Impacts of Ambient Hydrogen Sulphide Exposure to Workers in Olkaria Geothermal Power Station, Kenya

Gikunju Patrick Irungu

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

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DECLARATION

This thesis is my original work and has not been presented for a degree award in any other university.

Signature ______________________________ Date __________________

Gikunju Patrick Irungu

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

Signature ______________________________ Date __________________

Dr. Njogu Paul

JKUAT - Kenya

Signature ______________________________ Date __________________

Mr. Pius Makhonge

JKUAT - Kenya

DEDICATION

Thesis dedicated to

Sarah, Emmaculate and Grace for encouragement and support.

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LIST OF NOMENCLATURE AND ABBREVIATIONS

EPA - Environmental Protection Agency

ERC - Energy Regulatory Commission

GC/FID - Gas chromatography /Flame Ionization Detector

GRD - Geothermal resource development

H_2S - Hydrogen Sulphide

HSDB - Hazardous Substances Data Bank

ILO - International Labour Organisation

IPCS - International Programme on Chemical Safety

IRIS - Integrated Risk Information System

JKUAT - Jomo Kenyatta University of Agriculture and Technology

KenGen - Kenya Electricity Generating Company Ltd

L.N. - Legal Notice

MSDS - Material Safety Data Sheets

MW - Mega Watt

OEL - Occupational Exposure Level

OSHA - Occupational Safety and Health Act

OLK…. Olkaria

ppm - Parts per million

SCOEL - Scientific Committee on Occupational Exposure Limits

TWA - Total weighted average

WHO - World Health Organisation

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ABSTRACT

Geothermal exploration and power generation taps on the heat of the earth crust to meet mans energy demands. In the process, non condensable gases escape into the atmosphere. One of the most noticeable gases of public health concern is Hydrogen sulphide (H_2S). This study sought to investigate the exposure to H_2S concentration to workers in Olkaria geothermal power plants in Kenya. Olkaria geothermal power plants operated by KenGen at Hells gate national park in Nakuru County are the largest geothermal power plants in Africa. There is a general workplace belief that smell of rotten eggs in the power plants is mere nuisance; and no hazard if it exists below the total weighted average (TWA) for occupational exposure limits (OEL) of 10ppm. Using questionnaires administered to a sample of the operations and maintenance team, impacts of exposure to ambient H_2S were investigated. Ambient measurements of H_2S were taken at hourly intervals at purposely selected sampling points in the two power stations. Clinical records for staff working in the operations department indoor conditions were reviewed and compared with those who worked in other sections. In most occurrences (> 80%), the measurements of H_2S ranged between 0.1-1.0ppm which is a weak smell above the odor detectable threshold. According to Costigan, 2003 exposure to H_2S within 2.0 -7.0 ppm levels may cause nausea, tearing of the eyes, headaches, loss of sleep and airway problems. Respondent who work in operations and maintenance required a combination of physical, mental and visual - audio skills where ($p > 0.37$, n=40) at 95% confidence levels. The study found out that presence of H_2S smell at workplace contributed to quick exhaustion of employees which would affect performance. Notably, however this was not the only contribution to exhaustion hence T- test P value = 0.193, at $p<0.05$ were not significant to cause the rejection of null hypothesis. Again the probability that strong pungent smell of rotten eggs at workplace in Olkaria geothermal power stations does cause discomfort to employees at workplace is not significantly proven (df=39, P value = 0.112, at $p<0.05$). However it was shown that physical work environment satisfactorily impact on the employees causing fatigue (df=39, P value = 0.0001 is significant at $p<0.05$). When a smell is persistent at workplace for a long time, the results satisfactorily showed that a worker significantly gets accustomed to the condition (exhausted (df=39, P value = 0.0295 is significant at $p<0.05$). The study concluded that there were weak direct associations between exposure to low ambient H_2S concentrations to workers in the Olkaria Geothermal power plant and the impacts on their health and comfort and subsequent performance. Analysis of clinical cases with similar diagnosis to exposure to H_2S was 114.8% higher for the 12 hr operations and maintenance shift staff than the rest of the population working in the same department for 8hour shift. Since identification of an occupational disease by ILO is not necessarily a pure science, associations that are consistent with other researchers are considered. In Iceland, action to adjust the OEL was reached by monitoring the rising complaint cases related to exposure despite lack of existence of a study confirming the correlation.

CHAPTER ONE.

INTRODUCTION

1.1 Background to the Study

Drilling activities in Olkaria geothermal fields to mine geothermal steam for power generation is driven by the demand for electricity from renewable sources. Since 4th July 1904 in Larderello when the first geothermal power generator was tested in Italy, technology for harnessing the geothermal steam energy has been developing from the use of direct steam (flush steam technology) by 1958 in Wairakei in New Zealand to binary cycle power plant built in 1967 at Pauzhetka Russia and US 1981 (Simiyu, 2010). In Kenya, the geothermal resource exploration was started in 1950's in the region between Olkaria and Lake Bogoria leading to construction and commissioning of Africa's first geothermal power plant at Olkaria with 45MW capacity from 1981 to 1985 (Simiyu, 2010). According to ERC, 2012; the growth has been steady reaching 150MW capacity with KenGen targeting to generate 75% of 3000MW by 2030 from geothermal power source installed capacities as indicated in Table 1.1 below.

Table 1.1: Installed energy capacity at KenGen

Energy source	**Installed Capacity (MW)**	**Effective capacity (MW)**
Hydro	788	770
Geothermal	157	150
Petro- Thermal	259	236
Emergency power producers	120	120
Wind	5.3	5.1
Total	1329.3	1276

Source: Energy Regulatory Commission 2011-12 Reports

1.1.1 Emissions from Geothermal Plants.

Geothermal plants do not emit sulfur dioxide directly but once hydrogen sulfide is released as a gas into the atmosphere, it spreads into the air and eventually changes into sulfur dioxide and sulphuric acid which is the source of corrosion problems (Costigan, 2003). Hydrogen sulphide at room temperature is a colourless gas with a strong pungent odour of rotten eggs at low concentration. This smell is typical of geothermal power generation though the gas can be found in many other places such as sewer lines, oil drilling among others (Costigan, 2003).

The main use of hydrogen sulphide is in production of sulphuric acid and elemental sulphur. Hydrogen sulfide is used in preparation of reagents for pesticide manufacture, leather, dyes and pharmaceuticals. Flower farmers around Olkaria use H_2S as agricultural disinfectant. Hydrogen and water have similar structures except that intermolecular forces in H_2S are weaker than those of H_2O. The gas would also find use in heavy water in nuclear reactors and metal cutting as a coolant. Without release to the environment, its uses under controlled environment is beneficial.

Hydrogen Sulphide is part of the gases trapped in the steam and leakages in the atmosphere occur during venting and reticulation leakages in the geothermal plant. Other gases are carbon dioxide (CO_2,) Ammonia, (NH_3), Hydrogen (H_2), Methane (CH_4), Oxygen (O_2), Nitrogen (N_2,), Argon (A_r) and Helium (He) (Patterson *et al*., 1992). Hydrogen Sulphide is classified as a chemical asphyxiant, similar to carbon monoxide and cyanide gases as it inhibits cellular respiration and uptake of oxygen, causing biochemical suffocation.

Hydrogen sulphide can be detected by its rotten smell at concentrations between 1-30ppm and a sickening sweet smell up to 100ppm where a person's detection ability is affected by rapid temporary paralysis of the olfactory nerve in the nose which leads to loss of smell (Costigan, 2003). According to Costigan, an exposure below 30 ppm causes irritation of the eyes, nose and throat. It is suspected that discomfort can lead to occupational hazards associated with loss of concentration and focus at workplace. Exposure to the gas at this concentration even for thirty minutes can also cause headache, dizziness nausea and vomiting in addition to coughing and breathing difficulties with symptoms similar to upper respiratory tract infections (URTI). Continued working in an environment that is uncomfortable or un-conducive will compromise the health of the workers and ability to execute duties (Lowana, 2011). In the long run, the organisation loses productivity when health issues lead to absenteeism and low morale.

1.2 Statement of the problem

Presence of pollutants in the workplace such as H_2S workplace besides being unpleasant and distracting to workers, also leads to poor morale and decreased productivity (Matheson, 2008). Some workers in Olkaria geothermal power plants are noted to make verbal complain of breathing difficulties, red eyes and repeated headaches. Repeated exposure to H_2S causes headache, dizziness, digestive disturbances, and at worse, collapse and death (Matheson, 2008). In Olkaria geothermal power plants, records of H_2S as an occupational disease are scanty and verbal complaints where the workers suspect the H_2S is affecting their health and performance have not been verified. A verbal report given to a researcher from Iceland indicated that a photographer went into a manhole to photograph the inside of a flash tank to record corrosion on its walls. He was knocked down and the person who followed to assist him was also knocked down unconscious. A third person who tried to save the two suffered same fate (OECD, 2009)

In Olkaria geothermal power plant, presence of the H_2S is recognised by the installed H_2S gas detection system in the low poorly ventilated sections of the plant. The stationery alarm systems are set to raise alarm at concentrations of 10ppm (WHO, 1981) or more which is in line with the local legislation (OSHA, 2007). However at lower concentration the perception is that exposure is a nuisance having no impact on health and performance of the employee. Ventilation is expected to introduce fresh air from the environment and replace the polluted indoor air. This holds beneficial when the outdoor air is of superior quality which has not been investigated for the Olkaria geothermal power plants. Increased drilling activity near the plant, steam leakages and venting, increase the concentration of H_2S in the power plant.

Polluted work environment has the potential to affect the health of a worker. Establishing the prevailing conditions and corresponding effects would ensure the comfort and health of a worker is protected. It had not been established whether there are impacts of chronic exposure to the ambient H_2S in Olkaria geothermal power plants. If exposure to ambient concentrations of the gas causes discomfort and poor health to workers, this may also affect focus at work and performance.

1.3 Justification of the Study

The occupational exposure levels for H_2S are set with industrial discharges in mind and make an assumption that the industry is in control of the discharge of the pollutant (NIOSH, 1977). In Kenya, the occupational limits are regulated under the safety regulation (OSHA 2007) while the environmental limits are regulated under the environmental law (EMCA, 1999). The pollutants in a workplace whose concentrations fluctuate between the two limits can be easily overlooked as each authority enforces their respective requirements.

The current monitoring of H_2S at Olkaria geothermal power plants by installed warning systems is primarily to ensure that workers are not exposed to 10ppm and above. This would expose workers to a risk to their comfort and health while working even at low concentrations. Impacts of exposure of H_2Seven in low concentrations could be such as bronchial problems similar to upper respiratory truck infections (URTI), bronchitis, coryza, mouth sores, pharyngitis, rhinitis, sinusitis, sore throat and tonsillitisas well as depressing the nervous system. If these were to occur in Olkaria geothermal power plants, then productivity would be affected. Any release to environment including undetectable noxious agents that may adversely affect people's health or business environment against their consent may lead to litigations as a violation of constitutional rights (GoK, 2010).

The demand for geothermal power and exploration is growing and by 2018, this source is expected to contribute about 30% of the total electrical energy sources in Kenya (ERC, 2009). There is more potential for geothermal exploration in the Rift Valley as shown in figure 1.1 on proposed locations for geothermal exploitation. The quantity of H_2S released from geothermal activities and the people exposed would increase commensurate to release in other co-released greenhouse gases. The growing public awareness on right to a healthy environment against this increase could make it more difficult for the organisation to continue maintaining the status quo.

An investment in mitigation against release would be justifiable when the impacts on health and comfort of exposed workers are established. Such mitigation would reduce the levels of H2S a worker is exposed to and the duration of exposure. Reversible impacts of exposure can be addressed while ways to address non reversible impacts would be addressed as per the medical examination rules and workmen injury benefit act (OSHA, 2007). Industries with similar exposures such as paper and leather industries may find the recommendations useful. Combine approach in mitigation measures adopted to reduce H_2S concentration in local atmosphere could consequently reduce co-release asphyxia gases thus improve the quality of life of the workers.

Figure 1.1: Map showing existing and proposed geothermal locations

(Source: Simiyu, 2010)

1.4 Research Hypothesis

The null hypothesis

> Exposure to H_2S levels in the Olkaria Geothermal power does not affect health and performance of workers.

1.5 Objective of the Study

1. General objective

The objective of the study was to assess impacts of exposure to H_2S on performance and health workers of Olkaria Geothermal power plants.

2. Specific objectives

1) To investigate impacts of ambient H_2S on the health and performance of the workers at Olkaria Geothermal power plants.
2) To determine the ambient air concentrations of H_2S at Olkaria Geothermal power plants.
3) To assess the clinical history of the staff at Olkaria Geothermal power plants

1.6 Scope of the study

The study identifies the effects of exposure to ambient concentrations in Olkaria I and Olkaria II geothermal power stations. The study investigates the ambient levels of H_2S at the power plants by measurements at sampled areas. A review of clinical history of employees using the Mvuke clinic is done to determine if there are possible clinical cases of exposure to H_2S exposure. Investigation is done on operation and maintenance workers to determines the effects on health and comfort where exposed to ambient H_2S in indoor environment. The research investigates effects of heath and comfort on the employees exposed to H_2S and its relationship with concentrations and focus at work which would impact on safety at work.

1.7 Study limitation

The study on impacts of H_2S was limited to the geothermal in Olkaria though the gas is generated in other sources which could not be included in this study. Geothermal co-release include a CO_2, NH_3, H_2, CH_4, O_2, N_2, Ar and H_e (Patterson, *et al*., 1992), whose contribution to impacts on the workers at Olkaria Geothermal power plants was not isolated as this requires specimen tests. The study was limited to observable symptoms, measurements of ambient conditions and respondent's feedback. The study results apply to grown up persons who are in working age and cannot be applied to a different population without correction for the population characteristics.

CHAPTER TWO.

LITERATURE REVIEW

2.1 Theoretical Principles

2.1.1 Chemistry of H_2S

Hydrogen Sulphide (H_2S) is a colourless gas identified with a strong odour at low concentration and a naturally occurring gas in the atmosphere largely due to human activity such as drilling of geothermal steam, crude oil and natural gas accounting for 90% of H_2S in the atmosphere (US EPA, 1993). In unpolluted environment, the concentration of hydrogen sulphide in air is very low ranging between 0.03 and 0.1 $\mu g/m^3$ (US EPA, 2003). Due to its high density the gas tends to accumulate in low lying areas such as basements and pits. H_2S can also be found around hot springs and decomposing human and animal waste. It's also a by-product in tanneries, food processing plants and petrol chemical plants. Sulphates at temperature below 20^oC in anaerobic conditions can produce H_2S by sulphate reducing bacteria. Also the bacteria in the human mouth and gastrointestinal tract could also be as source of the gas though in small quantities (Noguel *et al.,* 2011).

In drilling and operations of old power generation technologies; where steam condensate commonly referred to as brine was not immediately and directly re-injected back to the ground, plenty of H_2S escapes to the environment from the cooling brine. Development of technologies has seen less ambient interaction with brine such as the technology used at Olkaria II where non condensable gases are released at the cooling tower with most dissolving in the water mist used for cooling the condensate.

Direct measurements of quantity of gases released by both plants in Olkaria are not installed. This lack of measurement occurs in many geothermal power plants and quantities of release are estimated as a proportion of released steam. Gas chromatograph can be used for direct measurement of the gases coming from the condensers to the vacuum pump (Gunnarsson, *et al.* 2013). Drilling activities adjacent to generation plant would cause reasonable increase in environmental H_2S which could easily find its way into the power plant. The proposed geothermal power stations in future expansions are expected to use better generating technologies than Olkaria I and Olkaria II. New technologies would improve the handling of brine associated with the release of the gas into the environment. The current technology used in generation at the geothermal power plants allows escape of H_2S to atmosphere at different points such as; the silencer, separator, turbine, degassing, cooling towers and re-injection wells as shown in Appendix 7 of Power plant layout. Additionally in Olkaria I Geothermal power station which is older, the brine or condensate is pumped from an open pit into the re-injection wells giving an opportunity for co-release gases to escape which is not the case in Olkaria II Geothermal power station. The accumulation of H_2S has an effect on corrosion of structures at Olkaria I geothermal power station as shown in Plate 2.1 due to formation of sulphuric acid as source of hydrogen ion H+ as in equation 2.1 where hydrogen sulphide in presence of water forms a sulphate salt.

$$Fe + H_2S + H_2O \text{ ------> } FeS_x + H_2 + H_2O,$$

Equation 2.1

Plate 2.1: Corrosion of structures around seal pit in Olkaria I

2.1.1 Physiological effects of H_2S

The presence of respiratory irritants such as H_2S in the workplace can be unpleasant and distracting, leading to poor morale and decreased productivity. Exposure to H_2S can cause irritation to eyes and respiratory tract, conjunctivitis, pain and photophobia may persist for several days. Coughing, pain in breathing, pain in nose and throat occurs with further exposure. Repeated exposure causes headache, dizziness and digestive disturbances or at worse collapse and death (Matheson, 2008)

Upper respiratory truck infections may be triggered by other environmental irritants other than H_2S exposure such as dust, cold weather and individual lifestyle and health status. The air passage as one breath enters through the nose or mouth and into the bronchi then divides into the two bronchioles. It then enters the alveoli where oxygen is exchanged with carbon dioxide through the epithelium of alveolar wall. It is shown as in the Figure 2.1 on overview of respiratory system below shows that particles of different sizes can pass along the air and can get deposited along the air way including pathogens that cause infections. As the air goes in, particles also get smaller ranging from 10 μm which would pass through the nose to 1-2 μm which would reach the alveolar duct. Only particles less than 1 μm would get to alveolar sacs (Carlsen, 2014).

