Risk analysis of the effect of ionizing radiation exposure on employees and the possible health implications: A case study in radiological or X-Ray departments in selected health facilities

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By

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DECLARATION

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

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ABSTRACT

This study assessed the risk level of employees who routinely work in x-ray units in ten (10) different hospitals in three regions of Ghana. Questionnaire was used to assess employees and employers safety procedures in the performance of their duties. Occupational doses were measured for three months and average monthly dose determined and extrapolated to estimated annual dose for each employee and then compared with internationally recommended limit. Regression analysis was used to establish the relationship existing between doses received by employees in a hospital against patients' attendance rate. Risk models fitted for the Life Span Study (LSS) of atomic bomb victims Hiroshima and Nagasaki was used to estimate the risk of Leukaemia and digestive cancers. The results obtained showed that lower proportion of employees who did not wear their Thermoluminiscence Dosimeters (TLD) always, suffered delay return of TLDs from reading institution while fewer hospital visited did not have medical physicists. The work established a rather insignificant correlation between employees' dosage received and patients' attendance rates with R^2 = 0.142. It was also revealed that all subjects monitored have their estimated annual dose far below the internationally recommended limit of 50 mSv. A mean of 276 μSv (98% CI 257,295) per month obtained in this study put virtually all subjects monitored at no risk as the comparison of this result with works done by others revealed a less than 15 days loss of life expectancy. The Probability of Causation (PC) for leukaemia digestive cancers was also extremely small in orders of 10^{-5}% to induce any of these cancers in the subjects monitored.

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CHAPTER ONE

1.0 Introduction

1.1 Background to the Study

Occupational health and safety is a cross-disciplinary area concerned with protecting the safety, health and welfare of people engaged in work or employment. The goal of all occupational health and safety programs is to foster a safe work environment.[1]It may also protect co-workers, family members, employers, customers, suppliers, nearby communities, and other members of the public who are impacted by the workplace environment.

Since 1950, the International Labour Organization (ILO) and the World Health Organization (WHO) have shared a common definition of occupational health. It was adopted by the Joint ILO/WHO Committee on Occupational Health at its first session in 1950 and revised at its twelfth session in 1995. The definition reads: "Occupational health should aim at: the promotion and maintenance of the highest degree of physical, mental and social well-being of workers in all occupations; the prevention amongst workers of departures from health caused by their working conditions; the protection of workers in their employment from risks resulting from factors adverse to health; the placing and maintenance of the worker in an occupational environment adapted to his physiological and psychological capabilities; and, to summarize, the adaptation of work to man and of each man to his job".[1]

The effect of an incident at work such as legal fees, fines, compensatory damages, investigation time, lost production, lost goodwill from the workforce, from customers and from the wider community create uncomfortable situations in organisations. It is important to recognize hazards and measure health and safety risks, set suitable safety controls in place,

and give recommendations on avoiding accidents to management and employees in an organization. An effective training program can reduce the number of injuries and deaths, property damage, legal liability, illnesses, workers' compensation claims, and missed time from work.

Safety training classes help establish a safety culture in which employees themselves help promote proper safety procedures while on the job. It is important that new employees be properly trained to embrace the importance of workplace safety as it is easy for seasoned workers to negatively influence the new hires. That negative influence however, can be purged with the establishment of new, hands-on, innovative effective safety training which will ultimately lead to an effective safety culture. A 1998 Institute for Occupational Safety and Health (NIOSH) study concluded that the role of training in developing and maintaining effective hazard control activities is a proven and successful method of intervention.[2] Also, certain EU member states admit to having lack quality control in occupational safety services, to situations in which risk analysis takes place without any on-site workplace visits and to insufficient implementation of certain EU Occupational Safety and Health (OSH) directives. Based on this, it is hardly surprising that the total societal costs of work-related health problems and accidents vary from 2.6% to 3.8% of GNP between the EU member states.[1]

Some of the main required tasks of an Occupational Health and Safety Practitioner include:

- Systematic evaluations of the working environment
- Endorsing preventative measures which eliminate reasons for illnesses in the work place
- Giving information in the subject of employees' health

- Giving information on occupational hygiene, ergonomics and also environmental and safety risks in the work place
- Voluntary medical examinations
- A consulting room on the work environment for the workers
- Health check assessments (if needed for the job concerned) [2]

Modern occupational safety and health legislation usually demands that a risk assessment be carried out prior to making an intervention. It should be kept in mind that risk management requires risk to be managed to a level which is as low as is reasonably practical.

This assessment should:

- Identify the hazards
- Identify all affected by the hazard and how
- Evaluate the risk
- Identify and prioritize appropriate control measures

The calculation of risk is based on the likelihood or probability of the harm being realized and the severity of the consequences.[1] This can be expressed mathematically as a quantitative assessment, or qualitatively as a description of the circumstances by which the harm could arise. The assessment should be recorded and reviewed periodically and whenever there is a significant change to work practices. The assessment should include practical recommendations to control the risk.

Occupational health and safety has come a long way from its beginnings in the heavy industry sector. It now has an impact on every worker, in every work place, and those charged with

managing health and safety are having more and more tasks added to their portfolio. The most significant responsibility is environmental protection. The skills required to manage occupational health and safety are compatible with environmental protection, which is why these responsibilities are so often bolted onto the workplace health and safety profession.

