ASSESSMENT OF OCCUPATIONAL EXPOSURE AND RADIATION PROTECTION IN SOME SELECTED WELL-LOGGING AND INDUSTRIAL RADIOGRAPHY FACILITIES IN NIGERIA

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NIGERIA

AUGUST, 2017

DECLARATION

I declare that the work in this dissertation entitled "Assessment of occupational exposure and radiation protection in some selected well-logging and industrial radiography facilities in Nigeria" has been carried out by me in the Department of Physics. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at this or any other Institution.

Muhammad Bello GUSAU ……………………… …………………….

Signature Date

CERTIFICATION

This dissertation entitled "ASSESSMENT OF OCCUPATIONAL EXPOSURE AND RADIATION PROTECTION IN SOME SELECTED WELL-LOGGING AND INDUSTRIAL RADIOGRAPHY FACILITIES IN NIGERIA" by Muhammad Bello GUSAU meets the regulations governing the award of the degree of Master of Science Degree in Radiation Biophysics of the Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

To my parents, late Mallam Muhammad Abubakar Yahaya and Malama Hawa'u Abubakar and my late son, Muhammad Bello Muhammad.

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ACRONYMS

ALARA	as Low as Reasonably Achievable
BSS	Basic Safety Standard
DDE	Deep Dose Equivalent
DDREF	Dose and Dose Rate Effectiveness Factor
DR	Diagnostic Radiology
DSP	Dosimetry Service Provider
EPA	Environmental Protection Agency
FAO	Food and Agricultural Organization
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
ILO	International Labour Organization
IR	Industrial Radiography
ISO	International Organization for Standardization
MDL	Minimum Detection Limit
NDT	Non-Destructive Testing
NiBIRR	Nigeria Basic Ionizing Radiation Regulation
NM	Nuclear Medicine
NNRA	Nigerian Nuclear Regulatory Authority
NSPR Act	Nuclear Safety and Radiation Protection Act
OECD	Organization for Economic Cooperation and Development
PAHO	Pan American Health Organization
RT	Radiotherapy
SDE	Shallow Dose Equivalent

Sv	Sievert
TLD	Thermo Luminescent Dosimeter
UNSCEAR	United Nation Scientific Committee on the Effects of Atomic Radiation
USDOE	United State Department of Energy
WINS	World Institute for Nuclear Security
WL	Well-Logging

ABSTRACT

Nigeria has for a very long time engaged in the peaceful application of nuclear technology. The use of ionizing radiation due to its unique properties has considerably increased over the years in oil and gas industry. In this study, the radiation safety procedures have been evaluated and whole-body occupational exposure for workers in some selected industrial radiography and well-logging facilities were assessed using thermoluminescent dosimeters (TLDs) for a 10y period. The TLDs were read using Harshaw dual-4500 TLD reader on quarterly basis. During the 10y study period, the average annual effective doses were found to be 1.3 mSv and 0.96 mSv for the industrial radiography and well-logging practices respectively. The annual collective dose received by the exposed workers in industrial radiography and well-logging practices were found to be between the ranges 27.8-99.6 man mSv and 12.1-32.2 man mSv respectively, while the two practices contribute 768 man mSv to the total world collective dose value. On the TLD return rates, well-logging practice records the highest with 95.7% while industrial radiography practice scored 90.1%. The overall result showed that 89% of the workers received doses lower than 1 mSv and there was no instance where a worker received dose greater than the dose limits prescribed by Nigerian Nuclear Regulatory Authority (NNRA). The average annual effective doses obtained from this study were compared and discussed with the results obtained from other countries and UNSCEAR. Although, the radiation workers covered by this study received doses less than the dose limits set by the NNRA, licensees and all stakeholders involved should make sure that, the radiation workers are regularly and properly trained on operational procedures and radiation protection matters, so that the doses to the individual and the working environment are kept as low as reasonably achievable (ALARA).

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Nigeria has, for a very longtime, engaged in the peaceful application of nuclear technology. The use of ionizing radiation, because of its unique properties, has considerably increased over the years in oil and gas industry.

Due to the adverse health effect when people are over-exposed to ionizing radiation, radiation is feared by many, worldwide, and Nigerians are no exception. This concern is even much higher with inhabitants living at close proximity to nuclear establishments and other facilities using ionizing radiation sources. What most people do not realize is that radiation is present everywhere, in everything in the environment and even in the bodies (Oyeyinka et al, 2012). There is cosmic radiation made up of protons, alpha particles and heavy nuclei bombarding the earth from space which, upon interaction with the atmosphere results into large assortment of secondary particles, including pie (π) and mu (μ) mesons, electromagnetic photons, neutrons, protons and electrons contributing high radiation dose burden to man even at sea level (Maduemezia et al, 2008). Other natural radiation includes the terrestrial gamma rays from land, sea and walls of houses we live. Humans are also internally exposed from radiation emitted by radionuclides absorbed into the body through the consumed food (Oyeyinka et al, 2012). Examples of such radionuclides are potassium-40, heavy elements and carbon-14. Therefore, living isolated from radiation is almost impossible in the modern world as humans and animals are subjected to both natural and artificial radiation in the environment, due to increase in living standard (Zakari et al, 2009). There is no need for fear of radiation but there is the need to understand its properties, make use of it and reduce the exposure to dose levels which the society judged as acceptable, with minimum associated risk. As long as the contribution from the artificial radionuclides does not push the annual dose equivalent level beyond 1mSv for the public and 20mSv averaged over five years for classified workers, then there is no need to fear radiation (NNRA, 2003).

Oil and gas industry utilize many radiation sources in various applied radiation-based technologies (Abu-Jarad, 2008). Those technologies provide significant benefit to society through the daily operations of the industry. Gamma radiation sources such as Caesium-137 (^{137}Cs) and Cobalt-60 (^{60}Co) and neutron source like Americium-241/Beryllium (^{241}Am-Be) are extensively used in well logging operation while Barium-133 (^{133}Ba), ^{241}Am and ^{137}Cs sources are used in multiphase flow meters technology at platform of oil and gas production facilities (Abu-Jarad et al, 2007; Abu-Jarad, 2008). Transmission level gauges for tanks in refineries use gamma radiation sources such as ^{137}Cs and ^{241}Am while X-ray fluorescence (XRF) techniques are used for sulfur gauges in laboratories. Refineries employ Cadimium-109 (^{109}Cd) and Iron-59 (^{59}Fe) in alloy and Sulfur analysis. Neutron sources such as Californium-252 (^{252}Cf) and ^{241}Am-Be are used in operating nuclear density gauges in Oil and Gas Industry. Iridium-192, ^{192}Ir and ^{60}Co are radioactive sources widely used in industrial radiography (Abu-Jarad et al, 2007; Abu-Jarad, 2008).

1.2 Statement of the Problem

For nearly a century, radiation-based technologies have been positively contributing to industries, medicine, agriculture, and research. The use of radiation sources in industry has significantly increased in the past 20 years due to advances in technologies that take advantage of the unique properties of ionizing radiation (Abujarad 2008).

Radioactive materials, sealed sources and radiation generators are used extensively by the oil and gas industry, in areas such as oil and gas exploration, production, industrial inspection, refineries, laboratory analysis and security inspection. All equipment, tools and machinery have hazards associated with their use, and radiation-based technologies are no different. The presence of these radioactive materials and radiation generators results in the need to control occupational exposures to ionizing radiation (IAEA, 2010).

It is important to follow proper operating and protection procedures to maximize the benefits and minimize the risk associated with ionizing radiation-based practices. To achieve maximum radiation safety objectives in dealing with artificial radiation sources, national and international radiation protection regulations should be strictly adhered to. However, many Oil and Gas companies have been in operation in Nigeria even before the establishment of Nigerian Nuclear Regulatory Authority (NNRA) by the Act 19 of 1995 which only becomes operational in 2001 (NNRA, 1995). Therefore many Radiation Sources have been imported into the country and many practices involving the use of ionizing radiation sources have been in operation without proper regulation by the Competent Authority.

A strong correlation has been found between oil and gas activities and elevated environmental ionizing radiation (Avwiri et al, 2007a; Avwiri et al, 2007b; Chad-Umoren, 2012, Chad-Umoren and Briggs-Kamara, 2010; Ononugbo et al, 2011) which are attributed to the industries' input raw materials and effluent discharge such as gas flaring and other output products. Environmental Protection Agency (EPA) reported in 2009, that the more radiation dose from Oil and Gas installation a person receives, the greater the chance of developing cancer, leukemia, eye cataracts, hematological depression and incidence of chromosomal aberrations.

1.3 Aims and Objectives

The Aim of this study is to assess occupational exposure in the oil and gas facilities in Nigeria and to evaluate operational procedures on radiation safety practices issued by the NNRA.

The Objectives of the study are;

i. To assess the dosimetry data of classified workers (radiation workers) in the Oil and Gas companies using Thermo-luminescence Dosimeters (TLD)
ii. To assess the emergency exposure situation if any from the dosimetry records of classified workers
iii. To provide information on the capability of safety measures and the effectiveness of the national regulations
iv. To demonstrate or check the radiation safety practices and compliance of the Oil and Gas facilities with the relevant dose limits as required by the national regulations

1.4 Justification of the Study

The radiation monitoring program has started in Nigeria after the French weapons tests in the Sahara desert in the early sixties (Agu, 1965). Since then, the use of ionizing radiations in medicine, industry and research has increased considerably. To maximize benefits and minimize hazards associated with the use of ionizing radiation sources, national radiation protection law and regulations shall be implemented. The objective of radiation protection is to define how one can protect individual, property and environment from the harmful effects of ionizing radiation ICRP 60 (1990). The Federal Radiation Protection Service (FRPS) was established in 1965 in the Department of Physics, University of Ibadan, Ibadan, Nigeria and assigned the responsibility of ensuring radiation safety throughout the country. FRPS has managed over the years to carry out duties such as environmental and personnel monitoring, facility inspection, research and training services (Farai and Obed, 2001). Due to lack of infrastructure, enabling laws and regulations, the FIRS was unable to effectively execute some vital roles such as personnel monitoring, authorization and enforcement. Most private establishments operate without dosimetry coverage or supervision by a Regulatory Body (Farai and Obed, 2001). Moreover, many Oil and Gas companies have been in operation in Nigeria prior to the establishment of Nuclear Regulatory Body in the country. Therefore, many Radiation Sources have been imported into the country and many practices involving the use of ionizing radiation sources have been in operation without proper regulation by a Competent Authority.

In 1995, the Nuclear Safety and Radiation Protection (NSRP) law came into being, with the passage of Act 19 of the Federal Republic of Nigeria (NSRP) (NNRA, 1995). The enactment of this law brought about the establishment of a nuclear regulatory authority known as the Nigerian Nuclear Regulatory Authority (NNRA) in 2001. Since its inception NNRA has brought all Oil and Gas establishments using ionizing radiation sources in Nigeria under Regulatory control. NNRA has also accredited many Radiation Safety Advisers (RSAs) and Dosimetry Service Providers (DSPs) for proper environmental and personnel monitoring. For all justified practices which could expose individual to ionizing radiation, dose limits are prescribed so that no exposed worker will be subjected to an unacceptable risk due to radiation exposure. The dose limits which are set and specified by the NNRA are to prevent the occurrence of deterministic effects and limit the probability of stochastic effects. Occupational exposure of any worker is controlled such that effective dose of 20 mSv averaged over five years, and equivalent dose to the lens of the eye of 150 mSv and/or equivalent dose to the extremities or the skin of 500 mSv are not exceeded in any single year (NNRA, 2003).

Radiation Monitoring is also of primary importance for environmental protection purpose (El-Bahi, 2004). Thus, many operational activities involving the use of ionizing radiation source are taking place in oil and gas sector in Nigeria and to the best of my knowledge there is no regular assessment of occupational exposures and analysis of related trends to examine changes that have taken place over time due to regulatory operations or technological improvements conducted in this sector. This research work intends to assess the occupational exposure in some well logging and industrial radiographs and evaluate operational procedures on radiation safety practices issued by the NNRA in the oil and gas facilities in Nigeria

1.5 Significance of the Study

i. The outcome of this research will help NNRA to review its radiation safety requirements in the oil and gas facilities

ii. The outcome of this study will assist NNRA to establish national dosimetry register of radiation workers

iii. The licensee/operator can also use the data obtained from this work in assigning responsibilities to radiation workers

iv. The study will assist the operating organization in implementation and maintenance of its Radiation Safety Programme (RSP)

v. The outcome of the study will indicate the contribution of well-logging and industrial radiography practices to the collective dose

1.6. Scope of the Study

This work;

i. Evaluated operational procedures on radiation safety practices using the inspection parameters issued by the NNRA

ii. Assessed the occupational exposure of radiation workers, working in well logging and industrial radiography facilities within the period 2001-2016 based on the UNSCEAR, 2008 guidelines

iii. Assessed the emergency exposure among the radiation workers using dosimetry records.

CHAPTER TWO

LITERATURE REVIEW

2.1 Radiation

Radiation is a form of energy that is propagated through matter or space (IAEA, 2004). Radiation is classified into **ionizing** and **non-ionizing**; the former is a form of high-energy that is able to penetrate matter and knock off electrons of the material through which it is passing, that is, cause ionization in the matter, for example a cell or molecule in a biological system while the latter is a low frequency electromagnetic radiation that does not have enough energy to cause ionization (Obioha, 2007). Ionizing radiation is further divided into high frequency electromagnetic radiation (photons) which exists in form of waves and particulate radiation which appears as particles (Obioha, 2007).

For this research work the radiation of interest is ionizing radiation and the emissions of alpha, beta, gamma and neutron radiation are the most important processes.

