University of Nairobi

ASSESSMENT OF OCCUPATIONAL RADIATION EXPOSURES: A CASE STUDY OF NUCLEAR MOISTURE-DENSITY GAUGE IN CONSTRUCTION INDUSTRY IN KENYA

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DECLARATION

This thesis is my original work and has not been submitted in support of award of any degree or qualification at the university of Nairobi or any other university or institution of higher learning.

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DEDICATION

I dedicate this research work to my family for their continued love and support.

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ABSTRACT

In construction industry, nuclear technologies are widely used in quality control; use of nuclear gauges in direct measurements of in-situ moisture and density of compacted granular pavement layers. In Kenya, nuclear gauges are usually recommended for use in most construction projects, but the use of these equipment are not fully integrated in the construction industry to date, partly due to alleged fear of radiation exposures.

This research study sought to investigate the safety of construction workers using the nuclear gauge in Kenya for their occupational exposures as well as general public at various construction sites. The methodology used in the study, involved radiation exposure measurements and the use of questionnaires. A portable multi-purpose survey meter RADOS RDS-110, suitable for detecting and measuring small quantities of gamma, x-ray and beta radiation was used in this study. Radiation exposures measurements were done between 9th September 2015 and 10th October 2015 at a construction site in Marsabit County-Kenya; Lake Turkana Wind Power Project. Radiation dose measurements were taken in-situ during density measurements at 0 m, 5 m and 10 m interval relative to the nuclear density radiation source and at 0^0, 90^0 and 180^0 angular orientations respectively, relative to the front phase of the nuclear gauge equipment. The calculated annual effective doses were 2.9±0.3 mSvyr–^{1,} 1.4±0.1 mSvyr–^{1} and 0.5±0.1 mSvyr–^{1} for 0 m, 5 m and 10 m linear intervals respectively, compliant to occupational limits. Statistical analysis (ANOVA) showed no significant difference exists between measurements in the angular variation. However, the radiation levels were considered a radiological exposure risks at 7.5 m for general public exposure. The overall compliance for radiation safety, amongst the 31 respondents who use nuclear gauge operators was slightly above average at 51%; about a third of the users were untrained, 79% use film badge personal radiation dosage monitoring, surveillance by the regulator for safety compliance was at 59%, whereas use of portable survey meters to monitor radiation was at 42%. In overall, the study, recommends for improvement on the use of the nuclear gauge equipment including training of operators on awareness on radiation safety and monitoring, etc.

***Key words**: Radiation safety, personal radiation exposure and monitoring, nuclear density gauge.*

ABBREVIATIONS

ASNT	-	American Society for Nondestructive Testing
BEIR	-	Biological Effects of Ionizing Radiation
CoK	-	Constitution of Kenya
DCGL	-	Derived Concentration Guideline Level
GSR	-	General Safety Requirements
HASL	-	Health and Safety Laboratory
HPS	-	Health Physics Society
HSS	-	Office of Health Safety & Security
IAEA	-	International Atomic Energy Agency
ICRP	-	International Commission on Radiological Protection
INST	-	Institute of Nuclear Science & Technology
KENHA	-	Kenya National Highways Authority
LET	-	Linear Energy Transfer
LNT	-	Linear No Threshold
LTWP	-	Lake Turkana Wind Power
MARLAP	-	Multi-Agency Radiological Laboratory Analytical Protocols
MARSSIM	-	Multi-Agency Radiation Survey and Site Investigation Manual
NCS	-	Nucleonic Control Systems
NDT	-	Non-Destructive Testing
NRC	-	Nuclear Regulatory Commission
NRRW	-	National Registry for Radiation Workers
PPE	-	Personal Protective Equipment
SPAR	-	Standards for Protection against Radiation
U.S EPA	-	United States Environmental Protection Agency
UNSCEAR	-	United Nations Scientific Committee on the Effects of Atomic Radiation
USNRC	-	United States Nuclear Regulatory Commission

WNA - World Nuclear Association

WTG - Wind Turbine Generator

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CHAPTER ONE: INTRODUCTION

1.1 Introduction

Since time immemorial, all living creatures have been, and are continuously exposed to ionizing radiation; naturally or artificial sources. Radiation source refers to any physical entity or activity which leads to a potentially measurable radiation dose to an individual or group of persons (ICRP, 2007a). The natural and artificial radiation sources account for 85% and 15% of total radiations respectively (IAEA, 2003 & World Nuclear Association, 2016). Natural radiation results from the radioactive decays of primordial radionuclide such as ^{232}Th, ^{238}U and their decay products, as well as other naturally occurring radio-nuclides present in the earth's crust such as ^{40}K (UNSCEAR, 2000). Exposures from artificial sources results from planned emissions through man-made activities majorly during medical and industrial applications (USNRC, 2014); Figure 1-1.

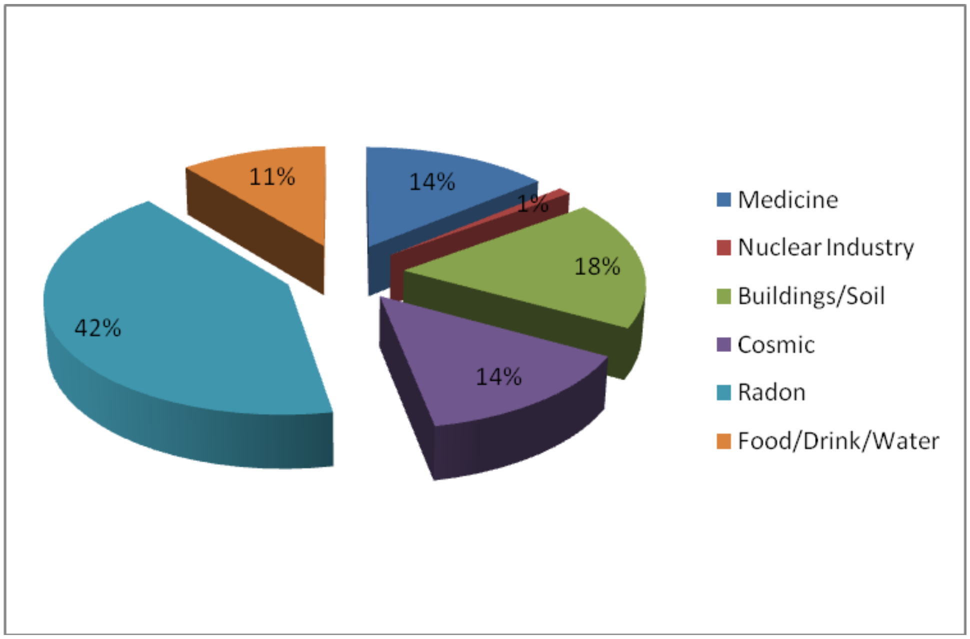


Figure 1-1: Classification of Radiation Sources (World Nuclear Association, 2013)

1.1.1 Safety Regulations and Standards in the Nuclear Industry

Radiation sources present numerous beneficial applications, ranging from nuclear power electricity generation, medical diagnosis and treatment, industrial and agricultural processes to improved yields. The risks posed by radiation exposures to workers, general public and to the environment arising from these applications must be assessed and regulated. All activities of radiation related applications, must therefore, be subjected to standards for safety of users and the public. Safety regulation is a national responsibility; however, radiation risks will at times extend beyond international borders during which international cooperation may therefore be required to enhance and promote safety globally through exchange of experience and improved capabilities to control hazards, prevent accidents, emergency response and in mitigation of harmful consequences (IAEA, 2011). Countries are therefore under obligation to undertake their national and international obligations with due diligence. International safety standards for countries in meeting their obligations under the general principles of international law relating to environmental protection exist under global nuclear safety agencies. One such body is the International Atomic Energy Agency, autonomously established on 29th July 1957 through its own international treaty, the IAEA Statute. IAEA reports to both the United Nations General Assembly and Security Council. Its core function is to promote peaceful application of nuclear energy, and to inhibit its use for military purpose including nuclear weapons. Its safety standards program which was started in 1958 supports the implementation of binding international safety instruments and national safety infrastructures (IAEA, 2011).

Locally, Radiation Protection Board of Kenya; a statutory body established under an Act of parliament of the laws of Kenya (the Radiation Protection Act, Cap 243), bears the national mandate and responsibility for protecting the health and safety of people and environment from the harmful effects of ionizing radiation. It regulates the use of ionizing radiation, exportation, importation, distribution and possession of radiation sources as well as monitoring their applications (CoK, 2010).

There are regulations and standards relating to occupational health and safety of workers in a vast range of occupational settings including in construction works (EPA, 2006). Enacted by the US Congress in 1970, the Occupational Safety and Health Act (OSHA) is the primary federal law governing occupational health and safety in the private sector and federal governments in the

United States and has now attained global recognition and acceptance in the whole world. OSHA requires employers to keep their work environment safe for workers and free from recognized hazards such as exposure to toxic chemicals, harmful radiation, excessive noise levels, mechanical dangers, heat or cold stress, unsanitary conditions etc. The employers bear the obligation to provide workers with information in identifying hazardous substances or conditions at work place and training on how to treat injuries from such. Further to identifying the work place hazards, the employees must also be provided with information through training on the basic OSHA procedures including first aid procedures, emergency response plans and procedures as well as incidents reporting (OSHA, 2007). The EPA attributes potential nuclear hazard exposures at work places to improper usage of the radioactive sources. Therefore, in order to safely gain from the considerable beneficial applications of radiation and radioactive material in various sectors globally, the available standards and regulations of safety must be applied in assessing and controlling exposure risks to people and the environment as a whole that may arise from the use of radiation and radioactive material (IAEA, 2011).

1.1.2 Application of Radiation Sources

In general, radiation sources are globally utilized for various peaceful applications including in industries, medicine, research and education, energy (power), military as well as in the construction sector. The construction industry, utilizes nuclear gauges mainly in the field of nondestructive testing e.g. the nuclear gauge or nuclear densometer is used in quality control monitoring during construction to measure parameters such as thickness, compaction density, and moisture content or fill level.

The use of nuclear techniques has continuously expanded globally. For example, the first IAEA survey on NCS applications carried out in 1962-63 revealed that the total number of nucleic gauges reported by the then, twenty-one highly developed countries was about 20,000 (IAEA, 2005). The majority of gauges at that time comprised of level, thickness and density gauges. The numbers drastically increased to 100,000 units in 1975 and subsequently to 250,000 units worldwide as recorded in a more recent similar survey carried out in 2005. Forty years of NCS applications especially in industrialization has no doubt played a considerable role towards economic development worldwide (IAEA, 2005).

As a result, nucleonic control systems (NCS) have been globally incorporated in industrialization to improve the quality of products and optimize processes thereby saving energy and materials (IAEA, 2005). Nucleonic control systems are considered one of the most requested technologies among radioisotope technologies. It is estimated that several hundred thousand of nucleonic gauges are in use in industries all over the world. An increasing use of the nucleonic gauges has been noted among developing member states. Industries have demonstrated economic benefits from the use of nucleic control systems. It is evident that the benefits of NCS applications in industry are steadily increasing during these decades and the NCS technology is playing a considerable role in economic development worldwide (IAEA, 2005).

1.2 Statement of the Problem

Within a decade after the discovery of x-ray and radioactivity in 1895, scientists developed uses for radiation primarily, in the field of medical diagnosis and treatment, leading to the present application of radiation techniques for the improvement of human life.

Most radiation source applications, however, employ the use of sealed sources in which the radioactive material or source is contained in certain capsule housing; while others involve unsealed radioactive material sources. These sources pose risks depending on the type of radionuclide, the forms, activities etc. Sealed sources present risks to external radiation exposure only, while unsealed sources may lead to environmental contamination and the intake of radioactive materials into the human body. The risks associated by the use of radioactive materials must be minimized as a rule, and the public protected against exposure, by the application of appropriate radiation safety standards (IAEA, 2000).

The use of radiation techniques has seen researchers and users of such technologies getting exposed to radiation in the course of their work, through occupational radiation exposure. During the early days of experiments with radiation, it was known that there were radiation exposure levels at which damage to human tissues could occur (Health Physics Society, 2010). This therefore presented the need to control occupational radiation exposure for the safety of radiation workers.

In construction industry, nuclear technologies are widely used in quality control; use of nuclear gauges in direct measurements of in-situ moisture and density of compacted granular pavement layers (Tracerco, 1950) .

In Kenya, nuclear gauges are usually specified for use in most projects but the equipment are not fully embraced due to alleged fear of radiation (Kenya Standard Specifications for Road & Bridge Construction, 1997). There are reports that during the construction of Emali - Oloitoktok Road in 2007, a technician operating the densometer used in the project sought for compensation on claims that radiation from the equipment had affected his reproductive health (National Radiation Protection Board of Kenya, 2007). Such incidences only serve to create fear in the usage of radiation sources. In Kenya, no study has since been undertaken to investigate the occupational exposures in the construction industry.

This research study investigated the level of radiation exposures from the nuclear gauge during use at road construction sites. Figure 1-2 and Figure 1-3 illustrate an example of a nuclear gauge in use, at a typical construction project (Gacharage - Kangema Road) in Murang'a County. Note that, the operator seen in the figures, has not worn any personal protective gear in accordance to safety recommendations for use of the such equipment, indicative of the safety lapses in use of these equipment in the industry.

Figure 1-2: Use of nuclear gauge at a construction site- workers keep distance during density tests

Figure 1-3: Technician recording Readings from a Nuclear Density Gauge.

1.3 Justification and Significance of Study

Apart from manufacturer's claim on the safety of their products, little is mentioned on the use of most nuclear equipment as regards the safety of the radiation sources. In addition, the expected radiation levels emitted by the equipment during normal operations or emergencies are never indicated nor disclosed.

This study determined the level of radiation exposure for both occupational and to the general public as a result of using the nuclear gauge in construction projects. The study also monitored present practice conditions, for compliance and adherence to the safety regulations. The results of this study are intended to promote the safe use of nuclear technologies in the construction industry. The findings will also facilitate the authorities to improve on the control measures, for overall enhanced construction operations and contribute to faster construction projects completions.

1.4 Study Objectives

1.4.1 General Objective

To determine the extent of occupational radiation safety of workers in the construction industry in Kenya.

1.4.2 Specific Objectives

i) To determine radiation exposure levels from nuclear gauges used in the construction industry.

ii) To estimate the absorbed dose rate and the annual effective dose rate.

iii) To assess the safety practices employed with the use of the nuclear gauge in the construction industry.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

In this chapter, a brief outline of the health effects of radiation exposure is described; the linear hypothesis model has been described towards understanding effects of low-level radiation. Other topics include occupational exposures and finally, a review of the previous studies in the field of occupational radiation exposures.

2.2 Health Effects of Radiation Exposures

The major interest in any radiation studies whether natural or artificial lies in the need to establish reference levels, particularly in areas where the risk of radioactive materials being released into the environment is high. Studies have shown various sources of ionizing radiation exists in a wide range of occupational settings, including medical facilities, research institutions, nuclear reactors and their support facilities, nuclear weapon production facilities, construction industry, mining sites and other numerous industrial manufacturing settings etc. If not properly controlled, the sources can pose considerable health risks to users. This therefore presents the starting point for the need for technical and regulatory information with regards to the recognition, evaluation and control of occupational health hazards associated with ionizing radiation (Ramli, 1997).

Radiation exposure, subjects living organisms to either ionizing (harmful) or non-ionizing radiation. Upon interaction with a material, ionizing radiation produces ions or particles which are electrically charged. Ionizing radiations have been reported to pose detrimental health effects to living organisms including humans upon exposure. Numerous types of cancers have been attributed to over exposure to ionizing radiation like x-rays, gamma rays (Giri et al., 2007).

Radiation exposure of the reproductive organs has been reported to induce genetic mutations of the reproductive cells (sperms, eggs), and is believed to have increased the chances of genetic related diseases like diabetes, cystic fibrosis, hemochromatosis etc. over future generations (Caldicott, 2013). It is further reported that recessive mutations can take up to twenty generations to be expressed.

Potential risks associated with emergency occupational high-level radiation at work places have resulted to historical traumatic incidences. For instance, the Chernobyl disaster in Ukrainian Soviet Socialist Republic of the greater Soviet Union (USSR) in 1986 and the most recent Fukushima Daiichi nuclear disaster in Japan in 2011. These two are classified as level 7 event (maximum classification) on the International Nuclear Event Scale and record as the most traumatic nuclear power accidents in world history both in terms of casualties and cost. The effects are largely unforgettable as the end results were deaths (instant and gradual) from blast effects and acute radiation syndrome with potential for long term cancer still under investigations (IAEA, 2006). The resulting contamination of the environment with radioactive material forced the evacuation of resettlements. For example, the Chernobyl disaster in 1986 led to immediate evacuation of more than 100,000 from the affected regions and afterwards relocation of another 200,000 people (IAEA, 2006).

Radiation safety is an important aspect among the stakeholders in the nuclear industry, which comprise at large, the governments, citizens (public), researchers, media, companies, investors, employees, anti-nuclear activists etc. Their main objective is geared towards attaining socially responsible investments with enhanced safety approaches in the nuclear industry. The core safety concern lies in the discharge of emergency or unplanned radiation into the environment which is likely to cause harm to living organisms. The IAEA, 2011 report, recommends that the person or organization using radiation generating facilities or undertaking activities giving rise to radiation risks bears the prime responsibility for safety.

2.2.1 Linear No Threshold Theory Model

The health effects of radiation are broadly classified into two categories; deterministic also referred as tissue reactions and stochastic effects. Deterministic effects are acute in nature, caused by death or malformation of somatic cells exposed to radiation beyond a certain threshold value. On the other hand, stochastic effects are hereditary or cancerous in nature leading to cancer development and occur in mature somatic cells or through the mutation of reproductive cells (ICRP, 2007). Conservatively, the severity of radiation exposure is quantified using linear no-threshold (LNT) theory or model (NRC, 1972). The model (Figure 2-1) assumes that the linear relationship between radiation dose and its effects apply at all levels of dosage both at low and high levels hence contributes to conservative basis of occupational health and radiation control & protection standards. The model has helped in radiological protection to estimate the long-term biological effects of ionizing radiation (Paganini, 2012).

The opposition of the LNT theory by scientist has triggered further research on the effects of low-level radiation whose findings have failed in support of the so-called linear no-threshold theory hypothesis (Mossman, 2003). More evidence indicates that a threshold may exist between 0.1 and 1 Sv of absorbed dosage above which harmful effects of radiation occur. However, the WNA (2012) considers that this information still lacks sufficient evidence to be incorporated into formal standards hence should not yet be adopted by national or international radiation protection bodies. Those opposed to the theory argue that at low levels of radiation, the body's natural defense system repairs the damage caused to cells by radiation as soon as it occurs and stimulates some adaptive response to protect cells and tissues (Mossman, 2003).