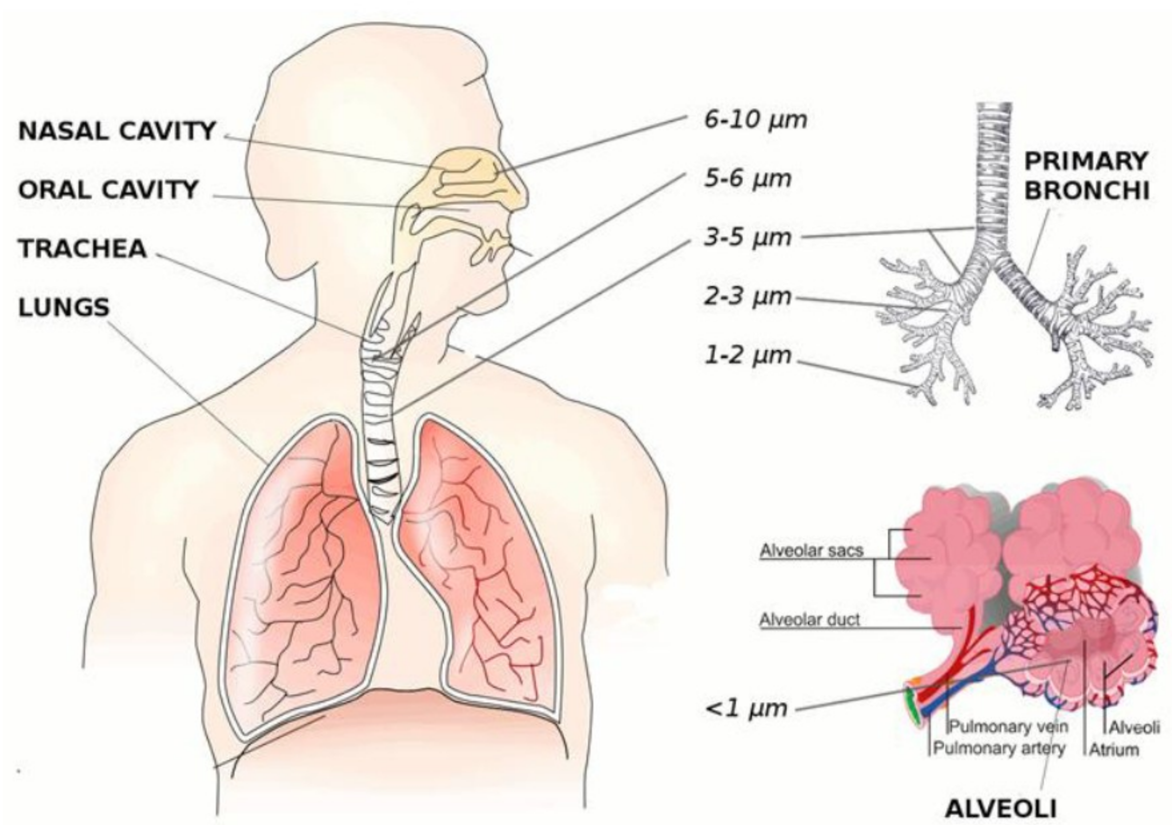


Figure 2.1: Overview of respiratory system

(Source: Carlsen, 2014)

In addition to the respiratory problems, prolonged exposure to H_2S at relatively low levels may result in painful dermatitis and burning eyes. This has been established since 1982 by Alberta Health where reported complaints of eye and lung irritation in Cynthia occurred after a maximum potential exposure of 14 ppm H_2S for 2hr (Alberta Health, 1988). Residents described their eyes as feeling "sandy" or "burning" and several people reported having blurred vision. It was reported inflamed conjunctiva on exposure to gaseous form. Conjunctivitis (also called pink eye) is inflammation of the conjunctiva which is the outermost layer of the eye and the inner surface of the eyelids as shown in Figure 2.2. It is most commonly due to an infection or an allergic reaction

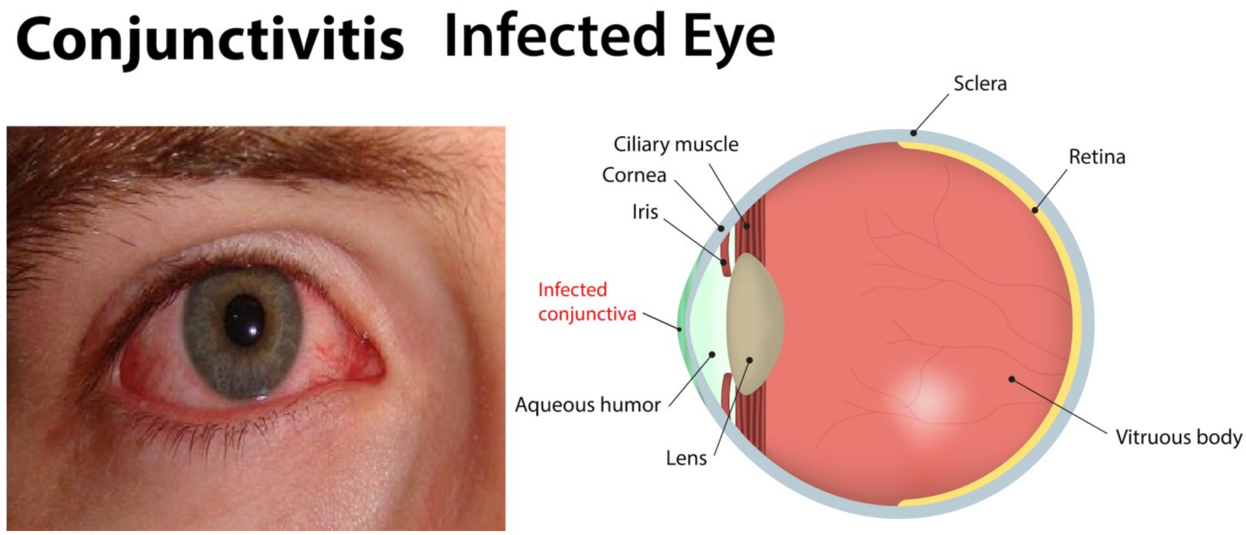


Figure 2.2: Infection of eye- conjunctivitis

Source: CDC, (2017)

Some studies in public health indicate that hydrogen sulfide is a potent neurotoxin, and that chronic exposure to even low ambient levels causes irreversible damage to the brain and central nervous system. There is a suggestion that the exposure to odor has an effect on secretory immune function and physiologic effect among neighbors who are exposed to the ambient gas in Eastern North Carolina Exposed people showed chronic neurobehavioral impairment (loss of balance, memory and reaction time) months to years afterwards (Carlsen, 2014).

2.1.2 Exposure and health effect of H_2S

In assessment of toxicity in the dose-response relationship assumption is made to the existence of a causal connection between exposure to a given agent and the resultant effect. For a perfect relationship in an experimental case, this would imply that for the response to be present, the risk factor is present. However it is noted that in chronic cases, some responses may be contributed by other background factors which can be identified and isolated with further studies.

As shown in Table 2.1 on exposure levels and effects, irritation of the eyes, nose and throat can be detected at concentrations below 30ppm. As the exposure progresses, headache, dizziness nausea and vomiting occurs with coughing and breathing difficulty at exposure of up to 100ppm, above this level it is known to cause instant death as it blocks the oxidative capacity of the blood, reducing the oxygen carrying capacity of the blood. The gas has capacity to depress the nervous system as well as cause respiratory failure and asphyxiation (Selene *et al,* 2003).

Figure 2.3 shows a range of effects of exposure on breathing, eyes and smell to varying concentrations of H_2S mapped against respective concentration from Table 2.1.

Depending on the duration and concentrations of H_2S, employees would respond with symptoms that reflect the dosage in dose-response relationship.

Table 2.1: Effects of different Exposures levels of H_2S on human

H_2S concentration	**Observations and description of smell (odor)**
0.00011-0.00033	Typical background concentrations below odor threshold
0.003-0.02	Detectable odor (EPA 1993)
0.1-1.0ppm	**Weak Smell** which is within detectable odor range 0.1ppm is 24 hr WHO average (Amoore and Hautala, 1983)
1.0-2.0ppm	Notable Smell between detectable smell and irritating
2.0-3.0ppm	**Irritating** smell (Kilburn, 1999)
3.0- 5.0ppm	Offensive Smell. Eye irritation start increase at 5.0 ppm (Vanhoorne *et al.,* 1995) Eye irritation between 5-29ppm (IPCS, 1981) 5.0ppm OEL UK exposure levels
5-29 ppm	Eye irritation between 5-29ppm (IPCS, 1981) Nose irritation, sense of smell starts to become "fatigued" 20-50 ppm (EPA, 2003). 10ppm WHO exposure levels, Local OEL (OSHA, 2007)
30-50 ppm	Nose irritation, sense of smell starts to become "fatigued" 20-50 ppm (EPA, 2003). Fatigue, loss of appetite, headache, irritability, poor memory, dizziness (Ahlhorg, 1951)
100-150 ppm	Ability to smell odour completely disappears (EPA, 2003). Olfactory paralysis (Hirsch and Zavala, 1999)
>150 ppm	Respiratory distress at 500 ppm (Spolyar, 1951) Collapse and death at 700 ppm (Beauchamp *et al*., 1984)

(Source: Selen *et al*.,

2003).

The figure 2.3 shows the characteristic of the smell or odor changes with increase of H_2S concentration. At 0.33 parts per billion, the H_2S could exist in the background environment undetected by smell until it gets to around 0.1- 1.0 ppm when the odor becomes detectable.

Above 2.0 ppm the odor is irritating and becomes offensive as the concentrations get between 3-5 ppm. Nose irritation occurs at 50-100 ppm when the sense of smell starts to become "fatigued", and ability to smell completely disappears as concentrations reach 100-150 ppm (EPA, 2003). Other effects on eyes include increased eye complaint at 5.0 ppm, eye irritation at 5-29 ppm, breathing problems and feeling of stuffiness among other identifiable form of responses of the doses within the dose range. However repeated exposure to the same hazard may lead to accumulation of effects which are different from a onetime exposure. Such effects may have symptoms of discomfort, poor health and clinical cases.

Analysis of clinical records of employees' associated with cumulative exposure to ambient concentrations of H_2S would indicate the health impacts of chronic exposure. This would also assess the effectiveness of existing controls in preventing exposure though not part of the scope.

When an exposed employee experiences discomfort, the focus or concentration required in execution of work is affected. Poor work environment and workplace ergonomics would expose workers to occupational hazards associated with unstable mental focus, work errors and weariness.

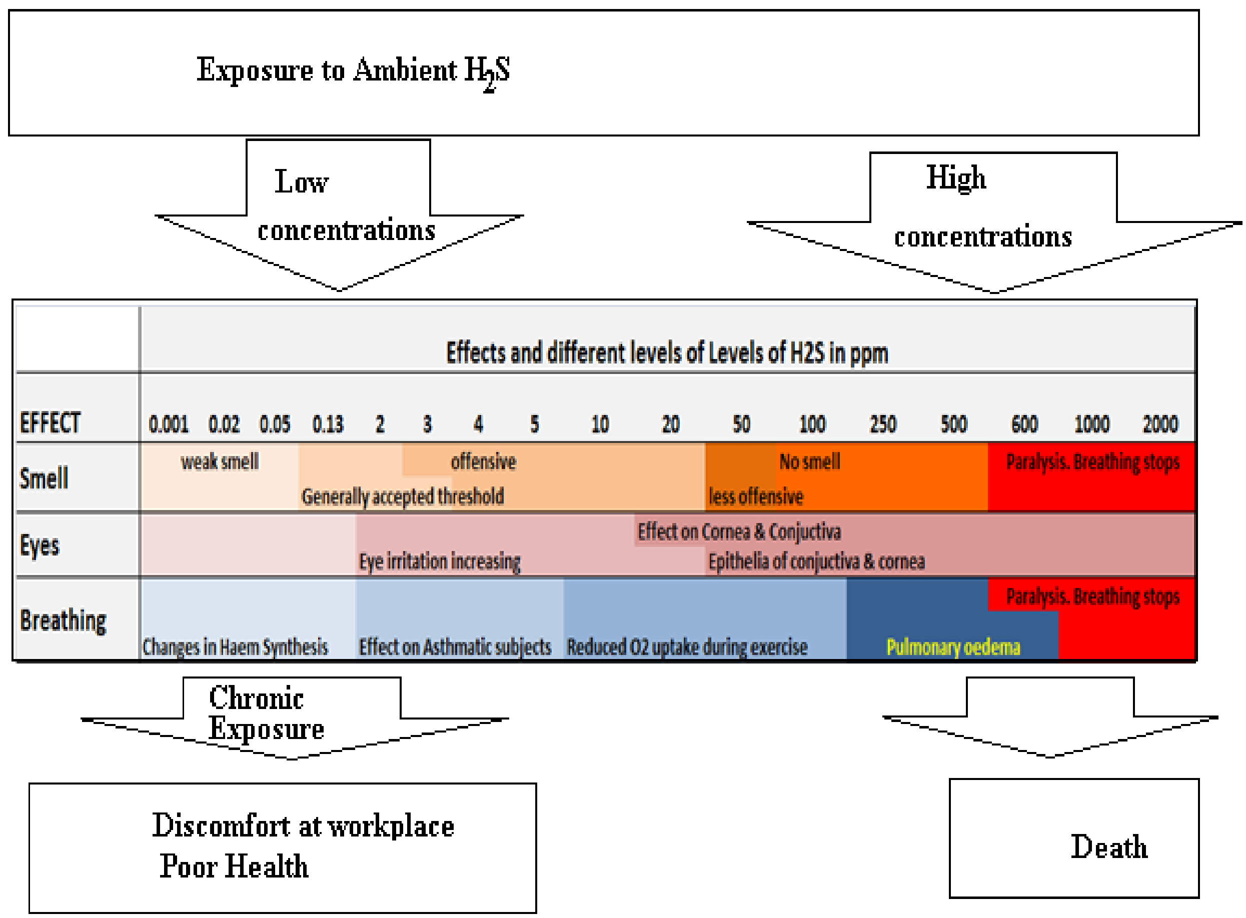


Figure 2.3: Effects at different levels of exposure of H_2S

(Source: Selen *et al*., 2003).

2.1.3 Management of exposure

Avoiding areas that have potential of having H_2S is a safe way to keep out of harm. Whereas this is not practical, provision of local exhaust or process enclosure ventilation system to ensure compliance with applicable exposure limits is recommended. Also recommended are splash resistant safety goggles with a face-shield for eye protection and provision of emergency eyewash fountain and quick drench shower in the immediate work area (Matheson, 2008).

The body is protected by having chemical proof overalls and hand gloves for a mild concentration. Air-purifying respirator with cartridge providing protection against exposure is used in cases of significant exposure places (Matheson, 2008).

Use of chemical sensors such as personal one attached to a worker, a hand held which supervisors carry around with them and remote monitors which are fixed devices are suitable for detection and warning. Such gadgets are normally calibrated and set to raise alarm at 10ppm exposure. Detector tubes are used to establish a rough measure of the gas concentrations and do not have alarm or continuous measuring.Hydrogen sulphidecan be measured in biological samples such as human breath (as expired air), biological tissues, and fluids, including blood and saliva using gas chromatography coupled with flame ionization detection (GC/FID) or iodometric titration. Iodometric titration is a method when an analyte that is an oxidizing agent is added to excess iodide to produce iodine, and the iodine produced is determined by titration with sodium thiosulfate.

2.2 Legal framework on workplace safety in Kenya

2.2.1 The Kenya constitution, 2010

In the Kenyan constitution, every person has the right to a clean and healthy environment. This right includes right to have the environment protected for the benefit of present and future generations through legislative and other measures, particularly those contemplated in Article 69 touching on natural resources. Any release to environment including undetectable noxious agents that may adversely affect people's health against their consent may lead to litigations as a violation of constitutional rights (GoK, 2010).

2.2.2 EMCA 2015

In addition, environmental laws mainly environmental management coordinating act of 2015 under section 93 prohibits the discharge of hazardous substances or chemicals into any waters or other segments of the environment. There is a penalty besides the cost of cleaning and restoring the environment (EMCA, 1999). Further Environmental Management and Co-ordination (Air Quality) Regulations, 2009, has identified pollutants that should be controlled and should not exceed the ambient air quality at property boundary for general pollutants. Under these regulations, ambient condition include atmosphere surrounding the earth and does not include the atmosphere within a structure or within any underground space which is covered under the occupational safety and health legislations. These regulation sets limits of H_2S at 150 μgm^3 for 24 hours and should not be exceeded for 2 consecutive days and 2% of the time (EMCA, 2009)

2.2.3 OSHA, 2007

Occupational safety and health act Clause 88 gives the minister in charge of labour, power to establish or adopt exposure limits on hazardous substances in the workplace so as to protect employees (GoK, 2007). The limits H_2S substance under Hazardous Substances Rules L.N. 60/2007 sets the total weighted average for OEL for 8 hrs at 10ppm (14 mg/m^3) and short term OEL at 15ppm (21 mg/m^3). The law further recommends monitoring the oxygen content of the air to ensure safety of workers should not fall below 18% by volume under normal atmospheric pressure in a workplace. This would generally cater for a combination of all pollutants, H_2S included in pits, confined spaces and other low lying areas where ventilation is likely to be poor. However, exposure to low concentrations may still have impacts and recommendations by Robert

Henderson. Instrumentation to set the TWA sensor alarm at 1.0, and the STEL alarm at 5.0 ppm makes sense rather than to leave the instantaneous low and high alarms at the old values of 10.0 ppm and 15.0 ppm for TWA and STEL respectively (Henderson, 2011). Medical examinations are recommended in accordance with L.N. 24/2005, and should be conducted as a way of evaluating the effectiveness of the mitigation measures.

2.2.4 Public health act 242, 1984

There is a prohibition under the public health section 115 against causing nuisance or condition injurious or dangerous to human health. Such nuisance or conditions are defined under section 188 as wastes, sewers, drains or refuse pits in such a state, situated or constructed as in the opinion of the medical officer of health to be offensive or injurious to health. Noxious matter discharged from any premises into a public is also deemed as a nuisance. Management of H_2S so as to protect the staff and public is a responsibility of the organisation and has legal consequences.

2.3 Previous studies on H_2S exposure at workplace

The existing regulations with occupational exposure levels (OEL) for H_2S in the occupational environment are based on the UK recommendations of 10 ppm for low exposures for 8 hrs (Costigan, 2003). The UK legislation was based on experiment carried out by Bhambhani (1996) during exercise of healthy men and women which showed a shift in anaerobic respiration blood lactate and found to increase following maximal exercise at 5 ppm and sub maximal exercise at 10 ppm (Costigan, 2003). The experiment was carried out for 30 minutes.

Other recommendation from the Scientific Committee on Occupational Exposure Limits (SCOEL) for H_2S (2007) in United States (US) gave 5ppm (7mg/m^3) for 8hour exposure or a short term exposure level of 10ppm (14mg/m^3) for 15 minutes. Further exposure was not recommended. Studies carried out on assessment of toxicity of H_2S have shown a consistent dose-response relationship (Costigan, 2003).

Hydrogen sulphide remains a cause of morbidity and mortality despite increased awareness on its potentially lethal consequences. Out of 5563 exposures in US, it has caused 29 deaths (Snyder, 2003). Studies on chronic low-level exposure to Industrial sulphide where symptoms of adverse health effects were analysed showing that exposure has effect on central nervous system. The symptoms related to the central nervous system, followed by the respiratory category and the blood category (Legator *et al.,* 2001).

Older studies on H_2S were carried out by Mitchell and Yant (1925) with respect to exposure to low concentrations (0.005% to 0.02% of 50 to 200 ppm H_2S) of the gas for several hours showing that; conjunctivitis, pharyngitis, or bronchitis usually occurred after from an exposure of 5–10 minutes to a relatively high concentration 0.05% to 0.06% of gas. These symptoms of poisoning could disappear in some hours after exposure (Mitchell and Yant, 1925).

Alberta Environment health surveillance technical review noted that evidence of eye irritation rarely was reported in the controlled clinical studies that were reviewed where exposure to H_2S was by mouthpiece. Review of studies conducted by Kilburn (1997) had found that subjects reportedly exposed to 1 to 50 ppm of H_2S for "hours", had complained of irritation and fingernail changes when completing a self-administered questionnaire 2 to 6 years after the exposure events. However, there were only 6 respondents and the study had low confidence index (Davies, *et al.,* 2002).

CHAPTER THREE.

MATERIAL AND METHODS

3.1 Study Design

The research design employed empirical inquiry to investigate effects of exposure to ambient condition in a real life context at Olkaria geothermal power plant. The methodology used was a case study where an in-depth investigation of the effects of H_2S at Geothermal Power plant was carried out. The study investigates the prevailing ambient conditions, clinical history of workers in Olkaria geothermal power plants and effects of H_2S on health and comforts on staff. The study carries out an exploratory study in order to investigate the real life problems of exposure to the indoor ambient concentrations of the gas.

3.2 Location of study site

Olkaria Geothermal power stations are located in the rich geothermal resources area in Africa. This is in the Rift valley at Olkaria in Naivasha where the study area is located.Olkaria I Geothermal power plant is the oldest operational plant in Kenya having been commissioned in 1997 followed by Olkaria II was commissioned in 2003 (ERC, 2009). Both plants were located in Naivasha Sub-County in the Rift Valley at Hells Gate National Park and operated by KenGen.