2.1.1. Alpha Radiation

An alpha particle is actually the nucleus of a helium atom because it has two protons. Due to the fact that it is a heavy particle and that it has a charge of +2, an alpha particle will give up its energy within a very short distance mostly by causing ionization. The implication of this is that alpha radiation is not very penetrating. However, if the material becomes ingested or inhaled into the body then the alpha particles can ionize atoms in living cells. Another implication of the lack of penetrating power is that it makes alpha radiation difficult to detect. Special instruments with very thin windows or even without windows are required. In summary then, alpha radiation:

a Is not very penetrating, and can be shielded even by a sheet of paper;

b Is a significant internal hazard;

c Is detected only by special instruments. (Plate 2.1) (IAEA, 2004)

2.1.2. Beta Radiation

Beta particles, which are electrons, are very much smaller and lighter than alpha particles. The rate of ionization of β-particles is much less than that of alpha particles. The penetration range of beta particles depends on their energy and the density of the material they are passing through. In summary then, beta radiation:

a Is more penetrating than alpha radiation, but can be shielded by a sheet of metal, and is an external hazard to the skin and eyes;

b Is an internal hazard;

c Its detection is dependent on the energy of the radiation. (Plate 2.1) (IAEA, 2004)

2.1.3. Gamma Radiation

Gamma radiation is an electromagnetic radiation which is very penetrating depending on the energy of the radiation. High density material, or a large bulk of material, is required to shield gamma radiation. Consequently, it is relatively easy for gamma radiation to completely penetrate the body. Thus gamma radiation in summary:

a Is very penetrating, but can be shielded by dense materials such as lead and steel;

b Is an external as well internal hazard;

c Is easily detected at very low levels (IAEA, 2004)

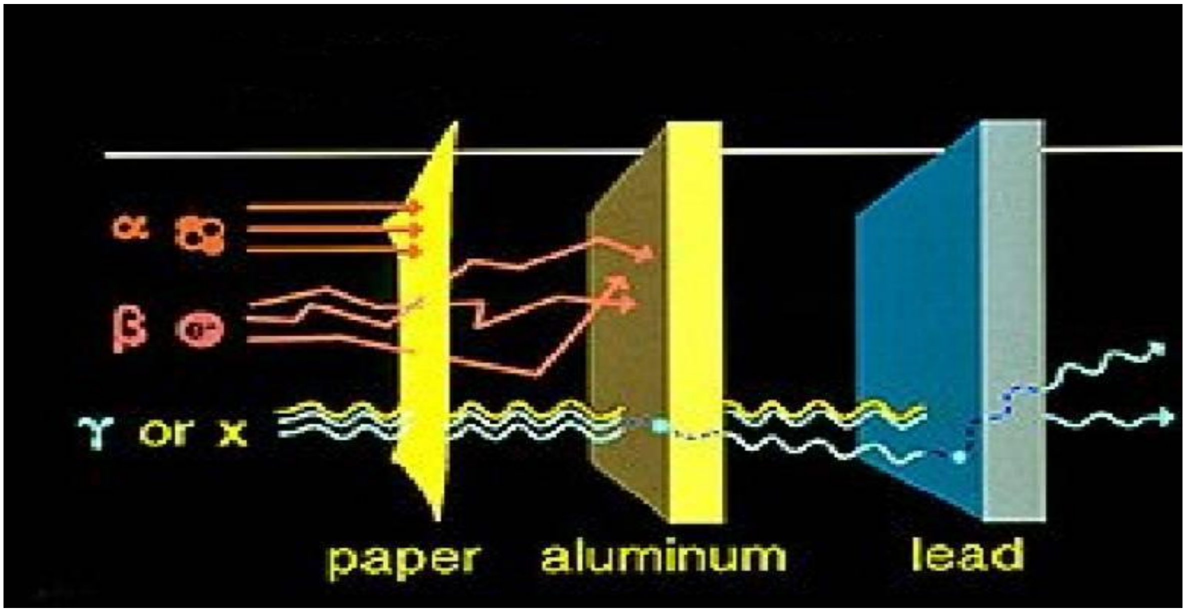

Plate 2. 1: The penetrating power of external radiation: alpha, beta and gamma (IAEA, 2010)

2.1.4. Neutron radiation

In addition to the existence of neutrons in the nucleus, it is possible to have free neutrons as a form of radiation. Neutrons are very penetrating and the ease with which they can be shielded and detected depends heavily on their energy. In summary then, neutron radiation:

- a Is very penetrating, but can be shielded by hydrogenous material for fast neutrons, and by cadmium or boron for slow thermal neutrons;
- b Is an external as well as internal hazard;
- c Is detected only with special instruments (IAEA, 2004)

2.2 Interactions of Radiation with Matter

When radiation passed through absorbing medium, it transfers part or all of its energy to the absorber atoms. The mechanism or type of the interaction that will occur depends on the type and the energy of the radiation as well as the nature of the absorbing medium (Knoll, 2000).

2.2.1 Interaction of Heavy Charged Particles with Matter

Heavy charged particles (such as α-particles, fission fragments and protons), interact with matter through coulomb forces between the positive charge of the particle and the negative charge of the orbital electron of the absorbing medium (Knoll, 2000).

The maximum energy that can be transferred from a charged particle of mass M with kinetic energy E to an electron of m_o in a single collision is: (Knoll, 2000)

$$E_{max} = {}^{4Em_{\circ}}\!/_{M} \qquad 2.1$$

Ionization occurs when the electron obtains enough energy to leave the atom of the absorbing medium and become a free particle with kinetic equal to;

$$(KE)_e = \begin{pmatrix} Energy\ given\ by \\ a\ particle \end{pmatrix} - \begin{pmatrix} Ionization \\ potential \end{pmatrix} \qquad 2.2$$

The electron freed from the atom may cause secondary ionization of another atom if its energy is high enough. It will interact with matter, lose its kinetic energy, and finally stop (Nicholas T and Sheldon S, 2015).

On the other hand, excitation occurs when the electron acquires enough energy to move to an empty state in the orbit of higher energy. The electron is still bound, but it has moved from a state with energy E_1 to one with E_2, thus producing an excited atom

(Nicholas T and Sheldon L, 2015).

2.2.2 Interaction of Fast Electrons (β-particles)

Fast electrons lose their energy at lower rate and follow a much more tortuous path through absorbing medium (Knoll, 2000). For electrons or positrons with kinetic energy T (MeV) moving in a material with atomic number Z, the energy loss $(dE/dx)_{rad}$. is given in terms of the ionization and excitation energy loss by:

$$\left({}^{dE}\!/_{dx}\right)_{rad} = \frac{ZT(MEV)}{750}\left({}^{dE}\!/_{dx}\right)_{ion} \qquad 2.3$$

where $(dE/dx)_{ion}$ is the stopping power due to ionization and excitation (Nicholas T, 1995)

2.2.3. Interactions of Photons with Matter

Photons, also called x-rays or γ-rays are electromagnetic radiations that travel with the speed of light c and they have zero mass and charge. The relationship between the energy E of a photon, its wavelength λ, and frequency h is given as: (Nicholas T and Sheldon L, 2015)

$$E = hv = h\,{}^{c}\!/_{\lambda} \qquad 2.4$$

There are three most important interactions of photons with matter: the Photoelectric effect, Campton scattering and Pair production.

2.2.3.1 Photoelectric Effect

The photoelectric effect is an interaction between a photon and a bound atomic electron, the photon disappears and one of the atomic electrons is removed as a free electron as a result of the interaction. The ejected electron is called photoelectron with the kinetic energy T as:

$$T = E_{\gamma} - B_{e} \qquad 2.5$$

where E_{γ} is the photon energy while B_e is the binding energy of the electron (Nicholas T, 1995)

The photoelectric effect is the predominant mode of interaction for photons of relatively low energy. The effect is also enhanced for absorber materials of high atomic number Z. The equation below represent the rough approximation of photoelectric coefficient over all ranges of E_γ and Z

$$\sigma_{pho} \cong Constant\ x\ {Z^n}/{E_\gamma}^{3.5} \qquad 2.6$$

where the exponent n varies between 4 and 5 over the γ-ray energy region of interest.

2.2.3.2 Compton Scattering

The Compton scattering is a collision between a photon and a free electron. Of course under normal condition, all the electrons in a medium are not free but bound. However, if the energy of the photon is of the order of keV or more, while the binding energy of the electron is of the order of eV, the electron may be considered free. The photon does not appear after a Compton scattering, only its direction of motion and energy change

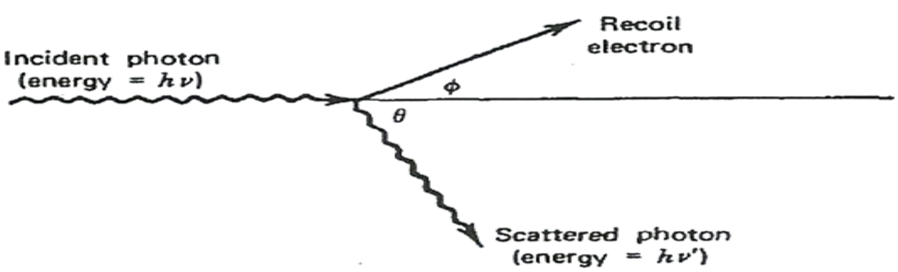

Figure 2. 1: Compton Effect (Knoll, 2000)

The photon energy is reduced by a certain amount that is given to the electron. Therefore, conservation of energy gives: (Nicholas T and Sheldon L, 2015)

$$T = E_\gamma - E_{\gamma'} \qquad 2.7$$

The energy of the scattered photon as a function of the scattering angle θ can be calculated using equation 2.8 (Nicholas T and Sheldon L, 2015)

$$E_{\gamma'} = \frac{E_\gamma}{1 + (1 - \cos\theta)\, E_\gamma / mc^2} \qquad 2.8$$

While the kinetic energy of the electron can be obtained from equation 2.9 below;

$$T = \frac{(1 - \cos\theta)\, E_\gamma / mc^2}{1 + (1 - \cos\theta)\, E_\gamma / mc^2} E_\gamma \qquad 2.9$$

A matter of great importance in radiation measurement is the maximum and minimum energy of the photon and the electron after the collision. The minimum energy of the scattered photon ($E_{\gamma' min}$) is obtained when θ = π and this correspond to the maximum energy of the electron (T_{max}) both represented by equations 2.10 and 2.11 below;

$$E_{\gamma', min} = \frac{E_\gamma}{1 + 2\, E_\gamma / mc^2} \qquad 2.10$$

$$T_{max} = \frac{2\, E_\gamma / mc^2}{1 + 2\, E_\gamma / mc^2} E_\gamma \qquad 2.11$$

The conclusion that can be drawn from equation 2.10 is that the minimum energy of the scattered photon is greater than zero. Therefore, in Campton scattering, it is impossible for all the energy of the incident photon to be given to the electron. The energy given to the electron will be dissipated in the material within a distance equal to the range of the electron. (Nicholas T, 1995)

2.2.3.3 Pair Production

Pair Production is an interaction between a photon and a nucleus. As a result of the interaction, the photon disappears and electron-positron pair appears. Although the nucleus does not undergo any change as a result of this interaction, its presence is necessary for pair production to occur. Another condition for pair production to occur is that, the available kinetic is equal to the energy of the photon minus 1.022Mev is necessary for the production of the two rest masses for the electron-positron pair. That is, the electron and positron share, for all practical purpose, the available kinetic energy (T) (Nicholas T and Sheldon L, 2015)

$$T_{e^-} = T_{e^+} = \frac{1}{2}\left(E_\gamma - 1.022MeV\right) \qquad 2.12$$

Pair production eliminates the original photon, but two photons are created when the positron annihilates. These annihilation gammas are important in constructing a shield for a positron source as well as for the detection of gammas (Nicholas T and Sheldon L, 2015).

2.3 Radiation Protection Principles

The International Basic Safety Standards for Protection against Ionizing Radiation and the Safety of Radiation Sources (the BSS) (IAEA, 1996a) which was published by the IAEA in 1996 is the key international standard in relation to radiation protection. The BSS is based on the recommendations of the International Commission on Radiological Protection (ICRP), principally those set out in ICRP, 1990 and was prepared jointly by the Food and Agriculture Organization (FAO) of the United Nations, the IAEA, the International Labour Organization (ILO), the Nuclear Energy Agency of the Organization for Economic Co-operation and Development (OECD), the Pan American Health Organization (PAHO) and the World Health Organization (WHO). The Nigeria Basic Ionizing Radiation Regulations (NiBIRR) was published by the NNRA in 2003 and is the key national standard in relation to radiation protection. The NiBRR is based on the Nuclear Safety and Radiation Protection Act 19 of 1995 (NNRA,1995) and the recommendations in BSS.

2.3.1. Some Quantities and Units

2.3.1.1. Absorbed dose

When radiation strikes a material, it will deposit energy in that material through a variety of interactions (e.g. ionization). A measure of the amount of radiation that a material has received is the quantity called absorbed dose. Absorbed dose, D, is the amount of energy deposited per unit of mass as a result of the interplay of ionizing radiation (this includes neutron radiation), and matter. The unit of absorbed dose is the gray (Gy), which is equal to an energy deposition of 1 J/kg.

One difficulty with the use of absorbed dose for radiation protection purposes is that the biological effect of an absorbed dose in tissue is dependent on the type and energy of the incident radiation. To overcome this difficult, a quantity called equivalent dose is used.

2.3.1.2. Radiation weighting factors and equivalent dose

To take account of the radiation quality of interest, a weighting factor called the radiation weighting factor, w_R is used. The equivalent dose in tissue, H_T, is given by the expression:

$$H_T = \sum_R w_R . D_{T,R} \qquad 2.13$$

Where $D_{T,R}$ is the absorbed dose averaged over the tissue or organ, T, due to radiation R. The SI unit of equivalent dose is J/Kg but it is given the special name sievert (Sv).

The value of the radiation weighting factor for a specified type and energy of radiation has been selected by the ICRP to be representative of values of the relative biological effectiveness of that radiation in inducing stochastic health effects at low doses ICRP 103 (2007). The values of W_R are shown in Table 2.1 below;

Table 2. 1: Recommended Radiation Weighting Factors (ICRP 60, 1990 & NNRA 2003)

Radiation Type	Energy range	Radiation Weighting Factor W_R
x-ray, gamma rays, electrons and muons	All energies	1
Neutrons	<10 KeV	5
	10 KeV – 100 KeV	10
	>100 keV – 2 MeV	20
	> 2Mev – 20 MeV	10
	> 20 MeV	5
Protons	All energies	5
Alpha particles, heavy Ions, Fission fragment	All energies	20

2.3.1.3. Tissue Weighting Factors and Effective Dose

There are circumstances where doses to individual organs can be assessed (e.g. for the purpose of determining limits on the ingestion or inhalation of radioactive materials). Thus a method is needed to combine the organ doses to give either an overall measure of the dose or an assessment of the biological risk. To do this, tissue weighting factors, W_T, have been determined that take account of the relative radiosensitivity of different tissues (T). The effective dose, E, is given by

$$E = \sum_T w_T H_T = \sum_T w_T \sum_R w_R D_{T,R} \qquad 2.14$$

The values have been developed from a reference population of equal numbers of both sexes and a wide range of ages (IAEA, 2010). The values of tissue weighting factors are shown in Table 2.2.

Table 2. 2: Recommended Tissue Weighting Factors (ICRP, 60 (1990) and NNRA (2003)

Tissue/organ	Radiation Weighting Factor (W_T)
Gonads	0.20
Bone marrow	0.12
Stomach	0.12
Lungs	0.12
Colon	0.12
Bladder	0.05
Breast	0.05
Liver	0.05
Esophagus	0.05
Thyroid	0.05
Skin	0.01
Bone surface	0.01
Remainder	0.05
Total	1.00

2.3.1.4 Committed equivalent dose and committed effective dose

The committed equivalent dose is a quantity that takes into account the time that a radionuclide will be resident in a person's body. When radioactive material is deposited inside the body, the various tissues of the body are committed to a certain dose. The magnitude of this dose is a function of many factors including the radionuclide, its half-life, and the metabolism of the element in the body. For the purpose of determining annual intake limits for occupationally exposed adults, the convention is adopted of assessing the total equivalent dose to an organ that will accrue in the 50 years following an intake of a radionuclide. The dose commitment assessed in this way is known as the committed equivalent dose, H_T (50). For members of the public, the time period is 50 years for adults and to age 70 years for infants and children. The summation of the committed equivalent dose in each significant organ or tissue multiplied by the weighting factor gives the committed effective dose. Thus, for adults: ICRP 60 (1990)

$$E(50) = \sum_{T} w_T H_T(50) \qquad 2.15$$

2.3.1.5 Collective equivalent dose and collective effective dose

In discussion of the effects of radiation on human populations, a number of collective quantities are useful. The collective equivalent dose, ST, is the summation of the individual equivalent doses received by a group of people. The collective effective dose, S, is similarly defined except that the effective dose is used in the summation. The unit of both of these quantities is person-sievert (person-Sv). A given source or practice may give rise to a collective effective dose rate which varies as a function of time. ICRP 60 (1990)

2.4. Biological Effects

The upper end of the range of interest for dose and dose rate can best be illustrated by reference to those levels required to cause short term biological effects.

2.4.1 Short term biological effects

Biological effects of radiation vary greatly depending on such factors as the amount of exposure, rate of exposure, area of body irradiated, type of radiation and individual biological variability. Relatively large doses of radiation are required to produce short term biological effects. At high dose rates, the appropriate dose quantity is absorbed dose (Gy). The radiation weighting factors, w_R, given in Table 2.1 and the tissue weighting factors, w_T given in Table 2.2 are appropriate only for low doses.

