	☐	☐	☐	☐	☐

	SECTION A **Assessing the effectiveness of plant safety programmes in enhancing safety and health of well site workers**	**Strongly Agree (5)**	**Agree (4)**	**Not sure (3)**	**Disagree (2)**	**Strongly Disagree (1)**
	determine earthing, insulation resistance, resistivity etc and ensure safe use					
28	Overally, there is a system in place to ensure statutory inspections for transmission machinery, handheld power tools, hoists, cranes, compressor and compressed air receivers	☐	☐	☐	☐	☐

Please proceed to Section B

	SECTION B **Evaluating the effectiveness of Personal Protective Equipment (PPE) programme in ensuring the safety of well site workers**	**Strongly Agree (5)**	**Agree (4)**	**Not sure (3)**	**Disagree (2)**	**Strongly Disagree (1)**
29	As far as I know, PPE selection is advised by risk assessment of the workplace characteristics and maintenance activities	☐	☐	☐	☐	☐
30	Management enforces the correct use of PPE at all times	☐	☐	☐	☐	☐
31	As users we participate in the process of selecting the right PPE	☐	☐	☐	☐	☐
32	There is continuous training for maintenance workers with special attention to increasing effects of not using PPE, understanding instructions for use and problems that may occur during use	☐	☐	☐	☐	☐
33	Areas of the rig where PPE must be used are clearly marked with proper safety signage	☐	☐	☐	☐	☐
34	Management ensures correct method of storage, maintenance, and necessary servicing of PPE	☐	☐	☐	☐	☐

	SECTION B **Evaluating the effectiveness of Personal Protective Equipment (PPE) programme in ensuring the safety of well site workers**	**Strongly Agree (5)**	**Agree (4)**	**Not sure (3)**	**Disagree (2)**	**Strongly Disagree (1)**
35	Management conducts audits to monitor the PPE programme so as to assure correct use, storage, technical conditions and training	☐	☐	☐	☐	☐
36	Despite the rig being a noisy plant, I am satisfied with the ear protection PPE that is provided (earplugs or earmuffs)	☐	☐	☐	☐	☐
37	When working at heights, it is mandatory to be provided with, and to use personal fall protection systems such as work restraint systems, rescue systems or fall arrest systems	☐	☐	☐	☐	☐
38	There are instances when work is done without PPE because supply of new PPE (gloves, safety boots etc) to replace those worn out has not been received	☐	☐	☐	☐	☐
39	There are instances when we have to share PPE because they are not adequate for every worker	☐	☐	☐	☐	☐

	SECTION B **Evaluating the effectiveness of Personal Protective Equipment (PPE) programme in ensuring the safety of well site workers**	**Strongly Agree (5)**	**Agree (4)**	**Not sure (3)**	**Disagree (2)**	**Strongly Disagree (1)**
40	Overally, I am satisfied that the PPE provided is adequate in providing appropriate protection against workplace hazards	☐	☐	☐	☐	☐

Please proceed to Section C

	SECTION C **Evaluating the effects of ergonomic and psychosocial hazards on health of well site workers**	**Strongly Agree (5)**	**Agree (4)**	**Not sure (3)**	**Disagree (2)**	**Strongly Disagree (1)**

41	Maintenance workers are not only at risk of being involved in a work related accident, but also of developing occupational diseases such as Musculoskeletal disorders and occupational stress.	☐	☐	☐	☐	☐
42	Maintenance work is stressful when there is time pressure and inadequate staff to deal with emergencies at the rig. This when there is pressure for swift resumption of production.	☐	☐	☐	☐	☐
43	Maintenance work is stressful when you are not familiar with the equipment and you have not been well trained on the equipment that you have to work on	☐	☐	☐	☐	☐
44	The times that I have to carry out maintenance work alone and in isolation are very stressful	☐	☐	☐	☐	☐
45	Maintenance work involves bending, lifting heavy items, pushing and pulling	☐	☐	☐	☐	☐