3.3 Study area and population

There are two power plants operated by KenGen and having 244 staff under operations department. Operations department carries out different functions including plant operations, plant maintenance, administrative and related support functions for the running of the power plant. The other staffs in Olkaria geothermal are 440 under geothermal resource development (GRD) and work in the fields as shown in Table 3.1 on population distribution. These workers in both departments are treated at Mvuke clinic operated by KenGen. The study area focussed on the monitoring of ambient H_2S concentrations in 37 sampling points distributed in the two power plants. It also focuses on the clinical records for the operations staff and compare with GRD staff whose work is largely outdoors in exploration, drilling and gathering of steam. The scope would cover clinical records for related cases reported to the clinic for period of three years (January 2009-Dec 2011).

Table 3.1: Population distribution by gender and workplace in Olkaria

Gender	Operations department	GRD department	Frequency	Percent for gender
Male	207	389	596	87.1
Female	37	51	88	12.9
Total	244	440	684	100
Percent for department	35.7	64.3	100	

In order to investigate the impacts of exposure to indoor ambient H_2S, a sample from 45 employees under operations and maintenance were studied. The maintenance and operational staff by the virtual of their job requirements work in the station in shifts of 12 hrs carrying out operations and maintenance mostly under indoor conditions. Other activities can be carried outside the plant such as finance, procurement, human resources, registry and others as shown on Table 3.2: Distributions of staff. Study population operate between the workshops and power plant where their activities cannot be undertaken away from the station.

Table 3.2: Distribution of staff at Olkaria Geothermal by sections

Sections	Department	Frequency	%
Plant Maintenance & Operations	**Operations**	**45**	**6.6**
Water treatment	Operations	22	3.2
TSI electrical/instrumentation	Operations	30	4.4
Training	Operations	8	1.2
Store	Operations	19	2.8
Registry	Operations	6	0.9
Procurement	Operations	13	1.9
Information/ICT	Operations	17	2.5
HR	Operations	16	2.2
Housing	Operations	5	0.7
Finance	Operations	8	1.2
Clinic	Operations	10	1.5
Catering	Operations	13	1.9
Admin/office	Operations	32	4.7
Subtotal Operations		**244**	**35.5**
Water supply	GRD	16	2.3
Transport	GRD	20	2.9
Survey	GRD	4	0.6
Steam/steam field	GRD	23	3.4
Rig operations/service/workshop	GRD	52	7.6
Rig Operations/ operator	GRD	55	8.1
Reservoir	GRD	17	2.5
Infrastructure	GRD	17	2.5
GIS	GRD	3	0.4
Geology/ geophysics /geo-chemists/ geo- planning	GRD	56	8.2
EHS/protective	GRD	43	6.4
Drilling /	GRD	100	14.6
Civil section	GRD	34	5
Subtotal GRD		**440**	**64.5**
Total		**684**	**100**

3.4 Sampling Method

Purposive sampling was used to establish the H_2S monitoring points. There were 37 monitoring points which are already established as H_2S monitoring points at Olkaria I geothermal power plant and Olkaria II geothermal power plants (Annex 6). In these monitoring points, hourly readings were undertaken in the period of March 2012 for 24 hrs period each day for the sampling points. The research also reviewed the past measurements from the time of commissioning to establish the past exposure trends.

Purposive sampling of review of clinical records at Mvuke clinic was done as the clinic is available to KenGen staff and treatment is given at the production of staff identity card. Non KenGen staff, such as, family dependants and local community going to the clinic are identified with a national ID or as minors. The clinic also offers emergency medical services to all staff in Olkaria. Available records of clinical cases with diagnosed symptoms similar to H_2S exposure were reviewed for the period between 2009 and 2011. Older records were not available at the Mvuke clinic.

To assess impacts of indoor exposure to H_2S, a sample was drawn from the staff carrying out operations and maintenance activities in the two power plants. The purposive sampling was to ensure persons who by nature of their work, would be exposed to H_2S as an occupational hazard form part of the sampling frame when distributing the survey questionnaires.

3.5 Sample size determination

Sampling of ambient H_2S conditions was done for the two power plants in 37 monitoring points.

Assessment of clinical cases recorded at Mvuke clinic in the period between 2009 and 2011 was conducted for the sample population and for the rest of staff in operations department as a control population.

To investigate the effect of the H_2S to the workers, questionnaires were administered to a sample purposively drawn for the operation and maintenance team in the operations department. The use of sample tables for a known population lower than 100, interpolation is used Mugenda and Mugenda (1999). For population of 30 and 50, the sample size is 28 and 45 respectively for a confidence of 95%. Therefore by interpolation, the sample size for population of 45 using the tables is 40

$$y - y_1 = \frac{y_2 - y_1}{x_2 - x_1}(x - x_1)$$

Where:

x_1=30, y_1= 28
x_2 50, y_2=45
x=45, y=40

Equation 3.1

3.6 H_2S measurements

Measurements were undertaken using gas monitors such as QRAEII 4 gas monitor type and at a height of 1.5 m for one minute maximum concentrations at each of the monitoring areas around Olkaria I and Olkaria II for 37 monitoring points. The readings were taken in the month of March 2012

Plate 3.1: Measuring H_2S at the cooling tower in Olkaria II using QRAEII 4 gas monitor

3.7 Qualitative data acquisition methodology

Questionnaires with structured and unstructured questions were administered to the employees in the month of April 2012. The aim of the questionnaire is to collect data on comfort factors and effort required to do the tasks in presence of H_2S at workplace. Questionnaires also assist in getting any information on employees detection senses variation due to prolonged exposure. The employees are given assistance on technical issues and clarifications so as to ensure most reliable information is acquired. The first set of questionnaires was administered in batches of questions 1-24 and 25-29 to the same respondents. Consultations with supervisor, health and safety personnel, management and other staff with technical insights on the research subject were done during the process. Assessment of clinical cases with symptoms similar to exposure of H2S was conducted between April and June 2012.

3.8 Data processing and analysis

The data collected from questionnaires and assessment of past records was coded for use in inferential statistics so that the hypothesis can be tested. Measurements of variables were entered into the computer for analysis using SPSS software. Descriptive statistics was done for quantitative data. Trends, patterns and relationships from the information gathered have been analysed. Descriptive statistics is used to give summary statistics of variables being studied. Narrative analysis is done to describe behaviours and the context they occur. Presentation of the data is done in tables, charts and graphs. The hypothesis was tested using t-test at confidence level of 95%

3.9 Data Validation

The questionnaires were administered at different times and over a period the month of March 2012. The respondents filled the questionnaires after explanation to the objectives and scope of the study and 40 questionnaires were received. Five questionnaires were not be filled as only 40 respondents were accessible during the study period. The response was 89% and the number was within the calculated sample size at a 95% confidence level.

Hourly measurements of ambient H_2S was taken during the month of March 2012for 37 monitoring points. The equipment used for the measurement was similar to what the environmental department was using for taking a single reading per monitoring point in a day. These instruments would record the same readings when they are placed side by side. The instruments are also calibrated by manufacture and used for the period of calibration validity.

In reviewing clinical symptoms and in the interpretation of clinical information, the medical practitioner's at Mvuke Clinic availed the records and assisted in interpreting the hand written diagnosis throughout the process. Review of clinical history was done to assess the historical information on morbidity of H_2S exposure. The records for staff in GRD were also reviewed as a control population in the analysis.

3.10 Ethical Considerations

Prior to data collection, permission to carry out the study was sought and granted by KenGen management (appendix 3) through the Human Resource office. During the collection, analysing and interpretation of data, ethical practices were upheld. All person involved in the research had a right to respond, give information and withdraw at any stage of the study and such decision respected. Throughout the research, there were no promises made which would have influenced the responses of the experimental group. No Minors were interviewed during the research and no cases of violation were raised. The privacy of individuals, right to confidentiality and not disclose the particulars of the person was be respected. Any findings of this study were used for the research purpose. The researcher acknowledges that one could argue that the data collected from the health care institutions for part 4.3 and from previous measurements of H_2S in part 4.2 of this report was used beyond its originally intended purpose. In this view, the researcher has taken extra care so that individual level data is not distributed beyond the source. Likewise care is taken so that the use of the data does not compromise the privacy of the patients.

CHAPTER FOUR.

RESULTS AND DISCUSSION

4.1 Demographic Data

In Olkaria geothermal power plants, staffs under maintenance and operations by nature of their job are exposed to indoor ambient conditions. These are 45 staff distributed in Olkaria 1 geothermal and Olkaria II geothermal power plant who work in operations and maintenance section. Questionnaires with closed, open and ritcher scale ratings were administered to the staff in order to investigate the health and comfort effects related to exposure of ambient H_2S is monitored. Results in Table 4.1 on gender distribution showed 22% of the 40 respondents were female where this technical work of operation and maintenance in the plants had been dominated by male gender up to date.

Table 4.1: Gender distribution of the respondents

Gender	Frequency	Percent
Female	9	22.5
Male	31	77.5
Total	40	100.0

Respondents aged 21-25 years and 41-45 years were 12.5% each while 5% were aged 36-40 years. Majority of the respondents (47.5%) were aged 26-30 years as shown on Table 4.2 on age bracket. According to management, there is a deliberate effort to ensure to ensure succession planning of the technical skills give youth job opportunities.

Table 4.2: Age distribution of respondents

Age Bracket	Frequency	Percentage
18-20	0	0.0%
21-25	5	12.5%
26-30	19	47.5%
31-35	7	17.5%
36-40	2	5.0%
41-45	5	12.5%
46-50	2	5.0%
Total	40	100.0%

In the questionnaires administered, respondents were asked to indicate for how long they had worked in the plant. Majority of the respondents indicated they had worked in the plant for 1-3 years (60%) and 25% indicated 4-7 years. Respondents who indicated they had worked in the plant for 8-11 years were 10% and only 5% of the respondents indicated they had worked in the plant for 12-15 years. Table 4.3 presents these results.

Table 4.3: Respondents duration worked in the plant

Years worked in plant	Frequency	Percent
1-3 years	24	60.0
4-7 years	10	25.0
8-11 years	4	10.0
12-15 years	2	5.0
Total	40	100.0

4.1.1 Workers' duration of exposure

Majority of the respondents were exposed for 8 hrs (55.0%) while those exposed for 12 hrs and 7 hrs were 15.0% each as shown on Table 4.4. Respondents who were exposed to H_2S for 2 hrs and 0.5 hrs were 7.5% each.

Table 4.4: Duration of exposure to ambient conditions at workplace

Time	Frequency	Percentage
12 hrs	6	15.0%
8 hrs	22	55.0%
7 hrs	6	15.0%
2 hrs	3	7.5%
0.5 hrs	3	7.5%
Total	**40**	**100.0%**

Only 22% (9) of the respondents indicated that they smoked while 78% (31) indicated they do not smoke. For those who indicated they smoke, they were further probed on how long they had smoked while working in the power plants. One respondent indicated 7 years, two indicated 2 years and another two 1.5 years. The rest four had smoked less than one year

Majority of the respondents (77.5%) had not involved in welding or other exposure to welding rays as compared to 22.5% who had been exposed to welding as shown in Figure 4.1 below

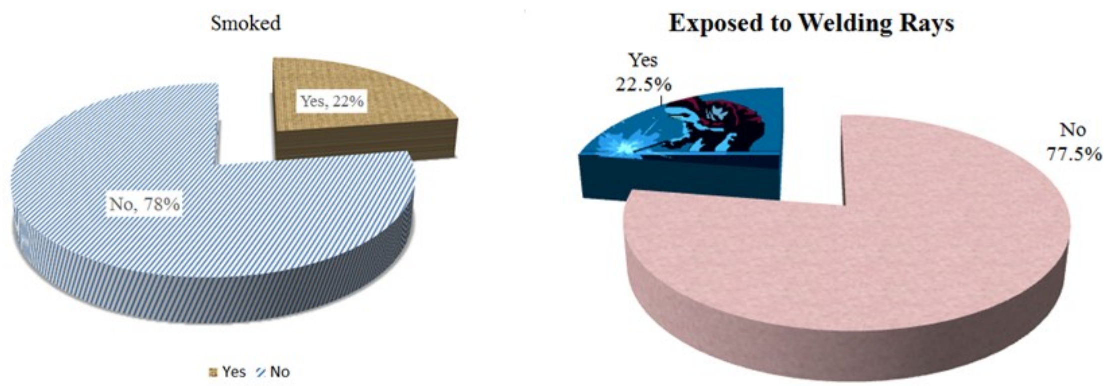


Figure 4.1: Smoked and exposed to welding rays

The type of eye protection against UV light that was used by those involved in welding or exposed to welding rays is a face shield with UV protecting shield. All the people (22.5%) who carry out welding indicated they use the UV protection when welding. This was noted as a good practice to protect from eye damage and compliance to legislation (OSHA, 2007)

Majority of the respondents (55.0%) who while performing their duties in the plant, are not required to use breathing apparatus (Table 4.5). However a significant percentage (45.0%) uses some form of breathing apparatus. According to management, breathing apparatus are used during major overhauls when maintenance staffs are expected to work in enclosed environment. Forced ventilation is also done to push out pools of H_2S

Table 4.5: Distribution of respondents who used breathing apparatus

Response to Use of Breathing apparatus	Frequency	Percent
No	22	55.0
Yes	18	45.0
Total	**40**	**100.0**

There existed some environmental conditions in the workplace which respondents would want changed to improve their comfort. Majority of the respondents indicated yes (76.9%) as compared to 23.1% of the respondents who indicated 'No' (Table 4.6). Majority of the staff would rather continue in the current environmental condition rather than disrupt the status quo.

Table 4.6: Respondents requiring changes in ambient environmental conditions

Response	Frequency	Percent
No	9	22.5
Yes	31	77.5
Total	**40**	**100.0**

On a ritcher scale of 1-10 where1 is dissatisfied with work environment and 10 strongly satisfied, the workers rated the ventilation of environment as adequate (mean =8.12) and satisfactory at mean = 7.63 as shown in Table 4.7 below on rating on work environment.

Table 4.7: Respondents satisfaction on work environment

Aspect of work environment	Mean rating	Std deviation
Ventilation is adequate	8.12	1.73
Improved in last three years	7.50	2.20
Conditions are satisfactory	7.63	2.06

4.1.2 Identification of H_2S by smell

Existence of ambient H_2S within the odor detectable range can be identified by smell which the majority of the respondent could positively identify. Majority (85.0%) of the respondents could confirmed the existing smell in the workplace was H_2S the smell as opposed to those who could not or not sure at 7.5% each in Table 4.8 on ability to smell the gas. Identification of gas by smell only applies when the gas is in low concentrations otherwise detection fails at higher concentrations

Table 4.8: Respondents ability to smell H_2S

Able identified	Frequency	Percent
Yes	34	85.0
No	3	7.5
Not sure	3	7.5
Total	**40**	**100.0**

Respondents described the smell of air during a normal working day in terms of its strength or irritation to the nose and the duration. Respondents were divided on this issue as shown in Table 4.9 on description of smell with 30.0% of the respondents describing the smell of air as comprising of strong continuous bad smell of rotten eggs. A close portion of 32.5% described it as weak continuous bad smell of rotten eggs each. Twenty two and a half percent of the respondents described the smell of air as intermittent strong bad smell of rotten eggs while only 15.0% of the respondents described the smell of air as intermittent faint bad smell of rotten eggs. Respondents who would identify presence of H_2S as strong continuous smell of rotten eggs risk ignoring the intermittent faint bad smell of rotten eggs which from the analysis of ambient H_2S in part 4.1 of this report shows that it exists.

Table 4.9: Respondents description of smell at workplace

Description of smell	Frequency	Percent
Strong continuous bad smell of rotten eggs	12	30.0
Weak continuous bad smell of rotten eggs	13	32.5
Intermittent strong bad smell of rotten eggs	9	22.5
Intermittent faint bad smell of rotten eggs	6	15.0
Total	**40**	**100.0**

4.1.3 Effort required for the job

On a ritcher scale of one to ten, the respondents were asked to rate the different work effort demands and the environmental comfort. The effort required to do the work by the respondents is generally above six on the scale as shown in the table 4.10 on efforts required for the job where the mean is 6.63 (audio effort) to 7.48 (visual effort) on a scale of one to ten. This indicates the respondents require physical, mental, audio and visual effort to carry out their duties. The distribution is quite flat with less peak (Kurtosis = -0.83 to 0.25) indicating that extreme outcomes exist on either side of the mean. The skewness of the sample is negative as the mean is less than the median and less than the mode in all effort parameters. In such a case, it is possible to find respondents with extremities which implies the demands of their jobs can demand one aspect more. People who do lifting and adjusting heavy loads may find extreme demand on physical effort to do the job. For precision work such as fitting rotors which turn at more than 3000rpm may demand a lot of visual and mental effort.

Table 4.10: Respondents effort required to do their job

Type of Effort	Mean	Standard Deviation	Kurtosis	Skewness
Physical effort	6.68	2.35	-0.83	-0.38
Mental Effort	6.6	2.34	-0.64	-0.4
Audio effort	6.63	2.24	0.11	-0.66
Visual Effort	7.48	2.26	0.25	-0.96

4.1.4 Comfort and work environment

Performance of respondents is influenced by the environmental conditions that make a workplace comfortable and conducive to work in. On a ritcher scale of 1-10, respondents rated ventilation at workplace as adequate at a mean of 6.93 and satisfactory conditions (6.90) while workplace had improved in the last three years. Table 4.11 shows response for more than eight hours work was positively skewed (0.2) around a mean of 5.4 while exhaustion at the end of the day had a mean of 4.63. The lowest mean rated was fatigue with little work (4.05) which would be an indicator of insufficient oxygen at workplace.

Table 4.11: Respondents perception on Comfort and work environment

Respondents comfort elements at work	Mean	Standard Deviation	Kurtosis	Skewness
Adequate Ventilation	6.93	1.97	(0.98)	0.02
Workplace improved in last 3 years	6.58	1.92	0.67	(0.36)
Satisfactory Conditions	6.90	1.98	(1.21)	(0.02)
Exhausting by end of day	4.63	2.44	(0.96)	0.27
Fatigue with little work	4.05	2.23	(0.72)	0.28
Mostly working hours >8hrs	5.40	2.87	(1.15)	0.20

4.1.5 Health Effect of detected gas at workplace

The presence of strong pungent smell of rotten eggs at workplace was rated at moderately (4.9) and regularity of the smell as regular (4.43) on a ritcher scale of 1-10. Use of a gas detector was rated at 5.30 without skewness (-0.01) and a relatively flat distribution (Kurtosis = -1.10). Respondents focus and comfort was affected and rated at mean of 5.35. The smell effects focus/concentration at work had a mean of 5.15 with a standard deviation of 2.24. Lack of concentration at work is a safety hazard as it can lead to human error. With repeated exposure (chronic exposure), respondents noted that they get accustomed to the smell of the gas rated at a mean of 5.33 and negatively skewed (0.22). The results on Table 4.12 also showed that when employees earlier in part 4.1.2 were asked a closed question requiring a yes or no answer on their ability to identify H_2S, they responded differently from when required to rate on a ritcher scale for the same enquiry.