If enough individual cells are damaged by ionizing radiation, then specific clinical symptoms will be evident. Most of these symptoms and effects can be classified as deterministic. A deterministic effect is one in which the severity of the effect is a function of the dose, and there is a threshold below which there is no clinically observable effect. Fig. 2.2 illustrates the form of this relationship. The plot shows that up to a certain dose the effect is negligible. As the dose increases, the effect increases up to a point where there is some maximum effect.

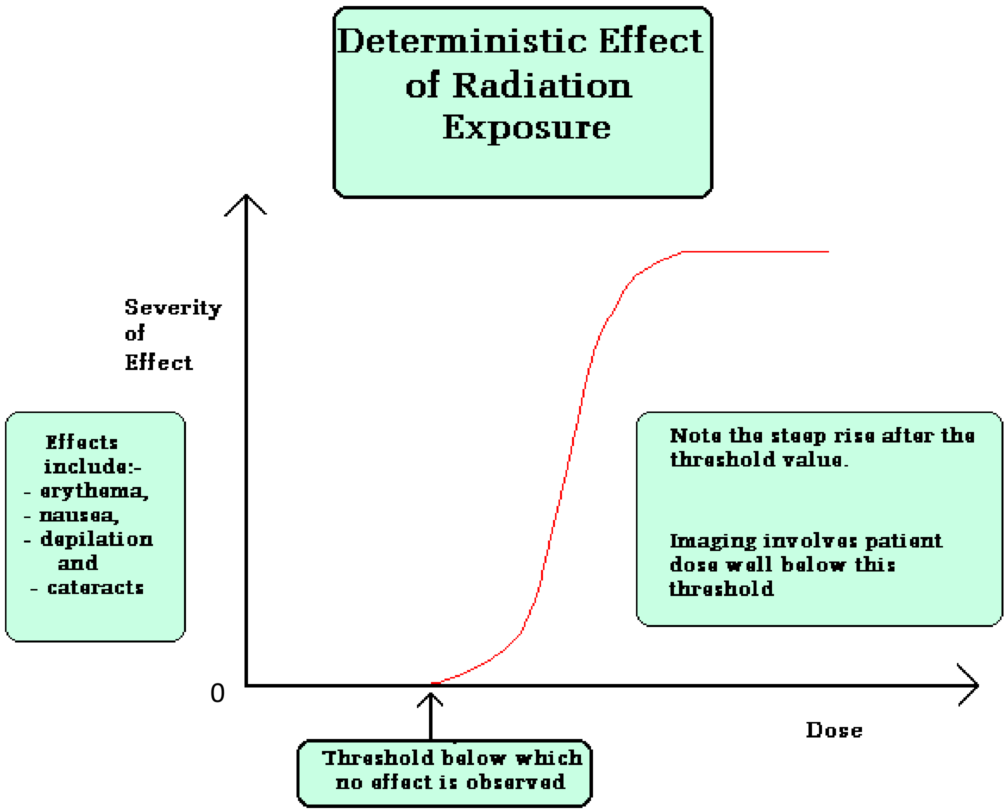

Figure 2. 2: Plot of Effect Severity per Dose (deterministic effects) (IAEA, 2010)

Radiation sickness is characterized by a group of symptoms that include diarrhoea and vomiting, nausea, lassitude, hemorrhaging, emaciation, infection and, ultimately death. The unset and severity of these symptoms is mainly a function of dose.

Table 2.3 gives a broad indication of the dose levels for certain short term effects following whole body irradiation over a short period of time. If only part of the body is irradiated it would require much larger doses to produce the same effect (IAEA, 2010).

Table 2. 3: Doses for Acute Biological Effects

Effect	Dose (Gy)
No discernible effect	0.25
Blood Changes, no illness	1.0
Radiation Sickness, no deaths	2.0
Death to 50% of irradiated people	4.5
Death to 100% of irradiated people	10.0

2.4.2. Long term biological effects

The major long term biological effects from smaller doses received over a longer period of time are the increased risks of cancer and severe hereditary effects in progeny.

2.4.2.1 Cancer

Cancer induction is a stochastic effect, in that the probability of the effect is a function of dose, perhaps with no threshold. The shape of the dose response function is uncertain. It is probably sigmoidal in shape, but is often conservatively assumed to be linear through the origin, giving rise to the so-called 'linear no-threshold' (LNT) approach to radiation protection. The forms of the two relationships are illustrated in Fig. 2.4.

Some organs are more sensitive to cancer induction than others. The sensitivities for different organs are given by the tissue weighting factors. All radiation-induced cancers have some long latent period before they appear.

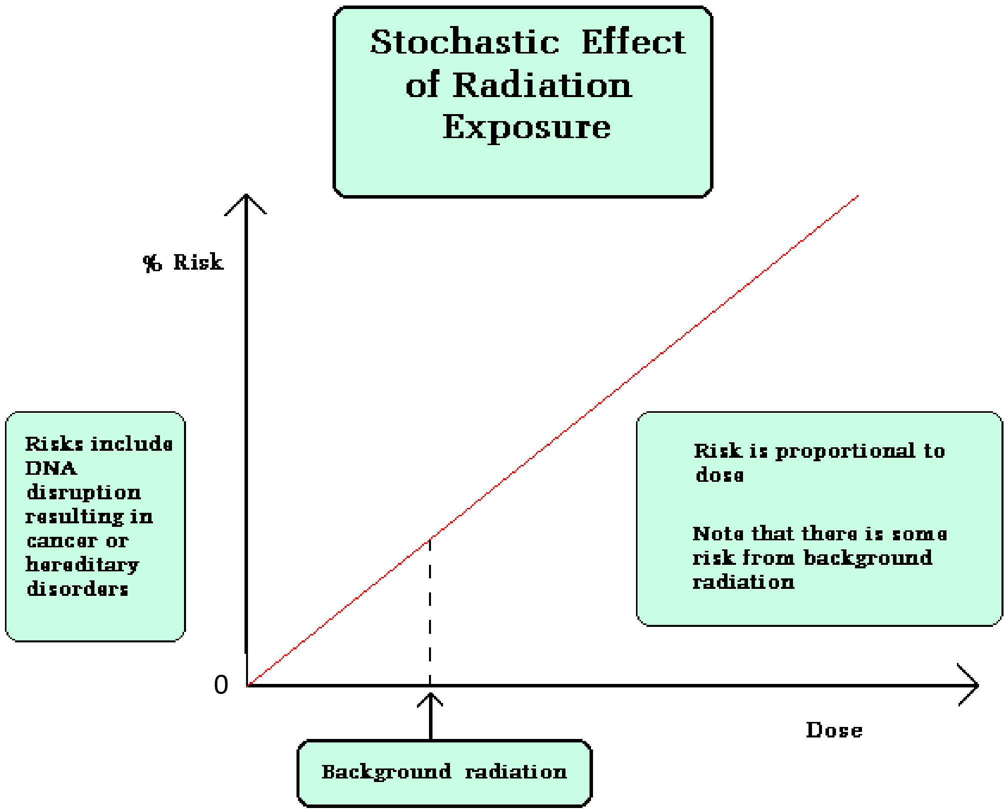

Figure 2. 3: Percentage Risk per Dose (stochastic effect) (IAEA, 2010)

2.4.2.2. Genetic Effects

In epidemiology, hereditable effects of radiation in humans have not been detected with a statistically significant degree of confidence. However, there is compelling evidence that radiation causes heritable effects in experimental animals. It is therefore prudent to assume also the existence of hereditary effects in humans. Risk estimation therefore, rests on genetic experimentation with a wide range of organisms and on cellular studies, with limited support from the negative human findings. With this in mind, ICRP estimates the risk of hereditable effects at 0.2×10^{-2} per Sv ICRP 103 (2007).

2.4.3. The Linear Non-Threshold Dose-Response Relationship

The basic philosophy of radiation protection, as developed by the ICRP, is to avoid short term biological effects and to restrict long term biological effects to an acceptable level.

It is based on the assumption that, at doses below about 100 mSv, a given increment in dose will produce a directly proportional increment in the probability of incurring cancer or heritable effects attributable to radiation. The ICRP considers that the application of the LNT approach combined with a judged value of the DDREF provides a prudent base for purposes of practical radiation protection, i.e. the management of risks from low-dose radiation exposure in prospective situations. ICRP 60 (1990); 103 (2007)

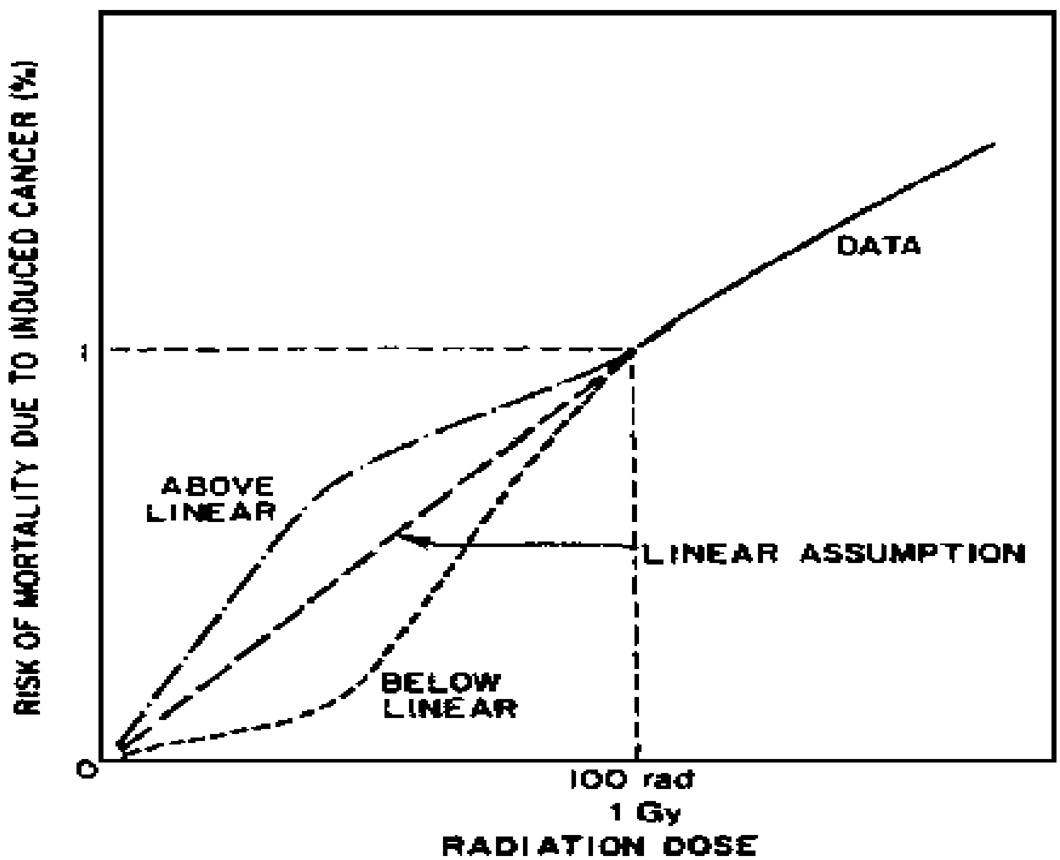

Figure 2. 4: Dose Response Relationship ICRP 60 (1990); 103 (2007)

2.5. Radiation Protection Procedures

Radiation protection requirements which define the system of radiation protection are contained in the BSS (IAEA, 1996a), Nuclear Safety and Radiation Protection Act 19 of

1995 (NNRA, 1995), Nigeria Basic Ionizing Radiation Regulation (NiBIRR) 2003 (NNRA, 2003), Nigerian Transportation of Radioactive Sources Regulations 2006 (NNRA, 2006) and Nigerian Safety Regulation in Nuclear Well Logging 2008 (NNRA, 2008)

2.5.1. Exposure Situations

There are three (3) types of exposure situation as defined in ICRP Publication 103 and Nigeria Basic Ionizing Radiation Regulations (NiBIRR) 2003 for the purposes of establishing radiation protection principles, namely, planned exposure situations, emergency exposure situations and existing exposure situations.

2.5.1.1 Planned exposure situations

Planned exposure situations are those involving the deliberate introduction and operation of radiation sources. Planned exposure situations may give rise both to exposures that are anticipated to occur (normal exposures) and to exposures that are not anticipated to occur (potential exposures), i.e. adding radiation exposure to that which people normally receive from existing radiation sources, or that increase the likelihood of their incurring exposure. In these situations, radiation protection can be planned in advance, before exposures occur, and the magnitude and extent of the exposure can be reasonably predicted. In the NiBIRR, planned exposure situations are generally referred to as ‘practices’. In introducing a practice, all aspects relevant to radiation protection should be considered, i.e. design, construction, operation, decommissioning, waste management, and remediation of contaminated land and facilities (IAEA, 2010).

2.5.1.2. Emergency exposure situations

Emergency exposure situations on the other hand, are those that may occur during the operation of a planned situation (practice), or from a malicious act, or from any other unexpected situation, and require urgent action in order to avoid or reduce undesirable consequences. Exposure of members of the public or of workers, as well as environmental contamination can occur in these situations.

Response actions should be planned because potential emergency exposure situations can be assessed in advance, to a greater or lesser accuracy, depending upon the type of installation or situation being considered. NiBIRR (NNRA, 2003) described emergency exposure situations as "Intervention".

2.5.1.3. Existing exposure situations

Existing exposure situations are those that already exist when a decision on control has to be taken, including prolonged exposure situations after emergencies. There are many types of existing exposure situations that may cause exposures high enough to warrant radiation protection actions, or at least their consideration. Exposures to natural sources of radiation, including radon in dwellings and workplaces, are well-known examples. But there are also man-made existing exposure situations, such as residues in the environment resulting from emissions of radionuclides from operations in the past that were not under regulatory control, and contaminated land resulting from an accident.

Radiation protection actions in existing exposure situations are addressed in the BSS and NiBIRR as 'chronic exposure situations' under the heading "Intervention". Existing exposure situations requiring remedial action to reduce or avert chronic exposure, include:

- i Exposure to natural sources, such as radon in buildings and workplaces;
- ii Exposure to radioactive residues from past events, such as to the radioactive contamination caused by accidents, after the situation requiring protective action has been terminated, as well as from the conduct of practices and the use of sources not under the system of notification and authorization;

iii Any other chronic exposure situation specified by the regulatory body or the Intervening Organization as warranting intervention.

2.5.2. Exposure categories

The BSS and NiBIRR distinguish between three categories of exposures: occupational exposure, public exposure, and medical exposure of patients.

2.5.2.1. Occupational exposure

The BSS (IAEA, 1996a) and NiBIRR (NNRA, 2003) defines occupational exposure as “All exposures of workers incurred in the course of their work, with the exception of exposures excluded from the Standards and exposures from practices or sources exempted by the Standards”. It is these occupational exposures that should be the responsibility of the operating management.

Excluded exposures are those that are essentially unamenable to control. Examples of such exposures given in the NiBIRR are those from potassium-40 in the body, from cosmic rays at the earth’s surface, and from unmodified concentrations of radionuclides in most raw materials.The main criterion for exemption is that the radiation risks to individuals caused by the exempted practice or source be sufficiently low as to be of no regulatory concern.

2.5.2.2. Public exposure

Public exposure encompasses all exposures of the public other than occupational exposure and medical exposure of patients. A broad range of different natural and manmade radiation sources contribute to the exposure of members of the public. The component of public exposure due to natural sources is by far the largest. This, however, provides no justification for reducing the attention paid to smaller, but more readily controllable, exposures to man-made sources.