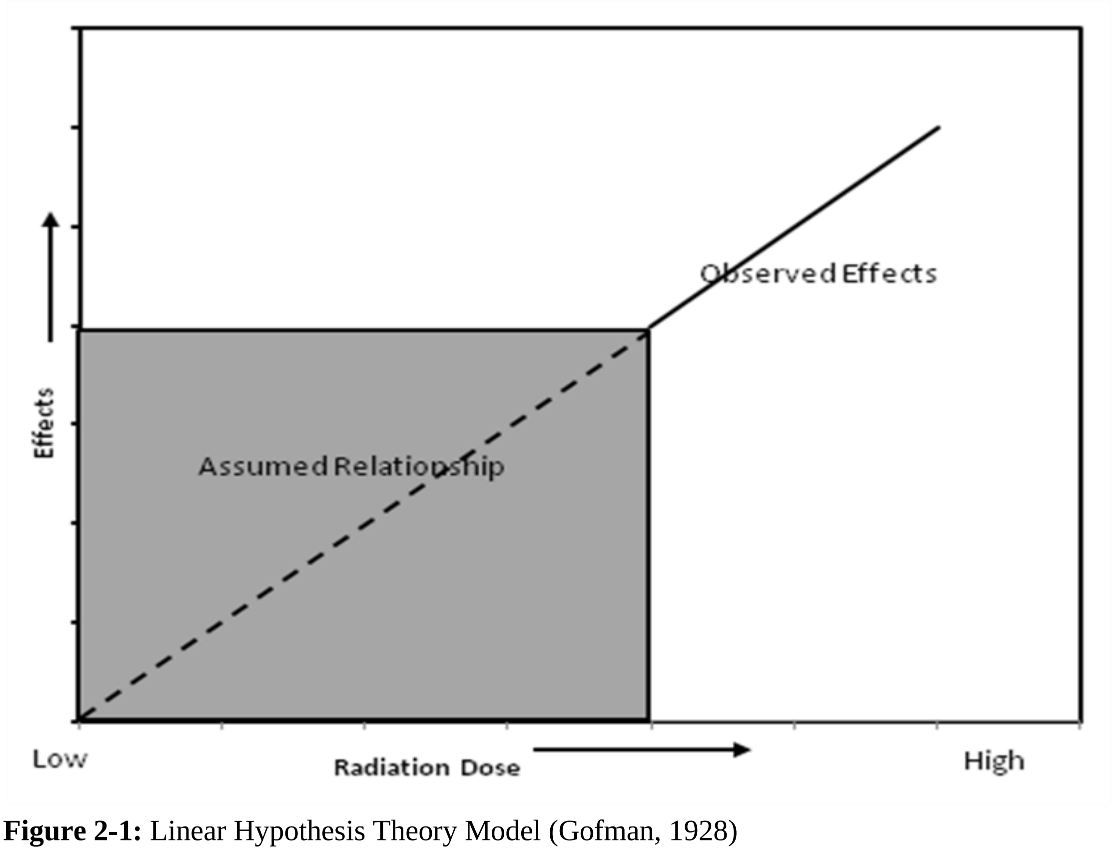


Figure 2-1: Linear Hypothesis Theory Model (Gofman, 1928)

The regulators in the radiation industry have used the LNT model in standards setting to approximate the number of cancers resulting from low level radiation exposures as it has proven difficult to do so by direct observations (Mossman, 2003). The model assumes that there is no safe level of radiation exposure hence provides a conservative approximation of risk. This serves as the guiding principle to the International Commission on radiological Protection in their formulation of the global guidance on radiation protection and regulation standards (ICRP, 2007). According to the ICRP (2007), the core objective of the commission's recommendations lies in providing an appropriate level of protection for humans and the environment against harmful effects from radiation exposure without control over the desirable human actions related to such exposure. The ICRP dose limits therefore serve to act as a boundary condition that prevents the occurrence of deterministic effects and limit the extent of stochastic effects (Butler and Cool, 2010).

Maximum permissible dose limits are provided by the ICRP (2007) for both public and occupational exposures. For occupational exposure, a limit of 20 mSv per year over a five-year averaged or 100 mSv in five years with a yearly maximum of 50 mSv is recommended whereas a limit of 1 mSv per year averaged over five years is set for public exposures. The figures specified for both exposure categories are measured over and above the background levels and do not include medical exposures (IAEA, 2005).

2.3 Occupational Radiation Exposure

Occupational exposure refers to those exposures to radiation of workers or employees in the course of undertaking their duties emerging from conditions considered as being the responsibility of the employer, company or the operating management (ICRP, 2007). When human beings are exposed to radiation by virtue of the work they do, measures are taken to protect against biological damage to the cells and DNA (genetic material) of the body and risk of illness. The measures involve both engineered controls as well as establishing regulatory controls (HSS, 2012). IAEA (2000) defines three exposure scenarios which may lead to generic radiation injury scenarios at work places; external exposure to an individual from a very close source, external exposure to several individuals from unshielded source and exposure from rupture of source casings. A common example in the first scenario occurs when an individual who may be a worker or a member of the public has put a radiation source into a pocket for reasons of theft or ease of transfer. The second scenario occurs when control of a source lost and it irradiates workers or members of the public without knowledge of those involved for instance faulty equipment left in a facility or a stolen, spent or disused source in a house or other location. The last scenario applies when a source that is not controlled ruptures resulting in contamination of individual equipment, exposures from inhalation of radioactive material, inadvertent ingestion of radioactive material, contamination of the skin and external exposure from the spillage (IAEA, 2000).

Radiation from the nuclear gauge lies in the broad category of planned exposure situation, which involves exposure to and operation of artificial or man-made sources (ICRP, 2007). The planned exposures may be anticipated (normal exposures) or non-anticipated (potential exposure). Standards for Protection Against Radiation (SPAR) recommends that before the occurrence of a planned special exposure, the individuals involved, among other things, to be informed of the estimated doses and associated health risks (SPAR, 1994). Both the employer and the worker should have explicit responsibilities with regards to occupational radiological protection. Classification of the work areas is recommended with a clear distinction between the controlled areas and supervised areas rather than classifying the workers themselves (ICRP, 2007).

2.3.1 Limiting Occupational Radiation Exposure

IAEA (2005) report has recommended four practical ways for limiting radiation exposure to the public and workers from identified radiation sources which include time, distance, shielding and prevention of access. Time is effective in controlling occupational situations on the basis that dose is reduced by limiting exposure time, while radiation levels decrease rapidly with increasing distance and hence the importance to keep as far as possible from source and never handle radiation sources directly. Specially designed tools with long handles are recommended for use if a source is to be replaced or manipulated. Shielding involves elimination or attenuation of radiation by use of barriers thereby reducing exposures and subsequent risks. High level penetrating radiation i.e gamma rays require good protection barriers made of lead, concrete or water. In cases where it is not possible to fully shield the source and the material to be examined, it is recommended to exercise prevention of access. Access to areas of high radiation are prevented by using shutters (manual or automatic), mechanical guarding or interlock systems. In some cases, the designation of controlled areas may be additionally required in order to restrict access to authorized persons only.

Radioactive sources in the nuclear gauges are shielded (Regimand, 2000). The Environmental Protection Agency (2006) publication outlines that the gauge becomes a considerable threat to the operator only when it is mishandled or damaged. Over the past several years of use of gauges, few accidents have been recorded and occupational exposures have been generally low. Radiation exposure to general public is not a major concern as long as the equipment is properly used (Nuclear Gauge Humboldt Model 3430 User Manual, 2006).

2.3.2 Good Work Practices in Control of Occupational Radiation Exposures

In complementary to the three basic principles of radiation exposure control; time, distance, shielding, it is recommended that individuals adopt the good industry practices that helps reduce exposures at work places:

- Familiarity with the Sources; it is advisable that one becomes familiar with the properties of the radioisotope or radiation emitting equipment. This equips one with the important detailed information or special precautions required with the use of material/equipment.

- Preoperational Survey; prior to use, ensure the equipment is free of contamination. It is encouraged to check the equipment for any leakages, malfunctions or damages before use.

- Rehearsing Procedures; rehearse and understand the unfamiliar radioisotope or nuclear equipment procedures before actual use. This helps one work efficiently and identifies moments during the procedure when exposure is most likely to occur.

- Radiation Monitoring Badges; wear radiation monitor badges when necessary. This helps in estimation of amount of radiation absorbed by the body during work.

- Operational Surveys; perform surveys while you use the equipment. It is a very good practice to survey frequently and extensively as work proceeds. This will help identify emergency radiations.

- Changing Gloves; Change your gloves frequently since it’s very easy to contaminate your gloves and spread the contamination.
- Shielding; when not in use, ensure the equipment is stored in purpose made enclosures or covers and put away from areas where people spend substantial amount of time.
- Post-Operational Surveys; Survey the equipment for any leakages when the work is finished and before leaving the lab.
- Do not eat or drink in any room labeled with a caution: Radioactive Materials sign on the door. Do not store any food, beverages, or medicines in refrigerators, freezers or cold-rooms where radioactive materials are used or stored.

2.3.3 Occupational Personal Protective Clothing

The standard protocol used to reduce radiation exposure include time, distance and shielding. Protective garments are a last line of defense and are designed to minimize the penetration of liquid chemicals and residual radioactive materials. The fabrics used in single use protective garments do not provide a barrier to ionizing radiation (e.g gamma rays, X-rays, or alpha or beta particles). Special garments that contain lead-based materials may provide limited shielding. When used in white zones in nuclear facilities, power generators and nuclear laboratories, nuclear protective clothing helps prevent dust particles and liquids from contamination of the skin and undergarments. Disposal or decontamination of the contaminated garments after use helps prevent secondary contamination (http://www.dupont.co.uk, 2017). When dealing with an open radioactive source, the required personal protective equipment (PPE) comprise a full-length laboratory coat worn closed with sleeves rolled down, disposable gloves made of latex or nitrile and closed toed shoes. Safety glasses should be worn during any radioisotope procedure especially, whenever there is potential for the build-up of pressure that could release a spray of material. Keep an extra set of clothing and shoes at your work place in case your clothing becomes contaminated. Avoid using petroleum-based hand creams when using gloves as they may increase glove permeability.

2.3.4 Signs and Labels of Occupational Work Place

Label radioisotope use rooms with caution radioactive material signs. Label any container of radioactive material or piece of equipment in which radioactive material is stored and any contaminated area or item, regardless of the level of radioactivity, with ‘Radioactive’ tape. Labeling of radioactive contaminated items and containers helps in contamination control and is a courtesy to other laboratory personnel.

2.4 Radiological Studies on Occupational Exposures

Since 1950, major research programs have been directed in monitoring the quantity and effects of natural and artificial ionizing radiation both at occupational and public exposure conditions. The studies have included the determination of radiation worker exposures at particle accelerators, nuclear reactors, and other nuclear facilities (Health and Safety Laboratory - 300, 1997). Of importance, the research studies contributed to the development and improvement of techniques for measurement and data interpretation of low-level radiation.

In 1990s, the United States National Research Council through various research institutions such as the National Academy of Sciences undertook a series of studies on the biological effects of ionizing radiation and the health effects of exposure to low levels of ionizing radiations. The primary objective of study was to develop a possible risk estimate for exposure to low dose, low linear energy transfer (LET) radiation in humans. The study which mainly focused on the Hiroshima and Nagasaki survivors reported increased cancer cases compared to the previous BEIR V report (NAS, 1998). In their conclusion, the research committee reported that the presented scientific evidence was consistent with the hypothesis of a linear, no-threshold dose-response relationship between exposure to ionizing radiation and the development of cancer in humans.

Giri et al. in 2007 measured radiation exposure levels at x-ray centers of a few selected hospitals in Kathmandu City, Nepal. In the study, they quantified radiation scatter levels prevalent at x-ray centers of hospitals, measured radiation emanating from special medical diagnostic and therapeutic machines (CT Scanning and Fluoroscopy) and delineated the level of occupational exposure of radiation to which the operators were exposed. Their findings showed increased exposure and, in some instances, very high levels of unintentional exposures to radiation. The study was aimed to alert the concerned hospital management to implement certain control measures.

Richardson et al., 2015, under the banner of International Nuclear Workers Study, studied the informative data on early nuclear workers (from 1940s) from three countries; France, UK and US cohorts. The study was aimed at improving the understanding of health risks associated with protracted low-level exposure to ionizing radiation. There was statistically significant evidence of a positive relationship between external exposure to ionizing radiation and death from all cancers as a single group among the 300,000 nuclear workers.

Gabriel et al., 2008, investigated the risk of cataract due to exposure of low doses of ionizing radiation: a 20-year prospective cohort study of US radiologic technologists. The study aimed to determine the risk of cataract amongst the radiological technologists with respect to occupational and non-occupational exposures to ionizing radiation and to personal characteristics. Baseline questionnaires were emailed to about 132,454 radiologic technologists who had been certified for at least two years, and which, attracted 68.2 percent response. The questionnaire elicited information about medical outcomes, socio-demographic and lifestyle factors such as smoking and alcohol consumption, and personal diagnostic and therapeutic radiation for medical reasons. The study results reported a hazard ratio of cataract of 1.25 (95% confidence interval: 1.06, 1.47) for self-report of ≥3 x-rays to the face/neck. For workers in the highest category (mean, 60 mGy) versus lowest category (mean, 5 mGy) of occupational dose to the lens of the eye, the adjusted hazard ratio of cataract was 1.18 (95% confidence interval: 0.99, 1.40). The findings challenged the National Council on Radiation Protection and International Commission on radiological protection measures, that the lowest cumulative ionizing radiation dose to the lens of the eye that can produce a progressive cataract is about 2Gy, and they support that the lowest cataractogenic dose in humans is substantially less than previously thought.

Richard et al. (2018) studied cancer mortality and incidence following external occupational radiation exposure, which is an update of the third analysis of the UK national radiation worker's registry. In his study, a group of 167,003 workers followed for an average period of thirty-two years, was statistically analyzed. The results showed increased mortality and incidence cancer risks from the additional ten years of follow up information. The study improved the precision of cancer risk estimation.

In Kenya, not much studies have focused on occupational radiation exposure from radio-technology equipment. Most local studies exist on naturally occurring radioactive material sources in the environment. For instance, Mangala (1987) undertook an elemental analyses study in Mrima Hill, Coastal Kenya, in which, high elemental concentration levels of rare earths and thorium were found.

Omari (2013) carried out a comparable study in Kerio Valley in Rift valley, Kenya. This region has been associated for long with high radioactivity levels. He noted that even though the obtained values were above the global mean, they were however within the permissible levels. The author further investigated various types of rocks like quartzite, granite and tuff for radioactivity. Quartzite exhibited indoor and outdoor dose levels above the global mean (60 nGyh^{-1}) at 157 nGyh^{-1}and 159 nGyh^{-1}, respectively. But, in a different part of the Kerio valley region, Nderitu et al. (2001), reported low annual effective dose levels, at 0.091 mSv/yr^{-1}.

Patel et al. (2012) undertook a radiological study survey, to assess the degree of exposure to radionuclides and dust of occupational gold miners in Migori, Western Kenya. The results showed that the absorbed dose rate ranged between 17 and 177 nGyh^{-1}, with a mean of 42 nGyh^{-1} below the global mean of 60 nGyyr^{-1}.

At Homa Mountains in Homabay County of Western Kenya Region, Otwoma et al. 2012 carried out a survey on radioactivity and dose levels in soil and rock samples. High levels of radionuclide activity were recorded at; 409.5 Bqkg^{-1}(^{232}Th), 195.3 Bqkg^{-1}(^{226}Ra) and 915.6 Bqkg^{-1}(^{40}K) relative to global mean of 30 Bqkg^{-1}(^{232}Th), ^{35} Bqkg^{-1} (^{226}Ra) and 400 Bqkg^{-1} (^{40}K). The outdoor absorbed dose rate measured at 1m high above the ground level was determined at 108 to 1596 nGyh^{-1}. The estimated annual equivalent/effective dose varied between 28 µSvh^{-1} to

1681 μSvh^{-1}, with a mean of 470 μSvh^{-1}. Based on the study results, Homa mountains can be classified as a high background radiation area (Otwoma et al. 2012).

A radiation exposure survey carried out by Kinyua et al. (2001), in the Tabaka soap-stone quarries mines in Kisii County (Kenya) recorded activity concentrations for ^{40}K, ^{226}Ra and ^{232}Th, radionuclides. The mean absorbed dose was determined nine times the global average, at 541.4 $nGyh^{-1}$. The external and internal radiation hazard index was above the recommended value. The results, raised concern over suitability of soapstone as a construction material and for sculpture making.

Prior to commencement of mining activities in Coastal Kenya, Osoro et al. (2011) carried out a baseline study research on radionuclide concentrations in surface soils in villages around two proposed titanium mines aimed at providing reference levels for future radiological monitoring studies during the mining process. The obtained activity concentrations were used to calculate absorbed dose rate in air. The activity concentrations for ^{40}K, ^{226}Ra and ^{232}Th were below the global mean as well as those obtained from similar studies in other parts of Kenya at 77 ± 15 $Bqkg^{-1}$, 20 ± 4.8 $Bqkg^{-1}$ and 28 ± 5.8 $Bqkg^{-1}$ respectively. Similarly, the calculated dose rate was lower than global mean at 29 $nGyh^{-1}$.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Introduction

In this chapter, the details of the study location are described, then a description of the equipment used is presented and finally the methods used to carry out radiation measurements as well as information collection using questionnaires are outlined.

3.2 Description of the Study Location site

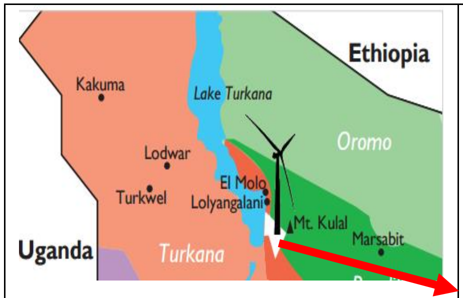
This research study was undertaken at Lake Turkana Wind Farm project in Marsabit County. The project development, involved construction of roads as well as hardstands linking the numerous wind turbine generators within the project site. In general, the Lake Turkana Wind Farm comprises of three hundred and sixty five (365) Wind Turbine Generators (WTG) distributed over fourteen different rows indicated as ; A, B, C, D, E, F, G, H, J, K, L, M, N and P (Figure 3-1 & Figure 3-2).

As part of quality control of construction work, compaction density measurements were taken using the nuclear density gauge equipment, thus providing the basis of undertaking measurements on radiation safety of users and the general public.

In this study, radiation measurements were done at fourteen (14) Wind Turbine Generator (WTG) location sites in Row M, which was under construction during the period between 9th September 2015 and 10th October 2015.

Radiation dose measurements were taken in-situ, at each site during density measurements at 0 m, 5 m and 10 m interval relative to the nuclear density radiation source and at 0^0, 90^0 and 180^0 angular orientations respectively, relative to the front phase of the nuclear gauge equipment(Figure 3-3 and Figure 3-4).

Figure 3-1: Study Location on Kenyan Map (Source: Lake Turkana Wind Power Project Environmental and Social Impact Assessment Report, December 2011)



Lake Turkana Wind Farm

365 No. WTG Locations distributed across 14 Rows:

Row A:	21
Row B:	21
Row C:	22
Row D:	35
Row E:	38
Row F:	9
Row G:	34
Row H:	21
Row J:	18
Row K:	61
Row L:	48
Row M:	14
Row N:	25
Row P:	13

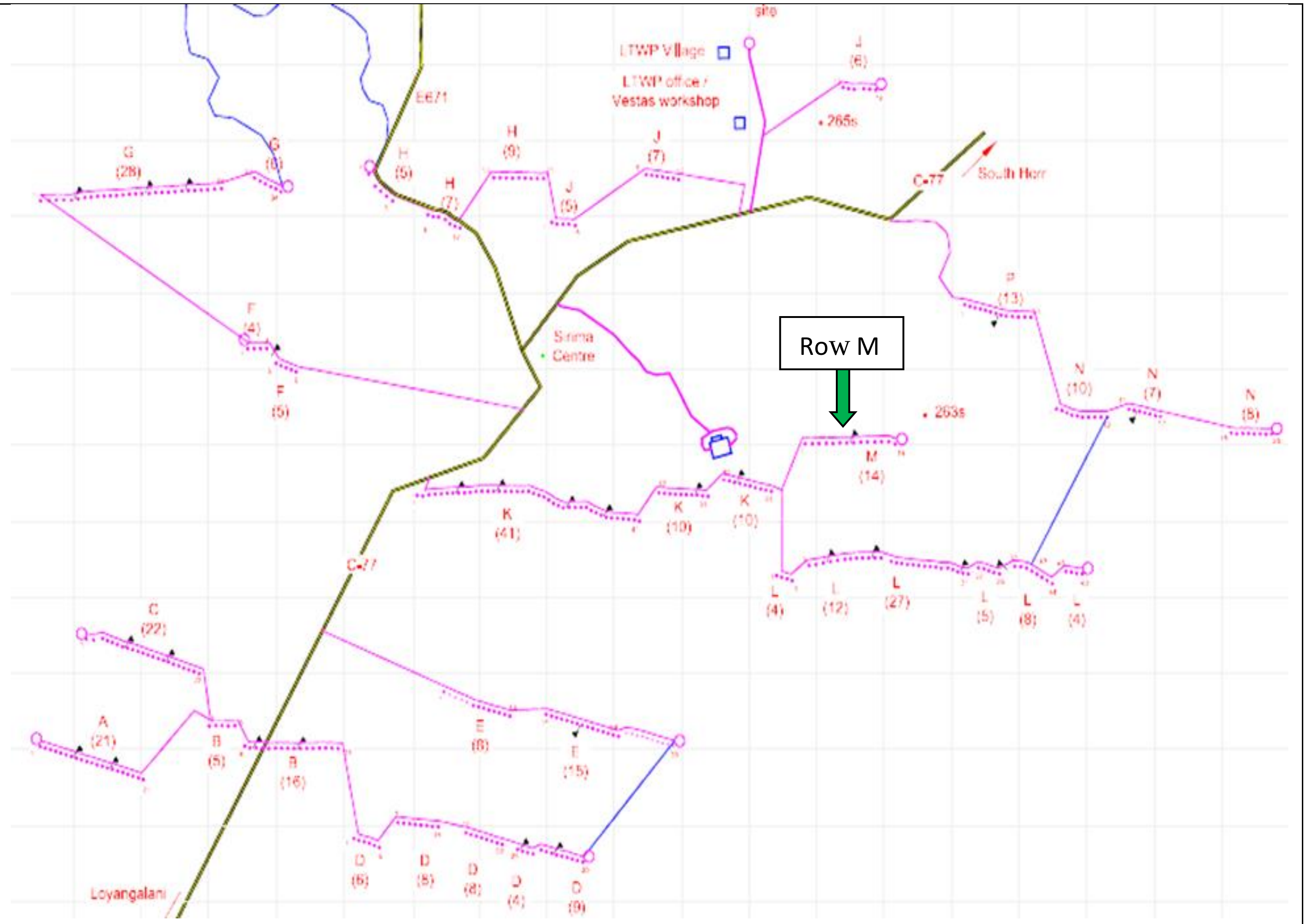


Figure 3-2: Distribution of Wind Turbine Locations and the Location of the Study Area, Marsabit County-Kenya (Source: LTWP Technical Project Specifications, 2011)

The wind turbines were spaced at approximately 80 m interval. Each wind turbine location site has a hardstand platform, measuring about 100m in length and 50m in width, constructed to provide support to the crane during installation of the wind tower. The three tests locations were spaced at approximately 50 m from each other.