Table 4.12: Health Effect of detected H_2S on focus on work

Detection and effects of H_2S on focus on work	Mean	Standard Deviation	Kurtosis	Skewness
Strong pungent smell of rotten eggs	4.90	2.17	(0.59)	0.26
Strong smell continuous in the day	4.43	1.88	0.54	0.51
Use gas detector where I work	5.30	2.92	(1.10)	(0.01)
Gas affects focus and comfort	5.35	2.18	(0.11)	0.09
Has effect on focus / concentration on work	5.15	2.24	(0.37)	0.09
Rarely smell gas when busy-accustomed to smell	5.33	2.39	(0.84)	(0.22)

4.1.6 Measures to control the adverse effects of exposure to H_2S

From the results regarding skills in managing exposure to H_2S, most of the respondents cited they would remove a colleague to a safe area to get fresh air (oxygen supply) while others would administer first aid. Some respondents indicated they would first remove their colleague from the exposure source and then seek medical help for them. However, there were a few who did not know or were not sure on what to do.

Additional information shared on personal experiences, incidents witnessed and recommendation as one would feel comfortable on this subject, respondents stated that it is important to provide respirators for the workers who work in the machine areas in both power stations. Others recommended medical examination to determine how much of the H_2S could have been absorbed in the blood stream while others cautioned that long exposure to H_2S concentrations could cause death. Some respondents suggested use of a monitor attached to the body while around the plant. The respondents further cited that while operating within cooling towers, one must have H_2S gas monitor as there is high presence of gas escaping from steam where non-condensable gases are vented off. The respondents also indicated that it is important for all to be always alert of H_2S around geothermal. The best way to approach the plant is from upwind according to the respondents and one should use detectors and awareness and training on H_2S should be enhanced. Those in the plant may not easily notice smells of the gas but someone from outside smells gas more easily. A correlation on being accustomed to the smell where there is persistent presence of H_2S is low (Pearson, p =0.077).

The proposed measures to control chronic exposure to low concentrations of H_2S undertaken by the power stations include reduction of employees in the station who are not required through out the shift. To this, there is a proposal to construct an office block in three years time to mitigate on this risk. Other measures include sharing of the daily monitoring enhanced use of hand equipment when accessing suspect places areas suspected to have H_2S even when the fixed sensors are indicating the situation is safe. In addition, where employees are expected to be exposed to a chemical hazard, medical surveillance is required to evaluate the effectiveness of the controls.

4.1.7 Discussion on effects of H_2S at Olkaria geothermal power plants

Reliance of identification of H_2S by smell only was not recommended as the gas causes olfactory paralysis at high concentration. Response against excess exposure would be initiated by alarm from installed detectors with set warning alarm at 10 ppm concentrations of H_2S. This however is a high setting for a 12 hr shift considering that in 2010 Iceland tightened the daily H_2S concentration limit to 3.5 ppm (50 µg/m3). This is about one-third of the World Health Organization guideline value of 10 ppm. The review by Iceland was in response to repeated complaints from residents (OECD, 2014). During the study, some people were not sure whether they could identify the smell of gas at work place in part 4.2.2 hence may not make a complaint. The same respondents could identify the smell of rotten eggs at varying degrees at workplace which is a gap in knowledge of H_2S odor at varying concentrations.

The operations and maintenance was male dominated with a fairly good distribution of age. This distribution is collaborated by other studies and reports of ILO, 2009 on Global trends for women. The ages of respondent and number of years respondent have worked had a positive correlation with significant 2 tailed Pearson's correlation of p = 0.686 at 95% confidence level showing that older people had worked longer in the organisation which was expected. Annex 8 shows the tabulation of Pearson coefficients. The results indicated that there was a high retention of employees in the organisation

There was no significant relation between physical efforts required for doing a task and age of a person or years worked in the organisation (Pearson Correlation =0.123 and 0.236 respectively) The work of maintenance and operation demanded more skills and manual handling was done using appropriate equipment. The result also indicated that the adequacy of ventilation and satisfactory work conditions was not influenced by age as the correlation was insignificant with p=-0.011 and 0.069 respectively. However, those respondents who had worked longer and were older used H_2S detectors more in their duties (p=0.313) as they had supervisory and leadership responsibilities.

In the operations and maintenance at Olkaria Geothermal Power Stations, the tasks were highly technical and required a combination of physical, mental, visual and audio skills and the correlation between the them was positive Pearson's correlation of $p > 0.37$ at 95% confidence levels. The tasks requiring mental effort also required listening (audio) skills ($p=0.656$) and visual ($p=0.719$). The relationship between visual and listening skills were positive and almost perfect relationship ($p=0.795$) which implied that the tasks undertaken in the plant required high levels of concentration and focus. Studies conducted by Wickens, 2000 showed that workers mental effort on the job is influenced more environmental factors rather than factors such as age, educational qualification or length of service.

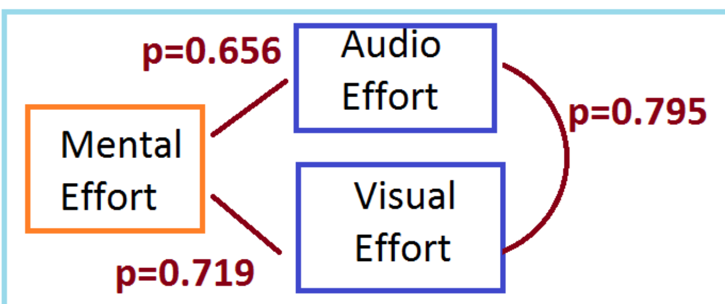


Figure 4.2: Job effort and mental, audio and visual

There was a weak positive correlation between adequacy of ventilation and strong pungent smell of rotten eggs at work place ($p=0.124$) and weak negative correlation with the smell being continuous during the day. The workplace ventilation was perceived as adequate. This situation can be explained where the indoor and outdoor conditions do not have a significant difference. The source of H_2S is predominantly from the escaping non condensable gases. It would therefore be located around the plant including non-enclosed places. Once released at the cooling tower H_2S, tends to drop back cumulate around the plant since its 19% heavier than air.

From the analysis of respondents, the continuous smell of H_2S at workplace had a negative correlation with physical, mental, audio and visual effort requirements to do the job. The continuous smell of the gas in workplace had an effect on listening/audio effort ($p= -0.357$) and visual effort ($p= -0.458$) indicating its interference with focus and concentration required in the processes and activities of operation and maintenance. There was a strong correlation where H_2S caused discomfort in workplace and interfered with focus and concentration at Pearson correlation of $p=0.626$. Comfort and focus on work had a positive correlation with audio effort ($p=0.426$) which indicated that there was a risk of miscommunication due to the presence of H_2S.

Further analysis showed that there was a significant correlation between adequacy of ventilation of workplace and improvements done at workplace in the last three years ($p=569$) and satisfaction with physical work environment ($p= 0.537$). These improvements had been in areas where respondents worked for longer than eight hours ($p=0.408$) and also in some areas that required one to use H_2S gas detectors. There was a strong correlation between workers who at the end of the day did not feel like working the following day and being accustomed to the smell of H_2S and rarely notes its smell when busy at work place with a significant positive Pearson correlation of $p=0.444$.Further, workers who get very exhausted at the end of the day also get exhausted on doing very little work ($p=0.542$). This could imply that though the ventilation in the workplace is adequate as perceived by the respondents, the presence of the gas is making them less vibrant.

Where the presence of H_2S is detected by a strong smell of rotten eggs, it's quite persistent throughout the period (p=0.350) affecting significantly the comfort and focus at work (p=0.436). Chronic or persistent presence of H_2S at workplace affects the comfort of respondents and interferes with focus on work (p=0.313) which has a significant effect on concentration at work (p=0.626). There is insignificant relationship between discomfort and getting accustomed indicating respondents may not be getting accustomed to discomfort (p=0.194) arising from the presence of H_2S. However, respondents had gotten used to interferences of concentrations and focus (p=0.326).

Based on the responses and correlations, effects of H_2S existence at workplace has adverse effects on the comfort and focus on work. This show that potential health risks to the workers exist as their well-being and ability to concentrate on work is affected by the ambient H_2S in the workplace.

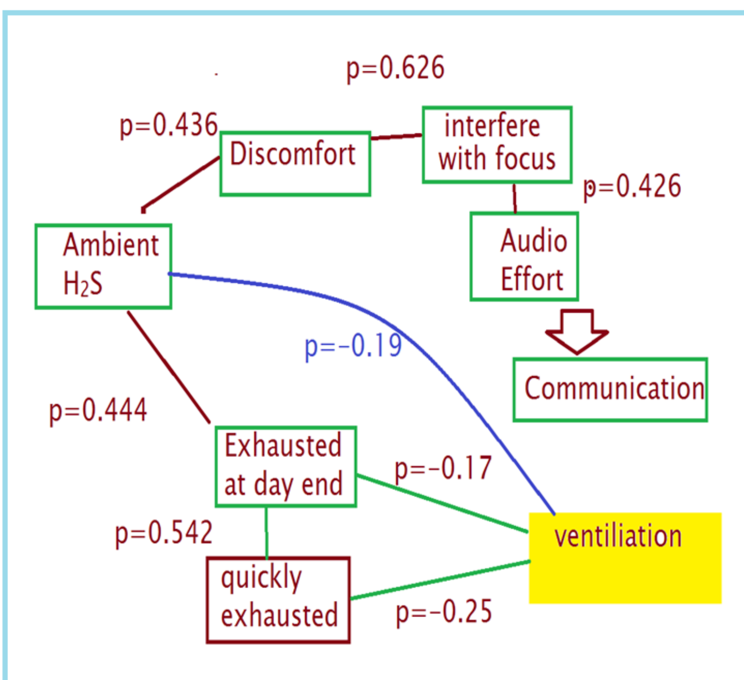


Figure 4.3: Presence of H_2S and discomfort, fatigue and ventilation

4.1.8 Effects of H_2S exposure at other geothermal plants

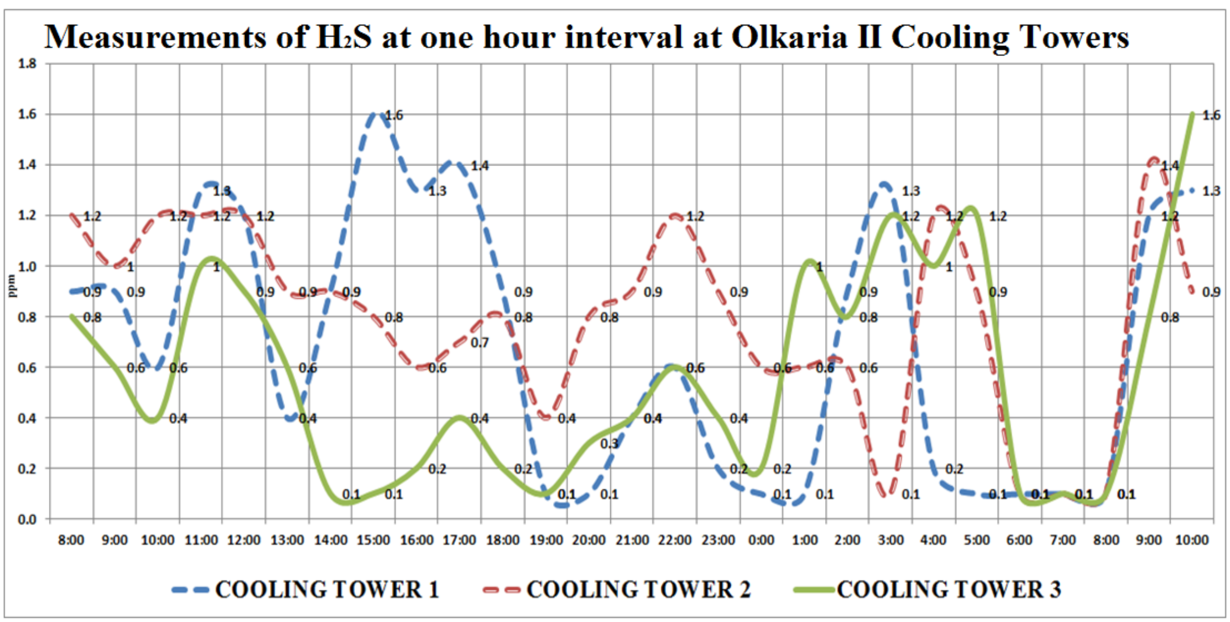
Recognition of occupational diseases is not an exact science but rather a question of judgement based on a critical review of all the available evidence. This research finding adds to other existing findings on impacts of exposure to environmental pollutants by adding to consistency of different research reports have generally similar results and conclusions (ILO, 2010). Studies of long-term effects of exposure to background sulphur gases including H2S from geothermal sources in Hawaii, New Zealand and the Azores, indicated that long-term exposure is associated with adverse cardiopulmonary effects, both measured and self-reported and increased rates of bronchitis. No association was found between chronic exposure to H2S in residents in a geothermal field and self-reported asthma symptoms (Bates *et al*., 2002). In other studies, the association has been found to be weak between the exposure to H_2S and the increase in dispensing of drugs for obstructive pulmonary disease in Iceland capital (Carlsen, 2012).

4.2 Ambient levels of H_2S at Olkaria Geothermal Power Plants.

4.2.1 H_2S concentrations at Olkaria I and II Geothermal Power Stations

These results of measurements of H_2S in this study showed erratic trends of ambient H_2S at various points. The mean and maximum values recorded in the two power stations were varied with the older recording higher readings. Results we reanalysed against a time scale without correction for factors such as wind direction and nearby discharge activities of wells around the power stations.

In Olkaria II power station, a maximums of 1.6ppm and lows of 0.1ppm were noted for cooling tower during the study as shown in Figure 4.4 H_2S Hourly readings at Olkaria II power plant which is newer compared to Olkaria I power plant. Hot well area of Olkaria II had generally higher readings in the morning reaching a maximum of 1.8ppm by 10.00am but reducing steadily to 0.0ppm by 1.00pm but still exhibited erratic trend. From analysis of past studies as summarised in section 1.8 of this report, the ambient H_2Sbetween 1.0ppm-2.0ppm is identified as notable smell. This describes the smell at Olkaria II Geothermal power stations during the period of measurement in the cooling towers and vacuum pump area. In other areas, the gas was not detected. The average ambient H_2Smeasured during the period is 0.411ppm. Most of the measurements in other monitoring points were low as shown in Figure 4.5 Maximum and average measurements in Olkaria II in March 2012.



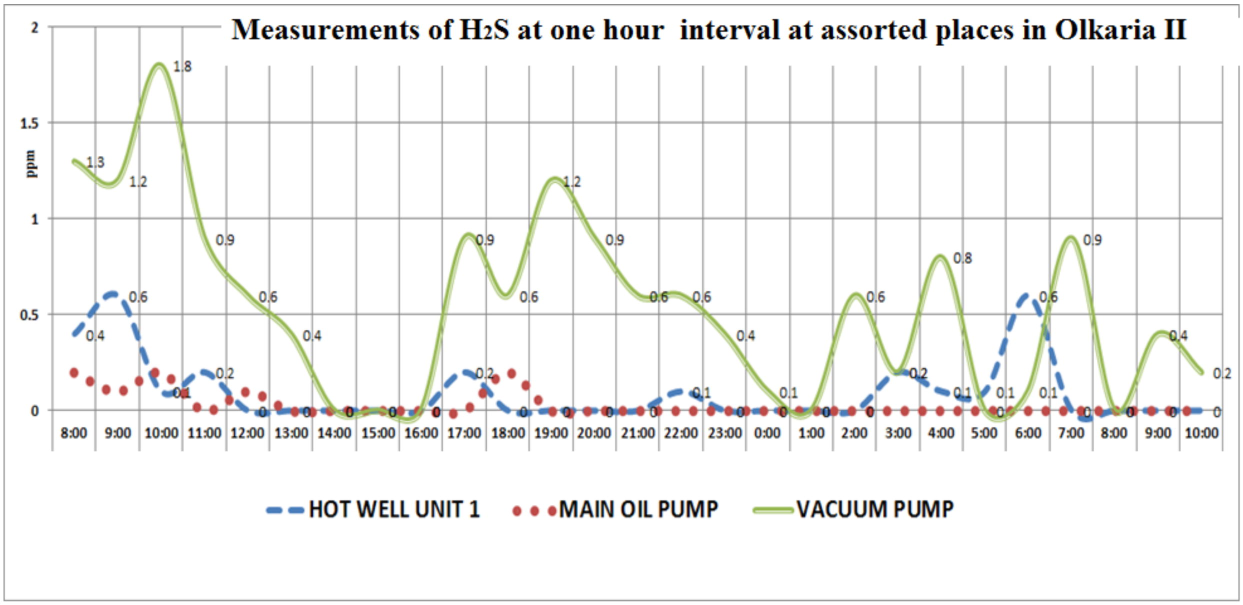


Figure 4.4: Measurements of H_2S at hourly interval at Olkaria II Power plant

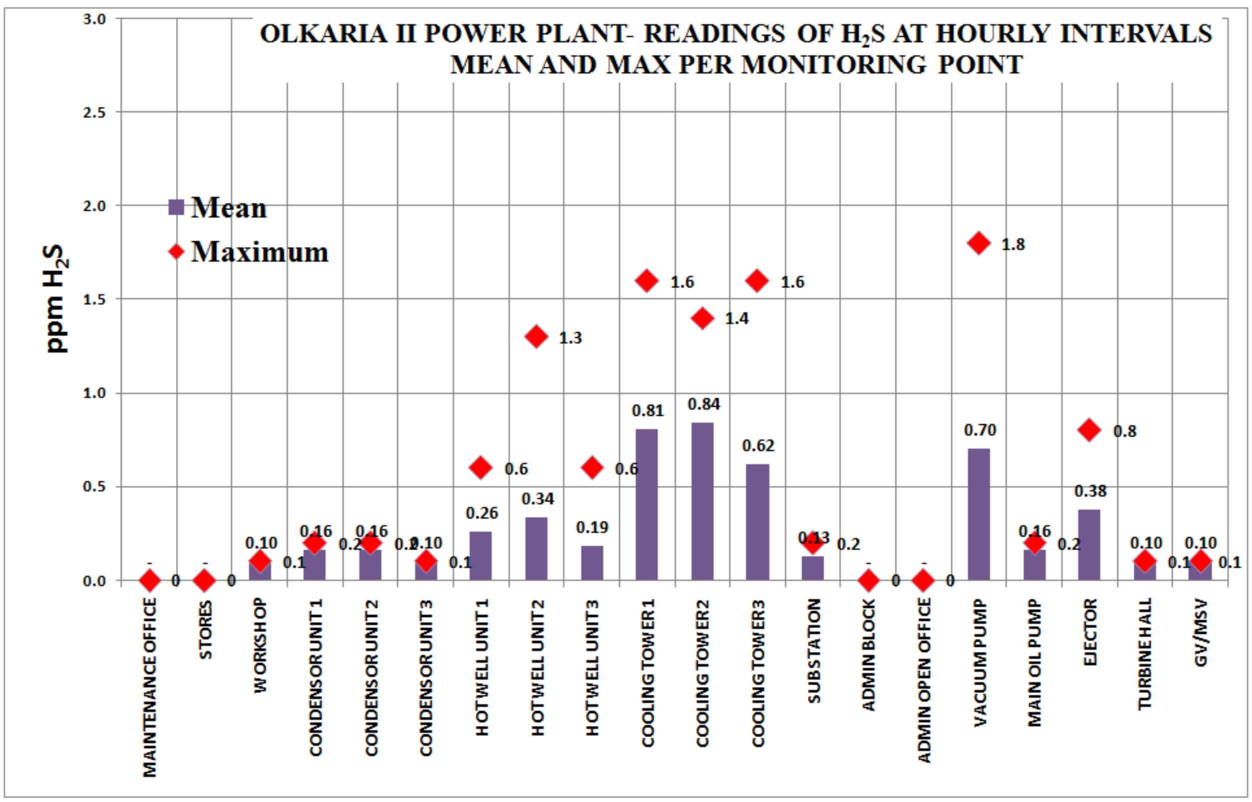
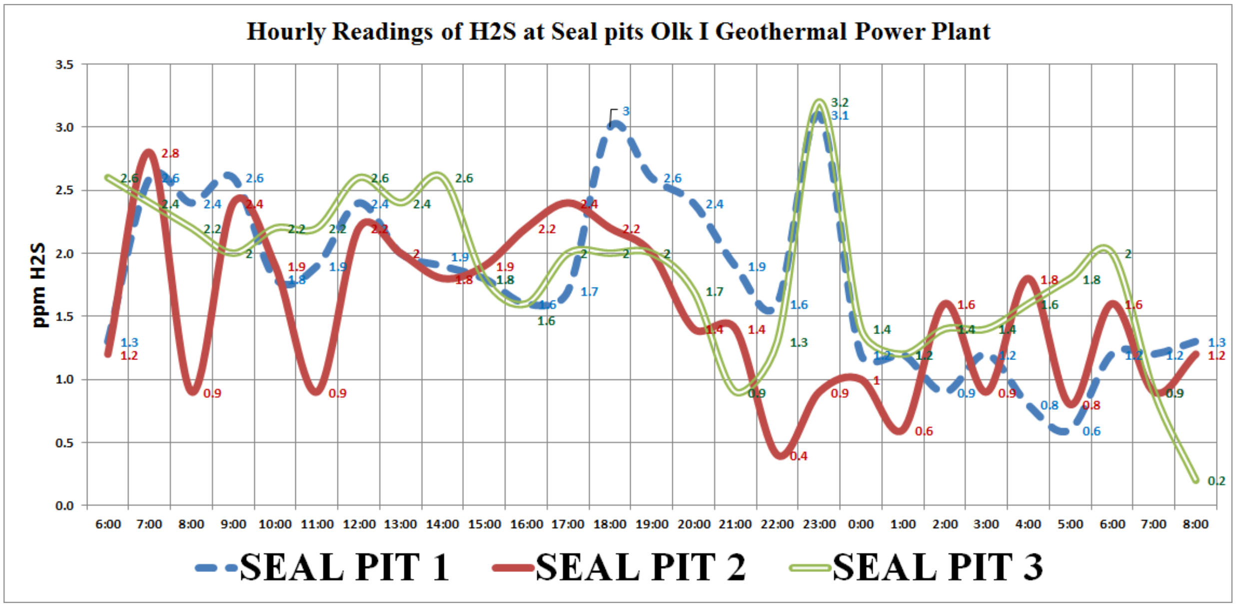