	SECTION C **Evaluating the effects of ergonomic and psychosocial hazards on health of well site workers**	**Strongly Agree (5)**	**Agree (4)**	**Not sure (3)**	**Disagree (2)**	**Strongly Disagree (1)**
	heavy loads, working in awkward body postures or performing the same or similar tasks repetitively					
46	Over time, I have noticed that maintenance work affects my arms, shoulders and back.	☐	☐	☐	☐	☐
47	Management uses engineering controls to eliminate or reduce exposure to ergonomic hazards during maintenance at the work place e.g. use of folklifts, ergonomic work stations etc	☐	☐	☐	☐	☐
48	Management have established systems so that workers are rotated away from tasks to minimize the duration of continual exertion, repetitive motions and awkward posture (job rotation)	☐	☐	☐	☐	☐

	SECTION C Evaluating the effects of ergonomic and psychosocial hazards on health of well site workers	Strongly Agree (5)	Agree (4)	Not sure (3)	Disagree (2)	Strongly Disagree (1)

Please write any further comments on this page

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Thank you for your comments

Appendix II: Self Assessment Checklist

See overleaf

HSE

Health and Safety Executive

Self assessment checklist

POLICY	Fully met (Score 2)	Partially met (Score 1)	Not met at all (Score 0)	Comments and actions
1. The company understands its responsibilities for H&S towards employees, customers, visitors and members of the public and has a clear, written policy for health and safety at work, signed, dated and communicated to all employees.				
2. The Management regards health and safety of employees as an important business objective.				
3. The Management is committed to continuous improvement in health and safety (reducing the number of injuries, cases of work-related ill health, and absences from work and accidental loss).				
4. A named Manager or Senior Manager has been given overall responsibility for implementing our health and safety policy.				
5. Our policy commits the Management to preparing regular health and safety improvement plans and regularly reviewing the operation of our health and safety policy.				
6. Our policy includes a commitment				

to ensuring that all employees are competent to do their jobs safely and without risks to health.				
7. Our policy encourages the involvement of employees and safety representatives in the health and safety effort.				
POLICY SCORES				
TOTAL SCORE (Maximum = 14)				

For advice on H&S policies see Chapter 2 of HSG65 or page 2 of free leaflet INDG275 and http://www.hse.gov.uk/simple-health-safety/write.htm

For advice re leadership see http://www.hse.gov.uk/leadership/smallbusinesses.htm

ORGANISING CONTROL	**Fully met (Score 2)**	**Partially met (Score 1)**	**Not met at all (Score 0)**	**Comments and actions**
1. We have identified the people responsible for particular health and safety jobs including those requiring special expertise (e.g. our health and safety advisor).				
2. Our company responsibilities for all aspects of health and safety have been defined and allocated to our managers, supervisors and team leaders.				
3. Our managers, supervisors and team leaders accept their responsibilities for health and safety and have the time and resources to fulfil them.				
4. Our managers, supervisors and				

team leaders know what they have to do to fulfil their responsibilities and how they will be held accountable.				
ORGANISING CONTROL SCORES				
TOTAL SCORE (Maximum = 8)				
For advice on the essential elements of organisation control see page 17 of HSG65 and page 6 of ING275.				

ORGANISING COMMUNICATION	**Fully met (Score 2)**	**Partially met (Score 1)**	**Not met at all (Score 0)**	**Comments and actions**
1. We provide clear information to people working on our site about the hazards and risks and about the risk control measures and safe systems of work (which is easily accessible in the relevant work area).				
2. We discuss health and safety regularly and health and safety is on the agenda of management meetings and briefings.				
3. Our Management, managers and supervisors are open and approachable on health and safety issues and encourage their staff to discuss health and safety matters.				
4. Our Management, Managers and Team Leaders communicate their commitment to health and safety through their behaviour and by always setting a good example.				
5. We provide clear information to persons working on behalf of the organisation (i.e contractors, visiting				

drivers) regarding site hazards and risks and about the control measures in place to protect them.				
6. We provide clear information to casual and irregular visitors to the site (i.e customers, school visits, auditors) regarding site hazards and risks and about the control measures in place to protect them.				
7. We have established clear feedback systems to customers on safety issues, such as drivers breaching traffic rules, climbing on loads, not wearing PPE etc.				
ORGANISING COMMUNICATION SCORES				
TOTAL SCORE (Maximum = 14)				
For advice on communications see page 23 of HSG65 and page 6 of IND275				