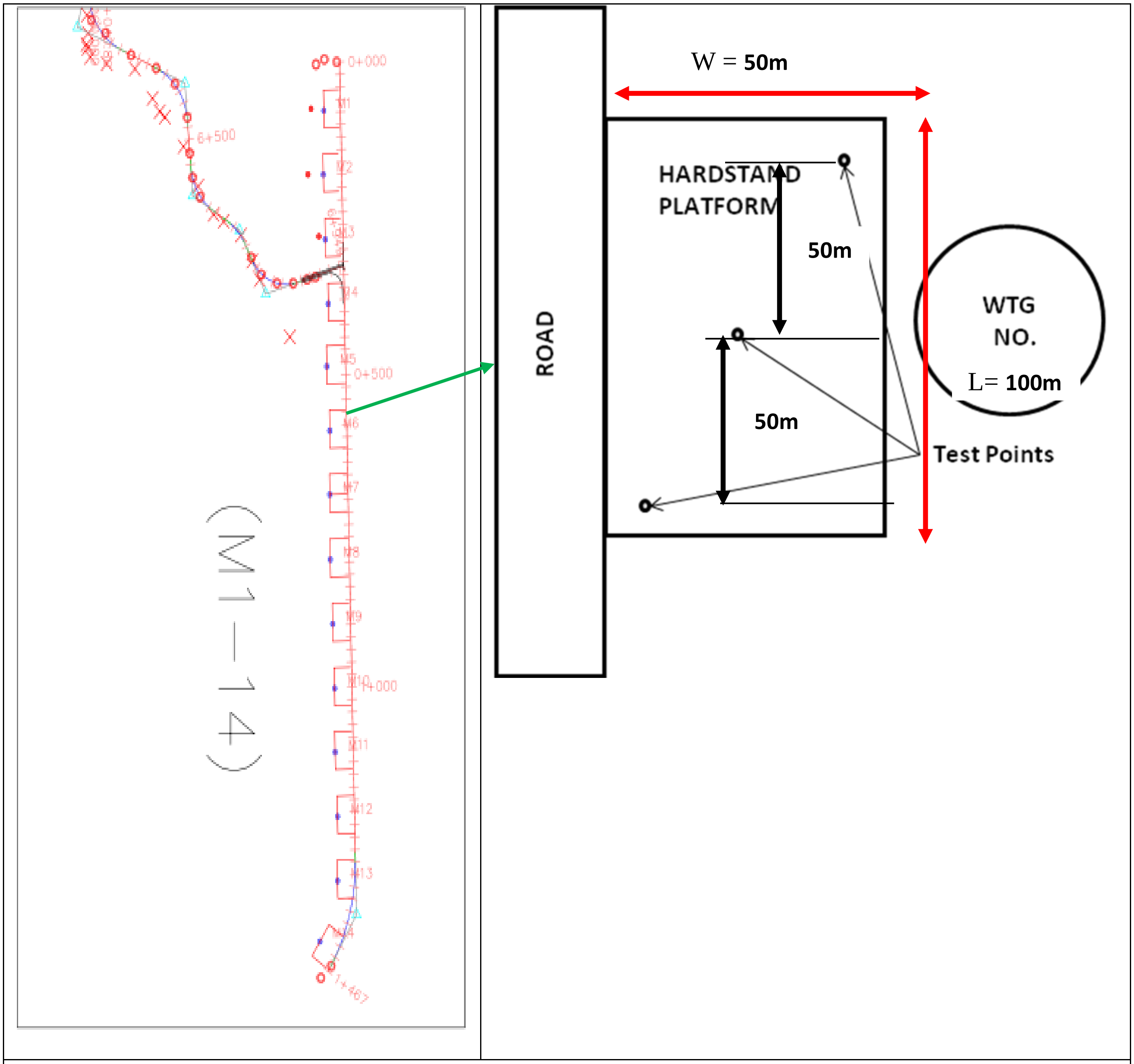


Figure 3-3: Radiation dose measurements at Test Location sites

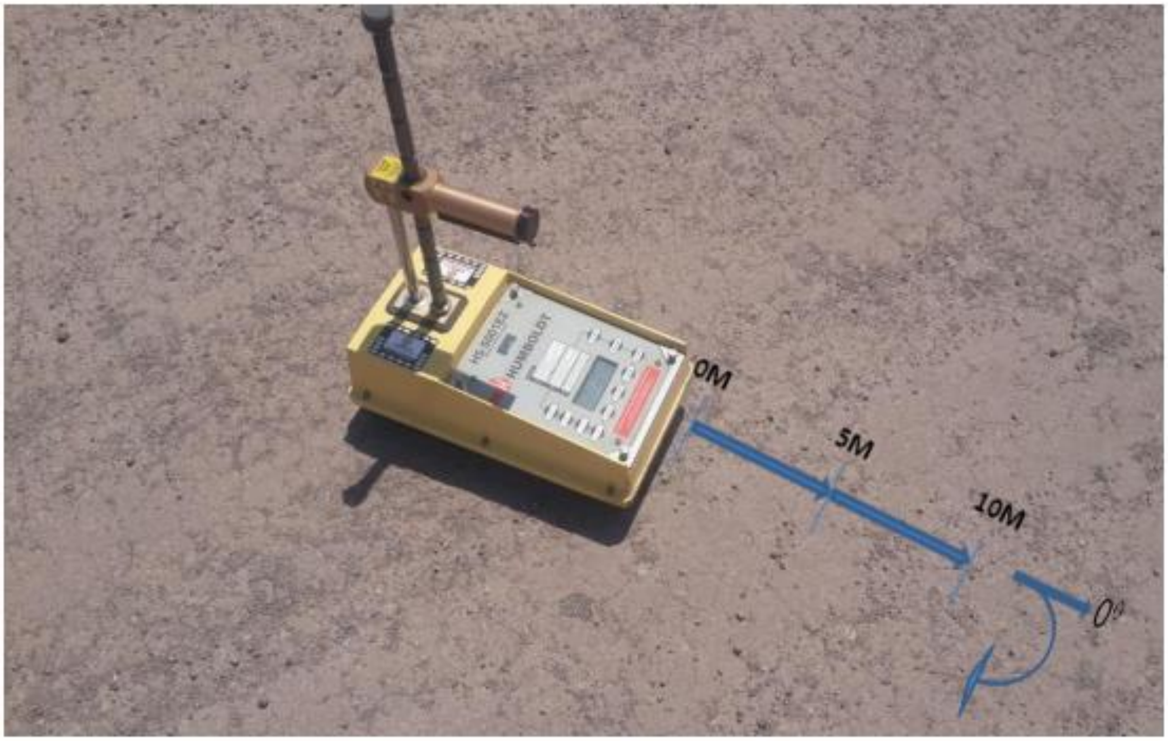


Figure 3-4: Radiation measurements Test Orientation (Linear & Angular)

3.3 Equipment Used in the radiation Measurements

The survey meter used for direct radiation measurement was model type RADOS RDS-110 (Figure 3-5), whereas, the nuclear gauge equipment from which the measured radiation emanated was model type Humbolt HS-5001EZ (Figure 3-6). Both equipment had valid documents on them indicating that they had been calibrated (calibration certificates attached in Appendix 1). RADOS RDS-110 is a multi-purpose portable survey meter suitable for measurements of x-ray, gamma and beta radiation. Humboldt HS-5001EZ is a nuclear densometer suitable for density and moisture measurements at shallow depths.

Figure 3-5: Radiation dose rate Survey Meter

Figure 3-6: Nuclear Density Gauge

In general, nuclear gauges use radioactive sources to measure parameters such as thickness, density, moisture or fill level, and normally comprise a nuclear source, a detector and a shutter. Radiation is emitted all the time from the gauges, however at idle mode i.e when the instrument is not in use; the shutter is closed to shield operators from the radiation beam (IAEA, 2005). The gauges are used mainly in the construction and petroleum industries, as well as in mining and archaeological studies. The radiation source emits a directed beam of particles that is either reflected by the test material or pass through it to the detector that has a sensor to count the received particles. The density of the test material is thus estimated by computing the proportion of particles that reach the sensor.

The operation of nuclear density gauges is principally based on either of the two modes; direct transmission and back scatter modes. The Humbolt HS-5001EZ used for this study, functions in direct transmission mode (Figure 3-7), in which the source emitter is positioned into the tested material below the level of the detector by lowering the source rod into a pre-drilled hole. The radiation emitted by the source then interacts with electrons in the material and loses energy and/or is redirected (scattered). A percentage of the photons passes from the source rod and is transmitted through the material under test and directed into the detector tubes. Radiation that loses considerable amount of energy or is scattered away from the detector is not counted. The resultant count in the detector is inversely proportional to material density. The denser the material, the higher the probability of interaction and the lower the detector count. Performing the test on a relatively flat and smooth surface reduces the surface roughness errors hence the measurement of density and/or moisture becomes more reliable (HS-5001EZ Manual, 2006).

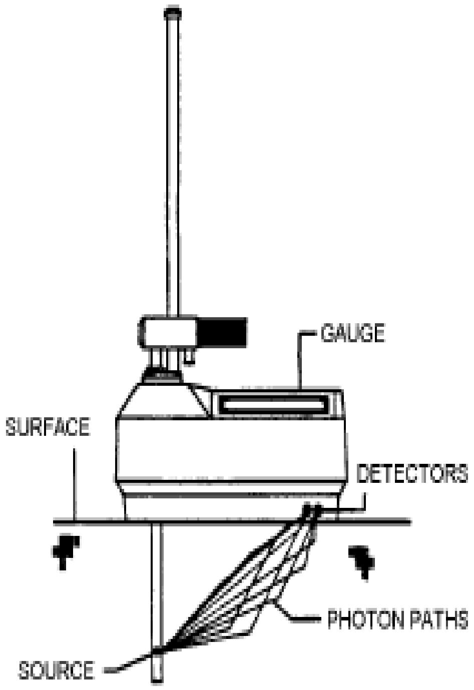


Figure 3-7: Detector in Direct Transmission Operation Mode

Other gauges employ the backscatter method (Figure 3-8) of operation in which the retractable source rod is lowered to the level of the detector though still within the instrument. Similar to the direct transmission mode, the source emits radiations, which interacts with electrons in the material and either loses energy and/or redirected (scattered). Radiation which gets scattered towards the detector is counted, hence unlike in the direct transmission mode, the denser the material, the higher the probability that radiation will be redirected towards the detector. Therefore, the radiation intensity is proportional to the density of the material through which it passes. In both cases, a calibration factor is used to correlate the count to the actual density of the material. In practice, density tests using nuclear gauges are conducted in a 4-minute cycle.

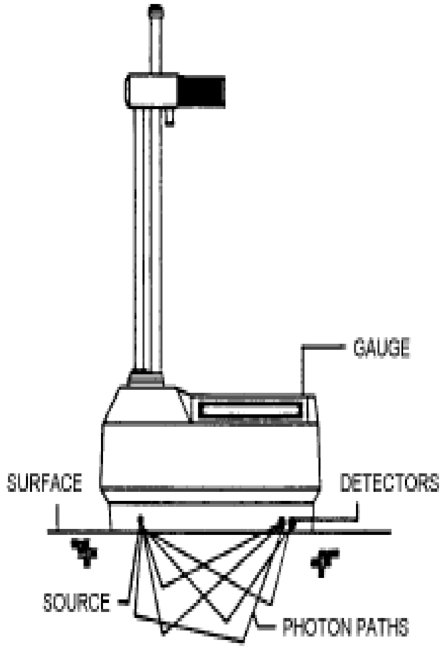


Figure 3-8: Detector in Back Scatter Transmission Operation Mode

The gauges give both density and moisture content of the material under test (Geir and Peter, 2004). Density and moisture form part of quality control parameters, which is very important in the construction industry (David and Murat, 1997). In construction, the nuclear gauges are used for density determination of different material including asphalt, soil, aggregates, concrete etc. as well as the moisture content of the soil or aggregate (Budinger et al., 2012).

3.4 Principle of Radiation Detection by Scintillation Detectors

When radiation (x or gamma ray) strikes a scintillator, it forces it to give off photons of visible light. The photons pass through the crystal and strike a thin metal foil known as a photocathode. When this happens, the light enters the photo-multiplier tube of the detector. When the photon hits the photocathode, it ejects electron which gets accelerated by the high voltage supply and cause it to strike a set of cups with enough energy that it ejects a number of other electrons. Each of the electrons are in turn accelerated towards the metal cup and additional electrons are ejected. This causes multiplication (amplification) of the initial signal electronically and counted by measuring device at the end of. The size of the signal at the anode is proportional to the energy dissipated in the detector by the incident radiation (William and Russell, 2002). A diagrammatic expression is given in figure below.

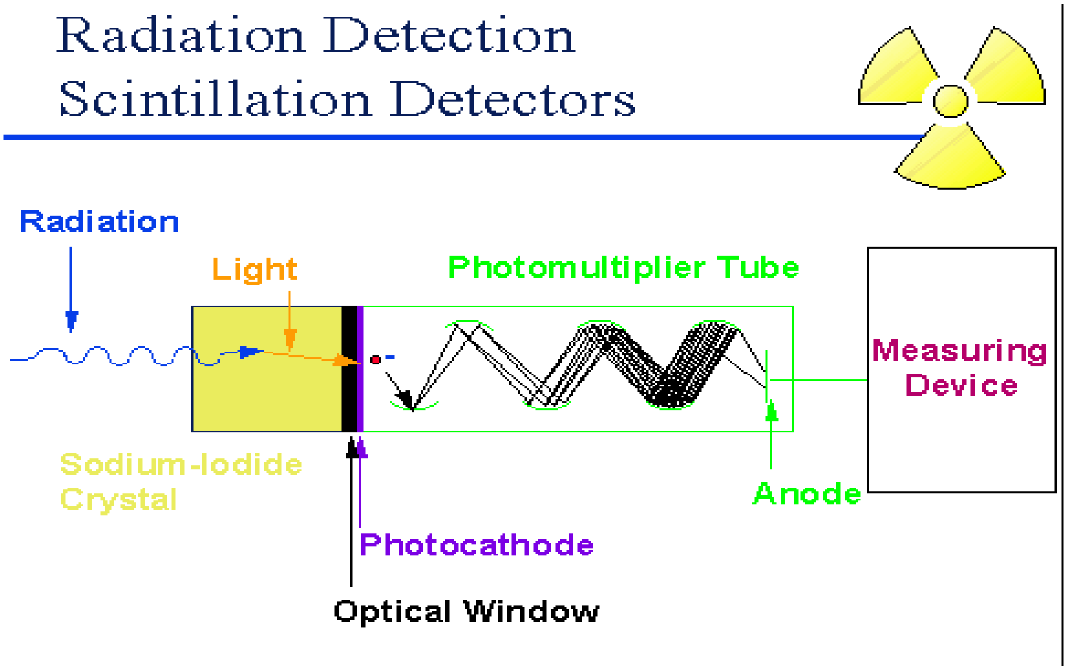


Figure 3-9: Radiation - Detector Interaction Process (NaI)

3.4.1 Field Radiation Measurements

For this study, field radiation dose rate in µSvhr^{-1} measurements were done during the period between 9th September 2015 and 10th October 2015.

Prior to each measurement, background radiation was recorded. Measurements were taken interchangeably all-round the nuclear gauge from three different radial locations approximated by 0^0, 90^0 and 180^0, at various linear distance intervals of 0m, 5m and 10m respectively from the nuclear gauge (Figure 3-4). The 0^0, 90^0 and 180^0 angular orientations were arbitrary chosen to ensure that representative measurements were made all round the equipment in order to assess whether radiation risk was isotropic. Users of this gauge claim that the equipment has a radiation risk only towards its front (0^0 position). 270^0 orientation as not considered as it was assumed it would yield similar results as 90^0.

The survey meter was turned off and on before taking fresh reading at every test location. A total of 126 meter readings were obtained from 42 test points (row M has 14 Wind Turbine Generator locations sites , each with three test points spaced 50 m apart as shown Figure 3-3) and each test point allowed three exposure readings at 0m, 5m and 10m respectively (Figure 3-4). The direct exposures measurements were recorded for angular orientation and linear distance from the equipment.

3.5 Determination of Annual Absorbed Dose

For stochastic health risk considerations, conversions are made from physical quantity absorbed dose into equivalent and effective doses depending on the type of radiation and tissues being considered. The International Commission on Radiological Protection (ICRP) and International Commission on Radiation Units and Measurements (ICRU) have published recommendations and relevant data for use in the conversions for applications in radiation protection and dosimetry assessment. Publication 103 recommendations in ICRP (2007) provide two weighting factors for adoption in the calculation of protection dose quantities:

- The radiation factor W_R, which depends and specific to the type of radiation R. It's used in computing the equivalent dose HT for the whole body or for individual organs.
- The tissue weighting factor W_T, which is a function of the tissue type T under irradiation. This is used in conjunction with W_R to calculate the contributory organ doses to arrive at an effective dose E in case of non-uniform irradiation.

The effective dose E, expressing the tissue-weighted sum of the equivalent doses in all specified tissues and organs of the body, is thus given by the expression

$$E = \sum W_T \sum W_R D_{T.R} \text{ or } E = \sum W_T H_T \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 4.1}$$

Where H_T or $W_R.D_{T.R}$ is the equivalent dose in a tissue or organ, T, and W_T is the tissue weighing factor (ICRP, 2007).

The revised dose coefficients (Table 3-1) as provided by ICRP (2007) were used to derive the equivalent dose from the absorbed dose averaged over a tissue or organ.

Table 3-1: Weighting factors for different organs (ICRP, 2007)

Tissue or Organ	**W_T**	**$\sum W_T$**
Stomach, colon, lung, red bone marrow, breast, remainder tissues	0.12	0.72
Gonads	0.08	0.08
Urinary bladder, esophagus, liver, thyroid	0.04	0.16
Bone surface, skin, brain, salivary glands	0.01	0.04
Total		**1**

3.6 Assessment of Occupational Safety Measures

A questionnaire was developed to assess the current practice conditions with regards to the occupational safety procedures recommended for use with the equipment. The questionnaire was divided into three parts; the first part requested for the background information of the respondent; the second part aimed at examining the current practice conditions with the use of the nuclear densometer gauge whereas the third part of the questionnaire sought the respondent's opinion on what improvements ought to be done to promote safe use of the equipment.