Figure 4.5: Maximum and average measurements in Olkaria II in March 2012

Measurements of H_2S in Olkaria I Geothermal Power plant were also erratic rising to 3.2 ppm at the seal pit and 2.8 ppm at the cooling towers as shown in Figure 4.6 Hourly readings at seal pit and cooling towers in Olkaria I geothermal power plant. Based on interpretation of smell against the measurements (section 1.8), the smell of ambient H_2S would be described as ranging from weak smell (0.1-1.0 ppm) to irritating smell (2.0-3.0 ppm) and at occasionally offensive (> 3.0 ppm). The average ambient H_2S during the measurements was 0.97 ppm for the Olkaria 1 geothermal power plant.



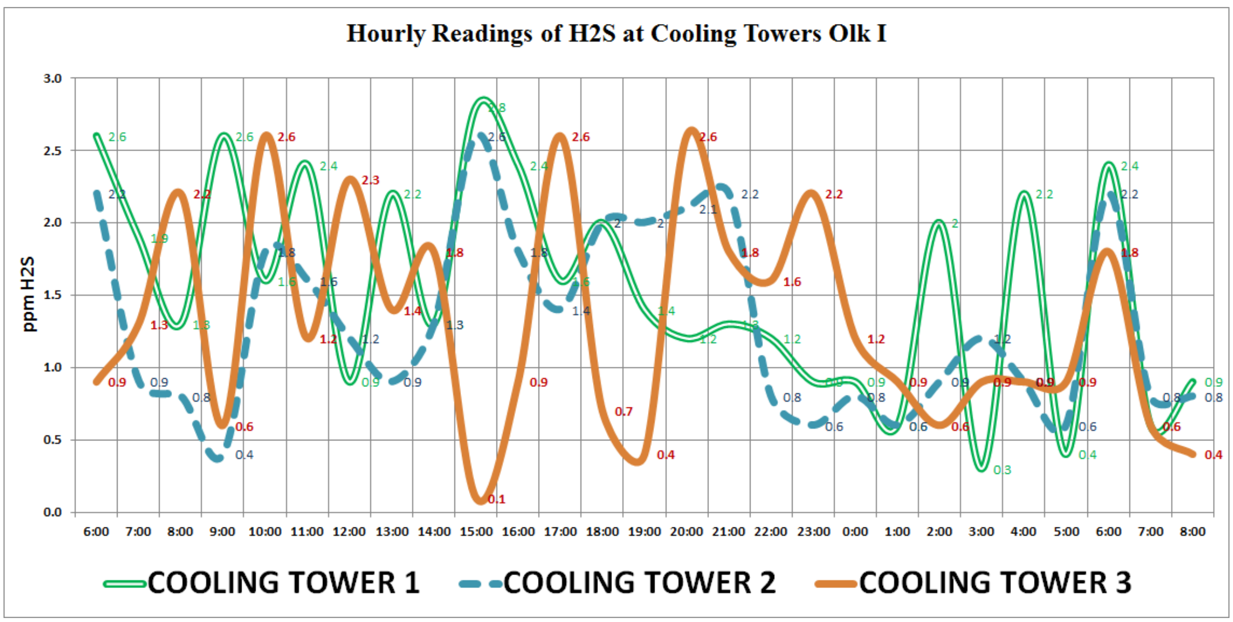


Figure 4.6: Hourly readings at seal pit and cooling towers in Olkaria I

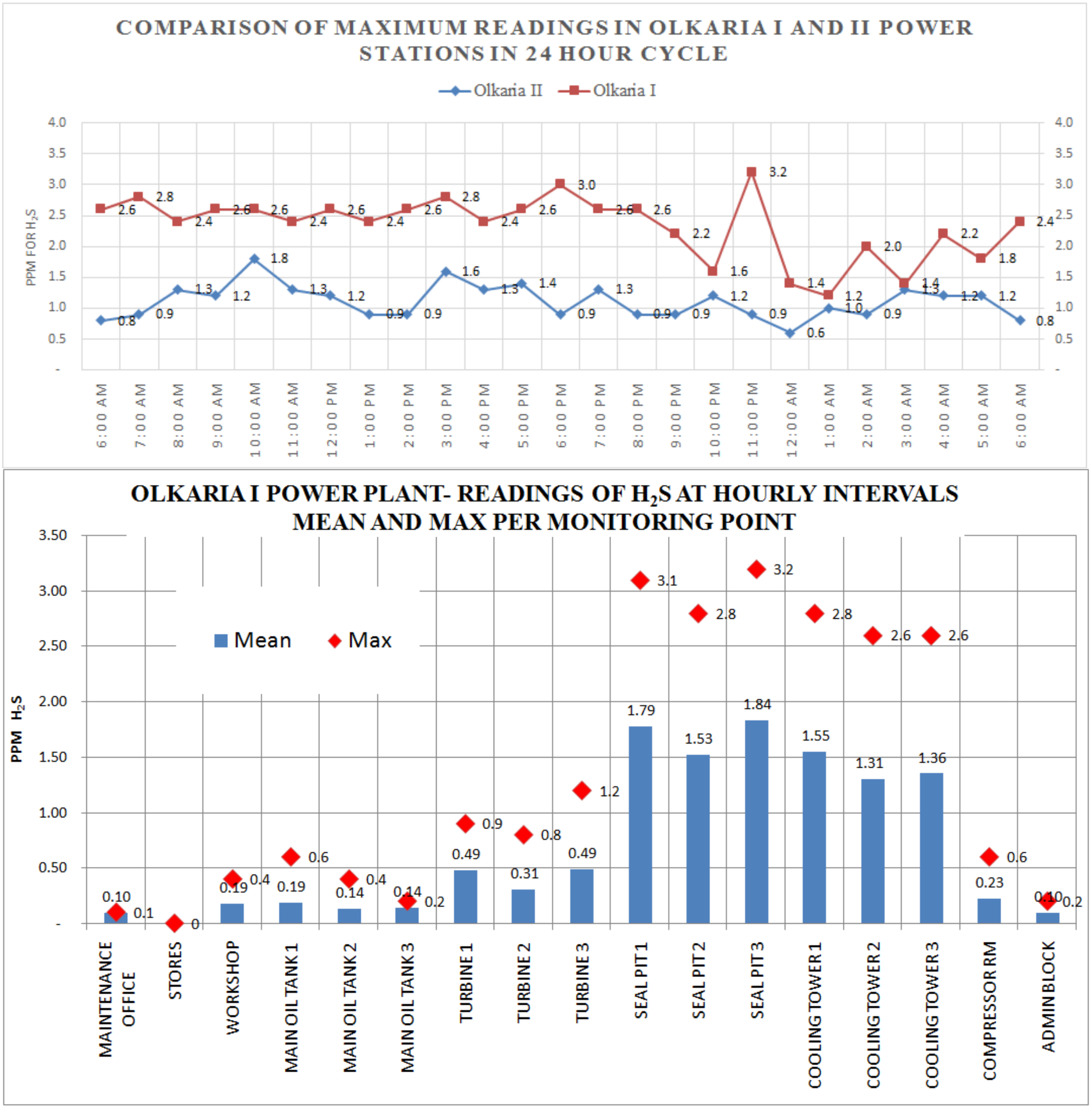


Figure 4.7: Maximum and average measurements in Olkaria I in March 2012

The results of measurement from the workplaces showed that mean ambient conditions were higher in Olkaria I than Olkaria II geothermal power plant. The average ambient conditions for similar workplaces for example at the cooling tower for older plant is

1.4ppm with maximum of recorded readings of 2.8ppm (in 24 hrs) while at the same time Olkaria II had a mean is 0.8ppm and a maximum one reading of 1.8ppm.

The occupational effect of exposure as discussed in section 2.2 of this report follows a dose response relationship. The dose depends on the duration of exposure and the quantity or levels in the ambient. It therefore requires analysis of past ambient conditions at Olkaria geothermal power plants which is done in next section.

Plate 4.1: Cooling Towers in Olkaria 1 Geothermal Power Station

4.2.2 H_2S trends at Olkaria I and II Geothermal Power Station

The results or data review for Olkaria II geothermal power station shown in Figure 4.8 for maximum H_2S readings at Olkaria II Between 2003-2011 indicate a gradually increasing quantities of with notable sharp rise in 2010.There were no readings of H_2S above 3ppm in the first six years of operation while the last two years correspond to the incidences when maximum concentrations at the Olkaria II were experienced.

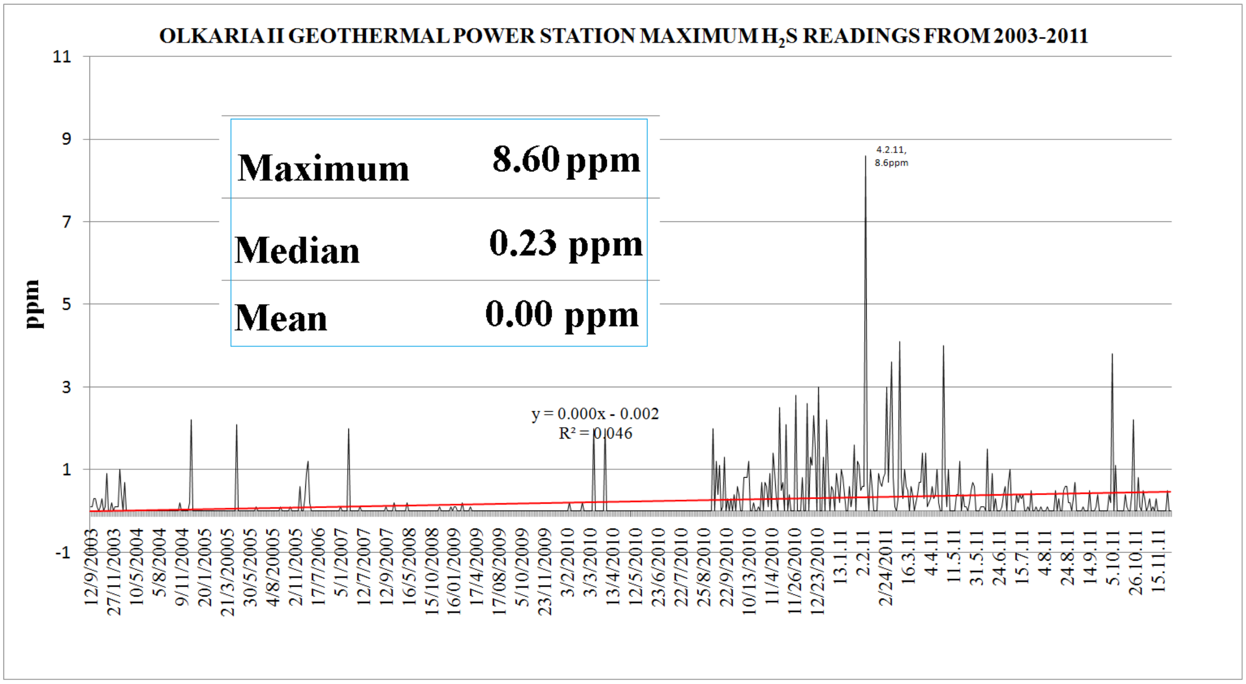


Figure 4.8: Maximum H_2S readings at Olkaria II between 2003-2011

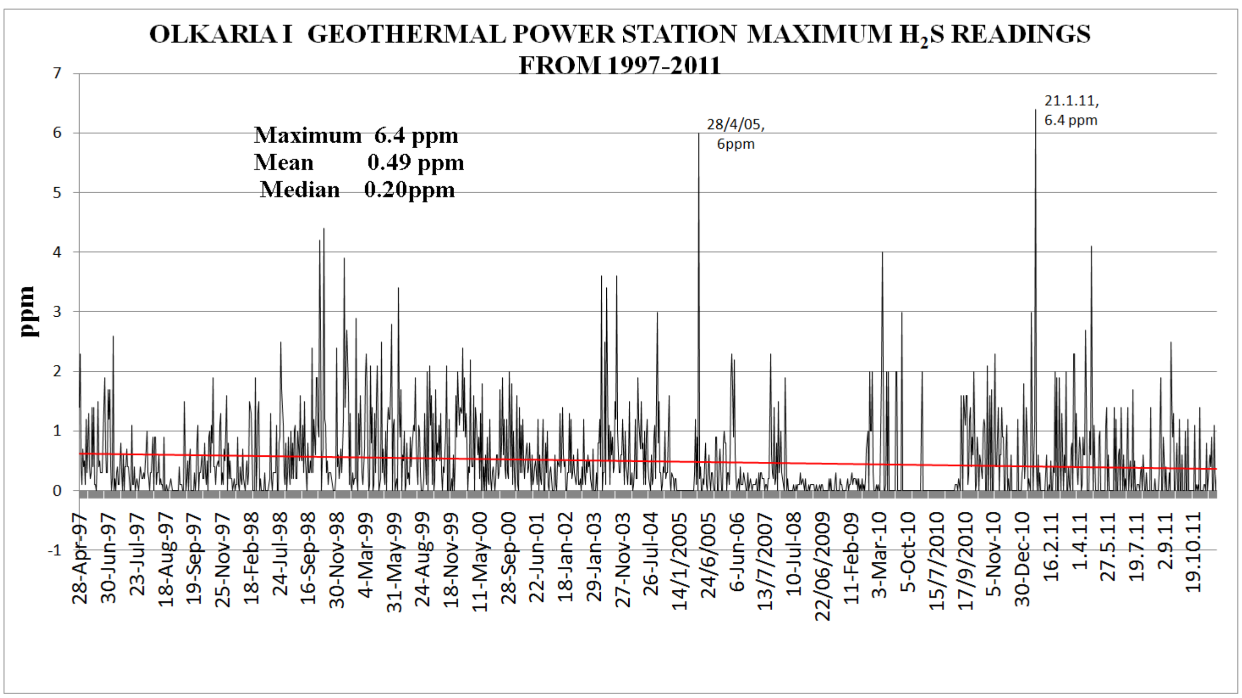


Figure 4.9: Maximum H_2S readings at OLK I from 1997-2011

Analysis of detected H_2S cases in the period from commissioning of operation for Olkaria II power station showed that in the first six years weak smell of H_2S occurred 80times (90.9%) or at a rate of 15 occurrences in a year while in the last two years, the recorded occurrences were 810 (89.9%) or an average of 450 occurrences per year. Availability of email communication for the early period and failure to consistently take measurements affected the record. As shown in Table 4.13 on recorded measurements, there was also an increase in notable smell from 6.8% to 7.99% in the two durations.

From 2010 -2011, notable to irritating smell measurements increased to 7.99% from 6.80% in the period 2003-2009 recording 72 instances in two years compared to previous 6 incidences in 6 years. Six times in the 2010-2011 period, offensive smell of H_2S was recorded. This is the period that coincided with expansion program which had additional drilling for 280 Megawatt plant. Drilling activities were conducted in Olkaria including the space between Olkaria 1 and Olkaria II where some of the constructions were proposed. This could have allowed escape of H_2S in the environment. There also seemed to have more focus on ensuring measurements were done promptly as the period coincided with organisation acquiring international standards certification on environmental management system (EMS). If this is true, then EMS certification had positive impacts

Table 4.13: Description of smell of H_2S in Olkaria II for Period 2003-2011

Description of smell of H_2S (ppm)	**Period 2003- 2009**	**Period 2010-2011**	**Overall period 2003-2011**
Weak Smell (0.1-1.0)	**80** (90.90%)	**810**(89.90%)	**890** (89.99%)
Notable Smell (1.-2.0)	**6**(6.80%)	72 (7.99%)	**78**(7.89%)
Irritating smell (2.0-3.0)	**2**(2.30%)	**13** (1.44%)	**15**(1.52%)
Offensive Smell (above 3.0)	**0** (0.00%)	**6** (0.67%)	**6** (0.61%)
Total count	**88 (100%)**	**901 (100%)**	**989 (100%)**

Comparing the hourly readings during the research and the single measurements of H_2S at a measuring point in a day, one notices that the parameters are erratic gas could be present earlier or after the measurement. The employees who work in such areas therefore must carry their own monitoring equipment besides the fixed monitoring equipment. This is to take confirmation before access particularly in low enclosed places due to the fluctuations of the ambient H_2S expected during the day.

Past trends of H_2S at Olkaria I have been done for measurements taken from 1997 to 2011 period. Olkaria I geothermal power plant utilizes an older technology where excess steam condensate, commonly referred to as brine is collected in a pool before being re-injected to the ground using electrical pumps.

The results of detected H_2S in the period1997-2011 are shown in Table 4.14 below indicating notable smell being higher at 325 (14.42%) occurrences in Olkaria I compared to 78 (7.89%). This collaborates with technology of Olkaria II which is a more modern plant and hence releases less H_2S in the process of energy generation. Likewise, results of irritating and offensive smell occurrences are higher at 1.42% (Tally=11) and 0.49% respectively in the period.