ORGANISING CO-OPERATION	**Fully met (Score 2)**	**Partially met (Score 1)**	**Not met at all (Score 0)**	**Comments and actions**
1. We involve the workforce in preparing health and safety improvement plans, reviewing our health and safety performance, undertaking risk assessments, preparing safety-related rules and procedures, investigating incidents and problem solving.				
2.We consult our employees and employee safety representatives on all issues that affect health and				

safety at work				
3. We have an active health and safety committee that is chaired by the appropriate Manager or Senior Manager and on which employees from all departments are represented.				
4. For contractors and employment agencies whose employees work on our site, we have arrangements for cooperating and coordinating on health and safety matters.				
ORGANISING CO-OPERATION SCORES				
TOTAL SCORE (Maximum = 8)				

For advice organising co-operation see page 22 of Chapter 3 of HSG65 and page 6 of INDG275

For worker involvement and consultation see also:

http://www.hse.gov.uk/involvement/index.htm

http://www.hse.gov.uk/simple-health-safety/consult.htm

ORGANISING COMPETENCE	**Fully met (Score 2)**	**Partially met (Score 1)**	**Not met at all (Score 0)**	**Comments and actions**
1. We have a system for ensuring that all our employees, including managers, supervisors and temporary staff, are adequately instructed and trained.				
2. We have assessed the experience, knowledge and skills needed to carry out all tasks safely.				

3. We have a system for ensuring that people doing particularly hazardous work or exposed to hazardous situations have the necessary training, experience and other qualities to carry out the work safely.				
4. We have arrangements for gaining access to specialist advice and help when we need it.				
5. We have systems for ensuring that competence needs are identified and met whenever we take on new employees, promote or transfer people or when people take on new health and safety responsibilities e.g. when we restructure or reorganise.				
6. We have systems for the selection of contractor companies and their personnel entering our organisation. Before contracts are agreed upon we ensure they have the right level of technical and safety competence.				
7. We have systems for ensuring that competence needs are identified and met whenever we take on contracted or agency personnel and we have systems to assess the individual can carry out tasks safely.				
ORGANISING COMPETENCE SCORES				
TOTAL SCORE (Maximum = 14)				

For advice on competence see page 22 of Chapter 3 of HSG65 and page 6 of INDG275

For training see also: http://www.hse.gov.uk/simple-health-safety/provide.htm

For competent advice: http://www.hse.gov.uk/simple-health-safety/decide.htm and http://www.hse.gov.uk/business/competent-advice.htm

PLANNING AND IMPLEMENTING	Fully met (Score 2)	Partially met (Score 1)	Not met at all (Score 0)	Comments and actions
1. We have a system for identifying hazards, assessing risks and deciding how they can be eliminated or controlled.				
2. We have a system for planning and scheduling health and safety improvement measures and for prioritising their implementation depending on the nature and level of risk.				
3. We have arrangements for agreeing measurable health and safety improvement targets with our managers and supervisors.				
4. Our arrangements for purchasing premises, plant, equipment and raw materials and for supplying our products take health and safety into account at the appropriate stage, before implementation of the plan or activity.				
5. We take proper account of health and safety issues when we design processes, equipment, procedures, systems of work and tasks.				
6. We have procedures for dealing with serious and imminent dangers and emergencies.				
7. We have health and safety rules and procedures covering the significant risks that arise in our day-				

to-day work activities including normal production, foreseeable abnormal situations and maintenance work.				
8. We set standards against which we can measure our health and safety performance.				
9. We have formally stipulated and agreed safety specifications for static plant and equipment used within our organisation, they include requirements to fit certain safety control devices as required i.e. interlock systems, guarding, e-stops etc.				
10. We have formally stipulated and agreed safety specifications for mobile plant and vehicles (whether owned, contract hired or leased) and they include requirements to fit certain safety devices as required i.e. reversing cameras, autosheeters.				
11. We have arrangements for dealing with unplanned / ad hoc work activities, in identifying the hazards, assessing the risks and deciding how they can be eliminated or controlled.				
12. We have arrangements for dealing with emergency situations, which includes assigning certain roles and responsibilities to persons.				
13. We have arrangements for managing work which is identified as having a particular high risk and requires stricter controls. The work is carried out against previously agreed safety procedures, a ‘permit-to-work’ system.				