2.5.2.3. Medical exposure of patients

Radiation exposure of patients occurs in diagnostic, interventional and therapeutic procedures. The exposure is intentional and for the direct benefit of the patient. The features of radiological practices in medicine, particularly in radiotherapy where high-dose biological effects such as cell killing are used to treat cancer and other diseases, require a radiation protection approach which differs from that in other planned exposure situations.

2.6. Principles

For proposed and continuing planned exposure situations (practice), the system of protection is based on the general principles given below:

2.6.1. Justification of practice

ICRP 103 (2007) refers to the principle of justification as: "Any decision that alters the radiation exposure situation should do more good than harm". It means that by introducing a new radiation source, by reducing existing exposure, or by reducing the risk of potential exposure, one should achieve sufficient individual or societal benefit to offset the detriment it causes.

In accordance with the ICRP recommendations, the BSS states that, "No practice, or source within a practice, should be authorized unless the practice produces sufficient benefit to the exposed individuals or to society, to offset the radiation harm that it might cause; that is, unless the practice is justified, taking into account social, economic and other relevant factors". Thus, all the merits and harm associated with the practice and the possible alternatives under consideration should be taken into account in reaching the decision. IAEA (1996b); ICRP 60 (1990); 103 (2007).

2.6.2. Optimization of practice

The principle of optimization of protection, with constraints on the magnitude of individual dose and risk, is central to the system of protection, and is intended for application to those situations that have been deemed to be justified. It applies to all three exposure situations, i.e. to planned, existing and emergency situations. ICRP 103 (2007) defines optimization as the source-related process to keep the likelihood of incurring exposures, the number of people exposed, and the magnitude of individual doses as low as reasonably achievable (ALARA), taking economic and societal factors into account ICRP 103 (2007).

A wide range of techniques is available to optimize radiation protection. Some of these techniques are drawn from operational research, some from economics, and some from engineering. The techniques available include procedures based on cost-benefit analysis. It is important to recognize that other techniques, some quantitative, others qualitative, may also be used in the optimization of radiation protection.

2.6.3. Dose limits

The BSS and NiBIRR state that, for practices: "The normal exposure of individuals shall be restricted so that neither the total effective dose nor the total equivalent dose to relevant organs or tissues, caused by the possible combination of exposures from authorized practices, exceeds any relevant dose limit specified in Table 2.4 "Dose limits shall not apply to medical exposures from authorized practices" (NNRA, 2003). It is important to recognize that dose limits are set so that any continued exposure just above the dose limits would result in additional risks that could be reasonably described as "unacceptable" in normal circumstances.

There are basically two objectives in limiting dose. The first is to keep doses below the threshold level for deterministic effects and the second is to keep the risk of stochastic effects at a tolerable level. The stochastic effects occur at considerably lower doses and are therefore the basis for dose limitation. The dose limits prescribed in the NiBIRR are summarized in Table 2.4.

Table 2. 4: Dose Limits in Planned Exposure Situations ICRP 103 (2007); NNRA (2003)

Type of limit	Occupational	Public
Effective Dose	20 mSv per year, average over 5 consecutive years, 50 mSv in any single year	1 mSv in a year
Equivalent Dose		
Eye lens	150 mSv in a year	15 mSv in year
Skin	500 mSv in a year	50 mSv in year
Extremities	500 mSv in a year	-------------------

2.7. Basic Concepts of Occupational Radiation Protection

2.7.1. Control of Exposure to External Radiation

Optimization of protection is one of the key principles of radiation protection, in terms of which “the magnitude of individual doses, the number of people exposed and the likelihood of incurring exposures all be kept as low as reasonably achievable (ALARA), economic and social factors being taken into account” (IAEA, 1999b).The dose received is the product of the dose rate and the time exposed:

$$\text{Dose} = \text{Dose rate} \times \text{Time} \qquad 2.16$$

Therefore, dose from external radiation can be reduced by either reducing the dose rate, or by shielding, or by moving a greater distance from the source, or by reducing the time spent near the source (IAEA, 2010):

- Reducing the time spent near the source of radiation will reduce the total dose that a person receives. This principle is applied in many situations as a safety measure.
- Increasing distance from a source is a very good way of reducing the radiation dose rate and hence the total dose. For small sources emitting gamma rays, the inverse square law applies. Doubling the distance will reduce the dose rate to one quarter.
- Placing shielding material between a source and the person will also reduce the dose rate. For gamma radiation, dense materials such as lead and steel are the most effective shields.

2.7.2. Radiation Protection Programmes

A radiation protection programme is a system of measures that primarily ensures the health and safety of workers and the public from radiation and radioactive material. Measures are also taken with the objective of minimizing environmental impact. The nature and extent of these measures are related to the magnitude and likelihood of radiation exposures. The radiation protection programme should include a training programme for the personnel concerned.

The BSS (IAEA, 1996a), the Safety Guide on Occupational Radiation Protection RS-G-1.1 (IAEA, 1999b) and Nigeria Basic Ionizing Radiation Regulation 2003 (NNRA, 2003) provide specific objectives of radiation protection programmes and guidance on how to achieve these objectives. The basic components of a typical radiation protection programme set down by NNRA, 2003 in its regulatory requirements includes; individual dosimetry for workers handling the radiation sources as well as dose rate and contamination surveys of working areas, Policy on Female Worker, Training of both classified and unclassified workers, Emergency Preparedness and Response and Medical Supervision of Classified

Workers. Record keeping is also an important element of any radiation protection programme.

2.7.3. Application of Annual Limits

When a dose limit is exceeded, employers are required by Nigeria Basic Ionizing Radiation Regulation 2003 (NNRA, 2003) to promptly communicate this to the regulatory body (NNRA) and the worker(s) involved in the event. Suitable arrangements should therefore be in place for such communication.

Situations in which workers exceed the single year limit of 50 mSv should be considered exceptional. These may occur as the consequence of an emergency, accident or intervention. In the event that a worker receives a single year exposure that exceeds 50 mSv, it would be appropriate for the worker to continue working with radiation provided that:

a The regulatory body, having due regard to the health of the worker, considers there is no reason to prevent continuing work with radiation;

b The management and the regulatory body, in consultation with the worker (through his or her representatives where appropriate), agree on a temporary dose restriction and the period to which it applies.

A restriction based pro rata on the remaining period of time to which the dose limit relates might be appropriate, and further restrictions may need to be applied in order to keep within the dose limit of 100 mSv in five years.

Regulatory bodies should ensure that systems are in place that prevents workers who have received an exposure close to a relevant dose limit being deprived of their right to work. Situations may arise in which a worker has unintentionally received a total dose that is close to the relevant dose limit, such that further planned exposures may result in that limit being exceeded (IAEA, 2010). This situation should be treated in a similar manner to that of a worker who exceeds a dose limit.

In general, the dose limits apply equally to male and female workers. However, because of the possibility of a greater sensitivity of the foetus to radiation and the requirement for the foetus to receive the same broad level of protection as for members of the public, additional controls may have to be considered for pregnant workers (NNRA, 2003).

2.8 The Oil and Gas Industry

2.8.1. Industry Structure

The oil and gas industry is a global industry that operates in many countries. There are several facets to the industry including:

- The construction sector responsible for manufacturing and fabricating of facilities and equipment;
- The production sector responsible for developing and exploiting commercially viable oil and gas fields;
- 'Downstream' sectors dealing with transport of the raw materials and their processing into saleable products;
- Marketing sectors responsible for the transport and distribution of the finished products.

The oil and gas industry involves a wide range of organizations, companies and individuals in the mapping and evaluation of geological formations, the development and maintenance of facilities to extract and process natural hydrocarbon resources, and the distribution of their products. Although some reserves are extracted at low to moderate production rates by 'independent' oil and gas companies of relatively small size, the industry is dominated by a limited number of 'majors'—multinational organizations large enough to mobilize resources, equipment and manpower on a global scale. Some countries have State-owned oil and gas companies. (IAEA, 2010)

The industry is organizationally and technically complex and consequently has developed an extensive specific vocabulary. It often occurs that a number of oil and gas companies invest in the development of a particular field and an 'operator' is appointed with the responsibility for managing the development and production of the field. The operator usually establishes contracts with numerous 'service companies' and 'supply companies' that provide the necessary equipment and expertise. The work of such companies may include the use of radioactive sources and machines that generate ionizing radiation. (IAEA, 2010)

2.8.2. Application of Radiation Technologies in Oil and Gas Industry

2.8.2.1. Industrial Radiography

Oil and gas operators commonly employ service companies that carry out industrial radiography. Radiography is a form of non-destructive testing (NDT) performed to provide quality assurance during engineering projects. The oil and gas industry uses radiography techniques (gamma and x-ray energized) to assess the validity of construction and fabrications works to ensure compliance with the set standard. It is essential for all components and connections, particularly welds in the plant and equipment, to withstand the very high physical forces (for example, forces generated by hydrostatic pressures) associated with oil and gas production. Radiography is carried out during the construction and maintenance of rigs and platforms, particularly during the development of the plant and equipment above the waterline. It is also common when pipelines are being laid and prior to the 'hook up' when the production and export systems are to be connected (IAEA, 1999a, 1990b).

The radiography service companies usually set up independent bases close to construction yards and other land based facilities where oil and gas are processed. These facilities enable them to store and maintain their radiation sources and ancillary equipment and to be readily available to carry out specific jobs on demand. Where the oil or gas field being developed or worked is at a more remote location, such as offshore, a radiography service company typically has a permanent presence often in facilities made available by the operator. Radiographers will follow the construction phase overland during pipe laying projects. They are typically crew members on pipe-laying barges when subsea pipelines are installed between oil and gas production installations and their processing facilities and markets. X ray and gamma pipeline crawlers are normally used on pipe laying barges and in the field during the construction of overland pipelines.

The oil and gas production industry contracts out underwater radiography almost exclusively. The work is usually carried out to examine seabed pipelines, subsea assemblies and platforms or rigs below the waterline. Different service companies may employ the divers and radiographers. The radiography company may subcontract the services (or rent equipment) to a specialist diving company. Alternatively, the operator may manage the workers directly. These approaches demand close supervision and cooperation from the separate service companies that specialize in diving and radiography.

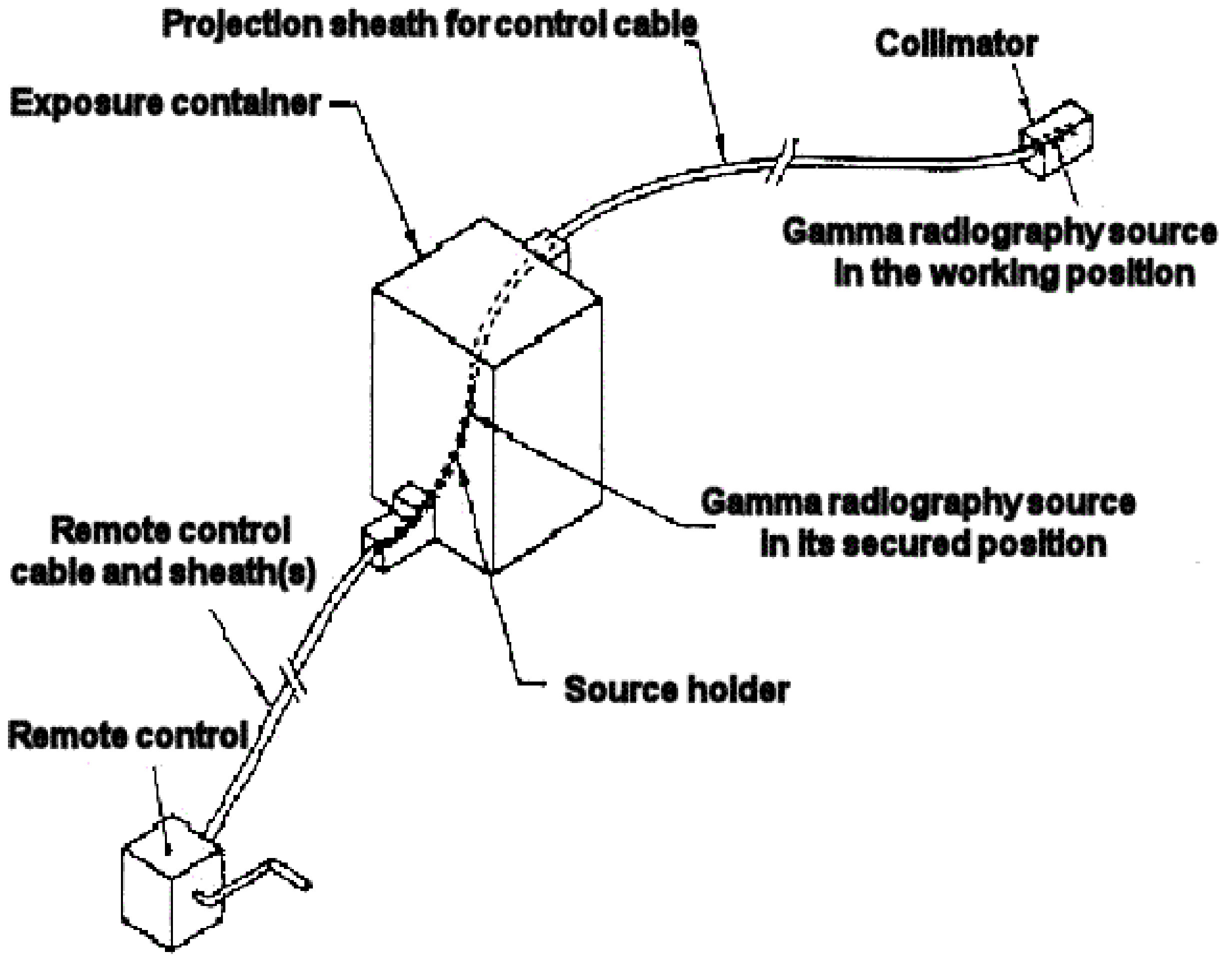

Table 2. 5: Industrial Radiography Set Up (IAEA, 1999a)

2.8.2.2. Well logging

2.8.2.2.1. Logging tools and techniques

Well logging companies place rugged, highly technical ‘logging tools’ in the well to measure physical parameters in the well, the geological properties of the rocks around the well, and the presence of elements in the rocks. Among the many types of tools there are those used to measure fluid temperature, pressure, density, and flow rates; detect casing corrosion and hardware; and measure rock density, porosity and isotopic content. Some of the tools contain one or more radiation detectors and radioactive sources or a machine that generates ionizing radiation. These are referred to as nuclear logging tools.