Copies of the questionnaires were dispatched both in soft (electronic) and hard copies to the identified research assistants attached to selected ongoing construction projects country wide. The research assistants had prior to that been briefed about the sections contained in the questionnaire. They were requested to distribute each copy to all relevant knowledgeable technicians who could fill them independently. A total of fifty-eight (58) copies were distributed with an expectation of at least thirty respondents.

3.7 Statistical Data Analyses

The direct radiation exposure measurements from the field were classified into three population groups based on their angular orientations and linear interval. The data obtained, as responses from the questionnaires were classified according to the item questions responded to by the participants. The data were then statistically analyzed using Microsoft Office Excel package and the results presented in form of tables, graphs, pie charts and bar charts for ease of reference.

One-way ANOVA analysis (F-test) was used to evaluate for any significance difference between the means of angular orientation and linear measurements intervals. Cronbach's alpha coefficient method was used to evaluate the internal consistency of the questionnaire. A brief description of the statistical packages is presented as follows:

3.7.1 ANOVA (F-Test)

Analysis of variance is a statistical package used where three or more means need to be compared, and where Student T-test (used to comparing two means) cannot be applied. When only a single variable needs to be tested within a group in this case, "the mean", One Way ANOVA is used, otherwise Two way or Multi- Variable ANOVA is adopted.

For comparing three or more means using the F-Test, the following basic assumptions are made: the samples are obtained from a normally or approximately normally distributed population, the samples are independent of each other and that the variances of the populations must be equal.

The first step of variance analysis involves statement of hypothesis. A null hypothesis (H_0) is stated to assume that all group means are equal i.e $\mu_1 = \mu_2 = \mu_3 = \ldots\ldots, = \mu_n$, while the alternative hypothesis (H_1) is stated that at least two group means are significantly different from each other. If the result is statistically significant, the alternative hypothesis is accepted.

The mean and variance for each individual group is then determined as well as the grand mean for the combined group. The results are used to determine the between the group and within the group variances respectively.

The F-Test value is then calculated as the quotient of between the group variance divided by the within the group variance:

F Value = Between the Group Variance / Within the Group Variance

Using F test table for this study $\alpha = 0.05$ and degree of freedoms (dfN = k-1 and dfD = N-k where k and N are number of groups and sum of sample sizes respectively, the P-value is determined. The absolute p-value is then compared to the F-test value. There's no difference in the means if the F-test value is less than P-value and null hypothesis accepted.

3.7.2 Assessment of Internal Consistency (Reliability) of the Questionnaire

Cronbach’s alpha or coefficient alpha, developed in 1951 by Lee Cronbach, is used to measure reliability or internal consistency of questionnaires. Reliability refers to how well a test measures what it should or how effective a designed questionnaire is accurately measuring the variable of interest from the target group. High reliability shows effectiveness or satisfaction while low reliability means it measures something else (or possibly nothing at all), (Tavakol and Dennick ,2011).

The determination of coefficient alpha is based on the Cronbach’s formulae reproduced below;

$$\alpha = \frac{\mathrm{N.C}}{\mathrm{v} + (\mathrm{N}-1).\mathrm{C}}$$

……………………………………….Equation 3.1 (Cronbach, 1951)

where N = number of items, C = average covariance between the item pairs and V = average variance.

Interpretation of alpha for dichotomous questions is based on Likert Scale shown below:

Table 3-2: Cronbach's Alpha Scale

Cronbach’s Alpha (α)	**Internal Consistency**
$\alpha \geq 0.9$	Excellent
$0.9 > \alpha \geq 0.8$	Good
$0.8 > \alpha \geq 0.7$	Acceptable
$0.7 > \alpha \geq 0.6$	Questionable
$0.6 > \alpha \geq 0.5$	Poor
$0.5 > \alpha$	Unacceptable

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Introduction

In this section, the results and discussions of study are presented. The results of radiation exposures measured from the nuclear density gauge are presented, interpreted and discussed, then followed by analysis of information extracted from the questionnaires.

4.2 Exposure Measurements

4.2.1 Exposure at Various Intervals

Table 4-1 shows the summary of exposure measurements at various linear and angular intervals in this study. Table 4-2 and Figure 4-1 show the exposure measurements for each distance and angular intervals at the various test locations. A sample of the field data collection sheets is attached as Appendix 2.

Table 4-1: Summary of Exposure Measurements

Angular Orientation	Exposure (μsvhr^{-1})					
	0 m		5 m		10 m	
	Mean	Range	Mean	Range	Mean	Range
0^0	2.7±0.3	1.9-2.9	1.4±0.1	1.2-1.6	0.5±0.1	0.3-0.7
90^0	2.6±0.3	2.0-2.9	1.4±0.1	1.2-1.5	0.5±0.1	0.3-0.7
180^0	2.8±0.1	2.6-2.9	1.3±0.1	1.1-1.5	0.5±0.2	0.2-0.7
Combined	2.7±0.2	1.9-2.9	1.4±0.1	1.1-1.6	0.5±0.1	0.2-0.7

Table 4-2: Radiation Exposure Readings at Various Test Locations

Test Location	**Orientation**	**Measurements (µsvhr^{-1})**			Test Location	**Orientation**	**Measurements (µsvhr^{-1})**		
	Interval	**0 m**	**5 m**	**10 m**	No.	Interval	**0 m**	**5 m**	**10 m**
M1	0^o	2.92	1.53	0.28	M8	0^o	2.77	1.31	0.6
	90^o	2.78	1.42	0.25		90^o	2.67	1.4	0.43
	180^o	2.87	1.37	0.34		180^o	2.9	1.43	0.71
M2	0^o	2.91	1.49	0.69	M9	0^o	2.86	1.24	0.59
	90^o	2.31	1.2	0.60		90^o	2.53	1.5	0.43
	180^o	2.64	1.12	0.21		180^o	2.69	1.27	0.57
M3	0^o	1.91	1.29	0.49	M10	0^o	2.84	1.38	0.63
	90^o	2.88	1.38	0.43		90^o	2.76	1.36	0.64
	180^o	2.83	1.45	0.47		180^o	2.79	1.47	0.39
M4	0^o	2.9	1.51	0.30	M11	0^o	2.81	1.37	0.44
	90^o	2.1	1.32	0.61		90^o	2.64	1.29	0.6
	180^o	2.82	1.43	0.27		180^o	2.79	1.41	0.25
M5	0^o	2.87	1.59	0.53	M12	0^o	2.46	1.28	0.63
	90^o	2.89	1.39	0.32		90^o	2.92	1.35	0.53
	180^o	2.79	1.41	0.42		180^o	2.71	1.26	0.56
M6	0^o	2.41	1.19	0.51	M13	0^o	2.81	1.41	0.47
	90^o	2.74	1.35	0.60		90^o	1.97	1.2	0.64
	180^o	2.57	1.27	0.49		180^o	2.88	1.24	0.59
M7	0^o	2.81	1.5	0.56	M14	0^o	2.71	1.37	0.67
	90^o	2.73	1.46	0.7		90^o	2.83	1.41	0.71
	180^o	2.79	1.43	0.63		180^o	2.76	1.32	0.65

4.2.2 Statistical Analysis of Exposure Data

The three group means at 0^0, 90^0 and 180^0 angular measurements were subjected to one-way ANOVA analysis to determine any significance differences for each linear measurement (Table 4-5). The results presented in Table 4-3 showed that there is no significance difference between the angular measurements for 0 m, 5 m and 10 m, respectively.

Table 4-3: Summary of ANOVA Analysis of Group Means of Angular Measurements

Linear Interval	Grand Mean	Between Group Variance	Within Group Variance	F-Test Value	Degree of Freedom		P- Value α=0.05	Remarks
					dfN=k-1	dfD=N-k		
0 m	2.70	0.078	0.058	1.34	2	39	±3.24	F values < P-value hence no difference
5 m	1.37	0.006	0.011	0.60	2	39	±3.24	
10 m	0.51	0.019	0.020	0.94	2	39	±3.24	

Similarly, the means of individual groups at linear measurement intervals of 0 m, 5 m and 10 m were statistically evaluated for any significance difference (refer Table 4-5). Table 4-4 show a significance difference exist between measurements at linear intervals.

Table 4-4: Summary of ANOVA Analysis of Group Means of Linear Measurements

Angular Orientation	Grand Mean	Between Group Variance	Within Group Variance	F-Test Value	Degree of Freedom		P-Value α =0.05	Remarks
					dfN=k-1	dfD=N-k		
0^0	1.54	16.97	0.04	471.65	2	39	±3.24	F values > P-value hence difference
90^0	1.51	15.52	0.04	403.09	2	39	±3.24	
180^0	1.53	18.95	0.01	1270.62	2	39	±3.24	

Table 4-5: Statistical Analysis of Angular Mean Exposures

Reading No.	Radiation Exposures								
	0m (μSvh^{-1})			5m (μSvh^{-1})			10m (μSvh^{-1})		
	0^o	90^o	180^o	0^o	90^o	180^o	0^o	90^o	180^o
1	2.92	2.78	2.87	1.53	1.42	1.37	0.28	0.25	0.34
2	2.91	2.31	2.64	1.49	1.20	1.12	0.69	0.6	0.21
3	1.91	2.88	2.83	1.29	1.38	1.45	0.49	0.43	0.47
4	2.90	2.10	2.82	1.51	1.32	1.43	0.3	0.61	0.27
5	2.87	2.89	2.79	1.59	1.39	1.41	0.53	0.32	0.42
6	2.41	2.74	2.57	1.19	1.35	1.27	0.51	0.6	0.49
7	2.81	2.73	2.79	1.50	1.46	1.43	0.56	0.7	0.63
8	2.77	2.67	2.9	1.31	1.4	1.43	0.6	0.43	0.71
9	2.86	2.53	2.69	1.24	1.5	1.27	0.59	0.43	0.57
10	2.84	2.76	2.79	1.38	1.36	1.47	0.63	0.64	0.39
11	2.81	2.64	2.79	1.37	1.29	1.41	0.44	0.6	0.25
12	2.46	2.92	2.71	1.28	1.35	1.26	0.63	0.53	0.56
13	2.81	1.97	2.88	1.41	1.2	1.24	0.47	0.64	0.59
14	2.71	2.83	2.76	1.37	1.41	1.32	0.67	0.71	0.65
Sum, Σ	**37.99**	**36.75**	**38.83**	**19.46**	**19.03**	**18.88**	**7.39**	**7.49**	**6.55**
Mean, X	2.71	2.63	2.77	1.39	1.36	1.35	0.53	0.54	0.47
Grand Mean, $X_{GM} = \frac{\Sigma X}{N}$	2.70			1.37			0.51		
STDEV, S	0.28	0.30	0.09	0.12	0.09	0.10	0.13	0.14	0.16
Variance,S^2	0.08	0.09	0.01	0.01	0.01	0.01	0.02	0.02	0.03
Sample size, n	14	14	14	14	14	14	14	14	14
Between the Group Variance, $S_B^2 = \frac{\Sigma ni(Xi-XGM)}{K-1}$	0.078			0.006			0.019		
Within the Group Variance, $S_W^2 = \frac{\Sigma (ni-1)Si2}{\Sigma(ni-1)}$	0.058			0.011			0.020		
F- Test Value = S_B^2 / S_W^2	1.34			0.6			0.94		
P- Value (dfN = k-1 =2, dfD =N-k =39, α = 0.05)	± 3.24								
Inference	F value < P value hence no significant difference								

Table 4-6: Statistical Analysis of Linear Mean Exposures

Reading No.	Radiation Exposures								
	0^o (µSvh^{-1})			90^o (µSvh^{-1})			180^o (µSvh^{-1})		
	0 m	5 m	10 m	0 m	5 m	10 m	0 m	5 m	10 m
1	2.92	1.53	0.28	2.78	1.42	0.25	2.87	1.37	0.34
2	2.91	1.49	0.69	2.31	1.2	0.6	2.64	1.12	0.21
3	1.91	1.29	0.49	2.88	1.38	0.43	2.83	1.45	0.47
4	2.9	1.51	0.3	2.1	1.32	0.61	2.82	1.43	0.27
5	2.87	1.59	0.53	2.89	1.39	0.32	2.79	1.41	0.42
6	2.41	1.19	0.51	2.74	1.35	0.6	2.57	1.27	0.49
7	2.81	1.5	0.56	2.73	1.46	0.7	2.79	1.43	0.63
8	2.77	1.31	0.6	2.67	1.4	0.43	2.90	1.43	0.71
9	2.86	1.24	0.59	2.53	1.5	0.43	2.69	1.27	0.57
10	2.84	1.38	0.63	2.76	1.36	0.64	2.79	1.47	0.39
11	2.81	1.37	0.44	2.64	1.29	0.6	2.79	1.41	0.25
12	2.46	1.28	0.63	2.92	1.35	0.53	2.71	1.26	0.56
13	2.81	1.41	0.47	1.97	1.2	0.64	2.88	1.24	0.59
14	2.71	1.37	0.67	2.83	1.41	0.71	2.76	1.32	0.65
Sum, Σ	37.99	19.46	7.39	36.75	19.03	7.49	38.83	18.88	6.55
Mean, X	2.71	1.39	0.53	2.63	1.36	0.54	2.77	1.35	0.47
Grand Mean, $X_{GM} = \frac{\Sigma X}{N}$	1.54			1.51			1.53		
STDEV, S	0.28	0.12	0.13	0.30	0.09	0.14	0.09	0.10	0.16
Variance,S^2	0.08	0.01	0.02	0.09	0.01	0.02	0.01	0.01	0.03
Sample size, n	14	14	14	14	14	14	14	14	14
Between the Group Variance, $S_B^2 = \frac{\Sigma ni(Xi-XGM)}{K-1}$	16.97			15.52			18.95		
Within the Group Variance, $S_W^2 = \frac{\Sigma\,(ni-1)Si2}{\Sigma(ni-1)}$	0.04			0.04			0.01		
F- Test Value = S_B^2 / S_W^2	471.65			403.09			1270.62		
P- Value (dfN = k-1 =2, dfD =N-k =39, α = 0.05)	± 3.24								
Inference	F values > P value hence no significant difference								

The variance analysis showed no significance difference between the means at angular orientation measurements, therefore Figure 4-1, show a plot of the log of the grand mean exposure measurements versus the linear interval to demonstrate the inverse square law of radiation exposures.

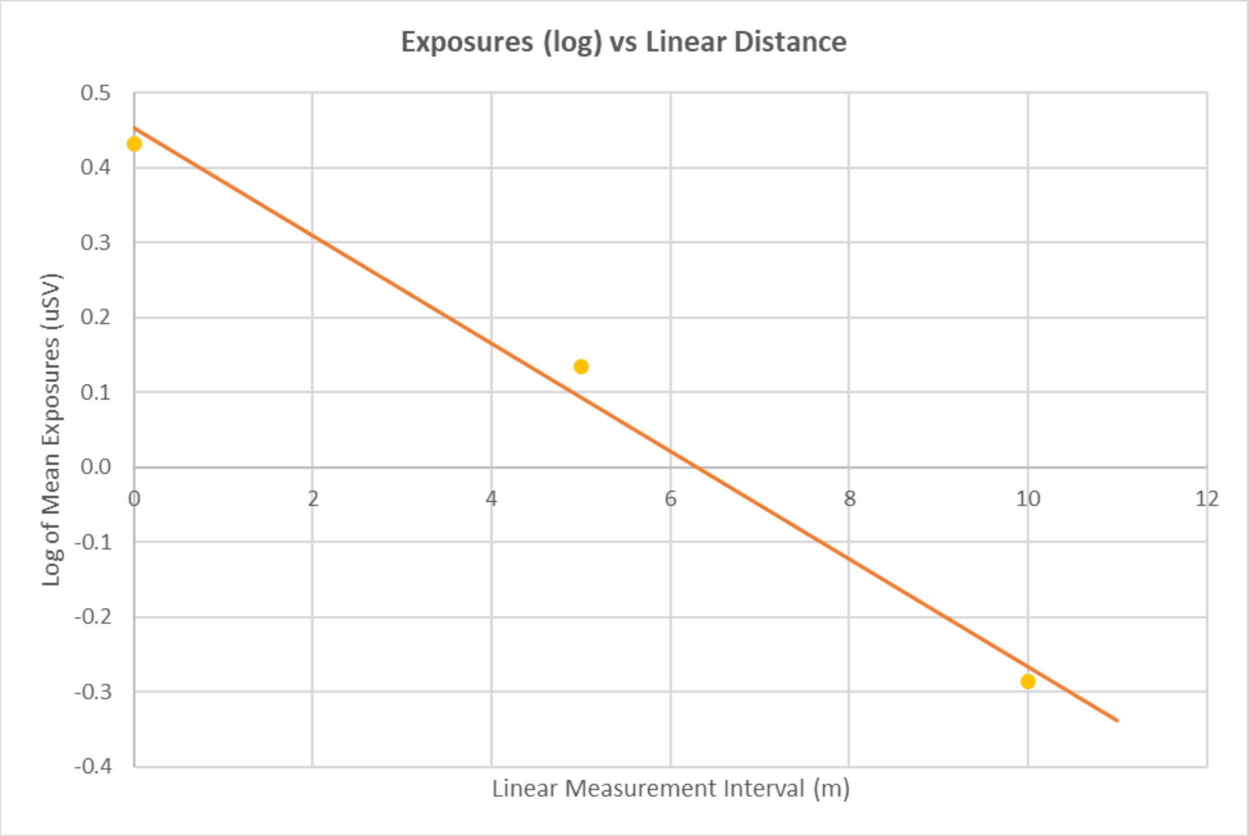


Figure 4-1: Variation between Log Exposure and Linear Distance from Source

In general, the radiation dose rate exposure data were as follows; mean values of 2.7 ± 0.2µsvhr^{-1} (1.9 - 2.9) µsvhr^{-1}, 1.4 ± 0.1 µsvhr^{-1}(1.1 - 1.6) µsvhr^{-1} and 0.5 ± 0.1 µsvhr^{-1} (0.2 - 0.7) µsvhr^{-1}at estimated distances at 0 m, 5 m and 10 m intervals, respectively.

There were no significant differences in exposures observed in angular orientations, implying that the equipment emits radiation isotopically.

The measured exposures reduced linearly with distance (Figure 4-1).

4.3 Evaluation of the Questionnaires

4.3.1 Results of Respondence from the Questionnaires

A sample of the completed questionnaire is attached as Appendix 3. Table 4-7 is a summary of responses of questionnaires from various projects sampled in this study.

Table 4-7: Summary of Respondence from Various Projects in the country

	Project Name	**Region** (Province)	**No. Issued**	**Number of Respondents**	**%Response**
1.	Webuye – Malaba Road	Western	10	7	70
2.	Kangema – Gacharage Road	Central	7	6	86
3.	Kitale – Webuye Road	Western	5	4	80
4.	Bondo – Misori Road	Nyanza	3	1	33
5.	Kadongo – Gendia – Kindu Road	Nyanza	3	1	33
6.	Bachuma Gate – Maji ya Chumvi Road	Coast	5	1	20
7.	Chiakariga – Mitunguu – Meru Road	Eastern	5	2	40
8.	Moyale – Turbi Road	North Eastern	3	1	33
9.	Jommo Kenyatta International Airport Road	Nairobi	5	3	60
10.	Lake Turkana Wind Power Project	Rift- Valley	5	2	40
11.	Southern Bypass Nairobi Road	Nairobi	7	5	71
			58	**33**	**57**

Out of the fifty-eight (58) questionnaires issued, a total of thirty-three (33) were received in response, from eleven (11) different ongoing projects spread across the country. An overall response rate of 57% was observed with individual projects response range of 20%-86%, and considered fairly good.

4.3.2 Estimation of Cronbach's Coefficient

The responses to dichotomous questions (questions with two possible answers) were subjected to Cronbach's internal consistency test. The responses were expressed into percentages for purposes of Cronbach's analysis. Since for this study either of the possible answers possess equal probability, the results of the possible answers were combined, no responses for such questions was regarded as ineffectiveness on the basis of assumption that the responder did not understand the question or required variable.

From Table 4-8 below, non-response ranging between 3% and 18% was estimated, implying the response rate ranged between 82% and 97%. This can be interpreted to an equivalent range of alpha (α) coefficients of between 0.82 and 0.97, classifying as "Good to Excellent". It can thus be deduced that the internal consistency of the questionnaire used in this study was satisfactory towards its intended purpose.