14. We have arrangements for ensuring that unauthorised operation of plant and equipment is effectively prevented.				
15. We have arrangements for performing 'Pre use' safety checks on vehicles, plant and equipment assessed as requiring such an inspection.				
16. We have procedures and arrangements for dealing with defects / breakdowns which occur during the course of work.				
17. We have a system for identifying hazards associated with moving, locating and relocating plant / work equipment around site, including skips, containers etc.				
18. We have arrangements for routinely inspecting plant and equipment in accordance with the OSHA 2007.				
19. We have arrangements with competent persons to perform statutory inspections of plant and equipment i.e. in accordance with the OSHA 2007 Examination of Plant Order.				
20. We have designed and constructed our site to take into account traffic and pedestrian movements and we have controls in place to ensure each user has a safe route around site.				
21. We have arrangements for performing routine site inspections which includes traffic management				

and behavioural safety.				
22. We have procedures for maintaining good housekeeping standards to minimise the risk of slips and trips.				
23. We have controls in place to reduce the risk of falls from height (eg into / from skips) by avoiding at height movements and having a system of work that does not require access at height.				
24. We have a system for identifying Manual Handling hazards, assessing risks and deciding how they can be eliminated or controlled, and all relevant employees have been trained accordingly.				
25. We have arrangements for ensuring employees are made aware of (and are provided with) the personal protective equipment which has been assessed as being required for a particular work activity.				
26. We have ensured that welfare facilities provided are suitable and sufficient to the work environment and those who will be required to use them i.e. staff, visitors, contractors.				
PLANNING AND IMPLEMENTING SCORES				
TOTAL SCORE (Maximum = 52)				

For advice on planning and implementing see Chapter 4 of HSG65 and page 7 of IND275

http://www.hse.gov.uk/simple-health-safety/manage.htm

http://www.hse.gov.uk/simple-health-safety/workplace.htm *http://www.hse.gov.uk/simple-health-safety/firstaid.htm* *http://www.hse.gov.uk/work-equipment-machinery/index.htm*

MEASURING PERFORMANCE	**Fully met (Score 2)**	**Partially met (Score 1)**	**Not met at all (Score 0)**	**Comments and actions**
1. We have arrangements for monitoring progress with the implementation of our health and safety improvement plans and for measuring the extent to which the targets and objectives set under those plans have been achieved.				
2. We have arrangements for active monitoring (i.e. checking) to ensure that our control measures are working properly, our health and safety rules and procedures are being followed and the health and safety standards we have set for ourselves are being met.				
3. We have arrangements for reporting and investigating accidents, incidents, near misses and hazardous situations.				
4. Where the arrangements in 2 and 3 above show that controls have not worked properly, our health and safety rules or procedures have not been followed correctly or our safety standards have not been met we				

have systems to identify the reasons why performance was substandard and where necessary we use disciplinary procedures.				
5. We have arrangements for analysing the causes of any potentially serious events so as to identify the underlying root causes including causes arising from shortcomings in our safety management system and safety culture.				
6. We have arrangements for measuring customer satisfaction in relation to safety of the products, services and activities we provide.				
7. We have arrangements to ensure supervisors continue to check that information, instruction and training has been fully understood by staff and continues to be taken on and used.				
MEASURING PERFORMANCE SCORES				
TOTAL SCORE (Maximum = 14)				
For advice on measuring performance see Chapter 5 of HSG65 and page 9 of INDG275				