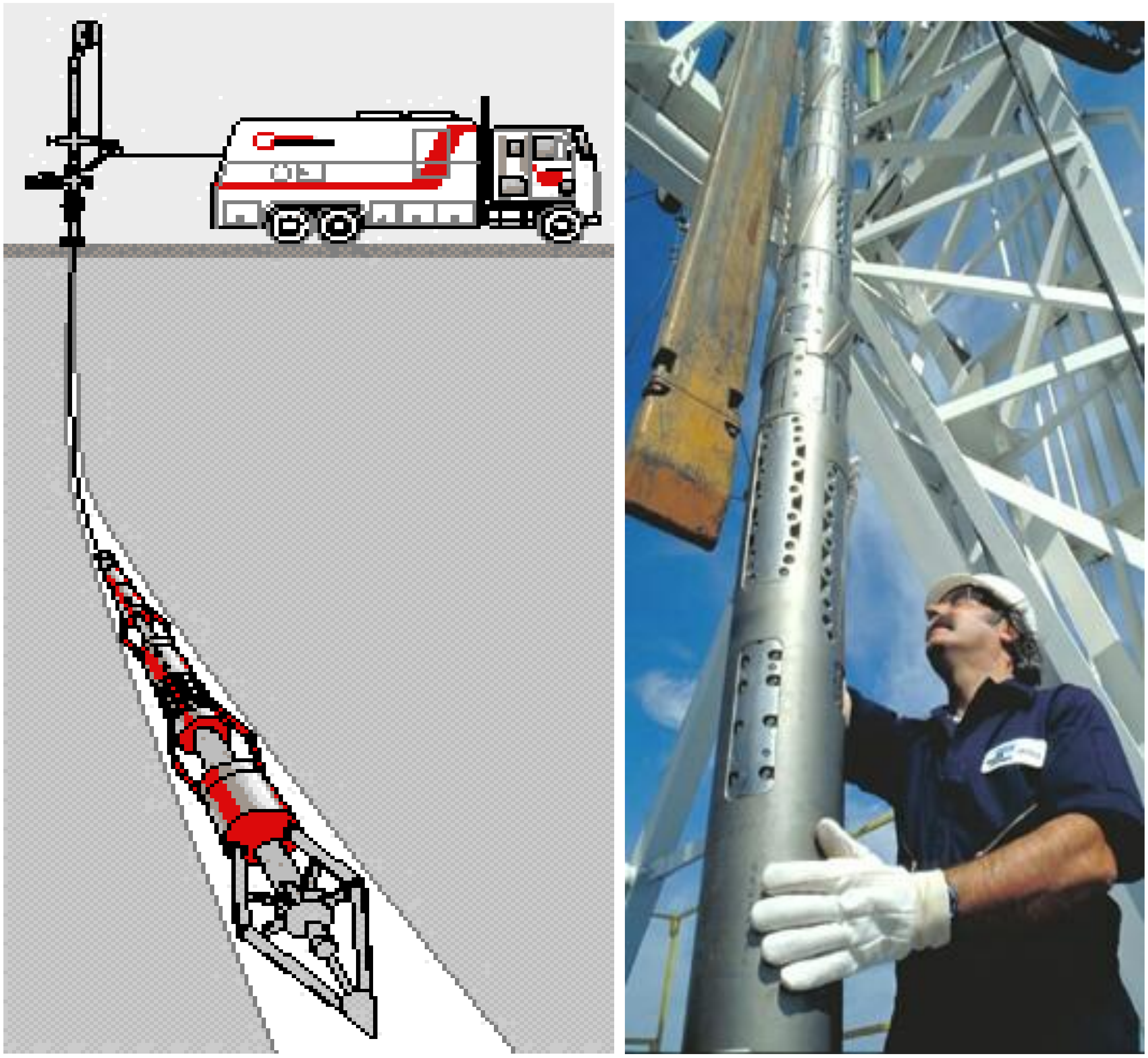

Plate 2. 2: Well Logging Tools (IAEA, 2010)

In ‘wireline logging’ systems, the drill string is first removed from the well and the logging string (a series of logging tools connected together) is then lowered to the bottom of the well on a cable (the wireline). The cable also carries the measurement data signals back to the surface where they are recorded on a log. As the wireline tool is slowly raised, the log plots the parameter being measured against the well depth. ‘Logging-while-drilling’ and ‘measurement-while-drilling’ systems avoid the need to first remove the drill string by incorporating the logging tools in the drill collar or coiled tubing. Signals are sent back to the surface by means of a positive mud-pulse telemetry system. Equipment at the wellhead interprets the mud pulses and logs the data.

There are four common nuclear logging techniques (IAEA, 1993):

i. The first, sometimes called the 'gamma measurement' technique, simply measures and identifies the gamma rays emitted by naturally occurring radionuclides in rocks to help to distinguish the shale content of sedimentary rocks for lithological identification. The log records the uranium, thorium and potassium content of the rocks.

ii. The second technique, which provides a neutron–neutron or compensated neutron log, requires a radioactive source of up to several hundred gigabecquerels of ^{241}Am–Be or Pu–Be in the tool to emit 4–5 MeV neutrons. An elongated skid hydraulically presses the tool against the wall of the well and two radiation detectors, located at different distances from the source in the tool, measure the neutrons backscattered from the rock formation. The relationship between the two readings provides a 'porosity index' for the rock. This indicates how porous the rock is and whether it is likely to contain hydrocarbons or water.

iii. The third type of tool, called the gamma–gamma or density tool, also contains two detectors and a ^{137}Cs source usually of up to 75 GBq. The amount of gamma backscatter from the formation provides the density log that, together with the porosity log, is a valuable indicator of the presence of gas.

iv. The fourth technique, called neutron–gamma logging, involves a tool that houses a miniature linear accelerator. It contains up to several hundred gigabecquerels of tritium (^{3}H, a very low energy beta particle emitter). When a high voltage (typically 80 kV) is applied to the device, it accelerates deuterium atoms (^{2}H) that bombard the tritium target and generate a large number of very high energy (14–15 MeV) neutrons in pulses lasting a few microseconds. Certain nuclides become radioactive when hit by this neutron flux, and their subsequent radioactive decay within the next few milliseconds can be monitored when the process is repeated a great number of times per second. Either the gamma radiation emitted as the activated atoms decay or the thermal neutron decay characteristics are measured to identify the activated species of atoms.

The gamma and neutron sources used in well logging tools are normally transported in separate heavy containers called shipping shields or carrying shields. They are Type A transport packages (or sometimes Type B for the neutron source) meeting the specifications for category III labeling as defined by the IAEA Regulations for the Safe Transport of Radioactive Material (IAEA, 2009) and Nigerian Transport of Radioactive Material Regulation 2006 (NNRA, 2006) . The radiation sources also may be transported by road in the vehicles of the well logging companies to the land well (Plate 2.3).

When radioactive sources are to be used offshore, the shields are usually contained in an overpack (Plate 2.4) (IAEA, 2009). This may be a large thick-walled box of stainless steel (external dimensions about 1.75 m x 1.75 m x 1.75 m) that also serves as a storage container at the well site. The shields do not provide adequate shielding for storing the sources without use of the large container.

When the tools are hoisted into position above the well, the logging engineer transfers the sources from the shields to the tools using a handling rod of approximately 1.5 m long.

The dose rates of the ^{137}Cs source are significant (Fujimoto et al, 1985., Gieger N and Moore RT, 1966), but not normally isotropic due to the construction of the source assembly. Dose rates may exceed 7.5 μSv/h for up to 30m in the forward direction and about 4m behind the engineer. The radiation from the source is directed away from any occupied areas. The dose rates of the neutron sources can exceed 7.5 μSv/h for distances up to about 4m. In addition to a 'set' of sources used in the logging tools, the logging engineer will need a number of 'field calibration sources' to carry out final checks on the tools before beginning the log. 'Master calibrations' are periodically performed on the tools at the logging company's operations base. These tests will involve putting the sources into the tools or a section of the tool (Plate 2.2), and either placing the tool inside a calibration block or placing a block over the source position on the tool. The master calibration for the neutron–gamma logging tool involves generating neutrons while the tool is inside a tank filled with a suitable fluid (for example, clean water). The tank and its contents remain radioactive for a short time (up to 30 min) after the tool has been switched off.

Plate 2. 3: Radioactive Material Transport Vehicle (IAEA, 2009)

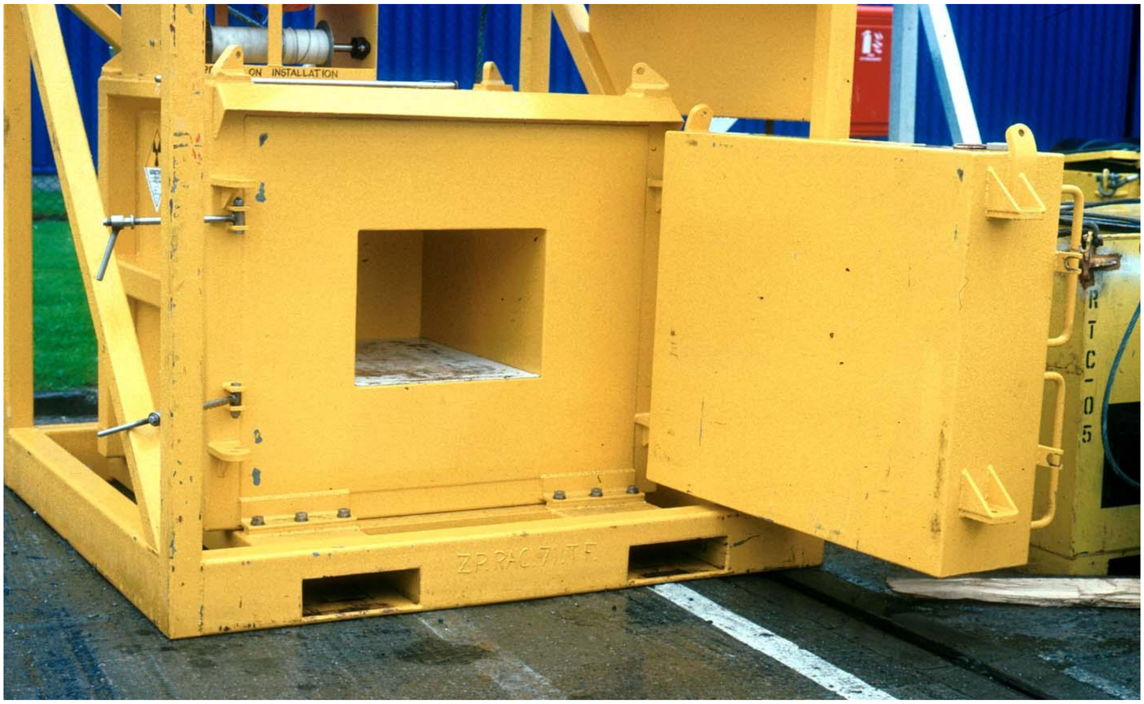

Plate 2. 4: Overpack for the temporary transport and storage of Radioactive Sources (IAEA, 2009)

The logging tools and the sources they contain are subjected to very high temperatures and pressures down hole. The sources normally fall within the definition of ‘special form radioactive material, as sealed sources satisfying the test criteria specified by the IAEA 2009 and ISO standards (ISO, 1990). Nevertheless the source(s) are normally given the further protection of a special container (a ‘pressure vessel’) whenever they are in the shield or logging tool. The sources also need frequent checks for leakage of radioactive material in accordance with test criteria specified by ISO standards (ISO, 1988).

2.9 Theory of Thermoluminescent Dosimeter (TLD)

TLD is a passive radiation detection device that is used for personal dose monitoring. It consists of LiF:Mg,Ti (TLD 100); phosphor which has the effective atomic number of 8.2, approximately equivalent to that of the soft tissue of the human body (Rahman et al, 2016). TL can provide a perfect passive measurement; it finds immense use in the monitoring of radiation workers on a routine basis; weekly, monthly or quarterly depending upon whatever a situation may warrant. The application potential of TL-dosimeter is very wide, found very useful in many fields on account of several favorable characteristics such as high sensitivity, small size, ability to cover wide range of exposure, reusability, insensitive to environmental conditions.

The two most common types of TLDs are calcium fluoride and lithium fluoride, with one or more impurities to produce trap states for energetic electrons. The former is used to record gamma exposure, the latter for gamma and neutron exposure. Other types include beryllium oxide (Tochilin, 1969) calcium sulfate doped with Tm. (Yamashita et al, 1971) as the radiation interacts with the crystal it causes electrons in the crystal's atoms to jump to higher energy states, where they stay trapped due to intentionally introduced impurities (usually manganese or magnesium) in the crystal (Faiz, 2003) until heated.

The lithium fluoride appears in form of crystals with three energy levels, viz;

a. The valence band (stable state)
b. The sensitive trapping band (caused by lattice imperfections of magnesium impurities)
c. The highest energy level called conduction band.

At stable state, the electrons are at the valence levels, when lithium fluoride crystals are irradiated, the electrons from the stable valence band become excited and the electrons wander and become trapped at the sensitive trapping bands. (Obioha, 2007)

The TLD reader consists of a heater, on getting heated the temperature of the LiF:Mg,Ti is raised usually above 300˚C (Annealing), the electron becomes excited again, jumped up to the conduction band and finally dropped to the valence band with the emission of light which is read out by photomultiplier tube (PMT). The intensity of the light emitted (thermo luminescence) is proportional to the amount of radiation received by the crystals initially (Obioha, 2007)

Sometime the electrons can also drop back to ground state after a long period of time; this effect is called **fading** and is dependent on the incident radiation energy and intrinsic properties of the TLD material. As a result, each material possesses a limited shelf life after which dosimetric information can no longer be obtained (Faiz, 2003).

2.10. Review of Previous Work

Rahman et al (2016a) assessed whole-body occupational radiation exposure in industrial radiography practices in Bangladesh during 2010-2014. The result shows that, majority (about 75%) of workers received doses below 1 mSv for the 5 years period and about 1% of the workers received doses higher than the average annual dose limit (20 mSv) but not higher than 100 mSv in 5 consecutive years. The results indicated that radiation protection situation at the majority of the workplace were satisfactory.

Rahman et al (2016b), assessed whole-body occupational radiation exposures in nuclear medicine practices in Bangladesh during 2010-2014, in this study the result shows that, the annual average effective doses of workers are well below the annual average dose limit prescribed by national regulations and international organizations. Majority (95%) of workers received doses less than 1 mSv and only 0.33% workers received doses higher than 10 mSv. The annual average effective dose of workers is three times lower than the worldwide average effective dose quoted by UNSCEAR. However, the annual average effective dose of monitored workers is comparable to dose received by workers in Turkey and France.

Zafar et al (2015), assessed personal occupational radiation exposures received by nuclear medicine and oncology staff in Punjab, in this study occupationally received radiation doses amongst Pakistani oncology staff in NM, RT and DR during the period (2003–2012) were assessed. The Film Badge Dosimetry (FBD) technique has been utilized to process over 81,000 films (13,237 workers) concerning the occupationally exposed workers data (2003–2012) at a national scale. The annual effective doses were found to range between 0.30–0.97 mSv for NM, 0.44–1.02 mSv for RT and 0.31–1.09 mSv for DR. The annual effective doses averaged over a period of 10 years were assessed to be 0.63, 0.70 and 0.68 mSv for NM, RT and DR respectively. The exposure data were categorized into three exposure levels (≤0.99, 1–4.99 and 5–9.99 mSv) to establish the staff distribution in these categories. It was found that 89.8–96 % in NM, 82–94.5 % in RT and 76–96.8 % staff workers in DR have received doses within the range from the Minimum Detectable Limit (MDL)- 0.99 mSv. The annual effective doses, in all categories, were measured to be less than the recommended annual limit of 20 mSv.

Lima et al (2014), estimated equivalent dose to the lens of the eye of planned exposure situations of industrial gamma radiography using the visual Monte Carlo Brazillian Software. The results show that during planned exposure situations, the operators of industrial gamma radiography could be exposed to annual doses in eye lens from 16.9 to 66.9 μGy/year, based on the investigation Scenarios. It means that the new annual limit on equivalent dose to the lens (20 mSv/year) can directly impact the activities of Industrial Gamma Radiography, mainly radioactive facilities with high number of exposures per year

Basic et al (2014) assessed fifteen years of occupational exposure monitoring in Federation of Bosnia and Herzegovina and reported that, 15, 000 TLD users were evaluated for annual doses. Majority of the annual doses received were less than 0.99 mSv/year (96%), some users received doses 1.00 -1.99 mSv/year (3.3%), and very few doses between 2.00 and 2.99 mSv/year (0.6%). There are no registered cases of exceeding the annual limit (20 mSv/year).