Table 4.14: Result of strength of smell of H_2S at Olkaria I in Period 1997-2011

Strength of Ambient H_2S for non-zero readings	Tally of readings	%
Weak Smell (0.1-1.0ppm)	1886	83.67%
Notable Smell (1.-2.0ppm)	325	14.42%
Irritating smell (2.0-3.0ppm)	32	1.42%
Offensive Smell (above 3.0ppm)	11	0.49%
Total Non-Zero measurements	2254	100%

Results of analysis of maximum daily readings at Olkaria I geothermal power station indicate the plant experienced higher concentrations of ambient H_2S as measured using the same equipment and at predetermined locations. Between 1997 and 2011, irritating smell had occurred 32 times and 11 times had been offensive. The presence of the gas had been spatial with maximum recordings above 4.0 ppm in one minute maximum reading at the power station, seal pit and stores.

4.2.3 Discussion of Ambient H_2S at Olkaria Geothermal Power Plants

In responding to the first research question, 'what are the ambient levels of H_2S at Olkaria Geothermal power plant' the results demonstrate that the ambient concentrations of H_2S is sporadic from hour to hour, day to day and different for different locations. The mean conditions show Olkaria 1 to be 0.64ppm for the period 1997-2011 while Olkaria II is 0.23 ppm for the period 2003-2011. For the period of measurement in March 2012, the mean for Olkaria I was 0.97ppm while Olkaria II was 0.41ppm showing that H_2S in the workplace exists but in low concentrations. All these results show that the conditions are above the thresholds for a 24hour exposure (0.1ppm) and below interpolated WHO standards for 12 hrs (3.5ppm) and UK standards (2.3ppm) as shown in the appendix on interpolation graph.

Further, comparing the hourly readings in the geothermal power stations shows that the distributions of frequencies of readings had similar distribution as shown in the figure 4.10 below of distribution of researcher readings and past measurement. Olkaria II geothermal power station had correlation R^2 values of 0.204 for one hour interval readings by researcher and 0.208 for past measurements reviewed. Similarly R^2values for Olkaria I were 0.443 and 0.265 for measurements of March 2012 and past readings respectively. These results indicate that in the further investigation of effects of exposure to workers at Olkaria, previous measurements can be relied upon as ambient conditions. The levels are way below the threshold for occupational limits of 10ppm (WHO) and further investigation of clinical history was carried out.

The concentrations of H_2S in air surrounding some geothermal power plants, which has been associated with health impacts and corrosion of equipments are similar to Olkaria Geothermal power plants. For instance, Svartsengi, Iceland in 1993 had H_2S mean ambient readings 0.145 ppm while the highest values for Nesjavellir, Iceland was 2.5 ppm in 2005 (Rivera, 2007). Olkaria II Geothermal power plant in Kenya had a mean of 0.23 ppm for the period 2003-2011 and a maximum recorded 6.4 ppm. Other plants such as Hellisheidi, Iceland recorded 0.147 ppm, Onikobe, Japan recorded 0.40 ppm and San Jacinto Tizate, Nicaragua, 0.150 ppm (Rivera, 2007).

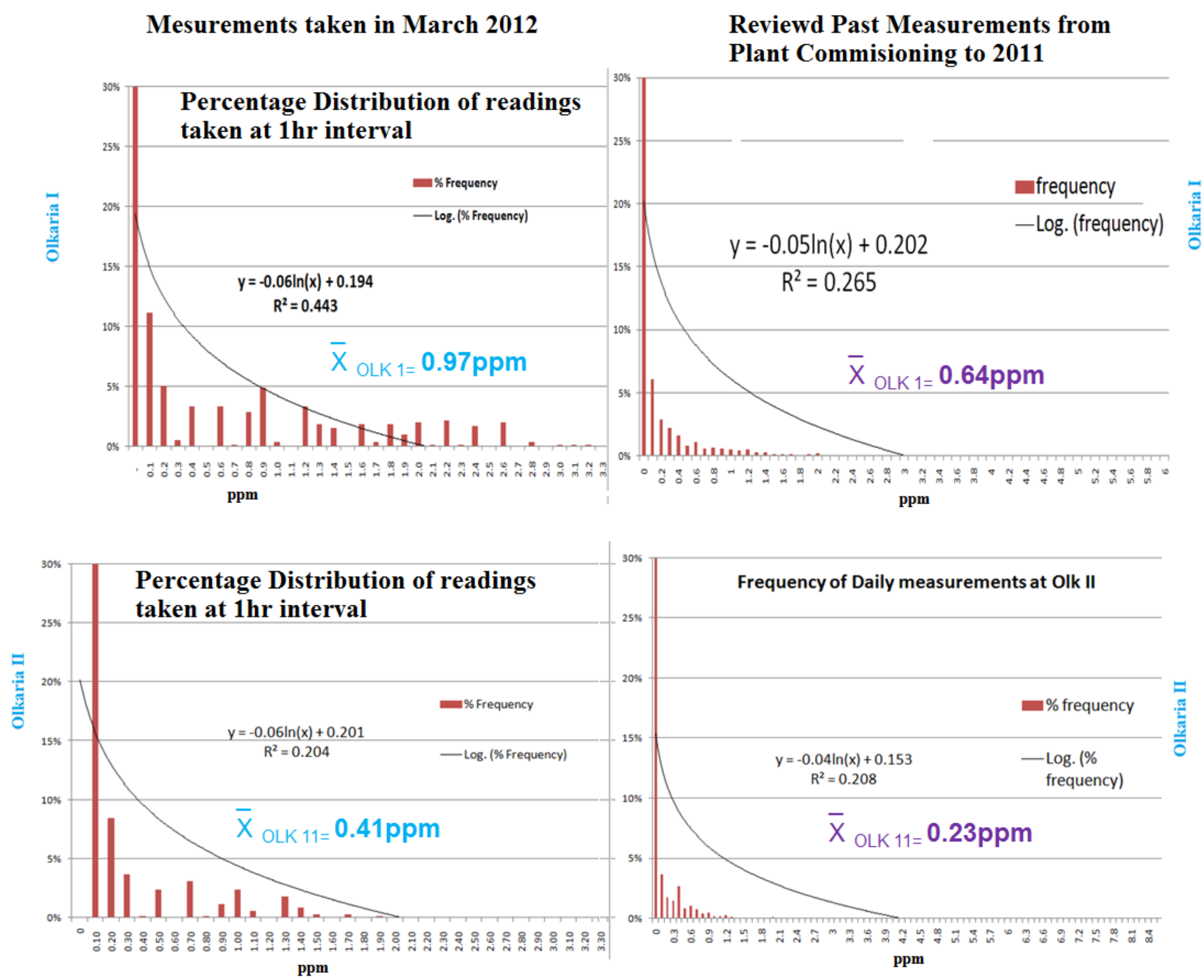


Figure 4.10: Distribution of researcher readings and past measurement

4.3 Clinical History of Staff at Olkaria Geothermal Power Plant

KenGen staff in Olkaria Geothermal attend Mvuke clinic for treatment. The clinic is located at the housing estate near the shores of Lake Naivasha. Staff who use the clinic are identified by staff identification number while members of public would be identified by national identity card. Staff who work in operations and maintenance work in indoor conditions for a 12 hr shift had their clinical records reviewed.

4.3.1 Cases related to exposure of H_2S at Mvuke Clinic 2009-2011

Diagnosed ailment cases at Mvuke Clinic which exhibited clinical symptoms similar with occupational exposure to H_2S were 157 cases were from the 37 persons from sample population of 40. Some of the common ailments with such symptoms related to breathing include; upper respiratory trunk infections (URTI), bronchitis, coryza, mouth sores, pharyngitis, rhinitis, sinusitis, sore throat and tonsillitis. Other symptoms that are related to H_2S exposure include in the review are cconjunctivitis which is related to reddening of the eyes, hypertension and headache including chronic headaches which are related to strain.

In this period 2009 and 2011, as shown in Table 4.15 on distribution of clinical cases, a total of 37 (92.50%) of the respondents from operations and maintenance section under Olkaria I and Olkaria II power stations visited the clinic at least once in the period with symptoms related to H_2S exposure at different times.

Table 4.15: Distribution of clinical cases by gender.

Record of diagnosis	Female	Male	Total	Percent
Related cases to H_2S exposure	9	28	37	92.50
No related cases H_2S exposure	0	3	3	7.50
Total	**9**	**31**	**40**	100.00
Percent	22.50	77.50	100.00	

In distribution of the 157 cases reported at the clinic 90.45% were cases made by male while 9.55% were female cases. Upper respiratory truck infections (URTI) were highest with 36.94% cases. Related to respiration was also rhinitis 14.65%, bronchitis 8.92% and the otherstonsillitis, sore throat, conjunctivitis, coryza, sinusitis and pharyngitis making up 29.93%. Cases related to uncomfortable workplace including hypertension and headache were 14.65% and 3.825 respectively.

Table 4.16: Frequency of clinical diagnosis of staff related to H_2S exposure

Diagnosis	Tally Female	Tally Male	Tally Total	Total Percent
URTI	4	54	58	36.94
Hypertension	2	21	23	14.65
Rhinitis	3	20	23	14.65
Bronchitis	2	12	14	8.92
Tonsillitis	2	7	9	5.73
Sore throat	0	7	7	4.46
Conjunctivitis	1	5	6	3.82
Headache	1	5	6	3.82
Coryza	0	5	5	3.18
Sinusitis	0	5	5	3.18
Pharyngitis	0	1	1	0.64
Total Tally	15	142	157	100.00
Total Percent	**9.55**	**90.45**	**100.00**	

Some staff were diagnosed with symptoms discussed before at the clinic a number of times more than others out of the 157 cases. The highest number of visits were fifteen (15) or a visit every 2.4months by the same person. The same person who made the 15 visits had symptoms of headache and coryza and hypertension as analyzed on Table 4.17 of analysis of cases. Further check on unrelated cases of the person revealed that the sample was diabetic which could contribute to weak health conditions. This particular person had worked in the Olkaria 1 power plant since its commissioning where the ambient H_2S conditions have been shown to have been higher than Olkaria II geothermal power plant. However contributions by other pollutants, pre-employment medical history were not available hence the contribution to the visits by H_2S cannot be claimed.

Another sampled case of a staff visited the clinic 14 times (every 2.57months) in the period had worked at Olkaria power plant 1 in operations and maintenance between 12-15years. The person had been diagnosed of conjunctivitis, headache, allergic bronchitis, rhinitis, tonsillitis, allergic sinusitis. The diagnosis was similar for the person who had visited 11 times. One staff who made 8 visits to had previously worked in the field at the steam wells before being deployed to Olkaria I. This person had worked between 4-7years and reported cases of URTI, Chronic and allergic Bronchitis and Rhinitis.

For visits below frequency of 8 counts, majority of reasons why people visited, common cases include URTI, rhinitis, bronchitis, tonsillitis, hypertension, headache, coryza, conjunctivitis, sinusitis, sore throat, pharyngitis mouth sores in all departments.

Table 4.17: Comparison of frequency of visits with the rest in department

Frequency by same person	Sample population	No of visits	Staff in the rest of the departmental	No of visits by other staff
15	1	15	0	-
14	1	14	1	14
13	0	-	0	-
12	0	-	3	36
11	1	11	0	-
10	0	-	3	30
9	0	-	3	27
8	2	16	1	8
7	4	28	4	28
6	2	12	5	30
5	1	5	9	45
4	4	16	7	28
3	7	21	11	33
2	5	10	29	58
1	9	9	36	36
0	3	-	92	-
Total	40	157	204	373
Average		3.93		1.83

In clinical cases with similarity to H_2S exposure, one observes that there were 157 clinical cases diagnosed from a sample of 40 staff translate to 3.93 clinical cases per staff in this period. Similarly the rest of the staff in operations (204) have had 373 cases in the same period translating 1.83 cases per person. As shown in Table 3.2 in chapter 3 of this report, the staff in Olkaria I and Olkaria II outside the sample frame work in 8 hr shift. These results shows that, a worker in operations and maintenance is about twice likely (2.14) to have these symptoms similar to exposure, compared to his colleagues working in other sections.

4.3.2 Cases of H_2S exposure in Olkaria I and Olkaria II

In section 4.2 of the report the average ambient conditions of H_2S showed Olkaria power plant 1as 0.64ppm for the period of 15years (1997-2011) and Olkaria II power plant as 0.23ppm for the period of 8 years (2003-2011). During the study, the average conditions were measured at0.97ppm and 0.41ppm for Olkaria I and Olkaria II respectively. Cases evaluated occurred between 2009- 2011 and showed that Olkaria I had 82 (52.23%) cases in the period while Olkaria II power plants had 75 (47.77%) cases. The table 4.18 shows that in the workplace where ambient H_2S was generally higher, the diagnosed cases related to health and comfort of the employees were generally higher

Table 4.18: Olkaria I and Olkaria II clinical cases summary

	Olkaria I (H_2S $_{Mean}$ = 0.97 ppm)		**Olkaria II** (H_2S $_{Mean}$ = 0.41 ppm)	
Diagnosis	**Tally**	**Percent**	**Tally**	**Percent**
URTI	26	16.56	32	20.38
Rhinitis	9	5.73	14	8.92
Hypertension	17	10.83	6	3.82
Tonsillitis	4	2.55	5	3.18
Conjunctivitis	2	1.27	4	2.55
Sore throat	3	1.91	4	2.55
Bronchitis	11	7.01	3	1.91
Coryza	2	1.27	3	1.91
Sinusitis	2	1.27	3	1.91
Pharyngitis	0	-	1	0.64
Headache	6	3.82	0	-
Total	82	52.23	75	47.77

The analysis of clinical cases reported to Mvuke clinic during the period 2009-2011 show that there was no clinical diagnosis of H_2S poisoning in all reviewed cases. There are several reasons for this finding in both stations. The first reason is that the ambient conditions has been below 30 ppm short term exposure where an exposed person would have been taken to the clinic with clear symptoms of H_2S poisoning such as eye irritation, fatigue, loss of appetite, headache, irritability, poor memory, dizziness as discussed in chapter 2 of this report. Secondly, there is lack of specific procedure for testing causes of symptoms associated with chronic exposure to ambient H_2S at the Mvuke clinic. This could result in a patient could be making 4 or 5 visits every year with recurring symptoms triggered by the workplace conditions without relating to the real cause. The hazard would remain undetected and most likely unmitigated. Lastly persons in residential areas exposed to other pollutants record increased cases of respiratory problems such as chronic bronchitis and phlegm (Carlsen, 2014). In the Mvuke clinic, there were no mechanisms of isolating the symptoms caused by other factors such as particulate matter pollutants, Nitrogen compound, arsenic, lead among other co-leases in the workplace as well as residential areas.

4.4 Hypothesis testing

The testing of hypothesis used paired sample t- test rather than z test as the population standard deviation is not known to test whether exposure to ambient H_2S significantly affect the comfort and health of workers at the geothermal power station as shown in Table 4.19 below.

The first test is to determine if the results demonstrate that strong pungent smell of rotten eggs experienced at workplace causes discomfort to employees in workplace and interferes with focus on work. Using sample T- test df=39, P value = 0.112 is not significant at $p<0.05$ therefore we cannot reject the null hypothesis. This implies that the variables are not dependent. The probability that strong pungent smell of rotten eggs at workplace in Olkaria geothermal power stations does cause discomfort to employees at workplace is not satisfactorily significantly proven.

Table 4.19: T-test for impacts of H_2S paired sample

Cases	Test Pair	Paired Differences					t	df	Sig. (2-tailed)	Sig (1-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference					
					Lower	Upper				
1	Strong Pungent Rotten eggs at workplace- Causes discomfort at work place	-0.45	2.309	0.365	-1.188	0.288	-1.233	39	0.225	0.112
2	Smell persistent in all time- Quickly exhausted	0.375	2.705	0.428	-0.49	1.24	0.877	39	0.386	0.193
3	Conditions are satisfactory and Fatigued by the end of working day	2.85	3.309	0.523	1.792	3.908	5.447	39	0	0
4	Adequate Ventilation andQuickly getting exhausted-	2.3	3.376	0.534	1.22	3.38	4.309	39	0	0
5	Smell of H_2S is continuous and now is accustomed	-0.9	2.925	0.462	-1.835	0.035	-1.946	39	0.059	0.0295

Exhaustion after doing little activity is an indicator that one may not be healthy or is not getting sufficient oxygen. There, the second test is to do determine if the chronic/persistent smell at workplace is the cause of quick exhaustion of employees. Using sample T- test df=39, P value = 0.193 is not significant at $p<0.05$ therefore we cannot reject the null hypothesis. The null hypothesis that workers in sections where the smell of H_2S is persistent do get quickly exhausted is not satisfactorily proven to be significance 1-tailed is 0.193 at $p<0.05$. The null hypothesis is therefore not rejected

Based on the first two pairs of tests above, the null hypothesis that exposure of low ambient H_2S concentrations to workers in the Olkaria Geothermal power plant has no effect on their comfort and health would not be rejected. However the other three tests shows that the physical work environment satisfactorily impact on the employees causing fatigue (df=39, P value = 0.0001 is significant at $p<0.05$). Despite a weak correlation on ventilations and ambient H_2S (p = -0.19), where there is inadequate ventilation at workplace, workers get quite exhausted (df=39, P value = 0.0001 is significant at $p<0.05$). When a smell is persistent at workplace for a long time, it's satisfactorily shown that a worker significantly gets accustomed to the condition (exhausted (df=39, P value = 0.0295 is significant at $p<0.05$).

CHAPTER FIVE.

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

The results demonstrated that levels of exposure to ambient H_2S were below OEL of10ppm for a shift of 8 hrs (WHO). The mean conditions show Olkaria 1 power plant to be 0.64ppm from commissioning in 1997 to 2011 and measured 0.97 ppm in March 2012 during the study. Olkaria II mean was is 0.23ppm for the period 2003-2011 and measured 0.41ppm during the study period of March 2012.The results of hourly measurements during the research compared well with secondary data taken from the same sampling points where distribution R^2 values were 0.208 and 0.204 for hourly and daily measurements in Olkaria II geothermal power station. R^2 values for Olkaria I geothermal power station were 0.265 and 0.443 for hourly and daily measurements respectively. There is therefore a low ambient concentration of H_2S at Olkaria geothermal power stations since the commissioning of the plants. The exposure risk would be for extended shift work as correction for the extra hours is required such as a shift for 12 hrs is interpolated between 0.1ppm (24hrs) and 10ppm (8hrs) giving about 3.5ppm (12hrs) as shown in appendix 2 Interpolation of UK and WHO

Working in the enclosed workplace experienced by staff working in operations and maintenance increases respiratory cases and other H_2S related exposures compared to those who work for 8 hr shift. A staff in operations and maintenance between 2009 and 2011 made 3.93 visits to the clinic on average compared to 1.83 visits for one working in the other areas in the same department.

Despite the research has shown that ventilation of workplace in operations and maintenance has been an improvement noted in the workplace in the last three years and leading to work satisfaction (Pearson coefficient, p=0.537), most recurrence visits in the period were staff working in operations and maintenance. The impact of these workplace improvement would have impacted those who work beyond eight hour shift (Pearson coefficient, p=0.408). Since workers who at the end of the day did not feel like working the following day, also get accustomed to the smell of H_2S and rarely notes the smell when busy at work place (Pearson correlation of p=0.444 at 95% confidence level), there is a risk of undetected exposure. This was a concern as explained in part 1.2 of this report especially with a perception that presence of the gas is a nuisance and not a danger. This research finding could not satisfactorily attribute the discomfort exclusively to the presence of H_2S at work place and thus rejected the hypothesis. However the research has demonstrated from the sampled from operation and maintenance that workplace conditions have impact on their quick fatigue and exhaustion after undertaking a task even for a short time (df=39, P value = 0.0001 is significant at $p<0.05$).