AUDITING & REVIEWING PERFORMANCE	**Fully met (Score 2)**	**Partially met (Score 1)**	**Not met at all (Score 0)**	**Comments and actions**
1. We have regular audits of our safety management system carried out by competent external auditors or				

competent auditors employed by our company who are independent of the department they are auditing.				
2. We use the information from performance monitoring and audits to review the operation of our safety management system and our safety performance.				
3. We regularly review how well we have met the objectives in our health and safety improvement plans and whether we have met them in the agreed timescales.				
4. We analyse the information from performance measurement and use it to identify future improvement targets and to identify particular causes of accident, ill health or poor control of risk, to target for future risk reduction effort.				
5. We formally review our risk assessments annually and as required by certain events i.e. changes in operation, site layout, new purchases, new developments or following an accident or incident on site.				
6. We analyse the information from customer safety breaches and use it to identify future improvement targets and to identify particular causes of accidents, near misses to target for future risk reduction effort.				
7. We analyse the information from plant and equipment breakdown / maintenance records to identify patterns of deterioration (cause analysis).				

8. We periodically review the site layout to take account of changes in work activities, traffic type, volume and circulation.				
AUDITING & REVIEWING PERFORMANCE SCORES				
TOTAL SCORE (Maximum = 16)				
For advice on auditing and reviewing see Chapter 6 of HSG65 and page 10 of INDG275				

Results

SECTION HEADING	**Possible points**	**Actual points**	**% score**	**Comments and actions**
Policy	14			
Organising control	8			
Organising communication	14			
Organising co-operation	8			
Organising competence	14			
Planning and implementing	52			
Measuring	14			

performance				
Auditing and reviewing	16			
Total points/overall	**140**			NB: The higher the % score the better
Date exercise carried out				**Date to repeat exercise**

Appendix III: Research Requesting Letter From IEET

JOMO KENYATTA UNIVERSITY
OF
AGRICULTURE AND TECHNOLOGY

INSTITUTE OF ENERGY AND ENVIRONMENTAL TECHNOLOGY

P.O. BOX 62000, Nairobi, Kenya. Tel: (067) 52251/52711/52181-4. Fax: (067) 52164 Thika. Email: director@ieet.jkuat.ac.ke

DATE: 26th September, 2016

The General Manager-Technical Services
The Drilling Operations,
Geothermal Development Company,
P.O. Box 100476-00100
NAIROBI

30/9/2016

Dear Sir/Madam,

SUBJECT: JKNC-EET32-2145/10- KACHILA PHILEMON

The above named person is a postgraduate student at the Institute of Energy and Environmental Technology (IEET) in Jomo Kenyatta University of Agriculture and Technology. He is pursuing the Master of Science degree in Occupational Safety and Health and he is currently undertaking his research on *"The impact of plant maintenance on occupational safety and health of workers in Geothermal Drilling activities in Kenya"*.

Any assistance given to him will be highly appreciated and the information given thereof shall be treated professionally and shall only be used for the purpose of producing the thesis. The student has undertaken to follow the research ethics as stipulated by the university.

Thank you for your assistance.

PROF. R. KINYUA
DIRECTOR, INSTITUTE OF ENERGY AND ENVIRONMENTAL TECHNOLOGY

JKUAT is ISO 9001:2008 CERTIFIED
Setting trends in Higher Education, Research and Innovation

Appendix IV: Research Approval Letter from GDC

GDC Geothermal Development Company
Green Energy for Kenya

KAWI HOUSE, SOUTH C BELLEVUE,
RED CROSS ROAD, OFF MOMBASA ROAD
P.O.BOX 100746-00101, NAIROBI
TEL: (254)20 2427516/0719036000
info@gdc.co.ke/www.gdc.co.ke

Ref: GDC/ D&I/02/1b/COO/co

September 30, 2016

Prof. R. Kinyua,
Director, Institute of Energy and Environmental Technology,
Jomo Kenyatta University of Agriculture and Technology,
P.O Box 62000,
NAIROBI

Dear Sir,

RE: JKNC-EET32-2145/10-KACHILA PHILEMON

We refer to your letter dated 26th September 2016 regarding assistance to be given to Kachila Philemon on his research on "*The impact of plant maintenance on occupational safety and health of workers in Geothermal Drilling activities in Kenya*".

As requested, we hereby permit Mr. Kachila to do his research at our rig sites in Menengai from 3rd to 6th October 2016. He should be in full protective gear when at the rig sites and should avoid access to any other unathorised site.