Table 4-8: Cronbach's Alpha Estimation

Questionnaire Item	Variable	% Response		
		Yes	No	None
(b)	Have you ever used this equipment in previous projects?	67	30	3
(c)	Did you receive any training before starting to operate the gauge?	67	27	6
(d)	What are the safety measures you employ while using the gauge? (i) Film badge: Yes/No	79	12	9
	(ii) Survey meters (To monitor emergency radiations): Yes/No	42	52	6
(h)	Has any radiation and protection monitoring body visited this site to assess handling of the nuclear gauge?	59	23	18
Average		**63**	**29**	**8**

4.3.3 Assessment of Radiation Occupational Safety

Figure 4-2 and Figure 4-3 show the assessment of the operator's prior experience and training in the use of the gauge. Figure shows the assessment of the operator's prior training before using the nuclear gauge.

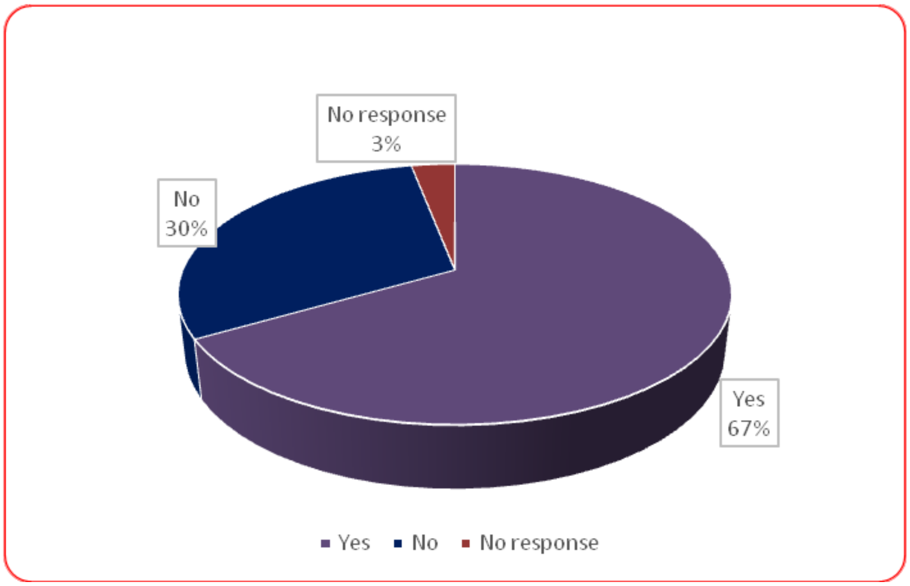


Figure 4-2: Assessment of Operator's prior experience

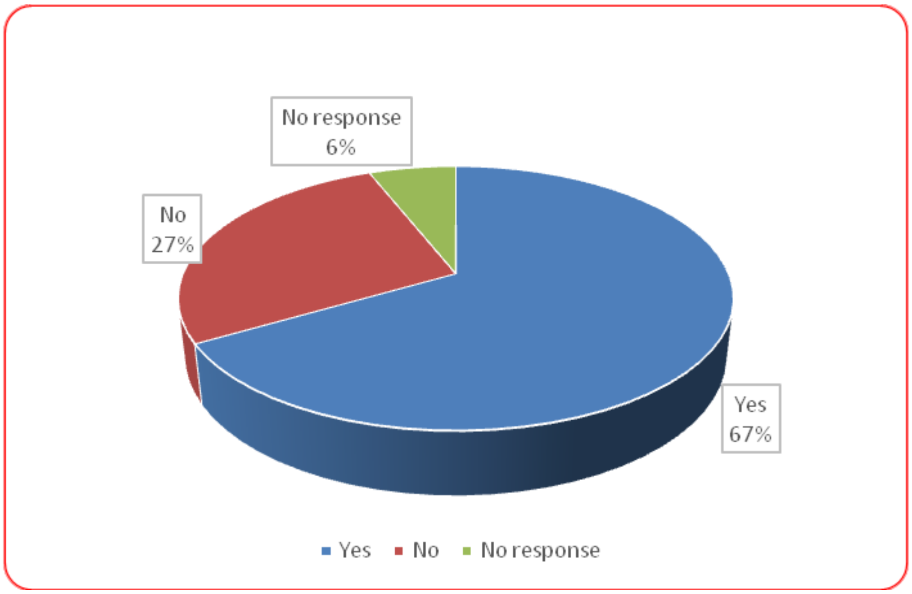


Figure 4-3: Assessment of Operator's prior Training

In general, it was observed that majority of the respondents at 67% in both cases, had previous experience and operator training on the use of the nuclear gauge whereas about 27-30% had no prior experience, therefore most operators are aware of the safety procedures.

Training is the most important requirement in operating this equipment, as it provides the basis for reliability of the results as well as acquiring the basic safety inductions on the possible risks and hazards involved in the use of the equipment.

Most operators, approximately 79% are monitored for radiation safety using film badges (Figure 4-4) at different periodic durations varying between 1 to 6 months' interval. However, most projects (52%) have no portable survey meters for monitoring unplanned radiation exposure levels during equipment use in the field (Figure 4-5). Only 42% of the projects had the survey meters.

This implies inability to detect any emergencies from malfunctions with possible exposure to high radiation level which may be detrimental to the users.

Other observed safety measures practiced while using the gauge include observing distance, time and shielding, use of PPE, training and awareness seminars, storage in purpose made enclosures, proper transportation, reporting malfunction problems for urgent repairs etc.

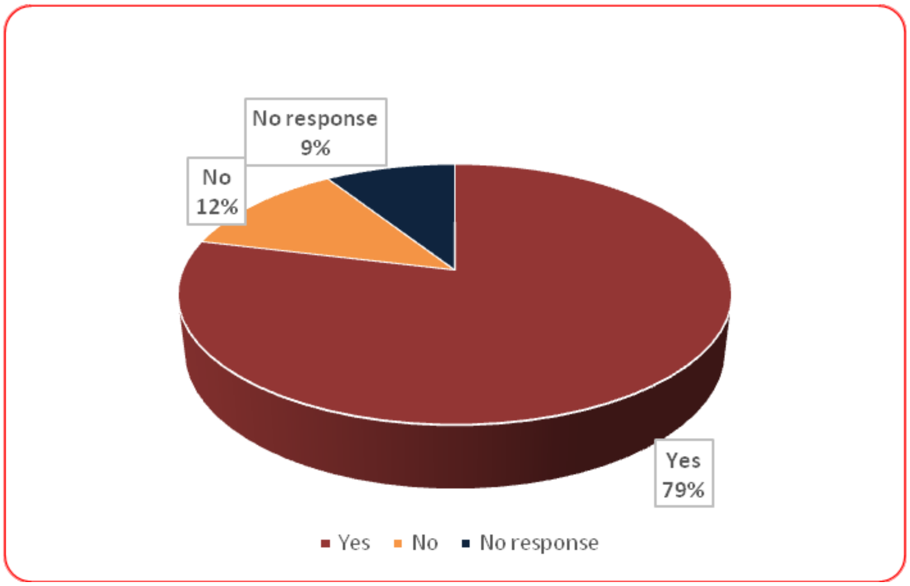


Figure 4-4: Personnel Monitoring using Film Badge

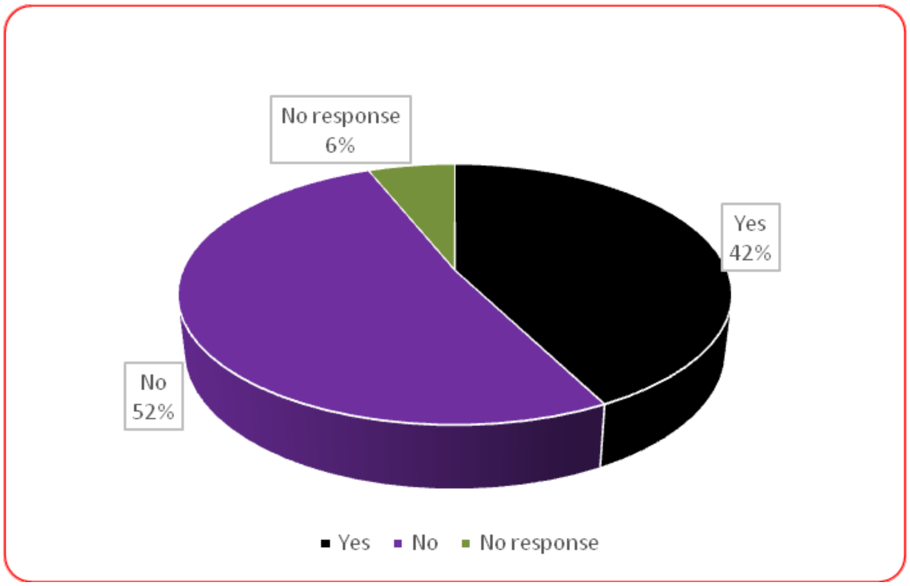


Figure 4-5: Possession of Portable Survey Meters

Figure 4-6 shows the assessment of the operator's opinion on the risk rating involved with the use of nuclear gauges. Almost half (49%) of the respondents think that the risk level is low, and an equally divided opinion amongst those who think otherwise.

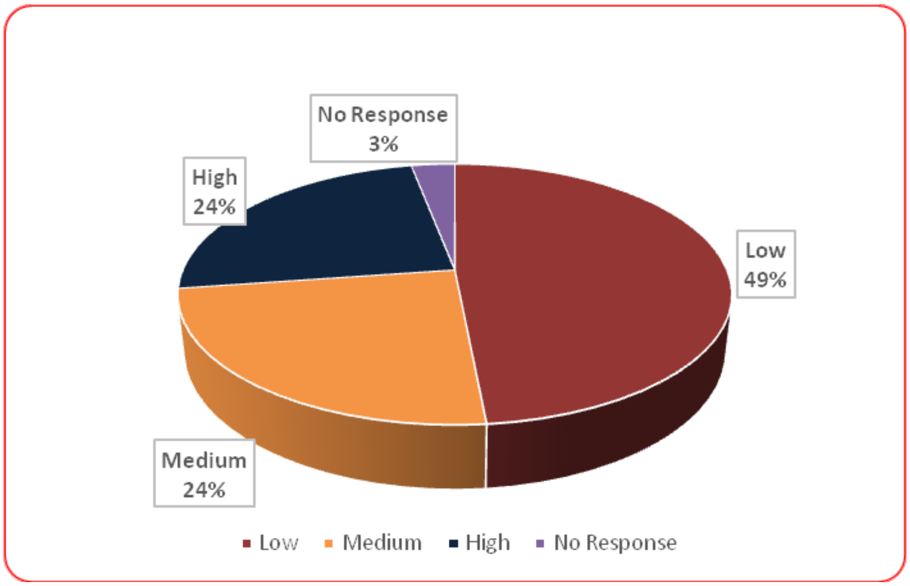


Figure 4-6: Assessment of Radiation Risk from the gauge

Table 4-9 summarizes assessment of the operators' exposure times while using the nuclear gauge. Daily exposures ranged from 1 to 10 hours with an average of 4.1±2.7 hours, while weekly exposures ranged from 2 to 7 days with an average of 5.2±1.6 days.

Table 4-9: Summary of Operator’s Exposure Times

No.	Hours/Day	Days/Week	No.	Hours/Day	Days/Week
1	4	4	29	2	5
2	3	6	30	4	5
3	6	6	31	6	7
4	4	_	32	7	7
5	3	6	33	7	7
6	_	No response_	**AVERAGE**	**4.1**	**5.2**
7	4	5	**STD**	**2.7**	**1.6**
8	2	6			
9	2	_			
10	2	3			
11	1	6			
12	5	7			
13	2	7			
14	10	7			
15	10	7			
16	_	2			
17	10	7			
18	8	7			
19	2	3			
20	2	3			
21	2	5			
22	2	5			
23	3.7	5			
24	3.6	3			
25	3.5	5			
26	3.4	_			
27	1	3			
28	1	2			

Figure 4-7 shows the results of regulator surveillance of usage of nuclear gauge. 59% of the respondents acknowledged having been visited by personnel from the Radiation Protection Board of Kenya, authorized regulator. This shows that enforcement of radiation laws is fairly satisfactory. Surveillance is critical in the enforcement of safety laws and procedures. However, public awareness and regulations need to be enhanced.

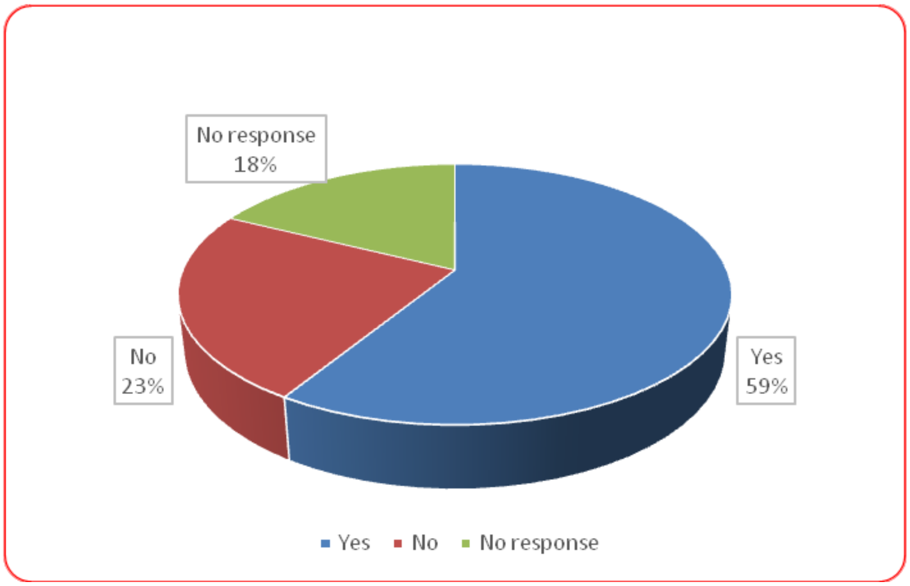


Figure 4-7: Surveillance by the Regulator

The respondents were asked to list the benefits of using the nuclear gauge in the construction industry. In summary, the following are among the benefits listed by the respondents; easier to use and requires less training, accurate and efficient, produces instant results, non-destructive to surface being tested, facilitates work progress resulting in high production rate and promotes quality control.

In practice, a single density/moisture test takes an average of about 4 minutes. In contrary, the standard sand replacement method (BS 1377, 1990) requires at least six hours to obtain the same results. However, the respondents listed radiation risks and high initial cost of the nuclear gauges as some of the disadvantages. Others include requirement of training or skilled labor, high level of safety requirements as well as the accuracy of the measurements being subjective to the experience of the operator.

Figure 4-8 summarizes the results of the respondents' proposals for improvements in safe use of the nuclear gauges. Majority of the respondents proposed that user training to include radiation safety and awareness (64%), periodic medical checkups (45%) and personal radiation monitoring (36%) as key priority areas.

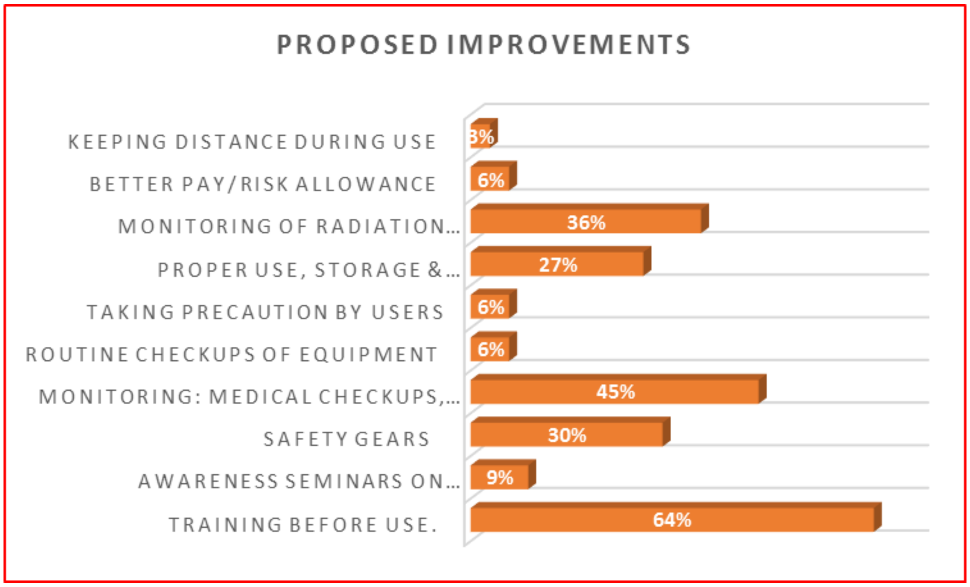


Figure 4-8: Proposed Improvements

4.3.4 Estimated Annual Effective Dose Rate

The calculated annual effective dose rates from the user exposures yielded 2.9±0.3 mSv, 1.4±0.1 mSv and 0.5±0.1 mSv at 0m, 5m and 10m respectively (Table 4-10).

The recommended maximum absorbed dose is limited to 20mSv averaged over five years for occupational exposure, 1 mSv per year for public exposure and between 1 to 2mSv per year, in some cases up to 20 mSv per year for natural background radiation (IAEA-ICRP, 2012). It thus follows that the radiation emitted by the equipment is safe for occupational use but unsafe for public exposures at a distance extrapolation of 7.5m (1.0 mSv) radius or less from the equipment.

These estimations assumed the following user exposure durations of 4.07 h per day, 21.20 h per week and 50 weeks per year.

Using the measured radiation exposures and the exposure durations obtained from the questionnaires, the annual effective doses were calculated to enable comparison with the recommended operational dose limits provided by the ICRP. Background radiation of 0.09 $\mu Svhr^{-1}$ was measured but treated as negligible in the calculation of the protection quantities. The annual effective dosages were obtained as below:

Table 4-10: Estimated Annual Absorbed Doses

Tissue Weighting Factors					
Tissue or Organ	W_T	$\sum W_T$	1m	5m	10m
Measured Radiation/Absorbed Dose (µsv/hr)			2.7	1.4	0.5
Stomach, colon, lung, red bone marrow, breast, remainder tissues	0.12	0.72	2063.7	1042.5	389.2
Gonads	0.08	0.08	229.3	115.8	43.2
Urinary bladder, esophagus, liver, thyroid	0.04	0.16	458.6	231.7	86.5
Bone surface, skin, brain, salivary glands	0.01	0.04	114.7	57.9	21.6
Total		**1**	2866.3	1447.9	540.6
Effective/Equivalent Dose (mSv)			**2.9**	**1.4**	**0.5**

ICRP publications regards low level radiations exposures as those doses particularly below the current limits recommended for protection of radiation workers and the general public. According to the results in table above, there seems to be negligible difference between the calculated annual effective dose and the estimated absorbed dose because a whole body irradiation was assumed.

CHAPTER FIVE: CONCLUSION & RECOMMENDATIONS

5.1 Conclusion

The main objective of this study was to assess the safety of radiation workers using the nuclear gauge in construction projects in Kenya. Radiation levels obtained with direct measurements from the nuclear gauge averaged 2.7±0.2μSv, 1.4±0.1μSv and 0.5±0.1μSv with corresponding annual operational effective doses of 2.9±0.3mSv, 1.4±0.1mSv and 0.5±0.1mSv for 0m, 5m and 10m source distance measurement respectively. Based on the ICRP recommended limits, the annual operational radiation doses were deemed safe for occupational exposure at all measurement distance intervals but unsafe for public exposure at a distance extrapolation of 7.5m radius or less from the equipment. Results of statistical analysis (One-way ANOVA) showed no significant difference exist between measurements at various angles of orientations where as significant difference was observed at different linear measurements intervals.

In general, compliance with the radiation safety aspects in the construction industry particularly in using the gauge can be rated as slightly above average, based on the results of this study.

This shows that enforcement of radiation laws is fairly satisfactory. Surveillance is critical in the enforcement of safety laws and procedures. However, public awareness and regulations need to be enhanced.

5.2 Recommendations

1) User training to include radiation safety and awareness.
2) Periodic medical checkups of operators.
3) Personal radiation monitoring.
4) Public awareness on radiation exposure risks.
5) Use of portable survey meters for monitoring emergency radiation at work place.