From the analysis of respondent feedback in this study, exposure of low ambient H_2S concentrations to workers in the Olkaria Geothermal power plant has not been directly associated with effect workers comfort and health. It acknowledged that that the health including environmental impact of long-term exposure to low ambient H_2S is still unknown. In 2010 and in response to repeated complaints from residents, the environment ministry in Iceland tightened the daily H_2S concentration limit to 3.5ppm (50 μg/m3), or one-third of the World Health Organization guideline value. If the limit is exceeded more than 5 times, it triggers financial penalties (OECD, 2014).

Despite lack of direct correlation with ambient occupational conditions, analysis of clinical cases with similar diagnosis to exposure of H_2S where the frequency of complaints is 114.8% higher for the indoor 12 hr shift compared to others in the department. It was also noted that, there were higher frequencies of visits by same persons in Olkaria I geothermal power plant. Like Iceland, repeated complaints even in the absence of scientific evidence should trigger a review process of the exposure limits (OECD, 2014). The influence of intervening variables of weather, dust, co-releases and other indoor pollutants have not been isolated as well as the individual health status.

5.2 Recommendations

It was anticipated that, geothermal as a renewable energy source would be the focus for sustainable energy source to spur industrial growth in Kenya. This would lead to increased drilling activities and usage of steam where co-releases gases could alter the ambient air conditions around Olkaria power stations. Continued exposure to the ambient conditions at a later date could significantly affect the employees comfort and health. This study therefore recommended investigation of the effects of geothermal co-release gases in Olkaria geothermal area and their interaction with ambient conditions at workplace. Further, current monitoring points at the time required to be reviewed to reflect new areas affected by drilling activities and to establish baseline data in areas where new geothermal power plants were to be constructed.

The study has demonstrated that ambient concentrations of H_2S have no significant effect on employees' health and comfort. However, a review of the sensors to factor the 12 hr shift duration and effect of chronic exposure is required. The sensors are to be reviewed from the normally set alarm point at 10ppmtotal weighted average of 8 hrs to 3.5ppm equivalence average for 12 hours shift. This corresponds to revised OEL in Iceland. The alternative to this is to ensure the shift sticks to 8 hrs which may be reviewed by additional shift. This option is to be assessed along other implications of shift changeover at night in a national park

Avoiding areas that have potential of having H_2S is a safe method of protection. This is not always practical and the study recommends provision of local exhaust or process enclosure ventilation system to ensure compliance with applicable exposure limits is recommended in Kenyan law on occupational limits. Splash resistant safety goggles with a face-shield for eye protection and provision of emergency eyewash fountain and quick drench shower in the immediate work area are required to be provided and usable.

The body is protected by having chemical proof overalls and hand gloves for a mild concentration. Air-purifying respirator with cartridge providing protection against exposure is used in cases of significant exposure places (Matheson, 2008). The best available technology (BAT) should be utilised in all future plants to mitigate exposure (Lowana, 2011).

Further, H_2Scan be measured in biological samples such as human breath (as expired air), biological tissues, and fluids, including blood and saliva using gas chromatography coupled with flame ionization detection (GC/FID) or iodometric titration. This medical research would investigate the impacts of each co-release of geothermal operations.

Training is recommended for the employees who were not confident in identification (7.5% in section 4.2.2) and who couldn't identify (7.5%) H_2S at workplace. Such employees are vulnerable to the hazard of exposure and require to be training to on characteristics of H_2S in the ambient air, the effect of shift on the exposure levels, use the monitoring equipment's, and appropriate response to exposure. The danger of relying on detection by smell in areas where H_2S is expected should be clearly communicated to all persons entering such workplaces. Detection by smell is possible at a concentration of about 0.03 ppm. However as the concentration increases, the odour becomes sweeter and finally disappears at around 150 ppm where it is at fatal concentration.

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APPENDICES

Appendix 1: QRAE II 4 Gas Monitor

Information

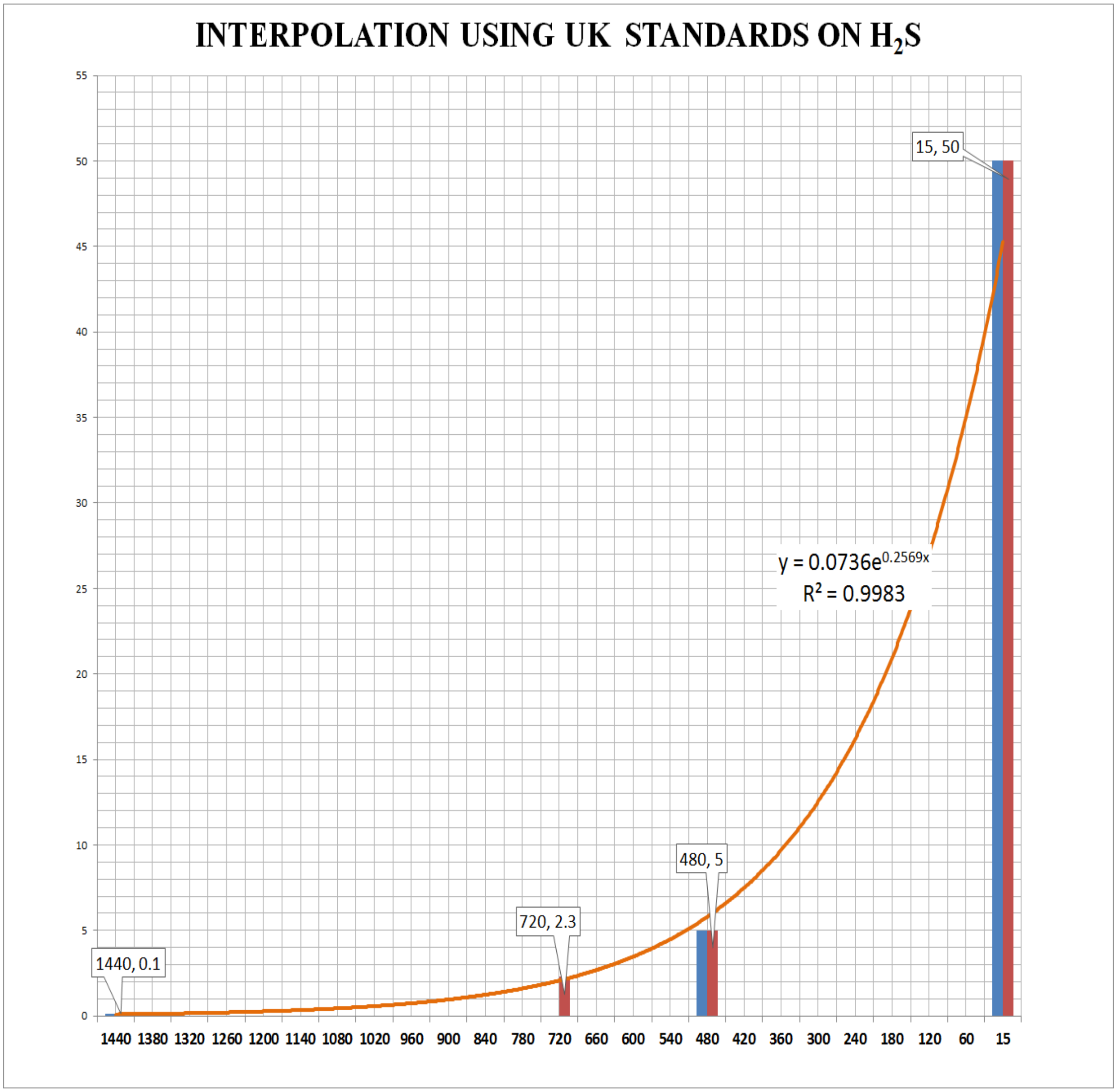
Monitors CO, H_2S and Oxygen level

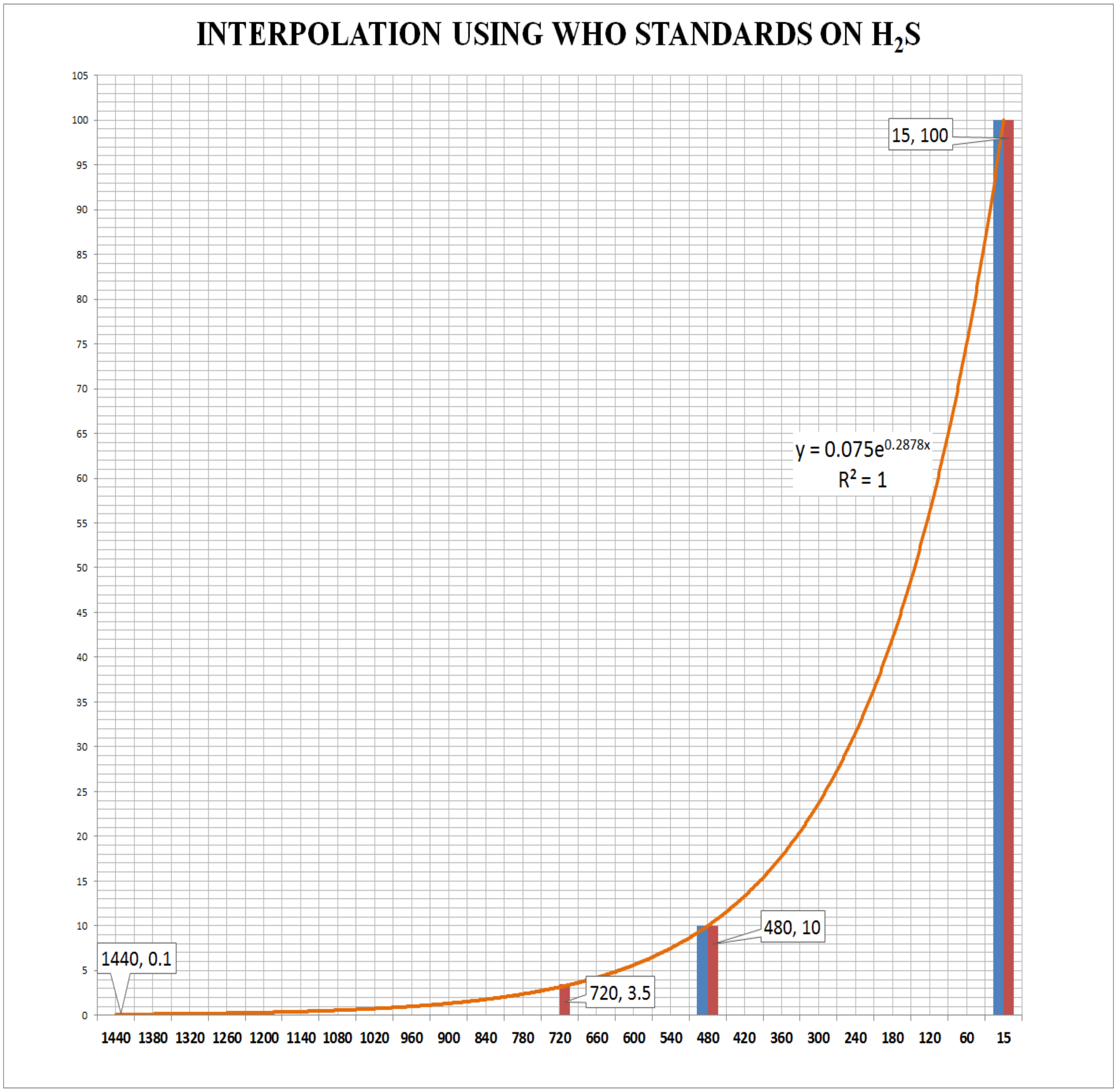
Internal vibrating and loud 95-dB audible alarms alert workers to dangerous levels of toxic gas.

CO Range 0-1000 ppm with 5% or ± 10 ppm **accuracy**. **...QRAE II**

Error =0.05ppm

Appendix 2:Interpolation of UK and WHO standards




INTERPOLATION USING WHO STANDARDS ON H2S
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
15, 100
y = 0.075e0.2878x
R2 = 1
480, 10
720, 3.5
1440, 0.1
1440 1380 1320 1260 1200 1140 1080 1020 960 900 840 780 720 660 600 540 480 420 360 300 240 180 120 60 15

Appendix 3:Letter of authority to undertake research

Our Ref: STAFF/001/KG/BO/eo

Date: 29 February 2012

KenGen
Kenya Electricity
Generating Company Ltd.
Stima Plaza, Kolobot Road, Parklands
P.O. Box 47936 - 00100 Nairobi, Kenya
Telephone: 254-20-3666000 Fax: 254-020-2248848

STRICTLY CONFIDENTIAL

Dear Sir/Madam,

REF: AUTHORISATION TO COLLECT DATA FOR MSC RESEARCH PROGRAM-PATRICK IRUNGU GIKUNJU S/N 70527

The above named employee is a student undertaking a MSC degree in Occupational Safety & Health at JKUAT.

As part of his coursework requirement, he is carrying out a research on 'Effects of Occupational exposure to low Hydrogen Sulphide concentrations in Geothermal Power Station"

Kindly assist him for period he will be there.

Yours faithfully,
For: KENYA ELECTRICITY GENERATING COMPANY LIMITED

B. OGWAYO
Ag HUMAN RESOURCES MANAGER

cc. Chief Human Resources Officer-Geothermal
Geothermal Development Manager
Operations Manager

Appendix 4:Sample Questionaire

Instructions:

This study is aimed at establishing the effects of hydrogen sulphide in geothermal power stations. The information given shall be treated with confidence and shall be used only for this research.

Kindly fill in the information as accurately as possible seek clarification for any part or whole of information not understood. You are free to give additional information related to this topic or decline to respond to any part or entire questions without having to explain your reasons.

Please give the most appropriate answer to each question.

Personal work information

1. For how long have you been working in the plant in years?________________ years
2. Please fill the details of section as you have moved within the organisation

Section	Dates from- to	Main activity

3. How long do you work inside the plant in a normal working day?

A	B	C	D	E	F	G	H	I	J
0-30min	30min-1hour	1-2hr	2-3 hrs	3-4hrs	4-6 hrs	6-8 hrs	8-9 hrs	9-12 hrs	12-16 hrs

4. Have you ever smoked?
   a) Yes
   b) No
5. If yes to above, how long do you smoke in years since you joined the organisation? ________________ years.

6. Tick your age bracket?

A	B	C	D	E	F	G	H	I	J
18-20	21-25	26-30	31-35	36-40	41-45	46-50	51-55	56-60	61-65

7. Does your work involve welding or exposure to welding rays?
   a) Yes
   b) No
8. What type of eye protection against UV light are you using?

9. While performing your duty in the plant are you required to use breathing apparatus

a) Yes
b) No

10. Do you wear respiratory protection during work?
a) Respirator
b) Dust mask
c) None

11. Are there some environmental conditions in your workplace you would want changed to improve your comfort?
a) Yes
b) No
If yes for above, is it related to air quality?__________________

Detection of H_2S

12. Can you identify the smell of H_2Sin the air around your work place?
a) Yes,
b) No
c) Not sure

13. If yes, during a normal working day, how would you describe the smell of air?
a) Strong continuous bad smell of rotten eggs
b) Weak continuous bad smell of rotten eggs
c) Intermittent strong bad smell of rotten eggs
d) Intermittent Faint bad smell of rotten eggs
e) No bad smell

14. How would you describe your breathing after a bad smell in air?
a) Breathing with difficulty
b) Breathing with Pain in the throat
c) Breathing with irritating cough
d) All the above
e) None of the above

15. How often do such experiences you have indicated above occur?
a) Daily
b) Weekly
c) Monthly
d) Quarterly
e) Once a year
f) Very rare

Health issues

16. How do your eyes behave after the exposure bright light?
a) Irritate and water for sometime

b) Irritate water and shy from bright light for a few days
c) Shy of light
d) None

17. Have you complain of constant headache?
    a) Yes Through out
    b) Yes several times
    c) Yes but rarely
    d) Yes but only occasionally.
    e) Not at all
18. Do you experience a stuffy chest while breathing?
    a) Yes throughout.
    b) Several times
    c) Rarely
    d) Occasionally
19. When is the last time you had a sick leave related to breathing problems?

    Date ----------- month-------------- year--------------

    How long was it?

    Days----------- months------------

20. How often have you taken a sick leave?
    a) Once a week
    b) Once a month
    c) Every three months
    d) Once a year
    e) Rarely
    f) None in the last ten years
21. Of the above sick leaves taken, how many would you associate with exposure to H_2S?

22. What other discomfort would you likely attribute to H_2Sgas exposure?

a)
b)
c)
d)

Please elaborate your answer

23. Are you aware of the actions you would take if your colleague collapsed after inhaling H_2S?

24. What other information on personal experiences, incidents, recommendation etc. on this subject would you share

EFFECTS OF OCCUPATIONAL EXPOSURE TO LOW H_2S CONCENTRATIONS IN GEOTHERMAL POWER STATION

After the feedback received, additional information became necessary to capture the individual experience at the work place. Kindly fill this checklist to enable the research incorporate the rich experience you have on your work place.

25	Summary of duties/Tasks: State in your own words briefly your main duties/tasks, i.e. what you do on a daily basis. (You may want to list jobs according to hours of the day e.g. 08.00-10.00, 10.00-12.00pm etc.)