GDC shall be indemnified against any damage, loss or injury sustained by Mr. Kachila or his property.

Yours Faithfully,

CORNEL OFWONA
Ag. GENERAL MANAGER, DRILLING & INFRASTRUCTURE

cc Ag. GM GRD & Area Manager, Central Rift
Manager, Drilling Operations
Manager, Quality and Safety
Deputy Manager, Security

Appendix V: Calibration Certificate For The Noise Meter

ORIGINAL

Kenya Bureau of Standards
Website: www.kebs.org

KEBS

Calibration Certificate

Page 1 of 10 Pages

BS/MET/19/15/3/7/11

REQUESTED BY:	GEOTHERMAL DEVELOPMENT COMPANY LIMITED
ADDRESS:	P.O. BOX 100746-00101 NAIROBI
EQUIPMENT:	SOUND LEVEL METER
TYPE/MODEL:	NL-42
SERIAL NO.:	01161047
MANUFACTURER:	RION
MICROPHONE TYPE:	UC-52
MICROPHONE SERIAL NO.	167496
LABORATORY:	ACOUSTICS AND VIBRATION - NP 15
DATE:	2019-03-28
CERTIFICATE NO.:	BS/MET/19/15/3/7/11
STICKER SERIAL NO:	40953

1.0 STANDARDS AND REFERENCE EQUIPMENT USED

Pulse 3630 calibration platform consisting of:
- B&K controller module type 3560C S/No. 2522655
- Agilent 34970A Data acquisition switch unit S/No. MYA 44010494
- B&K Inline capacitor WA 0302-A 20 pF S/No. 2354305
- Multifunction Acoustic Calibrator Type 4226 S/No. 2532069

2.0. CALIBRATION PROCEDURE

The Sound Level Meter was calibrated using Kenya Bureau of Standards Laboratory Procedure MET/15/CP/02: *Sound level meter calibration* and in accordance with the requirements of IEC60651 and IEC 60804.

Prepared By: **Collins Taiti** Date: **2019-03-20**

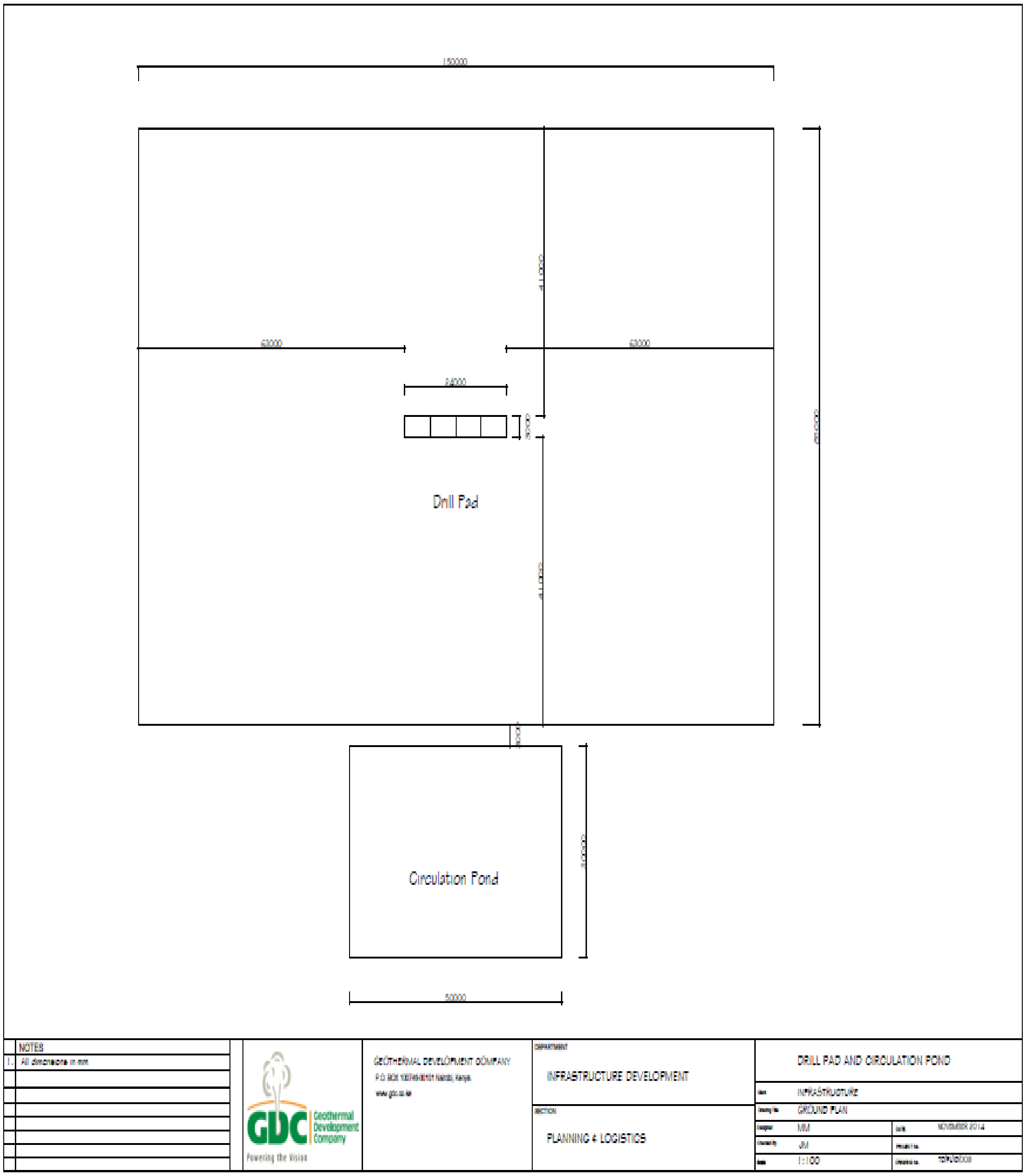
Checked By: Andrason Waura Date: 2019-03-21