5.2.1 Further Research in Low Exposure Radiation Effects

The cancer risk of radiation exposure at moderate to high dose ranges is well established. However, the risks remain unclear at low dose ranges, which is typical of occupational exposures. The effects of low-level radiation remain a great puzzle worldwide hence the need to undertake more research in this field if more cancer deaths have to be reduced in future. In the absence of scientific certainty on the relationship between low doses of radiation and health effects, and as a conservative approach for radiation protection purposes, the scientific community have generally assumed that any exposure to ionizing radiation can cause biological effects that may be harmful to exposed individual and that the severity or probability of the effects has direct proportionality to the dose (SPAR, 1994).

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APPENDICES

APPENDIX 1

CALIBRATION CERTIFICATE OF RADOS SURVEY METER

ORIGINAL

Kenya Bureau of Standards
P.O Box 54974-00200
NAIROBI
Tel:(+254 020) 6948000
info.metrology@kebs.org
Website: www.kebs.org

Page…1…of…2…pages

Calibration Certificate

REQUESTED BY : ANALYTICAL QUALITY SERVICES
ADDRESS : P.O. BOX 70711-00100, NAIROBI
EQUIPMENT : SURVEY METER
TYPE/MODEL : RADOS
SERIAL NO. : RDS-110
MANUFACTURER : RADOS TECHNOLOGY OY
LABORATORY : RADIATION DOSIMETRY LABORATORY
DATE : 2017-10-10
CERTIFICATE NO. : BS/MET/16/3/1/354

1.0 STANDARD EQUIPMENT USED

Cesium – 137 gamma irradiator course, calibrated using ionization chamber LSOI S/No TW32002-00349 calibrated at PTB (*Physikakisch- TechnischeBundesanstalt*).

2.0 PRECALIBRATION CHECKS

2.1 Batteries performance – Okay
2.2 Mechanical integrity – Okay
2.3 Speaker/audio – Okay
2.4 Check course response – Okay

3.0 CALIBRATION METHOD

3.1 The survey meter was calibrated according to procedure*MET-LP-19/17-Cs: Gamma Calibration procedure and Quality Control.*

3.2 The survey meter was calibrated at horizontal position along the central axis beam facing the source.

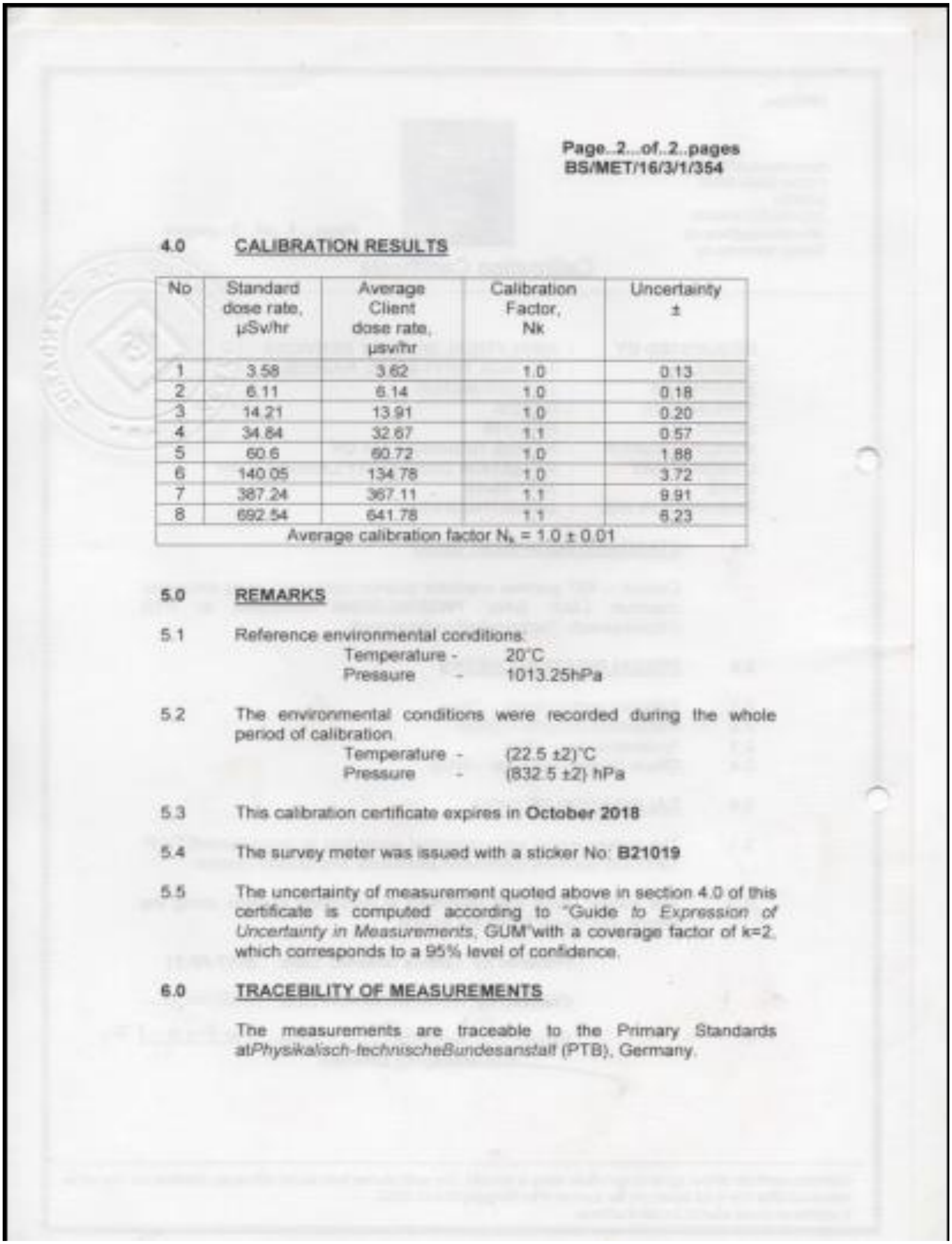
Prepared by: ***Collins Omondi*** Date: ***2017-10-11***

Checked by: Samuel [illegible] Date : [illegible]

Signed : Date: 2017-10-12
~~For:~~ ***Managing Director***

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

Page 1 of 2



Page..2...of..2..pages
BS/MET/16/3/1/354

4.0 CALIBRATION RESULTS

No	Standard dose rate, µSv/hr	Average Client dose rate, µsv/hr	Calibration Factor, Nk	Uncertainty ±
1	3.58	3.62	1.0	0.13
2	6.11	6.14	1.0	0.18
3	14.21	13.91	1.0	0.20
4	34.84	32.67	1.1	0.57
5	60.6	60.72	1.0	1.88
6	140.05	134.78	1.0	3.72
7	387.24	367.11	1.1	9.91
8	692.54	641.78	1.1	6.23
Average calibration factor N_k = 1.0 ± 0.01				

5.0 REMARKS

5.1 Reference environmental conditions:

Temperature - 20°C
Pressure - 1013.25hPa

5.2 The environmental conditions were recorded during the whole period of calibration.

Temperature - (22.5 ±2)°C
Pressure - (832.5 ±2) hPa

5.3 This calibration certificate expires in **October 2018**

5.4 The survey meter was issued with a sticker No: **B21019**

5.5 The uncertainty of measurement quoted above in section 4.0 of this certificate is computed according to "Guide *to Expression of Uncertainty in Measurements*, GUM"with a coverage factor of k=2, which corresponds to a 95% level of confidence.

6.0 TRACEBILITY OF MEASUREMENTS

The measurements are traceable to the Primary Standards at*Physikalisch-technischeBundesanstalt* (PTB), Germany.

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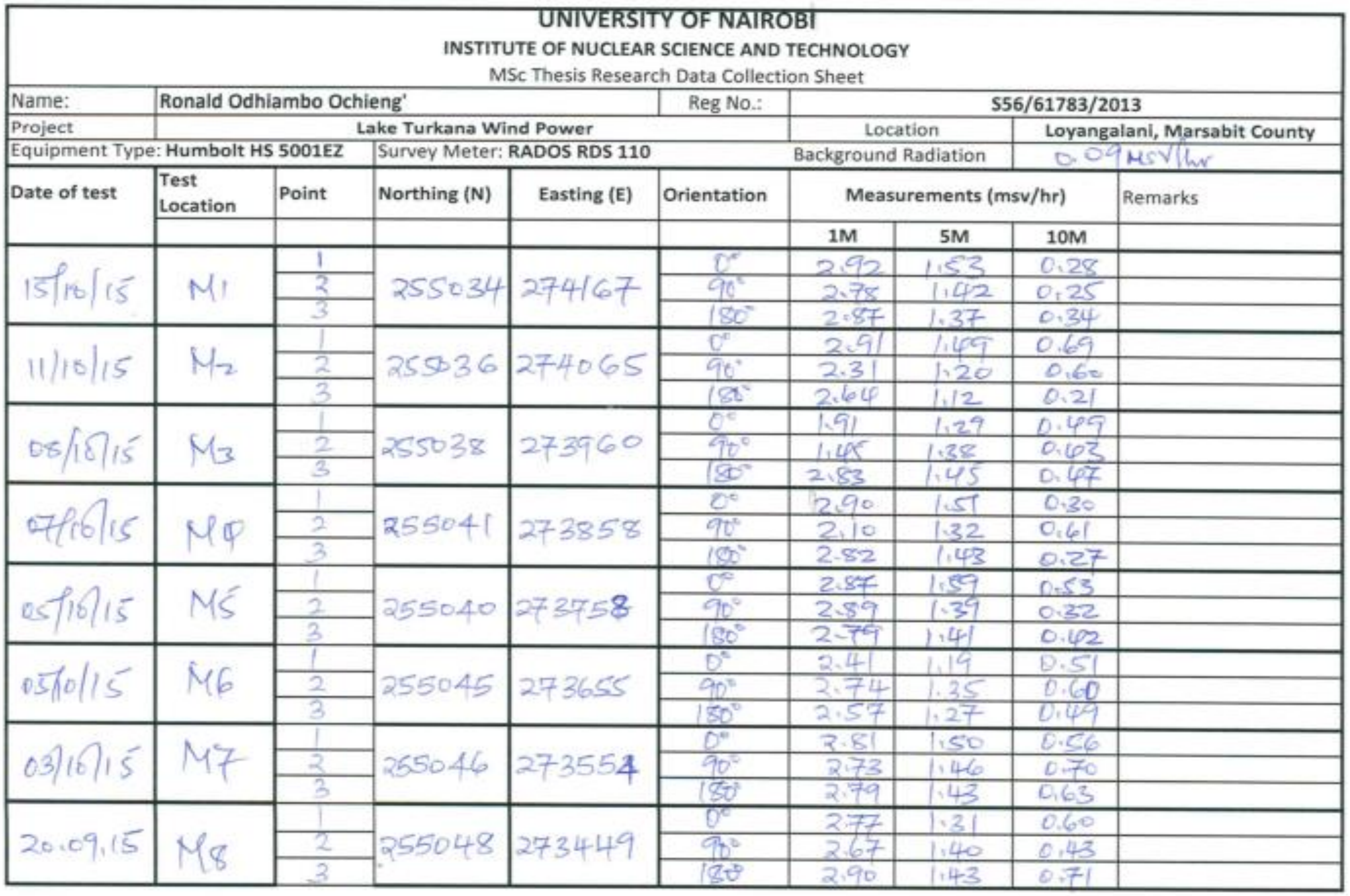
APPENDIX 2

FIELD DATA FOR RADIATION EXPOSURES



UNIVERSITY OF NAIROBI

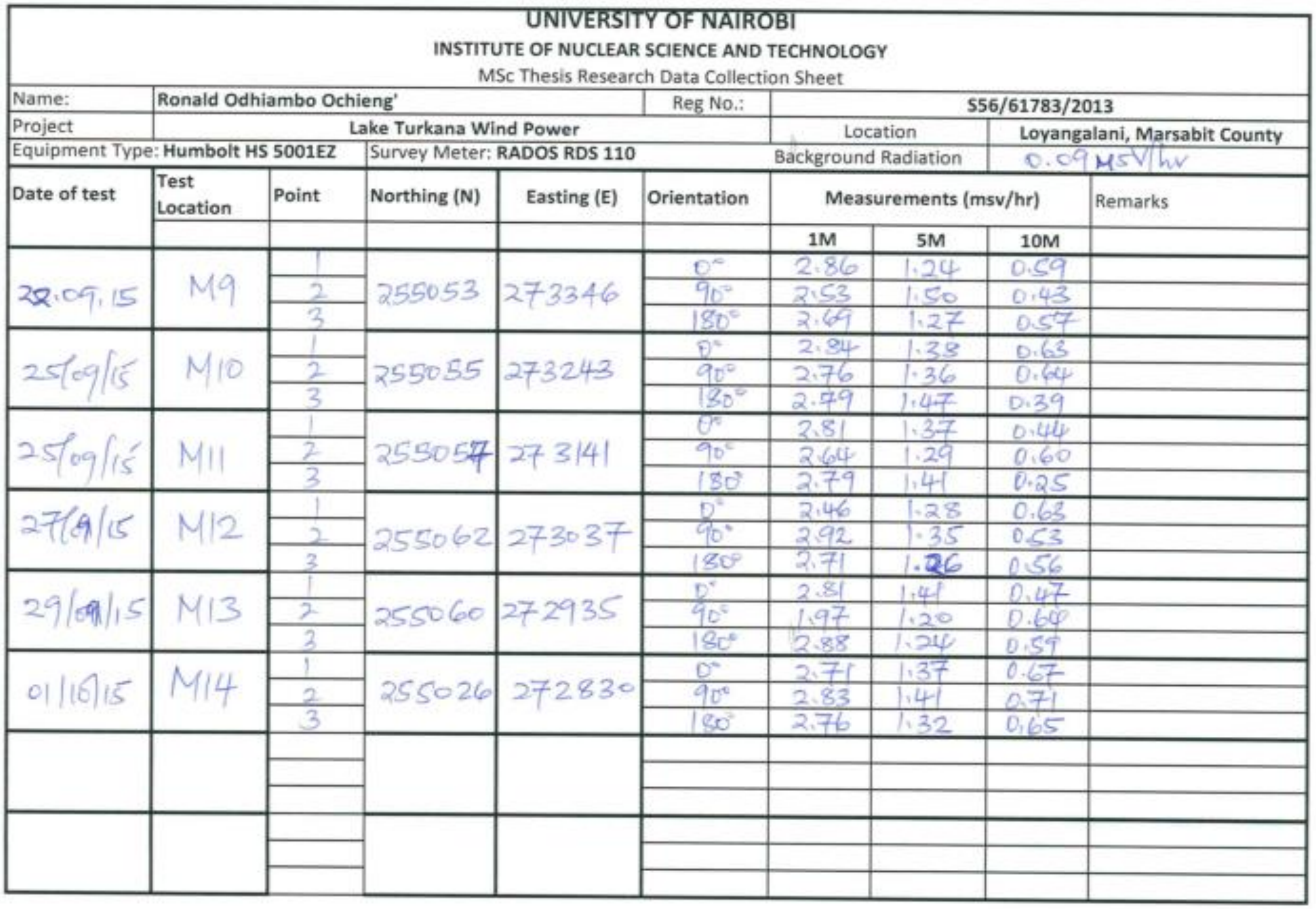
INSTITUTE OF NUCLEAR SCIENCE AND TECHNOLOGY

MSc Thesis Research Data Collection Sheet

Name:	Ronald Odhiambo Ochieng'	Reg No.:	S56/61783/2013
Project	Lake Turkana Wind Power	Location	Loyangalani, Marsabit County
Equipment Type: Humbolt HS 5001EZ	Survey Meter: RADOS RDS 110	Background Radiation	0.09 μSV/hr

Date of test	Test Location	Point	Northing (N)	Easting (E)	Orientation	Measurements (msv/hr)			Remarks
						1M	5M	10M	
15/10/15	M1	1	255034	274167	0°	2.92	1.53	0.28	
		2			90°	2.78	1.42	0.25	
		3			180°	2.87	1.37	0.34	
11/10/15	M2	1	255036	274065	0°	2.91	1.49	0.69	
		2			90°	2.31	1.20	0.60	
		3			180°	2.64	1.12	0.21	
08/10/15	M3	1	255038	273960	0°	1.91	1.29	0.49	
		2			90°	1.45	1.38	0.63	
		3			180°	2.83	1.45	0.47	
07/10/15	M4	1	255041	273858	0°	2.90	1.51	0.30	
		2			90°	2.10	1.32	0.61	
		3			180°	2.82	1.43	0.27	
05/10/15	M5	1	255040	273758	0°	2.87	1.59	0.53	
		2			90°	2.89	1.39	0.32	
		3			180°	2.79	1.41	0.42	
05/10/15	M6	1	255045	273655	0°	2.41	1.19	0.51	
		2			90°	2.74	1.35	0.60	
		3			180°	2.57	1.27	0.49	
03/10/15	M7	1	255046	273554	0°	2.81	1.50	0.56	
		2			90°	2.73	1.46	0.70	
		3			180°	2.79	1.43	0.63	
20.09.15	M8	1	255048	273449	0°	2.77	1.31	0.60	
		2			90°	2.67	1.40	0.43	
		3			180°	2.90	1.43	0.71	

Page 1 of 2



UNIVERSITY OF NAIROBI

INSTITUTE OF NUCLEAR SCIENCE AND TECHNOLOGY

MSc Thesis Research Data Collection Sheet

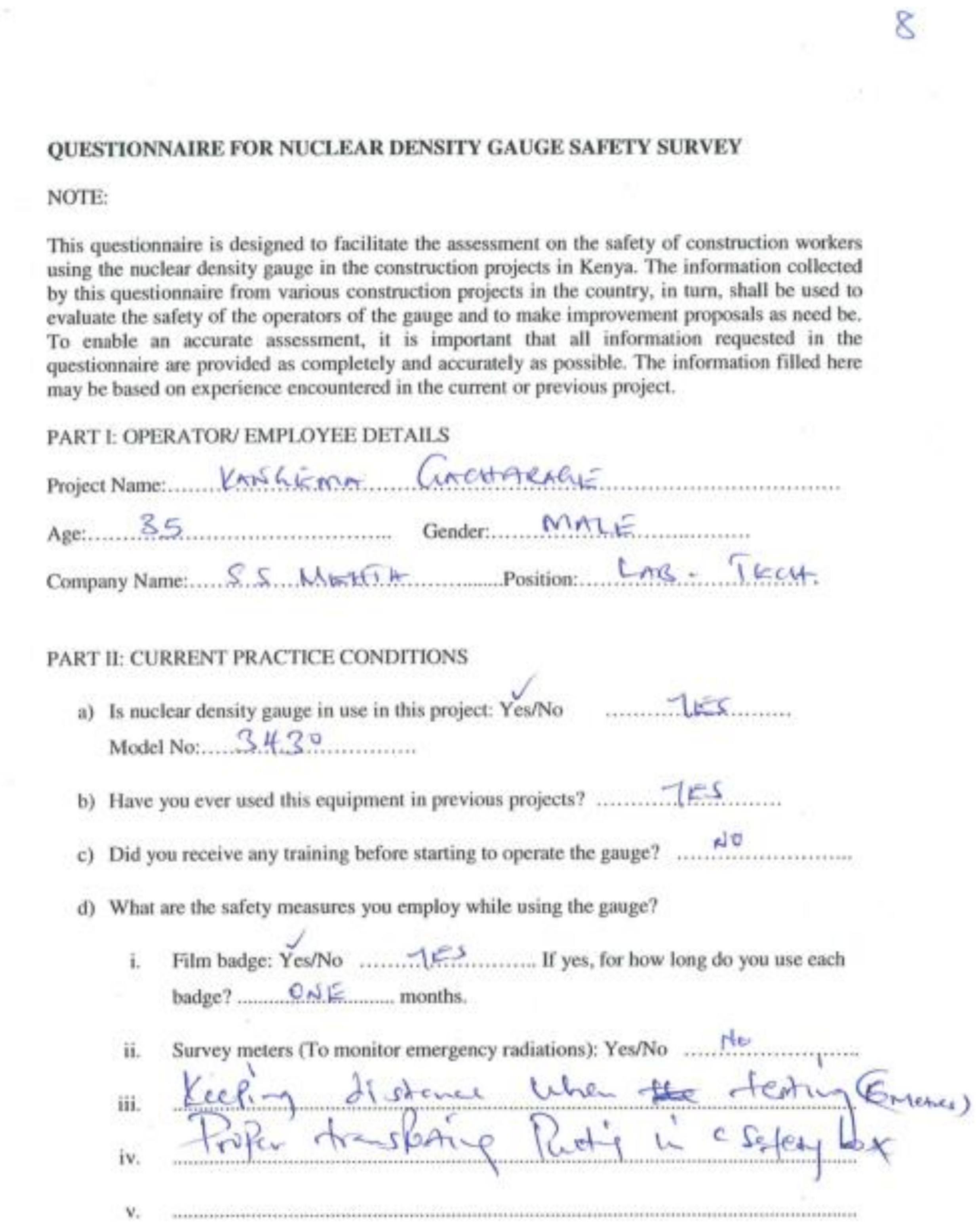
Name:	**Ronald Odhiambo Ochieng'**	Reg No.:	**S56/61783/2013**
Project	**Lake Turkana Wind Power**	Location	**Loyangalani, Marsabit County**
Equipment Type: **Humbolt HS 5001EZ**	Survey Meter: **RADOS RDS 110**	Background Radiation	0.09 MSV/hr