26	On a scale of 1-10 where 1 is lowest and 10 is highest, please provide an average rating of nature and scope of effort required to do your job										
	STATEMENT	**Strongly disagree ←----------------------→ Strongly agree**									
	Physical effort required to do this job.	1	2	3	4	5	6	7	8	9	10
	Mental effort required to do this job	1	2	3	4	5	6	7	8	9	10
	Audio effort required to do this job	1	2	3	4	5	6	7	8	9	10
	Visual effort required to do this job	1	2	3	4	5	6	7	8	9	10

27	On a scale of 1-10 where 1 is strongly disagree and 10 strongly agree, please indicate the extent to which you agree with the following statement on work environment										
	STATEMENT	**Strongly disagree ←----------------------→ Strongly agree**									
	The ventilation of my workplace is adequate	1	2	3	4	5	6	7	8	9	10
	My work environment is better than it was three years ago	1	2	3	4	5	6	7	8	9	10
	My physical work environment and conditions are satisfactory	1	2	3	4	5	6	7	8	9	10
	By the end of my working day, I don't feel like working the following day	1	2	3	4	5	6	7	8	9	10
	I feel tired even when I have done little work	1	2	3	4	5	6	7	8	9	10
	Most days I work for more than eight hours	1	2	3	4	5	6	7	8	9	10

28	On a scale of 1-10 where 1 is strongly disagree and 10 strongly agree, please indicate the extent to which you agree with the following statement on H_2S in the work environment										
	STATEMENT **Strongly disagree ←----------------------→ Strongly agree**										
	The smell of rotten eggs is strong pungent of rotten eggs in workplace	1	2	3	4	5	6	7	8	9	10
	The smell of H_2S (rotten eggs/ sour gas) is continuous during the working period	1	2	3	4	5	6	7	8	9	10
	I use gas detector (H_2S) when going to some of my working areas	1	2	3	4	5	6	7	8	9	10
	H_2S causes discomfort in workplace and interferes with my focus on work	1	2	3	4	5	6	7	8	9	10
	Discomfort in workplace interferes with my focus/ concentration on work	1	2	3	4	5	6	7	8	9	10
	I am used to the smell of H_2S and rarely notes the gas is smelling when busy at work	1	2	3	4	5	6	7	8	9	10

29. Kindly fill this information below each box

Olkaria I/II/GRD	Years in this plant	Current Section	Year of birth	Gender (male/female

Thank you

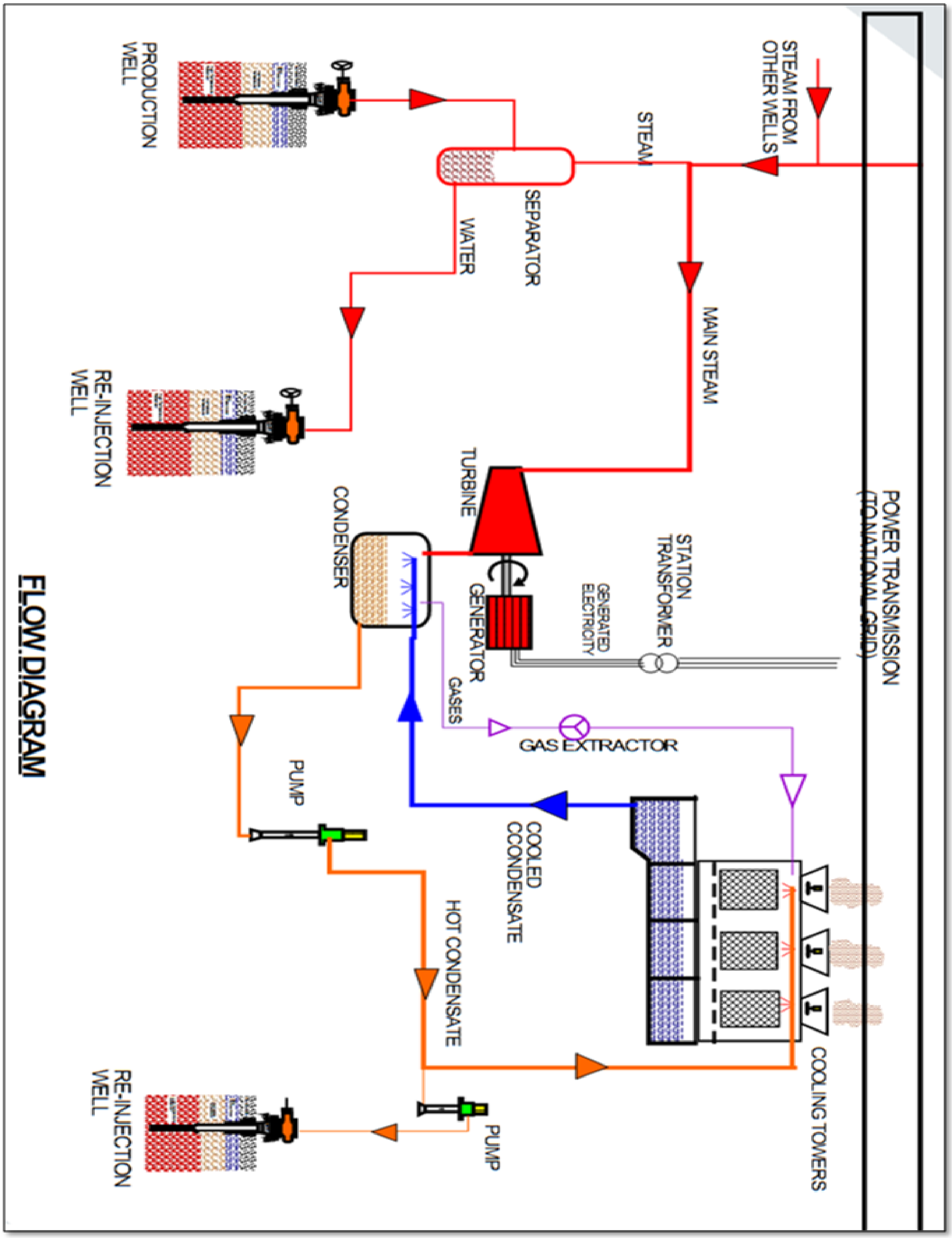
Appendix 5:Coordinates of Olkaria I Monitoring Points

	MONITORING POINT	NORTHINGS	EASTINGS	(m) ASL
1	OW-10	N9901720	E0200267	1951M
2	M/V & RIG W/SHOP	N9901054	E0200460	1941M
3	ADMIN BLOCK	N9901420	E0200426	1940M
4	GIS LAB	N9901389	E0200394	1945M
5	LIAISON OFFICE	N9901427	E0200403	1956M
6	OLKARIA LABS	N9901349	E0200349	1947M
7	OLKARIA STORES	N9901382	E0200305	1951M
8	SEAL PIT I	N9901490	E0200416	1943M
9	SEAL PIT II	N9901465	E0200426	1941M
10	COMPRESSOR ROOM	N9901515	E0200400	1940M
11	EJECTOR I	N9901490	E0200410	1942M
12	EJECTOR II	N9901473	E0200422	1938M
13	EJECTOR III	N9901456	E0200417	1939M
14	TURBINE I	N9901493	E0200382	1924M
15	TURBINE II	N9901467	E0200410	1935M
16	TURBINE III	N9901457	E0200412	1942M
17	OW-22	N9901128	E0201047	1935M

Appendix 6:Coordinates of Olkaria II Monitoring Points

	MONITORING POINT	NORTHINGS	EASTINGS	(m) ASL
1	KWS GATE	N9905385	E0198559	1967M
2	WORKSHOP	N9904632	E0199341	2045M
3	MECHANICAL OFFICE	N9904629	E0199371	2022M
4	MAINTENANCE 0FFICE	N9904632	E0199336	2051M
5	COMPRESSOR ROOM	N9904646	E0199371	2025M
6	HOT WELL I	N9904667	E0199347	2028M
7	HOT WELL II	N9904685	E0199324	2036M
8	HOT WELL III	N9904725	E0199309	2038M
9	COOLING TOWER I	N9904682	E0199381	2024M
10	COOLING TOWER II	N9904719	E0199359	2030M
11	COOLING TOWER III	N9904745	E0199342	2035M
12	ADMIN BLOCK	N9904597	E0199329	2033M
13	ADMIN OPEN OFFICE	N9904562	E0199325	2028M
14	VACUUM PUMP	N9904657	E0199354	2019M
15	MAIN OIL PUMP	N9904637	E0199339	2025M
16	EJECTOR	N9904662	E0199354	2021M
17	TURBINE	N9904659	E0199355	2003M
18	GV/MSV	N9904632	E0199334	2019M
19	D.U.C….POOL	N9904790	E0198924	1997M
20	D.U.C…CONFERENCE	N9904853	E0198854	1992M

Appendix 7:Schematic showing the geothermal power generation sequence



Appendix 8:Tabulation of results of questionnaires

Correlation with Effort require to do the job

		Age	Years	Mostly Requires manual effort	Mostly requires mental effort	Requires Listening	Visual effort required
Age	Pearson Correlation	**1**	**.686****	**-0.213**	**-0.172**	**-0.077**	**-0.189**
	Sig. (2-tailed)		0.0%	18.8%	28.7%	63.5%	24.2%
	N	**40**	**40**	**40**	**40**	**40**	**40**
Years	Pearson Correlation	**.686****	**1**	**-0.236**	**-0.059**	**0.242**	**0.029**
	Sig. (2-tailed)	0.0%		14.3%	71.5%	13.2%	85.9%
Mostly Requires manual effort	Pearson Correlation	**-0.213**	**-0.236**	**1**	**.625****	**.445****	**.377***
	Sig. (2-tailed)	18.8%	14.3%		0.0%	0.4%	1.6%
Mostly requires mental effort	Pearson Correlation	**-0.172**	**-0.059**	**.625****	**1**	**.656****	**.719****
	Sig. (2-tailed)	28.7%	71.5%	0.0%		0.0%	0.0%
Requires Listening	Pearson Correlation	**-0.077**	**0.242**	**.445****	**.656****	**1**	**.795****
	Sig. (2-tailed)	63.5%	13.2%	0.4%	0.0%		0.0%
Visual effort required	Pearson Correlation	**-0.189**	**0.029**	**.377***	**.719****	**.795****	**1**
	Sig. (2-tailed)	24.2%	85.9%	1.6%	0.0%	0.0%	
Ventilation is adequate	Pearson Correlation	**-0.011**	**-0.213**	**0.15**	**0.099**	**0.133**	**.348***
	Sig. (2-tailed)	95%	19%	36%	54%	41%	3%
Work place better than last 3 years	Pearson Correlation	**0.016**	**0**	**-0.009**	**-0.027**	**-0.062**	**0.148**
	Sig. (2-tailed)	92%	100%	96%	87%	70%	36%
Satisfactory work condition environment	Pearson Correlation	**0.069**	**0.052**	**0.004**	**0.162**	**0.084**	**.370***
	Sig. (2-tailed)	67%	75%	98%	32%	61%	2%
Cumulative fatigue	Pearson Correlation	**-0.126**	**0.089**	**-0.085**	**-0.13**	**0.063**	**-0.069**
	Sig. (2-tailed)	44%	59%	60%	42%	70%	67%
Quickly exhausted	Pearson Correlation	**0.142**	**0.052**	**-0.036**	**-0.094**	**-0.048**	**-0.081**
	Sig. (2-tailed)	38%	75%	83%	56%	77%	62%

Working beyond 8 hrs	Pearson Correlation	**0.25**	**-0.09**	**.328***	**0.108**	**0.064**	**0.136**
	Sig. (2-tailed)	12%	58%	4%	51%	70%	40%
Strong Pungent Rotten eggs at workplace	Pearson Correlation	**-0.252**	**-0.217**	**0.24**	**0.295**	**0.103**	**0.078**
	Sig. (2-tailed)	12%	18%	14%	7%	53%	63%
Smell persistent in all time	Pearson Correlation	**0.203**	**0.016**	**-0.154**	**-0.287**	**-.357***	**-.458****
	Sig. (2-tailed)	0.21	0.922	0.343	0.073	0.024	0.003
Risk of High exposure-	Pearson Correlation	**.313***	**.331***	**-0.086**	**-0.072**	**-0.018**	**-0.01**
	Sig. (2-tailed)	5%	4%	60%	66%	91%	95%
Causes discomfort at work place	Pearson Correlation	**-0.096**	**-0.006**	**0.228**	**0.244**	**0.143**	**0.173**
	Sig. (2-tailed)	56%	97%	16%	13%	38%	29%
Interferes with Focus and concentration	Pearson Correlation	-0.05	0.064	0.244	0.252	.426**	0.305
	Sig. (2-tailed)	76%	70%	13%	12%	1%	6%
Gets accustomed after some time	Pearson Correlation	0.024	0.183	0.138	0.134	.436**	0.298
	Sig. (2-tailed)	88%	26%	40%	41%	1%	6%

Correlation with work conditions and response to work

		Ventilation is adequate	Work place better than last 3 years	Satisfactory work condition environment	Cumulative fatigue	Quickly exhausted	Working beyond 8 hrs
Age	Pearson Correlation	**-0.011**	**0.016**	**0.069**	**-0.126**	**0.142**	**0.25**
	Sig. (2-tailed)	94.6%	92.1%	67.2%	44.0%	38.2%	12.0%
	N	**40**	**40**	**40**	**40**	**40**	**40**
Years	Pearson Correlation	**-0.213**	**0**	**0.052**	**0.089**	**0.052**	**-0.09**
	Sig. (2-tailed)	18.6%	99.7%	75.1%	58.7%	75.1%	57.9%
Mostly Requires manual effort	Pearson Correlation	**0.15**	**-0.009**	**0.004**	**-0.085**	**-0.036**	**.328***
	Sig. (2-tailed)	35.5%	95.8%	98.1%	60.3%	82.5%	3.9%
Mostly requires mental effort	Pearson Correlation	**0.099**	**-0.027**	**0.162**	**-0.13**	**-0.094**	**0.108**
	Sig. (2-tailed)	54.3%	86.7%	31.7%	42.2%	56.3%	50.6%

		Ventilation is adequate	Work place better than last 3 years	Satisfactory work condition environment	Cumulative fatigue	Quickly exhausted	Working beyond 8 hrs
Requires Listening	Pearson Correlation	**0.133**	**-0.062**	**0.084**	**0.063**	**-0.048**	**0.064**
	Sig. (2-tailed)	41.2%	70.4%	60.8%	70.0%	77.1%	69.6%
Visual effort required	Pearson Correlation	**.348***	**0.148**	**.370***	**-0.069**	**-0.081**	**0.136**
	Sig. (2-tailed)	2.8%	36.2%	1.9%	67.2%	61.9%	40.4%
Ventilation is adequate	Pearson Correlation	**1**	**.569****	**.537****	**-0.167**	**-0.251**	**.346***
	Sig. (2-tailed)		0%	0%	30%	12%	3%
Work place better than last 3 years	Pearson Correlation	**.569****	**1**	**.567****	**0.053**	**-0.169**	**.408****
	Sig. (2-tailed)	0%		0%	75%	30%	1%
Satisfactory work condition environment	Pearson Correlation	**.537****	**.567****	**1**	**-0.13**	**-0.231**	**0.228**
	Sig. (2-tailed)	0%	0%		42%	15%	16%
Cumulative fatigue	Pearson Correlation	**-0.167**	**0.053**	**-0.13**	**1**	**.542****	**0.147**
	Sig. (2-tailed)	30%	75%	42%		0%	37%
Quickly exhausted	Pearson Correlation	**-0.251**	**-0.169**	**-0.231**	**.542****	**1**	**0.249**
	Sig. (2-tailed)	12%	30%	15%	0%		12%
Working beyond 8 hrs	Pearson Correlation	**.346***	**.408****	**0.228**	**0.147**	**0.249**	**1**
	Sig. (2-tailed)	3%	1%	16%	37%	12%	
Strong Pungent Rotten eggs at workplace	Pearson Correlation	**0.124**	**-0.189**	**0.004**	**0.099**	**-0.084**	**0.023**
	Sig. (2-tailed)	44%	24%	98%	54%	61%	89%
Smell persistent in all time	Pearson Correlation	**-0.185**	**-0.048**	**-0.002**	**0.282**	**0.142**	**0.2**
	Sig. (2-tailed)	0.252	0.768	0.99	0.078	0.383	0.215
Risk of High exposure-	Pearson Correlation	**0.142**	**.366***	**.315***	**-0.002**	**-0.097**	**0.282**
	Sig. (2-tailed)	38%	2%	5%	99%	55%	8%
Causes discomfort at work place	Pearson Correlation	**-0.173**	**-0.062**	**0.002**	**0.243**	**0.223**	**0.284**
	Sig. (2-tailed)	29%	71%	99%	13%	17%	8%
Interferes	Pearson	-0.102	-0.253	-0.043	0.199	0.189	0.29

		Ventilation is adequate	Work place better than last 3 years	Satisfactory work condition environment	Cumulative fatigue	Quickly exhausted	Working beyond 8 hrs
with Focus and concentration	Correlation						
	Sig. (2-tailed)	53%	12%	79%	22%	24%	7%
Gets accustomed after some time	Pearson Correlation	0.049	0.254	0.158	.444**	0.3	0.309
	Sig. (2-tailed)	76%	11%	33%	0%	6%	5%

Correlation with ambient H_2S and comfort

		Strong Pungent Rotten eggs at workplace	Smell persistent in all time	Risk of High exposure-	Causes discomfort at work place	Interferes with Focus and concentration	Gets accustomed after some time
Age	Pearson Correlation	**-0.252**	**0.203**	**.313***	**-0.096**	**-0.05**	**0.024**
	Sig. (2-tailed)	11.7%	21.0%	4.9%	55.8%	76.0%	88.4%
	N	**40**	**40**	**40**	**40**	**40**	**40**
Years	Pearson Correlation	**-0.217**	**0.016**	**.331***	**-0.006**	**0.064**	**0.183**
	Sig. (2-tailed)	18.0%	92.2%	3.7%	97.2%	69.5%	25.8%
Mostly Requires manual effort	Pearson Correlation	**0.24**	**-0.154**	**-0.086**	**0.228**	**0.244**	**0.138**
	Sig. (2-tailed)	13.5%	34.3%	59.6%	15.6%	12.9%	39.5%
Mostly requires mental effort	Pearson Correlation	**0.295**	**-0.287**	**-0.072**	**0.244**	**0.252**	**0.134**
	Sig. (2-tailed)	6.5%	7.3%	65.9%	12.9%	11.7%	41.0%
Requires Listening	Pearson Correlation	**0.103**	**-.357***	**-0.018**	**0.143**	**.426****	**.436****
	Sig. (2-tailed)	52.7%	2.4%	91.4%	37.8%	0.6%	0.5%
Visual effort required	Pearson Correlation	**0.078**	**-.458****	**-0.01**	**0.173**	**0.305**	**0.298**
	Sig. (2-tailed)	63.3%	0.3%	94.9%	28.5%	5.6%	6.2%
Ventilation is	Pearson	**0.124**	**-0.185**	**0.142**	**-0.173**	**-0.102**	**0.049**

		Strong Pungent Rotten eggs at workplace	Smell persistent in all time	Risk of High exposure-	Causes discomfort at work place	Interferes with Focus and concentration	Gets accustomed after some time
adequate	Correlation						
	Sig. (2-tailed)	44%	25%	38%	29%	53%	76%
Work place better than last 3 years	Pearson Correlation	**-0.189**	**-0.048**	**.366***	**-0.062**	**-0.253**	**0.254**
	Sig. (2-tailed)	24%	77%	2%	71%	12%	11%
Satisfactory work condition environment	Pearson Correlation	**0.004**	**-0.002**	**.315***	**0.002**	**-0.043**	**0.158**
	Sig. (2-tailed)	98%	99%	5%	99%	79%	33%
Cumulative fatigue	Pearson Correlation	**0.099**	**0.282**	**-0.002**	**0.243**	**0.199**	**.444****
	Sig. (2-tailed)	54%	8%	99%	13%	22%	0%
Quickly exhausted	Pearson Correlation	**-0.084**	**0.142**	**-0.097**	**0.223**	**0.189**	**0.3**
	Sig. (2-tailed)	61%	38%	55%	17%	24%	6%
Working beyond 8 hrs	Pearson Correlation	**0.023**	**0.2**	**0.282**	**0.284**	**0.29**	**0.309**
	Sig. (2-tailed)	89%	22%	8%	8%	7%	5%
Strong Pungent Rotten eggs at workplace	Pearson Correlation	**1**	**.350***	**-0.056**	**.436****	**.341***	**-0.008**
	Sig. (2-tailed)		3%	73%	1%	3%	96%
Smell persistent in all time	Pearson Correlation	**.350***	**1**	**0.074**	**.313***	**0.155**	**0.077**
	Sig. (2-tailed)	0.027		0.649	0.049	0.339	0.637
Risk of High exposure-	Pearson Correlation	**-0.056**	**0.074**	**1**	**0.124**	**-0.113**	**0.111**
	Sig. (2-tailed)	73%	65%		45%	49%	50%
Causes discomfort at work place	Pearson Correlation	**.436****	**.313***	**0.124**	**1**	**.626****	**0.194**
	Sig. (2-tailed)	1%	5%	45%		0%	23%
Interferes with Focus	Pearson Correlation	.341*	0.155	-0.113	.626**	1	.326*

		Strong Pungent Rotten eggs at workplace	Smell persistent in all time	Risk of High exposure-	Causes discomfort at work place	Interferes with Focus and concentration	Gets accustomed after some time
and concentration	Sig. (2-tailed)	3%	34%	49%	0%		4%
Gets accustomed after some time	Pearson Correlation	-0.008	0.077	0.111	0.194	.326*	1
	Sig. (2-tailed)	96%	64%	50%	23%	4%	