Madharvan et al (2014) studied Occupational radiation aspects in a monazite based rare earth production facility. The study revealed that, the occupational radiation protection aspects for such facility is different from uranium mining and milling plants due to the presence of thoron and high energy gamma radiation from ^{208}Tl of thorium series. The radiological aspects for the rare earths were studied. The general radiation field in the rare earth production plant was 0.1 -10 μGy/h and the average short-lived air activity was 40±9 mWL. The occupational radiation exposure by the rare earths production plant was only 6% of the institutional dose, and the average individual dose was 1.6 mSv per year

Agbalagba et al (2013), studied *in-situ* the radiological impact of oil and gas exploration activities in the production land area of Delta State using two synchronized and calibrated radiation meters (Digilert 50 and 100) and GPS. Ten oil field facilities were assessed during the study. At each facility, nine sampling locations and their host communities were evaluated making a total of 100 study points. Measured exposure rate in the oil field facilities ranged from 0.011 ± 0.003 mRh^{-1} in Evwreni camp site to 0.031 ± 0.01 mRh^{-1} at the Otorogu gas plant. Mean field exposure rates/equivalent dose rates ranged from 0.016 ± 0.006 mRh^{-1}(0.839 ± 0.34 $mSvy^{-1}$) to 0.0213 ± 0.008 mRh^{-1}(1.134 ± 0.44 $mSvy^{-1}$). In the host communities the values ranged from 0.0115 ± 0.003 mRh^{-1} (0.612 ± 0.16 $mSvy^{-1}$) in Evwreni community to 0.021 ± 0.007 mRh^{-1} (1.117 ± 0.37 $mSvy^{-1}$) in Otujeremi town, while for the control study area the value obtained was 0.009 ± 0.002 mRh^{-1}(0.479 ±

0.11mSvy^{-1}). The results show that the radiation levels for the Ughelli East, Kokori, Eriemu, Evwreni, Eriemu, Oweh, Olomoro-Oleh oil and gas fields are within the 1mSvy^{-1} maximum permissible limit recommended for the public and non-nuclear industrial environment, while the levels for the fields at Otorogu, Ughelli West, Afiesere and Uzere West and East and the host communities of Olomoro, Uzere and Emeragha exceeded the maximum recommended value, an indication that the oil fields and host communities environment have been impacted radiologically. However, these results obtained may not have immediate health hazard, but will pose some long-term health side effects on the staff working in the facilities and residents of the host

United State Department of Energy (USDOE) (2012), indicated in its Occupational Radiation Exposure Report 2012 that the collective effective dose from photon exposure decreased by 23% between 2011 and 2012, while the neutron dose increased by 5%. The internal dose component of the collective total effective dose (TED) decreases by 7%. Over the past 5 year period, 99.99% of the individuals receiving measurable TED have received doses below 2 roentgen equivalent man (rems) (20 mSv) TED administrative control level (ACL) which is well below the DOE regulatory limits of 5 rems (50 mSv) TED annually. The report shows that, DOE facilities continued to comply with DOE dose limits and ACLs and worked to minimize exposure to individuals.

Hasford et al (2011a), assessed the annual whole-body occupational radiation exposure in education, research and industrial sectors in Ghana (2000-09) and reported that, thirty four (34) institutions belonging to the three sectors were monitored out of which 65% were in the industrial sector. During the 10 year study period, monitored institutions ranged from 18 to 23 while the exposed workers ranged from 156 to 246 between 2000 and 2009.

Annual collective doses received by all exposed workers reduced by a factor of 2 between 2000 and 2009. This is seen as a reduction in annual collective doses in education and industrial sectors by 39% and 62% respectively, for the 10 y period. Highest and least annual collective doses of 182.0 man mSv and 68.5 man mSv were all recorded in the industrial sector in 2000 and 2009, respectively. Annual average values for dose per institution and dose per worker decreased by 49 and 42.9%, respectively, between 2000 and 2009. Average dose per exposed worker for the 10y period was least in the industrial sector and highest in the education sector with values 0.6 and 3.7 mSv, respectively. The mean of the ratio of annual occupationally exposed worker (OEW) doses for the sector to the annual OEW doses for the education sector was 0.67 mSv, a suggestion that radiation protection practices are better in the industrial sector than in the education sector. An average dose per all three sectors of 11.87 mSv and average dose per exposed worker of 1.12 mSv were realized for the entire study period.

Hasford et al (2011b) assessed the annual whole-body occupational radiation exposure in medical practice in Ghana (2000–09) and reported that, One hundred and eighty medical facilities were monitored for the 10-y period, out of which ∼98% were diagnostic radiology facilities. Only one nuclear medicine and two radiotherapy facilities have been operational in the country since 2000. During the 10-y study period, monitored medical facilities increased by 18.8 %, while the exposed workers decreased by 23.0 %. Average exposed worker per entire medical institution for the 10y study period was 4.3. Annual collective dose received by all the exposed workers reduced by a factor of 4 between 2000 and 2009. This is seen as reduction in annual collective doses in diagnostic radiology, radiotherapy and nuclear medicine facilities by ∼76, ∼72 and ∼55 %, respectively, for the 10-y period.

Highest annual collective dose of 601.2 man mSv was recorded in 2002 and the least of 142.6 man mSv was recorded in 2009. Annual average values for dose per institution and dose per exposed worker decreased by 79 and 67.6 %, respectively between 2000 and 2009. Average dose per exposed worker for the 10-y period was least in radiotherapy and highest in diagnostic radiology with values 0.14 and 1.05 mSv, respectively. Nuclear medicine however recorded average dose per worker of 0.72 mSv. Correspondingly, range of average effective doses within the diagnostic radiology, radiotherapy and nuclear medicine facilities were 0.328–2.614, 0.383–0.728 and 0.448–0.695 mSv, respectively. Throughout the study period, an average dose per medical institution of 3 mSv and an average dose per exposed worker of 0.69 mSv were realised. Exposed workers in diagnostic radiology primarily received most of the individual annual doses >1 mSv. The entire study period had 705 instances in which exposed workers received individual annual doses >1 mSv. On thermoluminescent dosemeter (TLD) return rates, facilities in Volta and Eastern Regions recorded highest return rates of 94.3 % each. Ashanti Region recorded the least TLD return rate with 76.7 %.

Colgan et al (2008) assessed the annual whole-body occupational radiation exposure in Ireland (1996-2005). In this study, whole-body occupational exposure to artificial radiation sources in Ireland for the years 1996-2005 has been reviewed. Dose data have been extracted from the database of the Radiological Protection Institute of Ireland, which contains data on >95% of monitored workers. The data have been divided into three sectors: medical, industrial and education/research. There has been a continuous increase in the number of exposed workers from 5980 in 1996 to 9892 in 2005. Over the same period, the number of exposed workers receiving measurable doses has decreased from 676 in

1996 to 189 in 2005 and the collective dose has also decreased from 227.1 to 110.3 man mSv. The collective dose to workers in the medical sector has consistently declined over the 10y period of the study while that attributable to the industrial sector has remained reasonably static. In the education/research sector, the collective dose typically represents 5% or less of the total collective dose from all practices. Over the 10y of the study, a total of 77 914 annual dose records have been accumulated, but only 4040 (<6%) of these represent measurable radiation doses in any given year. Over the same period, there were 283 instances in which exposed workers received individual annual doses >1 mSv and 21 of these exceeded 5 mSv. Most of the doses >1 mSv were received by individuals working in diagnostic radiology (which also includes interventional radiology) in hospitals and site industrial radiography. There has been only one instance of a dose above the annual dose limit of 20 mSv. Evaluating the data for the period 2001-05 separately, the average annual collective dose from the medical, industrial and educational/research sectors are approximately 60, 70 and 2 man mSv with the average dose per exposed worker, who received a measurable dose being 0.32, 0.79 and 0.24 mSv, respectively. Diagnostic radiology and site industrial radiography each represents >60% of the collective dose in their respective sectors. Available data on radon exposure in one underground mine and in three indicate an annual collective dose of 75 man mSv from these activities. By comparison, previous estimates of exposure of Irish air crew to cosmic radiation have given rise to an estimated collective dose of 12,000 man mSv. It can be concluded therefore that the natural radioactivity sources account for well >90% of all occupational exposure in Ireland.

Jibiri and Oguntade (2007), assessed genetically significant dose of occupationally exposed individuals involved in industrial and medical radiographic procedures in certain establishments in Nigeria. The estimation was based on continuous personnel radiation dose monitoring data for the individuals in each of the establishments over a three year period (1998-2001). The estimated genetically significant dose values in the years considered were 12 mSv for the medical and 29 mSv for the industrial personnel.

Farai and Obed (2001) conducted occupational radiation protection dosimetry in Nigeria within the period 1990-1999. About 640 personnel, representing about 25% of the estimated number of radiation workers in Nigeria at that period were monitored by the TL dosimetry technique during the period, with the majority being the personnel of the teaching hospitals across the country. The weighted mean of the annual effective dose ranged between 0 and 28.97 mSv with the upper limit of collective effective dose being 18.47 man Sv per year. Individual risk estimate among the medical personnel was found to be 1.5×10^{-3} per year.

CHAPTER THREE

MATERIALS AND METHOD

3.1 Materials

The following materials and instruments were used in carrying out this research work. Thermoluminescent Dosimeters (TLD), Harshaw Manual 4500 TLD Card Reader, Masking Tape, Measuring Tape, Writing materials.

3.2 Research Methodology

3.2.1 Measurement Principles and Instrumentations

3.2.1. 1 Principles

A wide range of instruments are manufactured to carry out workplace monitoring for ionizing radiation and radioactive contamination. Instruments have not been developed specifically for use at oil and gas production and processing facilities and no single instrument is capable of detecting all types and energies of the radiation used in the industry. It is important to select and make available instruments that are appropriate and efficient for the different applications (IAEA, 2010).

The better use of instruments can be achieved mostly by accurate determination of energy absorbed from the radiation field and the possible distribution of this absorbed energy within the material. Measurements of these quantities form the basis of **radiation dosimetry** and systems used for this purpose are referred to as **dosimeters.** The important techniques developed and employed are as follows;

i. Thermo-luminescent (TLD) technique
ii. Optically stimulated luminescent (OSL) technique
iii. Electron paramagnetic resonance (EPR) technique

The main basis in the TLD is that TL output is directly proportional to the radiation dose received by the phosphor and hence provides the means of estimating unknown irradiations.

3.2.1.2 Instrumentations

3.2.1.2.1 Harshaw 4500 Manual TLD Reader

The Harshaw 4500 Manual TLD Reader provides versatile readout of TLD dosimeters. It incorporates both hot gas and planchet heating to read TLD cards, chipstrates, ringlets and unmounted dosimeters. Dual photomultiplier tubes and associated electronics enable it to read cards in two positions simultaneously. A start button and four indicator lights control and monitor the operation. The Model 4500 connects via a serial interface to an external PC, which provides control over the setup, time-temperature profiles (TTPs), analysis and data recording (Harshaw 2007)

Plate 3. 1: Experimental set-up of Harshaw TLD Reader and PMT

3.2.2 Read out Process and Dose Evaluation Procedures

In Nigeria, radiation monitoring of personnel begin immediately after a facility is licensed to operate. Dosimetry Service Provider (DSP) accredited by NNRA issues, collects and processes the TLDs. New dosimeters are issued to radiation workers prior to the dosimeters in use being returned.

In this study, two chips TLD cards kept in a holder were issued for quarterly (3-months) basis to the personnel working in well-logging and industrial radiography facilities. The workers wore the TLD on torso during the working time. After using the cards for three (3) month period, the cards were sent to the DSP for reading and annealing.

The exposure readings of the returned dosimeters, which are based on TLD card reader calibration to ^{137}Cs beam exposure on slap phantom for measurement of elemental correction coefficient (ECC), are obtained by loading the dosimeters into the Harshaw 4500 Manual TLD Reader connected to personal computer (PC) with installed winsREMS software.

TLDS output read by Harshaw TLD reader is the charges produced by electrons due to the annealing process. To convert the output readings of TLDs from charge (nC) to absorbed dose (Gy); the following equations are used: (Rahman et al, 2016)

$$Absorbed\ dose = \frac{equivalent\ dose}{quality\ factor} \qquad 3.1$$

The time between irradiation and readout should be the same to keep fading from one calibration to another for all TLDs. The calibration factor ($f_{calibration}$) is defined as follows:

$$f_{calibration} = \frac{D_{ionization\ chamber\ (mGy)}}{TLD_{reading\ (n)}} \qquad 3.2$$

Absorbed dose due to irradiation is obtained after background subtraction using equation 3.3

$$D_{TLD} = D_{av} - BG \qquad 3.3$$

The absorbed dose is obtained for each TLD using equation 3.4

$$D_{TLD}\,(mGy) = f_{cal}\left(\frac{mGy}{nC}\right) x\, TLD_{reading}(nC) \qquad 3.4$$

For all individual doses, the minimum detection level (MDL) is 0.05 mSv for 3 months after background subtraction. The MDL is a dose recording level, therefore worker who received doses lower than MDL is considered as unexposed.

Shallow dose equivalent (Skin) and deep dose equivalent (DDE) generated by the TLD reader are manually entered into a Microsoft Excel spreadsheet to calculate the corresponding personnel dose equivalent values H_p (0.07) and H_p (10).

The Skin and deep doses are calculated using Equations 3.5 and 3.6 (Hasford et al 2011)

Skin dose: H_p (0.07) = [(1.2958R_{skin}) + 0.0097] mSv 3.5

Deep dose: H_p (10) = [(1.3772R_{deep}) + 0.0566] mSv 3.6

Dose reporting was performed on quarterly basis and only those workers with doses exceeding a minimum detection level (MDL) of 0.05 mSv (exposed workers) after background subtraction were considered. The workers with doses less than MDL are considered as non-exposed. All evaluated values of H_p (10) are recorded and reported as effective dose, E (mSv) as per UNSCEAR protocol (UNSCEAR, 2008).

3.2.3 Result Analysis

3.2.3.1 Data Analysis

In this study, three quantities recommended by UNSCEAR, (2008) were used to analyze individual doses for the years 2007-2016. The recommended quantities include the collective dose, average annual effective dose and the individual dose distribution ratio.

a. Collective annual effective dose (S)

The collective annual effective dose (S) was obtained using Equation 3.7

$$S = \sum_{i=1}^{N} E_i \qquad 3.7$$

Where E_i is the annual effective dose received by the i^{th} worker and N is the total number of workers monitored. The parameter S, gives an estimate of the impact of particular practice on the population in given time frame.

b. Individual annual effective dose

The individual annual effective dose $\bar{E}$ was obtained from the Equation 3.8 below;

$$\bar{E} = \frac{S}{N} \qquad 3.8$$

where the meaning of symbols are the same as in Equation (3.3)

c. The individual dose distribution

The individual dose distribution ratio, NR_E was obtained using Equation 3.9 below;

$$NR_E = \frac{N(> E)}{N} \qquad 3.9$$

where N (>E) is the number of workers receiving annual dose exceeding E mSv. In this study, NR_E was analyzed for values of E of 15, 10, 5 and 1 mSv as per UNSCEAR Protocol. The parameter NR_E provides an indication of the fraction of workers exposed to higher levels of individual doses.