Date of test	**Test Location**	**Point**	**Northing (N)**	**Easting (E)**	**Orientation**	**Measurements (msv/hr)**			Remarks
						1M	**5M**	**10M**	
22.09.15	M9	1	255053	273346	0°	2.86	1.24	0.59	
		2			90°	2.53	1.50	0.43	
		3			180°	2.69	1.27	0.57	
25/09/15	M10	1	255055	273243	0°	2.84	1.38	0.63	
		2			90°	2.76	1.36	0.64	
		3			180°	2.79	1.47	0.39	
25/09/15	M11	1	255057	273141	0°	2.81	1.37	0.44	
		2			90°	2.64	1.29	0.60	
		3			180°	2.79	1.41	0.25	
27/9/15	M12	1	255062	273037	0°	2.46	1.28	0.63	
		2			90°	2.92	1.35	0.53	
		3			180°	2.71	1.26	0.56	
29/09/15	M13	1	255060	272935	0°	2.81	1.41	0.47	
		2			90°	1.97	1.20	0.69	
		3			180°	2.88	1.24	0.59	
01/10/15	M14	1	255026	272830	0°	2.71	1.37	0.67	
		2			90°	2.83	1.41	0.71	
		3			180°	2.76	1.32	0.65	

Page 2 of 2

APPENDIX 3

SAMPLE QUESSTIONAIRE RESPONSES



8

QUESTIONNAIRE FOR NUCLEAR DENSITY GAUGE SAFETY SURVEY

NOTE:

This questionnaire is designed to facilitate the assessment on the safety of construction workers using the nuclear density gauge in the construction projects in Kenya. The information collected by this questionnaire from various construction projects in the country, in turn, shall be used to evaluate the safety of the operators of the gauge and to make improvement proposals as need be. To enable an accurate assessment, it is important that all information requested in the questionnaire are provided as completely and accurately as possible. The information filled here may be based on experience encountered in the current or previous project.

PART I: OPERATOR/ EMPLOYEE DETAILS

Project Name: KANGEMA GACHARAGE

Age: 35 Gender: MALE

Company Name: S.S. MEHTA Position: LAB. TECH.

PART II: CURRENT PRACTICE CONDITIONS

a) Is nuclear density gauge in use in this project: [✓ Yes]/No YES
   Model No: 3430

b) Have you ever used this equipment in previous projects? YES

c) Did you receive any training before starting to operate the gauge? NO

d) What are the safety measures you employ while using the gauge?

   i. Film badge: [✓ Yes]/No YES If yes, for how long do you use each badge? ONE months.

   ii. Survey meters (To monitor emergency radiations): Yes/No No

   iii. Keeping distance when ~~the~~ testing (Emence)

   iv. Proper transporting Putting in a safety box

   v. ……

Q#1: Page 1 of 15

vi. ....

(From iii-vi, please list other safety measures you practice while using this gauge).

e) How do you rate the risk level arising from the use of this gauge: (low, medium, high)

Low

f) Reason/s, if any, for answer in (e) above?

No Cases has been reported Due to usage of the Machine

g) What is the approximate duration you get exposed to this equipment?

i. 2 hours per day.

ii. 6 days per week.

h) Has any radiation and protection monitoring body visited this site to assess handling of the nuclear gauge? Yes

i) In your personal opinion, what do you think are the benefits of using the nuclear gauge to this project and the construction industry in general?

i) Fast and gives results Immediately

ii) Requires ~~less~~ Minimal labour

iii) Saves time

iv) ....

j) In your personal opinion, what do you think are the negative effects of using the nuclear gauge to this project and the construction industry in general?

i) Risks to the users ~~the~~

ii) Minimises the Employment Opportunity

Q#1: Page 2 of 15

iii) Requires training

iv)

PART III: PROPOSED IMPROVEMENTS

k) What improvements do you think should be made to promote the safe use of this equipment?

i) Regular monitoring incase of rays leakage.

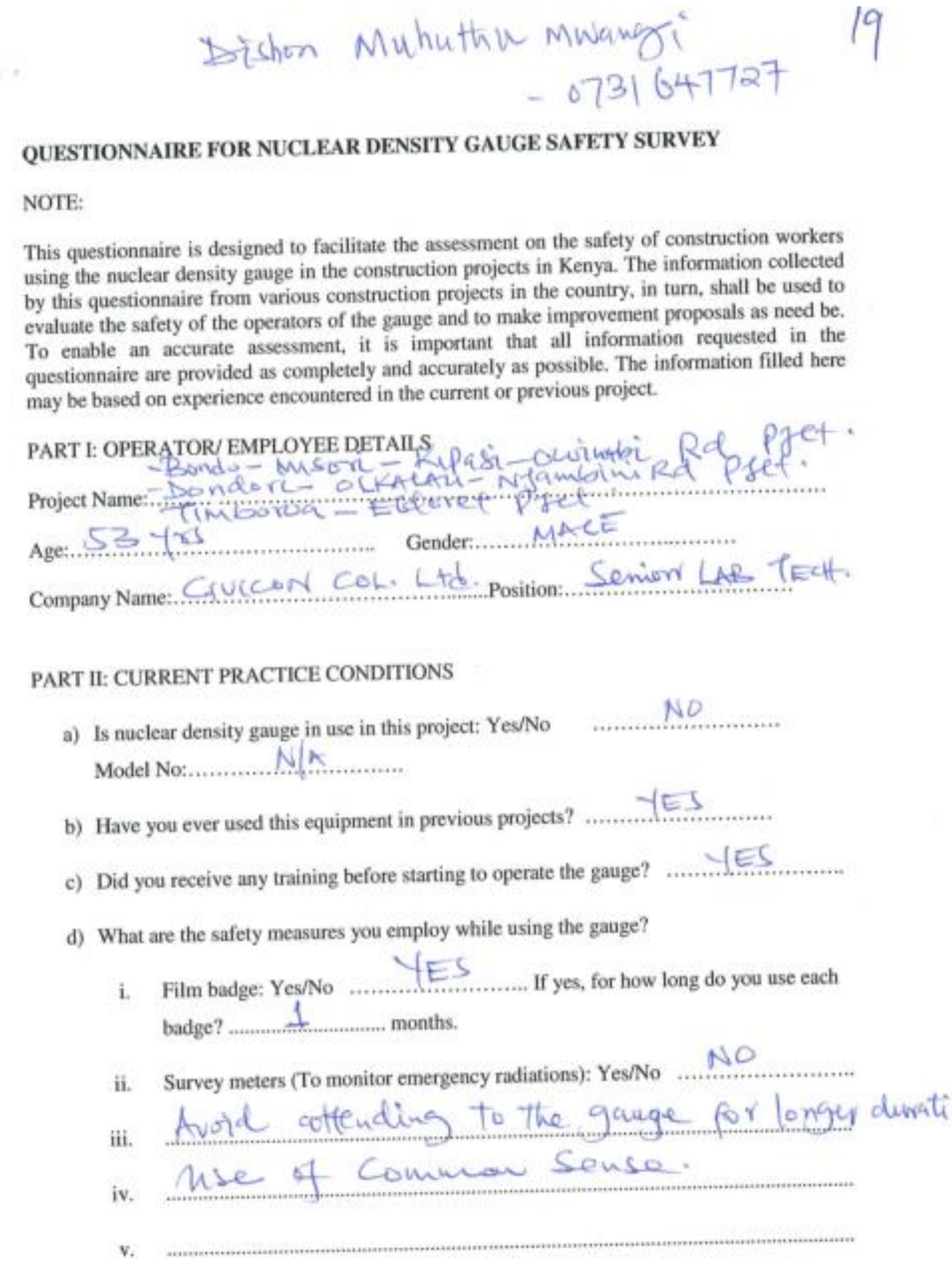
ii) More training to users on safety & handling

iii) Introducing schools & Centres to train more

iv) on Nuclear Gauge.

SIGN:

DATE: 22/1/2016



Dishon Muhuthu Mwangi

- 0731 647727

19

QUESTIONNAIRE FOR NUCLEAR DENSITY GAUGE SAFETY SURVEY

NOTE:

This questionnaire is designed to facilitate the assessment on the safety of construction workers using the nuclear density gauge in the construction projects in Kenya. The information collected by this questionnaire from various construction projects in the country, in turn, shall be used to evaluate the safety of the operators of the gauge and to make improvement proposals as need be. To enable an accurate assessment, it is important that all information requested in the questionnaire are provided as completely and accurately as possible. The information filled here may be based on experience encountered in the current or previous project.

PART I: OPERATOR/ EMPLOYEE DETAILS

Project Name: -Bondo - Misori - Kipasi - Owimbi Rd Pjct.
-Dondori - OLKALAU - Njambini Rd Pjct.
-Timboroa - Eldoret Pjct

Age: 53 yrs Gender: MALE

Company Name: CIVICON CO. Ltd. Position: Senior LAB TECH.

PART II: CURRENT PRACTICE CONDITIONS

a) Is nuclear density gauge in use in this project: Yes/No NO
Model No: N/A

b) Have you ever used this equipment in previous projects? YES

c) Did you receive any training before starting to operate the gauge? YES

d) What are the safety measures you employ while using the gauge?

   i. Film badge: Yes/No YES If yes, for how long do you use each badge? 1 months.

   ii. Survey meters (To monitor emergency radiations): Yes/No NO

   iii. Avoid attending to the gauge for longer durati

   iv. use of Common Sense.

   v. ……

Q#2: Page 4 of 15

vi. ....

(From iii-vi, please list other safety measures you practice while using this gauge).

e) How do you rate the risk level arising from the use of this gauge: (low, medium, high)

Low

f) Reason/s, if any, for answer in (e) above?

The risk is Low when the nuclear gauge is used properly.

g) What is the approximate duration you get exposed to this equipment?

i. 2 hours per day.

ii. 3 days per week.

h) Has any radiation and protection monitoring body visited this site to assess handling of the nuclear gauge? YES

i) In your personal opinion, what do you think are the benefits of using the nuclear gauge to this project and the construction industry in general?

i) It Saves Money

ii) The results are given in time.

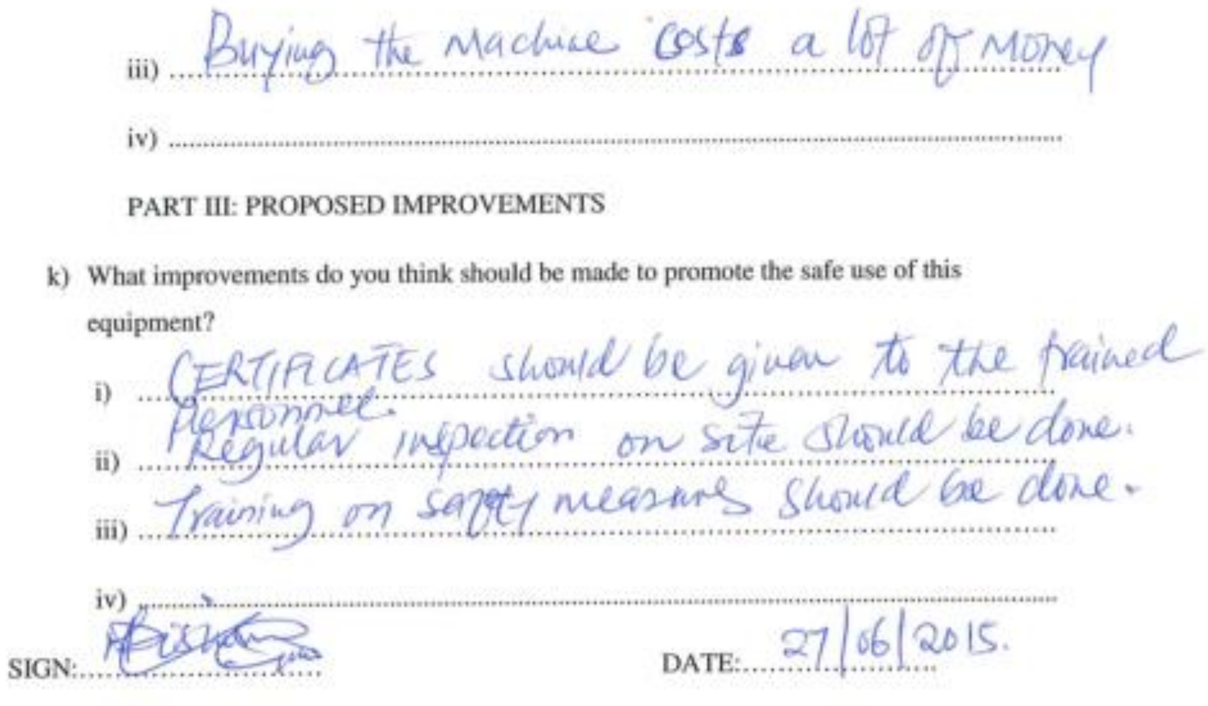
iii) It is accurate When used properly.

iv) ....

j) In your personal opinion, what do you think are the negative effects of using the nuclear gauge to this project and the construction industry in general?

i) - If not handled well, It can be fatal.

ii) - It uses Less Labour force, thereby denying able men and women the opportunity to work.



iii) Buying the machine costs a lot of money

iv) ……………………………………

PART III: PROPOSED IMPROVEMENTS

k) What improvements do you think should be made to promote the safe use of this equipment?

i) CERTIFICATES should be given to the trained personnel.

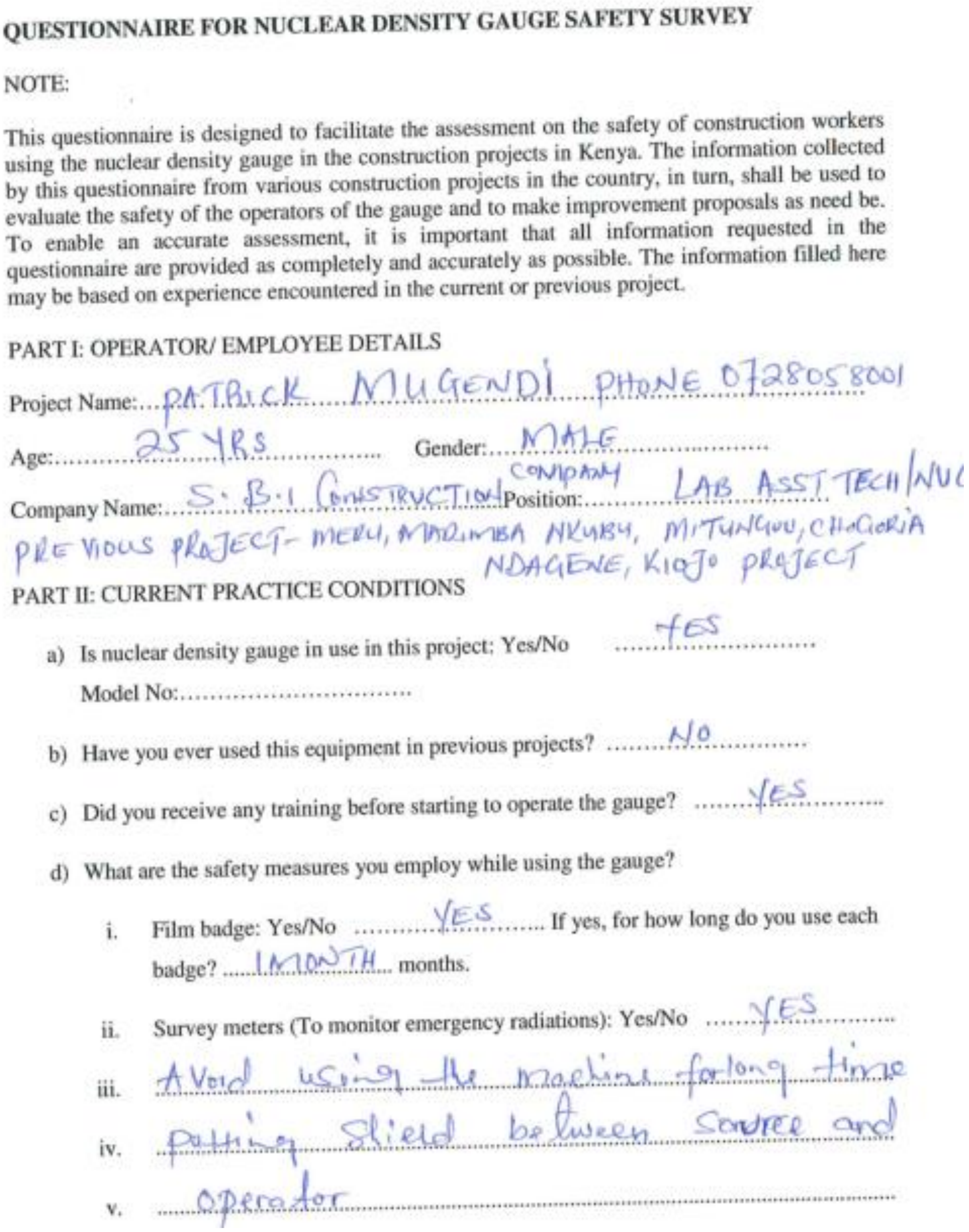
ii) Regular inspection on site should be done.

iii) Training on safety measures should be done.

iv) ……………………………………

SIGN:…………………… DATE: 27/06/2015.

Q#2: Page 6 of 15



QUESTIONNAIRE FOR NUCLEAR DENSITY GAUGE SAFETY SURVEY

NOTE:

This questionnaire is designed to facilitate the assessment on the safety of construction workers using the nuclear density gauge in the construction projects in Kenya. The information collected by this questionnaire from various construction projects in the country, in turn, shall be used to evaluate the safety of the operators of the gauge and to make improvement proposals as need be. To enable an accurate assessment, it is important that all information requested in the questionnaire are provided as completely and accurately as possible. The information filled here may be based on experience encountered in the current or previous project.

PART I: OPERATOR/ EMPLOYEE DETAILS

Project Name: PATRICK MUGENDI PHONE 0728058001

Age: 25 YRS Gender: MALE

Company Name: S. B. I CONSTRUCTION COMPANY Position: LAB ASST TECH/NUC

PREVIOUS PROJECT- MERU, MARIMBA NKUBU, MITUNGUU, CHOGORIA NDAGENE, KIAJO PROJECT

PART II: CURRENT PRACTICE CONDITIONS

a) Is nuclear density gauge in use in this project: Yes/No YES
   Model No:……………………………

b) Have you ever used this equipment in previous projects? NO

c) Did you receive any training before starting to operate the gauge? YES

d) What are the safety measures you employ while using the gauge?
   i. Film badge: Yes/No YES If yes, for how long do you use each badge? 1 MONTH months.
   ii. Survey meters (To monitor emergency radiations): Yes/No YES
   iii. AVoid using the machine forlong time
   iv. putting Shield between Source and
   v. operator

Q#3: Page 7 of 15

vi. ....

(From iii-vi, please list other safety measures you practice while using this gauge).

e) How do you rate the risk level arising from the use of this gauge: (low, medium, high)

Low

f) Reason/s, if any, for answer in (e) above?