Signed: [signature] Date: 2019-03-21

For: MANAGING DIRECTOR

Calibration certificate without signature and official stamp is not valid. This certificate has been issued without any alteration and may not be reproduced other than in full except with the approval of the Managing Director KEBS.
If undelivered please return to the above address.

Appendix VI: Drill Pad Plan



Appendix VII: Publication

Using Sound Mapping in Enhancing the Hearing Conservation Programmes of Geothermal Drilling Activities In Kenya: A Case Of Geothermal Development Company

Kachila, P., Njogu, P., and Makhonge, P.

Abstract— Kenya is endowed with 10,000 MWe of geothermal resource spread in 14 potential prospects along the Rift Valley. The government has prioritized geothermal power generation and specially formed The Geothermal Development Company (GDC) in 2008 to drive this agenda. GDC has purchased seven deep drilling rigs that are operated and maintained by a Kenyan crew for drilling geothemal wells. However the geothermal drilling rig has been identified as a high noise hazard workplace, exposing workers to the risk of permanent hearing damage. Traditional noise control measures that have been installed at work stations to comply with the Noise Prevention and Control Rules of 2005 includes: absorbers, sound-absorbing materials, soundproof doors, screens, vibration isolation, enclosures, silencers, sound isolated pipelines, sound-insulating cabins and sound-absorbing systems. While it may never be possible to eradicate all noise from the workplace, this study assessed the use of noise maps in enhancing the hearing conservation programmes by early detection, isolation and remedying problem areas. Noise reduction after the construction of the plant and the installation of machines and devices or during the full-scale operation stage is not only much more difficult, but also much less efficient, leading to only a slight reduction of noise at a relatively high cost. Moreover, the necessary alterations or adaptations are not always favourable to the technological process applied. It was established that the noise maps can be done for all combinations of activities and machinery at the rig site to show all the sources of noise and how it is dispersed, making it easier and cost-effective in establishing key areas for mitigation measures.

Index Terms— Calibrated noise meter, Geothermal drilling rigs, Hearing Conservation Programme, Noise control measures, Noise maps, Noise mitigation measures, Occupational noise, Sound mapping and simulation softwares, Sources of noise