3.2.3.2 Statistical Analysis

The data obtained were analyzed using descriptive statistical method of analysis. Statistical analysis were performed using statistical package for windows (SPSS version 17.0, SPSS Inc., Chicago II, USA)

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 RESULTS

This work assessed the occupational exposure and evaluated the radiation safety requirements of well-logging and industrial radiography practices that employ the use of ionizing radiation sources in its operations between the period 2007-2016. Collective annual effective dose, the individual annual effective dose and the total collective dose for the well-logging and industrial radiography practices were presented in Appendices A, B and C respectively. Tables 4.1 and 4.2 showed the individual dose distribution ratio for industrial radiography and well-logging practices respectively

Table 4. 1: The individual dose distribution ratio for the industrial radiography

Annual dose exceeding (mSv)	Individual dose distribution ratio									
	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
15	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1	0.033	0.041	0.034	0.042	0.038	0.035	0.074	0.029	0.018	0.015

Table 4. 2: The individual dose distribution ratio for the well-logging practice

Annual dose exceeding (mSv)	Individual dose distribution ratio.									
	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
15	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1	0.059	0.051	0.054	0.048	0.031	0.041	0.028	0.024	0.028	0.018

Table 4.3 presented the TLD return rate for the two practices. 90.1% and 95.7% of the TLDs distributed for industrial and well-logging practice respectively were returned to the operating organization from the dosimetry service provider.

Table 4. 3: TLD return rate for the two practices

	Practice	
	Industrial Radiography	Well-logging
TLDs distributed	334	254
TLDs returned	301	243
TLDs unreturned	33	11
TLD return rate (%)	90.1	95.7

Table 4.4 compared the average annual effective dose obtained from this study with the worldwide average effective dose as reported by UNSCEAR and the results of other countries.

Table 4. 4: Comparison of average annual effective dose of exposed workers of Industrial radiography (IR) and well-logging (WL) practices with results of other countries and UNSCEAR

		Average annual effective dose (mSv)		
Country	Period	IR	WL	Reference
Bangladesh	2010-2014	2.43	---	Rahman et al, (2016)
USA	2000-2003	5.51	---	UNSCEAR (2008)
Bosnia	1999-2003	5.80	---	Basic et al, (2010)
Ireland	1996-2002	1.20	---	Currivan et al, (2002)
Australia	1990-1994	0.46	---	UNSCEAR (2000)
UK	1990-1994	1.55	---	UNSCEAR (2000)
Nigeria	2007-2016	1.30	0.96	This work
Worldwide	2000-2002	1.50	0.96	UNSCEAR (2008)

Table 4.5 showed the radiation safety procedures of the industrial radiography and well-logging facilities. Checking at the inspection parameters, both the facilities have good radiation safety procedures in place. The overall results shows that radiation workers in industrial radiography practice received higher doses than their counterparts in well-logging practice; this is in agreement with the study of Currivan et al, 2001.

Table 4. 5: Radiation safety procedures of the industrial radiography (IR) and Well-logging facilities (WL)

Inspection Parameters	Facility			
	IR 1	IR 2	WL 1	WL 2
Radiation Protection Program	Yes	Yes	Yes	Yes
Radiation Monitors	Yes	Yes	Yes	Yes
Radiation Safety Officer (RSO)	Yes	Yes	Yes	Yes
Radiation Safety Adviser (RSA)	Yes	Yes	Yes	Yes
Presence of over pack	NA	NA	Yes	Yes
Radiation Source Storage bunker	Yes	Yes	Yes	Yes
Log Book for source movement	Yes	Yes	Yes	Yes
Transport Security Arrangement	Yes	Yes	Yes	Yes
Training Policy	Yes	Yes	Yes	Yes

IR= Industrial Radiography
WL= Well-Logging
NA= Not Applicable

4.2 DISCUSSION

Fig. 4.1 (Appendices A & B) showed the number of radiation workers per practices. The number of personnel in industrial radiography is slightly more than the workers in well-logging practices.

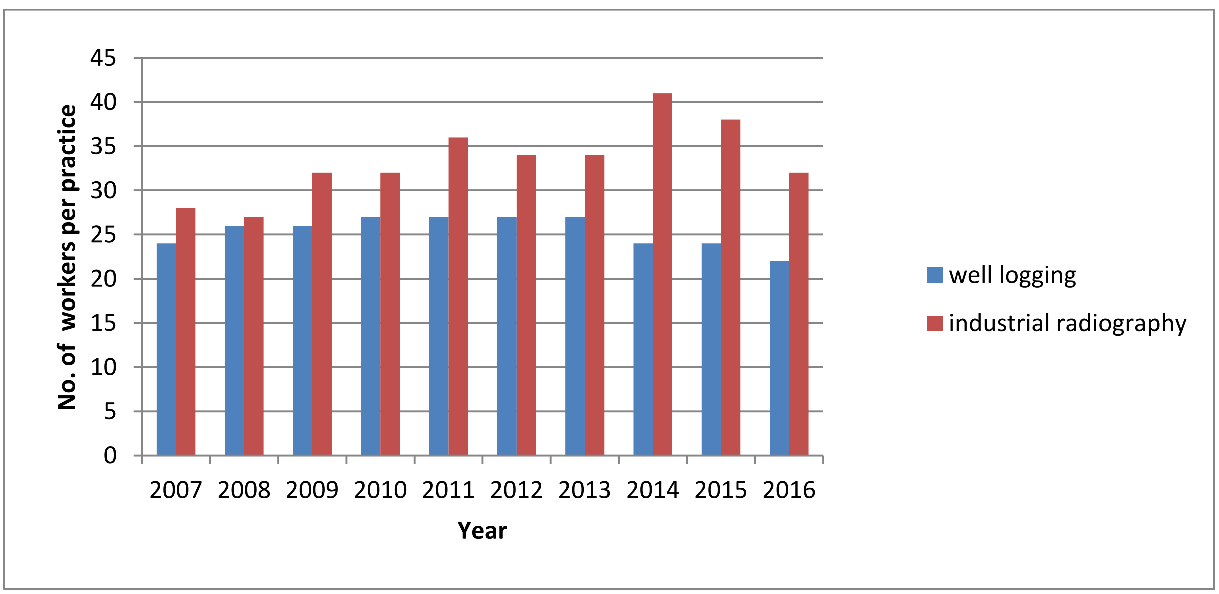

Fig. 4. 1: The number of exposed workers per practice for the period 2007-2016.

The fluctuation of the number of staff is because some of the workers are contract staff; they are only hired when their services is needed in the facilities. Another reason is that, some of the radiation workers received doses lower than MDL and they were considered as unexposed, therefore excluded from this research work.

Fig 4.2 and Fig 4.3 both obtained from Appendices A and B, compared the annual effective dose (mSv) and annual collective dose (person mSv) of exposed workers for the two practices;

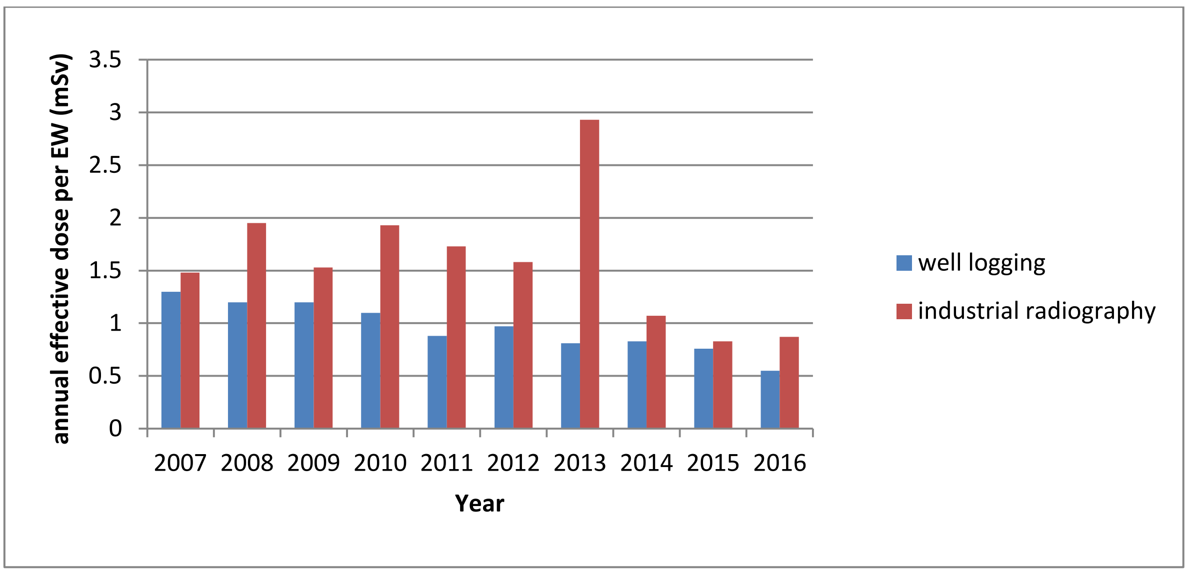

Fig. 4. 2: Comparison of the effective doses per exposed worker (EW) for well logging and industrial radiography practices for the period 2007-2016.

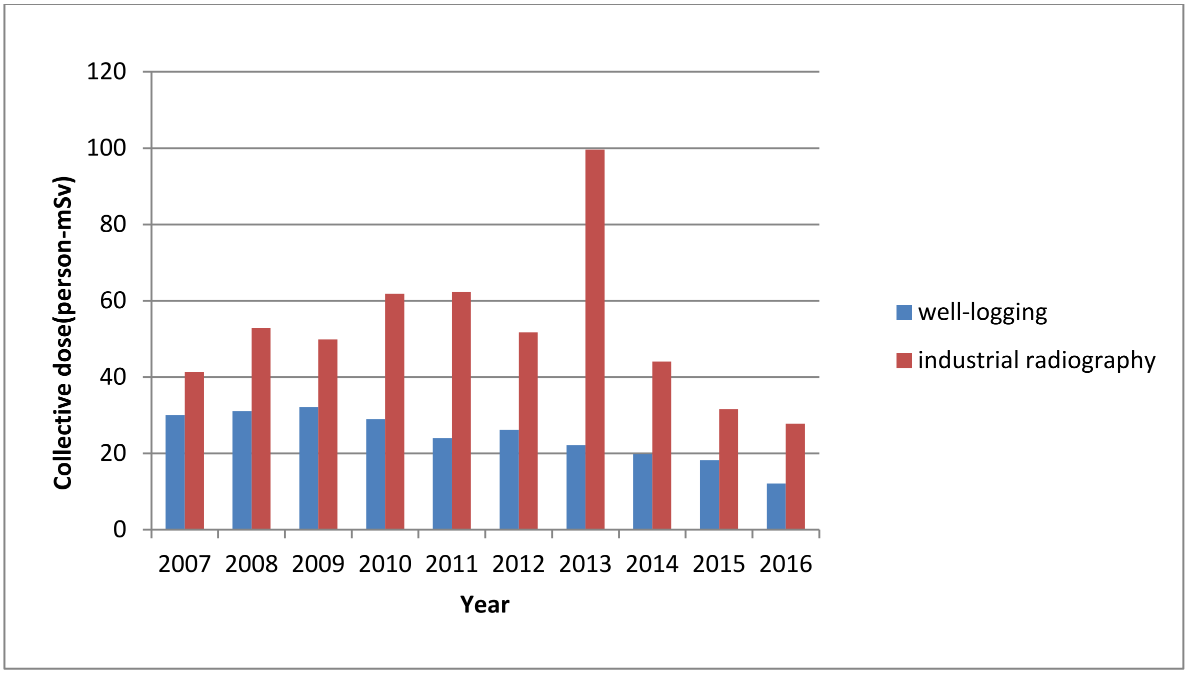

Fig.4. 3: Comparison of the collective doses for well-logging and industrial radiography practices for the period 2007-2016.

The annual effective dose and the annual collective dose did not follow a particular trend during the 10y period. The annual average doses for the exposed workers ranged between 0.87-2.93 mSv and 0.55-1.3 mSv during the period of 2007-2016 for the industrial radiography and well-logging practices respectively as shown in Fig. 4.2. The average annual effective dose of the exposed workers for the 10y study period was found to be 1.3 mSv and 0.96 mSv for the industrial radiography and well-logging practices respectively.

The annual collective dose received by the exposed workers in 10y study period ranged 27.8 -99.6 man mSv and 12.1-32.2 man mSv for the industrial and well-logging practice respectively as shown in Fig. 4.3

The highest annual effective dose 2.93 mSv and annual collective dose 99.6 man mSv were recorded in 2013 for the industrial radiography. This may be due to increase in work load which usually result in human error, inadequate or lack of proper training on radiation protection for the exposed workers involved, which result into improper handling of radiation sources and subsequently high doses, inadequate maintenance of equipment or improper handling of TLD badges. There was a sharp decrease of annual effective dose and annual collective dose between 2014-2016 for both the industrial radiography and well-logging practices as shown in Figures 4.2 and 4.3, this may be due to decrease in workload, improvement of equipment maintenance or improvement in the implementation of radiation protection and operational procedures during the handling of radiation sources by the radiation exposed workers.

Fig. 4.4 which is obtained from Appendices A and B illustrated the effective dose (mSv) per facility;

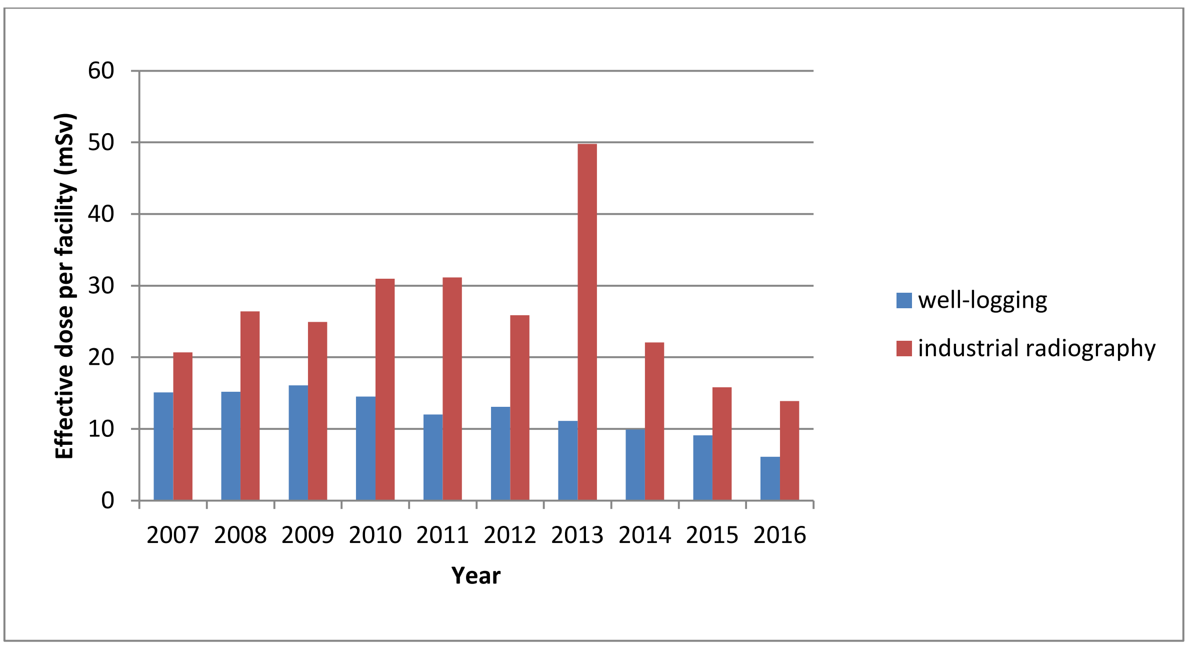

Fig. 4. 4: Comparison of the effective doses per facility for well logging and industrial radiography practices for the period 2007-2016.

The calculated effective dose per facility as shown in Fig. 4.4 has indicated that workers of industrial radiography facilities received more doses than their counterparts at well-logging facilities this is in agreement with the study of Currivan et al, 2001.