Risk levels are low if only safety procedures are followed properly

g) What is the approximate duration you get exposed to this equipment?

i. 3 hours per day.

ii. 5 days per week.

h) Has any radiation and protection monitoring body visited this site to assess handling of the nuclear gauge? YES

i) In your personal opinion, what do you think are the benefits of using the nuclear gauge to this project and the construction industry in general?

i) less labour

ii) High Saving

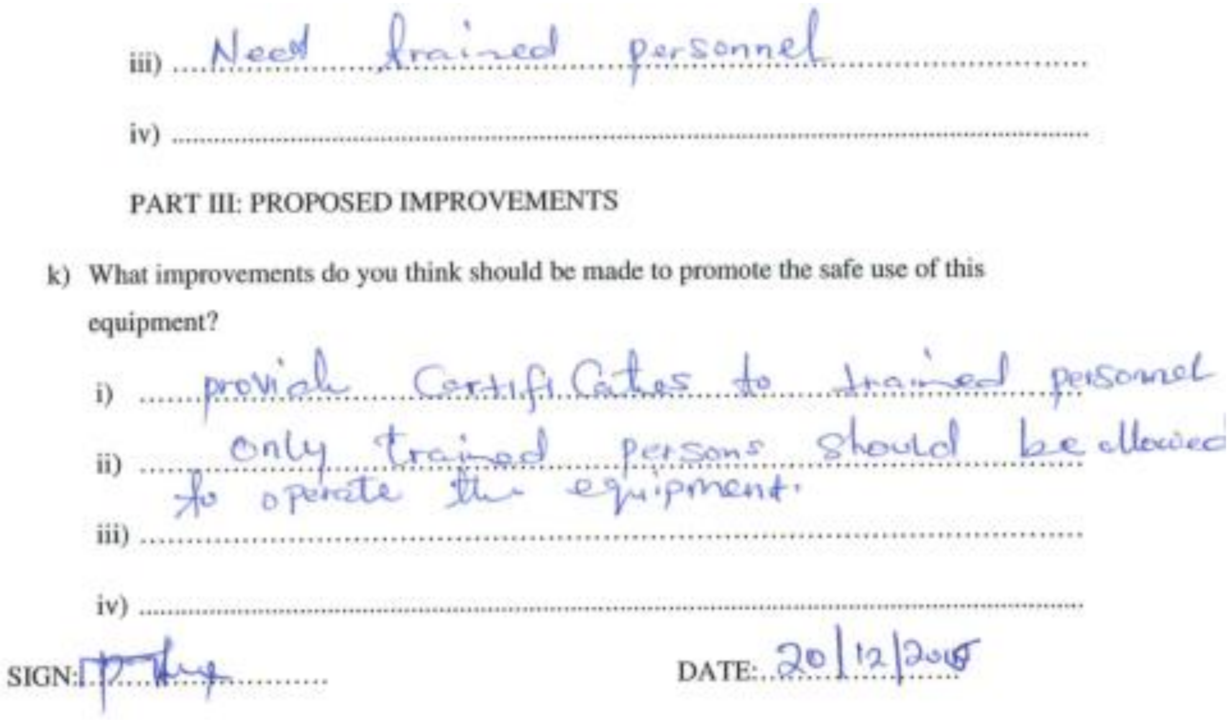
iii) Accurancy

iv) ....

j) In your personal opinion, what do you think are the negative effects of using the nuclear gauge to this project and the construction industry in general?

i) Loss of Jobs

ii) dangerous in Radiation



iii) Need trained personnel

iv)

PART III: PROPOSED IMPROVEMENTS

k) What improvements do you think should be made to promote the safe use of this equipment?

i) provide Certificates to trained personnel

ii) only trained persons should be allowed to operate the equipment.

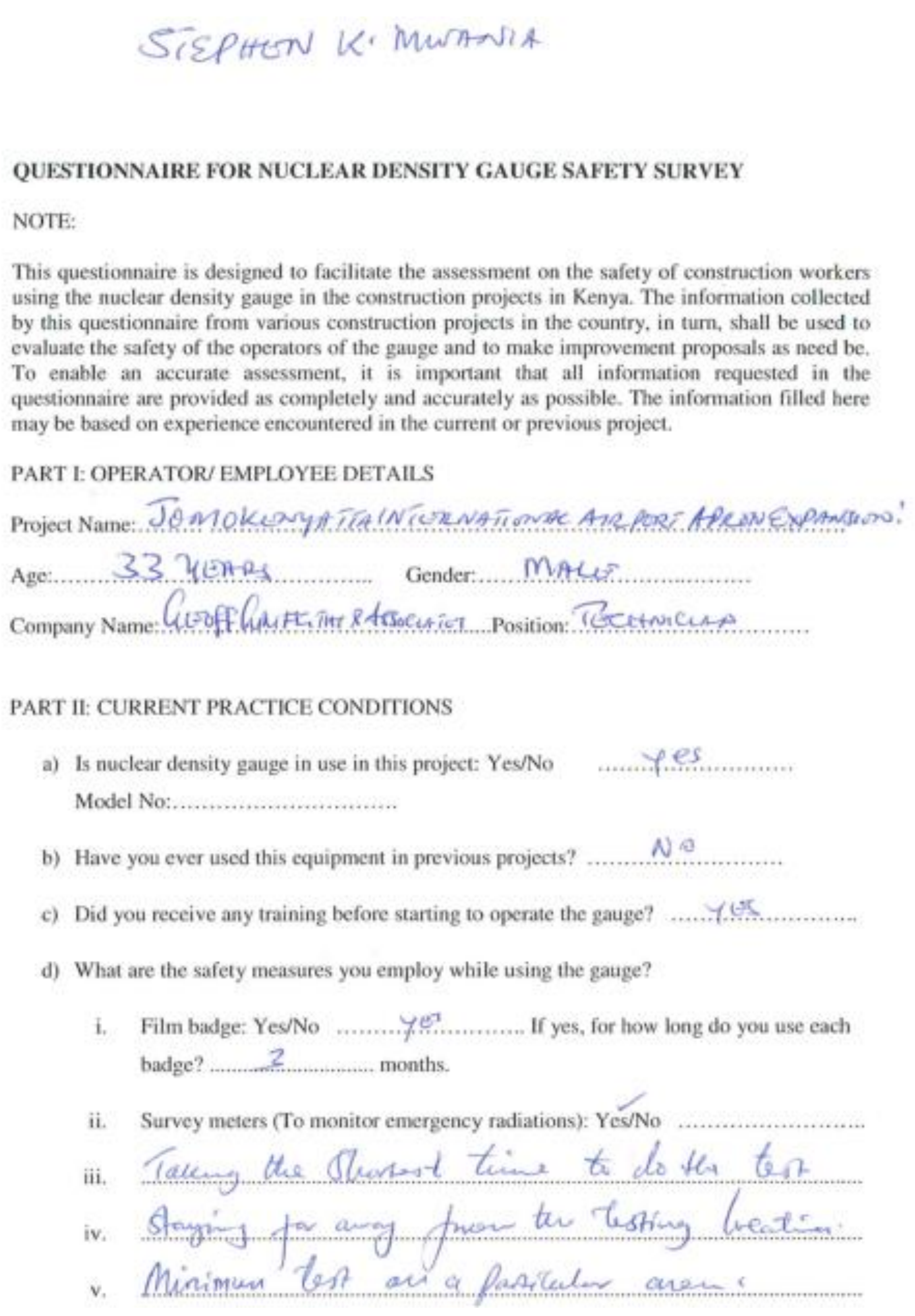
iii)

iv)

SIGN:

DATE: 20/12/2015

Q#3: Page 9 of 15



STEPHEN K. MWANIA

QUESTIONNAIRE FOR NUCLEAR DENSITY GAUGE SAFETY SURVEY

NOTE:

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PART I: OPERATOR/ EMPLOYEE DETAILS

Project Name: JOMO KENYATTA INTERNATIONAL AIRPORT APRON EXPANSION.

Age: 33 YEARS Gender: MALE

Company Name: GEOFF GRIFFITHS & ASSOCIATES Position: TECHNICIAN

PART II: CURRENT PRACTICE CONDITIONS

a) Is nuclear density gauge in use in this project: Yes/No yes
Model No:

b) Have you ever used this equipment in previous projects? No

c) Did you receive any training before starting to operate the gauge? Yes

d) What are the safety measures you employ while using the gauge?

i. Film badge: Yes/No yes If yes, for how long do you use each badge? 2 months.

ii. Survey meters (To monitor emergency radiations): [✓ Yes]/No

iii. Taking the shortest time to do the test

iv. Staying far away from the testing location.

v. Minimum test on a particular area.

Q#4: Page 10 of 15

vi. Few people on the testing area.

(From iii-vi, please list other safety measures you practice while using this gauge).

e) How do you rate the risk level arising from the use of this gauge: (low, medium, high) Low

f) Reason/s, if any, for answer in (e) above?

Because of the safety measures taken on project

g) What is the approximate duration you get exposed to this equipment?

i. 3 hours per day.

ii. 5 days per week.

h) Has any radiation and protection monitoring body visited this site to assess handling of the nuclear gauge? Yes

i) In your personal opinion, what do you think are the benefits of using the nuclear gauge to this project and the construction industry in general?

i) Made the work easier

ii) Reduced the number of technicians

iii) Safety in handling compared to hand tools

iv) Quite Economical in terms of manpower.

j) In your personal opinion, what do you think are the negative effects of using the nuclear gauge to this project and the construction industry in general?

i) People can get raditions if safety measures are not taken

ii) Needs an isolated location under key & lock!

iii) Reduction of Employment in the project

iv) Every radiation is low may be harmful to certain extent

PART III: PROPOSED IMPROVEMENTS

k) What improvements do you think should be made to promote the safe use of this equipment?

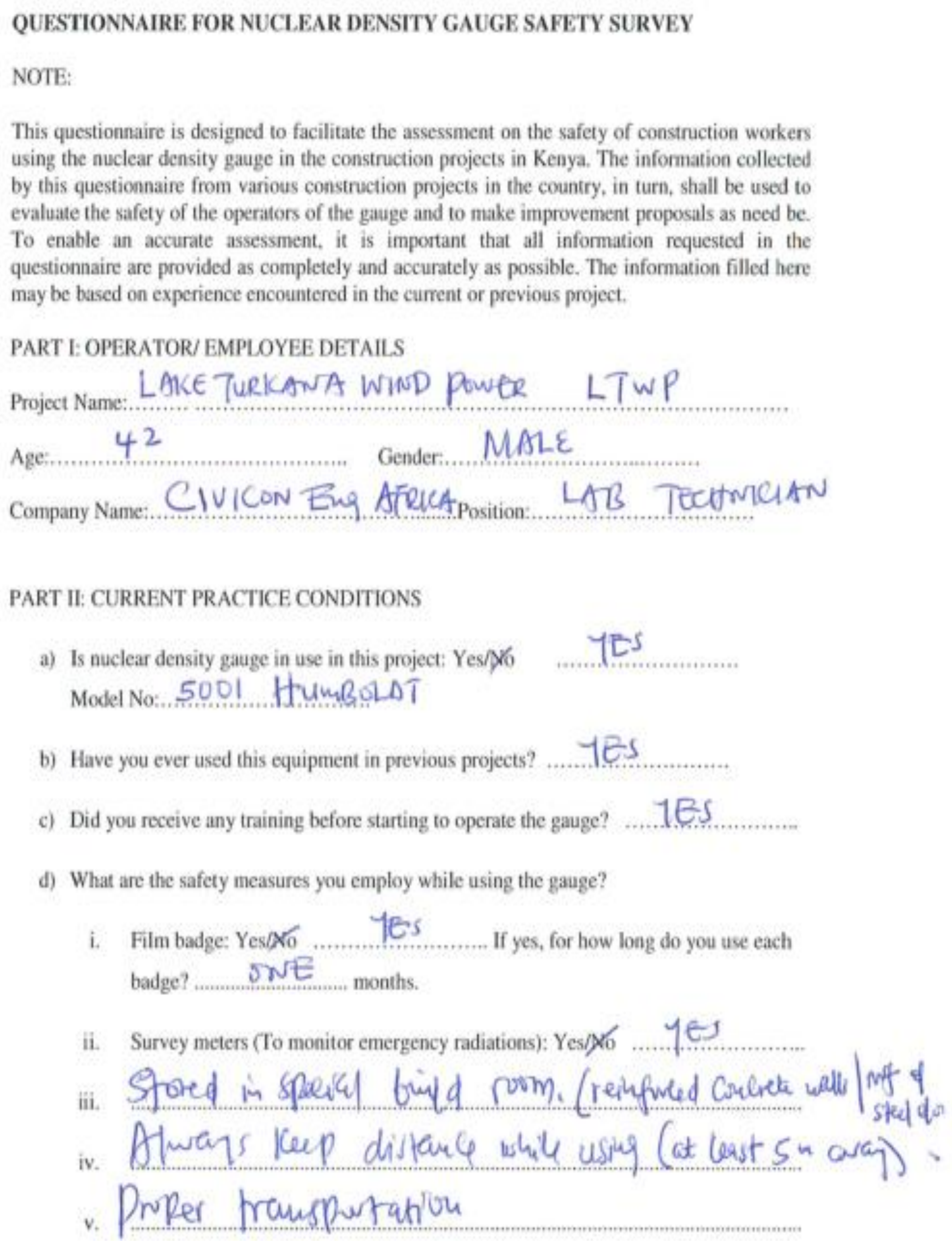
i) Training of the technicians using the Equipment

ii) Educating the Surrounding Community on its danger

iii) Design a nuclear equipment that does not need isolated places

iv) Research more on the radiation released by the Equipment.

SIGN:.......... DATE: 12/06/2015



QUESTIONNAIRE FOR NUCLEAR DENSITY GAUGE SAFETY SURVEY

NOTE:

This questionnaire is designed to facilitate the assessment on the safety of construction workers using the nuclear density gauge in the construction projects in Kenya. The information collected by this questionnaire from various construction projects in the country, in turn, shall be used to evaluate the safety of the operators of the gauge and to make improvement proposals as need be. To enable an accurate assessment, it is important that all information requested in the questionnaire are provided as completely and accurately as possible. The information filled here may be based on experience encountered in the current or previous project.

PART I: OPERATOR/ EMPLOYEE DETAILS

Project Name: LAKE TURKANA WIND POWER LTWP

Age: 42 Gender: MALE

Company Name: CIVICON Eng AFRICA Position: LAB TECHNICIAN

PART II: CURRENT PRACTICE CONDITIONS

a) Is nuclear density gauge in use in this project: Yes/~~No~~ YES
Model No: 5001 HUMBOLDT

b) Have you ever used this equipment in previous projects? YES

c) Did you receive any training before starting to operate the gauge? YES

d) What are the safety measures you employ while using the gauge?

i. Film badge: Yes/~~No~~ YES If yes, for how long do you use each badge? ONE months.

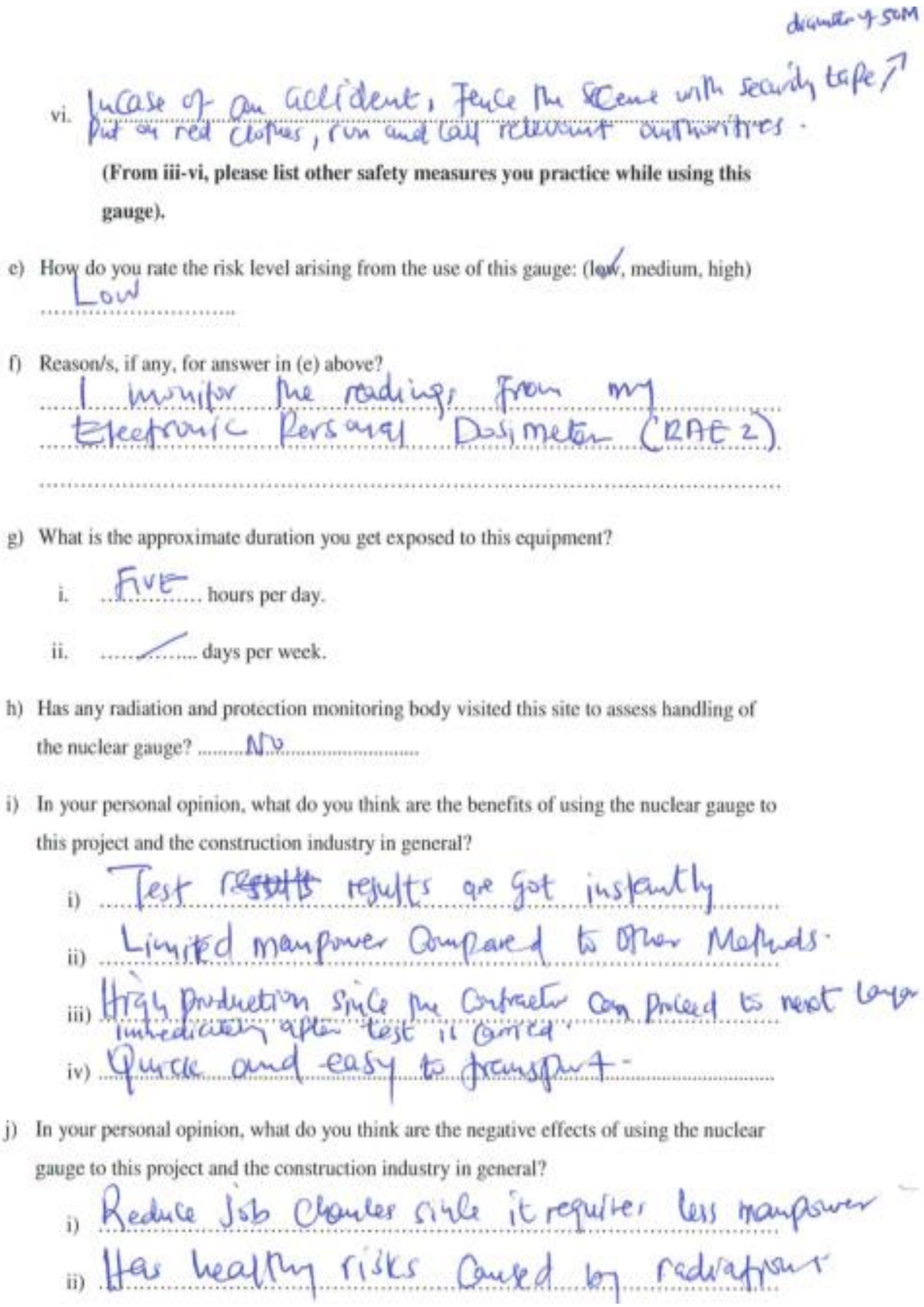
ii. Survey meters (To monitor emergency radiations): Yes/~~No~~ YES

iii. Stored in special build room. (reinforced Concrete wall | roof & steel door

iv. Always keep distance while using (at least 5m away).

v. Proper transportation

Q#5: Page 13 of 15



diameter of 50M

vi. Incase of an accident, Fence the scene with security tape ↗ Put on red clothes, run and call relevant authorities.

(From iii-vi, please list other safety measures you practice while using this gauge).

e) How do you rate the risk level arising from the use of this gauge: ([✓ low], medium, high)

Low

f) Reason/s, if any, for answer in (e) above?

I monitor the readings from my Electronic Personal Dosimeter (RAE 2)

g) What is the approximate duration you get exposed to this equipment?

i. Five hours per day.

ii. .... days per week.

h) Has any radiation and protection monitoring body visited this site to assess handling of the nuclear gauge? No

i) In your personal opinion, what do you think are the benefits of using the nuclear gauge to this project and the construction industry in general?

i) Test ~~results~~ results are got instantly

ii) Limited manpower compared to other Methods.

iii) High production since the contractor can proceed to next layer immediately after test is carried.

iv) Quick and easy to transport.

j) In your personal opinion, what do you think are the negative effects of using the nuclear gauge to this project and the construction industry in general?

i) Reduce job chances since it requires less manpower

ii) Has health risks caused by radiations

iii) Has dangerous risks incase of an ACCIDENT

iv) Its expensive to Small scale Contractors -

PART III: PROPOSED IMPROVEMENTS

k) What improvements do you think should be made to promote the safe use of this equipment?

i) Proper training to gauge operators.

ii) Special made vehicles ~~made~~ for the transportation

iii) Health insurance Scheme to Operators

iv) Good Payback for Operators.

SIGN:…………………… DATE: 18/6/2015