Fig 4.5 and 4.6 both plotted from Table 4.4 compared the average effective dose (mSv) for well-logging (0.96 mSv) and industrial radiography (1.3 mSv) obtained from this study with the baseline value provided by UNSCEAR (2008). The results from this work indicated that for industrial radiography the average annual effective dose for the exposed workers was found to be 1.30 mSv which is higher than the value obtained in Australia (0.46 mSv) but lower than that of USA (5.51 mSv) Bosnia (5.80 mSv), Bangladesh (2.43 mSv) and UK (1.55 mSv). Furthermore, the average annual effective dose for industrial radiographers from this work is comparable with those value obtained in Ireland (1.20 mSv) but slightly less than the UNSCEAR worldwide average effective dose for industrial radiography practice (1.50 mSv) (Table 4.4) for the period 2000-2002 as shown in Fig. 4.5.

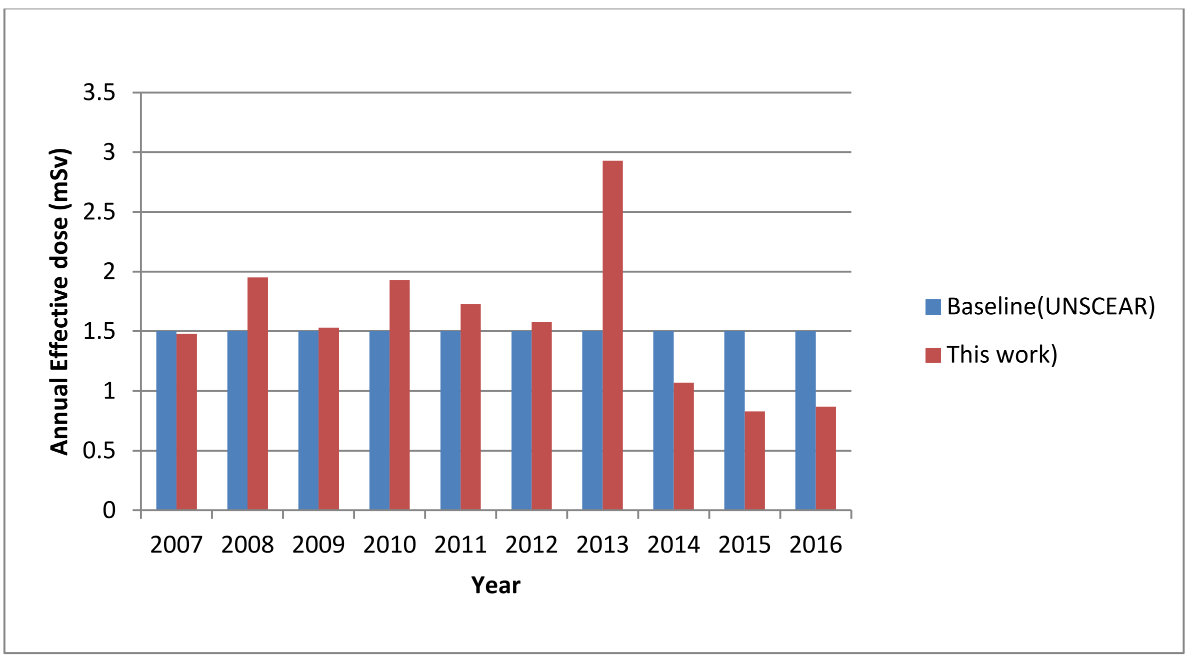

Fig. 4. 5: Comparison of the annual effective doses of the exposed workers for industrial radiography practice with the baseline value provided by UNSCEAR, 2008.

For well-logging, the average annual effective dose for the exposed workers from this study was 0.96 mSv which is in agreement with UNSCEAR worldwide average effective dose for well-logging practice for the period 2000-2002 (UNSCEAR 2008) as shown in Fig. 4.6.

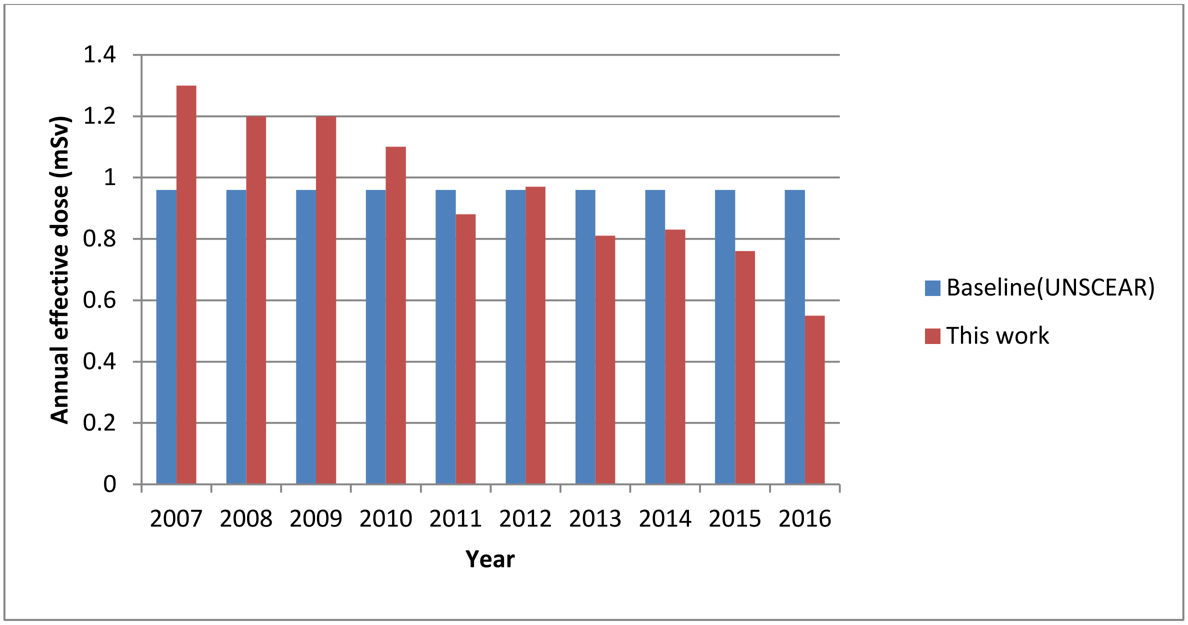

Figure 4. 6: Comparison the annual effective doses of exposed workers for well logging practice with the baseline value provided by UNSCEAR, 2008.

The variations of average annual effective dose for different countries at different time periods can be attributed to the workload differences in various practices, the effectiveness of radiation protection and operational procedures and to some extent the effectiveness of national regulations. Moreover, the exceptional result recorded by Australia (0.46 mSv) may be due to the considerable attention paid to quality management system (QMS) and performance measurement by Australian Radiation Protection and Nuclear Safety Agency (WINS, 2016)

Fig. 4.7 which was obtained from Appendix C has illustrated the contribution of these two practices to the total world collective dose. The total collective dose of occupational exposure for the two practices over the 10y study period was found to be 768 person mSv as shown in Appendix C illustrated by Fig. 4.7; the implication of which is that, these two practices have impacted to the whole population radiation workers 768 Person mSv over the 10y study period. Another implication is that the practices under study have contributed 768 person mSv to the total world collective dose (45,747,100 person Sv) UNSCEAR (2000)

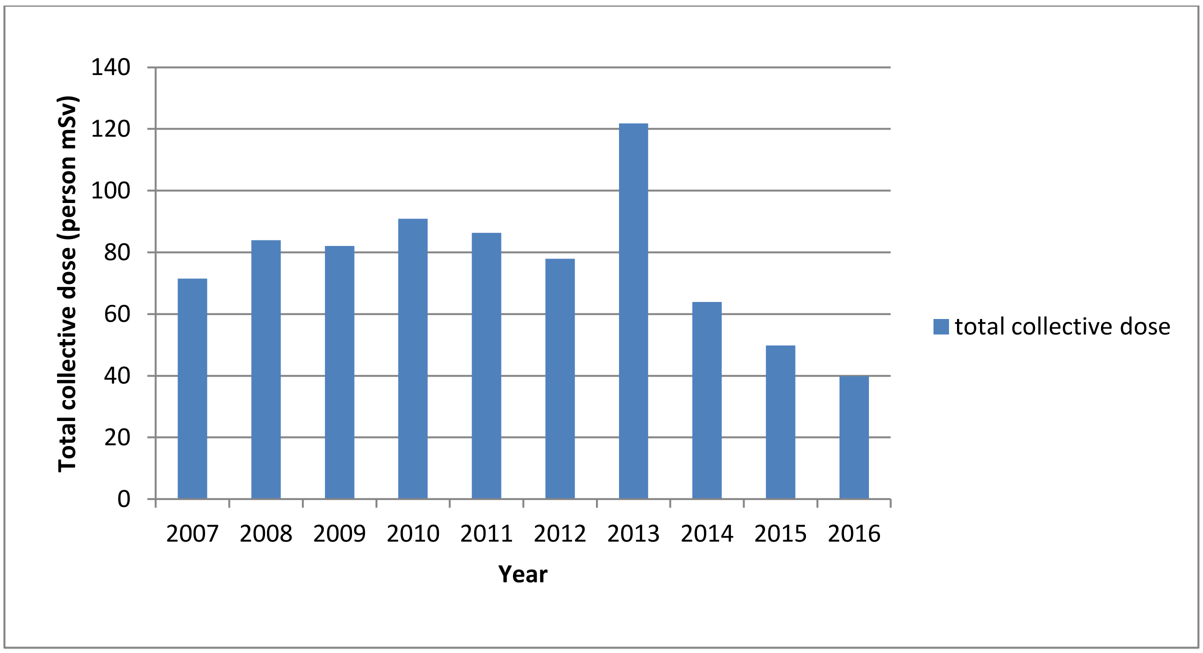

Fig. 4. 7: Contribution of well-logging and industrial radiography practices to the total collective dose.

On individual dose distribution ration, there is no instance where a radiation worker receives high doses, 6% of industrial radiographers received doses exceeding 1mSv (Table 4.1) while on the other hand 5% of the well logging personnel received doses greater than 1 mSv (Table 4.2).

89% of the workers received doses less than 1 mSv; this implies that, the exposed workers received very low doses. Moreover, no worker received doses higher than the annual dose limit of 20 mSv per year averaged over five years as prescribed by Nigerian Basic Ionizing Radiation Regulation (NNRA, 2003).

Furthermore, on the TLD return rates, the well-logging practice records the highest return rates, about 95.7% of the TLD distributed to the personnel were returned while industrial radiography records 90.1% as shown in Table 4.3. Although the rate of TLD returned is somewhat satisfactory, more effort should be made by all stakeholders involved in order to achieve 100% return rate.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 SUMMARY AND CONCLUSION

Occupational exposure and radiation protection procedures of some selected industrial and well- logging facilities in Nigeria have been assessed. The contribution of the two practices to the world total effective dose was found to be 768 man mSv and the average annual effective dose for industrial radiography practice was found to be 1.3 mSv which is slightly lower than the UNSCEAR worldwide average effective dose value for industrial radiographers (1.5 mSv), while for well-logging practice, the average annual effective dose from this study was found to be 0.96 mSv which is consistent with the UNSCEAR worldwide average effective dose for radiation exposed workers in well-logging practice. Majority of the workers (about 89%) received doses lower than 1 mSv and there is no instance where a radiation worker received doses greater than the annual dose limit of 20 mSv prescribed by Nigerian Nuclear Regulatory Authority (NNRA). Well-logging practice records the highest rate of TLDs returned (95.7%) followed by the industrial radiography (90.1%). All the facilities have radiation safety procedures in place. The conclusion that can be drawn from this, is that the facilities studied have complied with the administrative dose limit (20 mSv averaged over five years) set and specified by the national regulations.

Another conclusion that can be drawn from this study is that, the national regulations governing the use of nuclear energy and ionizing radiation source are effective considering that, no radiation worker received dose greater than the administrative dose and majority of the workers (89%) received dose lower than 1 mSv.

Although radiation workers covered by this research work received doses less than the administrative dose limit set by the competent Authority, licensee should ensure that, the radiation workers are properly train on radiation protection matters and operational procedures are strictly adhere to, so that the doses to the individuals and the working environment are kept as low as reasonably achievable (ALARA) taking social and economic factors into consideration.

5.2 RECOMMENDATIONS

Assessment of occupational radiation exposure and radiation protection in oil and gas sector is of paramount important, considering the wide application of ionizing radiation due it its unique properties in the industry. From the result obtained it is recommended that;

i. There should be regular assessment of occupational exposure and analysis of operational procedures to examine changes that have taken place over time due technological improvement or regulatory operations
ii. Radiation monitors present at the facilities should be calibrated at the Secondary Standard Dosimetry Laboratory (SSDL) at least once in a year as specified in the national regulation
iii. Harshaw 4500 manual TLD reader used in the study should always be calibrated using ^{137}Cs beam exposure on slap phantom before use
iv. There should be adequate maintenance of radiographic and well-logging equipment to prevent the equipment defects or malfunctions which result mostly into equipment failure and subsequently to radiation accident
v. Similar Study should be carry out using Harshaw automatic TLD reader 8800/6600 plus model due to its high accuracy, efficiency and precisions

vi. Assessment of occupational radiation exposure of workers in other sectors should be conducted in order to establish the contributions of these sectors to the total world collective dose

vii. Radiation workers should be adequately train on radiation protection and operational procedures

viii. Operational procedures should be strictly adhere to as enshrine in national and international regulations and other safety guides in handling ionizing radiation sources

ix. Workload on radiation workers that result in human error should be reduce through affordable time-schedule

x. Nigerian Nuclear Regulatory Authority (NNRA) should review its radiation safety requirements in line with the risks or hazards associated with the various practices.

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APPENDICES

Appendix A: Annual Collective doses (person mSv) and annual effective doses (mSv) for the Well-Logging Practice

YEAR	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Collective dose (person mSv)	30.10	31.10	32.20	29.00	24.00	26.20	22.20	19.80	18.20	12.10
No. of exposed workers	24	26	26	27	27	27	27	24	24	22
No. of Facilities monitored	2	2	2	2	2	2	2	2	2	2
Annual effective dose (mSv)	1.30	1.20	1.20	1.10	0.88	0.97	0.81	0.83	0.76	0.55
Effective dose per facility (mSv)	15.10	15.20	16.10	14.5	12.00	13.10	11.10	9.90	9.10	6.10

Appendix B: Annual collective doses (person mSv) and annual effective doses (mSv) for the Industrial Radiography Practice

YEAR	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Collective dose (person mSv)	41.40	52.80	49.90	61.90	62.30	51.70	99.60	44.10	31.60	27.80
No. of exposed workers	28	27	32	32	36	34	34	41	38	32
No. of facilities monitored	2	2	2	2	2	2	2	2	2	2
Effective dose (mSv)	1.48	1.95	1.53	1.93	1.73	1.58	2.93	1.07	0.83	0.87
Effective dose per facility (mSv)	20.70	26.40	24.95	30.95	31.15	25.85	49.8	22.05	15.80	13.90

Appendix C: Total annual collective doses (person mSv) and annual effective doses (mSv) for both practices

YEAR	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Total collective dose (person mSv)	71.50	83.90	82.10	90.90	86.30	77.90	121.80	63.90	49.80	39.90
Total No. of exposed workers	53	53	58	59	63	61	61	65	62	54
Total No. of facilities monitored	4	4	4	4	4	4	4	4	4	4
Total annual Effective dose (mSv)	1.4	1.6	1.4	1.5	1.4	1.3	1.9	0.98	0.80	0.74
Total effective dose per facility (mSv)	17.90	20.90	20.50	22.70	21.60	19.50	30.45	15.90	12.50	9.90