1.2 Statement of the Problem

For economic reasons man has to undertake certain profession in order to have a meaningful means of living and as man tries to solve his economic problems by engaging in work, he finds himself in situations that can override economic benefits to him. In some cases, people suffer injuries, diseases and in extreme situations, death from the kind of work they do for living. These misfortunes could be due to the work environment, altitudes, machinery and substances/chemicals that are used to undertake the kind of work. The effect of occupation on a worker's health is often dependent on the level of exposure of that worker to the relevant physical, chemical and biological agents at workplace [3]. In some cases also, management simply fail to provide the safe environment for their employees. Over the years, employees have suffered varied degrees of casualties as a result of injuries or diseases thus becoming liabilities as a result of these injuries or diseases, suffered during active service or after retirement. It can also lead to situation where productivity will decline as injuries and diseases prevent people from bringing out their maximum output. Occupation related cancers are believed to represent between 2–20% of all cases.[4] Every year, at least 200,000 people die worldwide from cancer related to their workplace.[5] Currently, most cancer deaths caused by occupational risk factors occur in the developed world.[5] It is estimated that approximately 20,000 cancer deaths and 40,000 new cases of cancer each year in the U.S. are attributable to

occupation.[6] Millions of workers run the risk of developing cancers such as lung cancer and mesothelioma from inhaling asbestos fibers and tobacco smoke, or lukaemia from exposures at their workplaces.[5] As stated earlier several issues affect occupational safety and health of an employee; notable among them are unsafe action of workers, working in an environment where dangerous chemicals and physical agents pose health risk to employees. One such dangerous agent is radiation from sources such as radionuclide and ionizing radiations. Man benefits greatly from the use of x-rays, radioisotopes, and fissionable materials in medicine, industry, research, and power generation. However, the realization of these gains involves the routine exposure of persons to radiation in the procurement and normal use of sources as well as exposures from accidents that might occur. Since any radiation exposure presumably involves some risk to the individuals involved, the levels of exposures allowed should be worth the result that is achieved. In principle, therefore, the overall objective of radiation protection is to balance the risks and benefits from activities that involve radiation. In fact, there are numerous areas of concern for this research but the researcher want to look at what goes on in the x-ray department of hospitals. Employees of these departments work here for most parts of their entire life. Any time they operate these machines they are exposed to some level of radiation that might over long period of time affect their health. Up to 10% of invasive cancers are related to radiation exposure, including both ionizing radiation and non-ionizing radiation.[7] What are their risk levels from the radiation dosage they receive and also do they observe safety procedures appropriately?

1.3 Objectives

1.3.1 General Objective

This thesis analyses the occupational risk of ionizing radiation exposure and its effect on selected health employees.

1.3.2 Specific Objectives

- To find out the extent to which employees use routine radiation monitoring device while working
- To measure the dosage received by employees using TLD over a period of time.
- To assess dosage received in relation to attendant rate.

1.4 Scope of the study

This research is limited to the radiation exposures in x-ray units of ten (10) hospitals in parts of the Volta, Eastern, and Greater Accra Regions. It does not involve radiation exposures from gamma ray, beta, alpha, nuclear plant and other uses of radiation.

CHAPTER TWO

2.0. Literature Review

2.1. Production of X-Rays

X-rays were discovered by Roentgen in 1895 while studying stream of electrons in a gas discharge tube. He observed that different type of radiation was produced from interaction of electrons with the glass walls of the tube that could be detected outside the tube. This radiation named x-rays could go through opaque substances, produce fluorescence, blacken a photographic plate and ionize a gas.

2.2. The x-ray Tube

The tube consists of a glass envelope which has been evacuated to high vacuum. At one end is a cathode and at the other an anode, both hermetically sealed in the tube.[8] The cathode is a tungsten filament which when heated emits electrons, a phenomenon known as thermionic emission. The anode consists of a thick copper rod at the one end which is placed in a small piece of tungsten target. When a high voltage is applied between the anode and the cathode, the electrons emitted from the filament are accelerated toward the anode and achieve high velocities before striking the target. The x-rays are produced by the sudden deflection of the electron caused by the attractive force of the tungsten nucleus. The x-ray beam emerges through a thin glass window in the tube envelope. In some tubes, thin beryllium windows are used to reduce inherent filtration of the x-ray beam.

The choice of tungsten as the target material in conventional x-ray tubes is based on the criteria that the target must have high atomic number and high melting point. The efficiency of x-ray production depends on the atomic number, and for that reason, tungsten with Z = 74 is a good target material. Also, tungsten with the melting point of 3,370°C is the element of choice for withstanding extreme heat produced in the target by the electronic bombardment.

Efficient removal of heat from the target is an important requirement for the anode design. This has been achieved in some tubes by conduction of heat through a thick copper anode to the outside of the tube where it is cooled by oil, water, or air. Rotating anodes have also been used in diagnostic x-rays to reduce the temperature of the target at any one spot. The heat generated in the rotating anode is radiated to the oil reservoir surrounding the tube. It should be mentioned that the function of the oil bath surrounding an x-ray tube is to insulate the tube housing from high voltage applied to the tube as well as absorb heat from the anode. Some stationary anodes are hooded by a copper and tungsten shield to prevent stray electrons from striking the walls or other non target components of the tube. These are secondary electrons produced from the target when it is being bombarded by the primary electron beam. Whereas copper in the hood absorbs the secondary electrons, the tungsten shield surrounding the copper shield absorbs the unwanted x-rays produced in the copper.

An important requirement of the anode design is the optimum size of the target area from which the x-rays are emitted. This area, which is called the focal spot, should be as small as possible for producing sharp radiographic images. However, smaller focal spots generate more heat per unit area of target and, therefore, limit currents and exposure. In therapy tubes, relatively larger focal spots are acceptable since the radiographic image quality is not the overriding concern.

Since the x-rays are produced at various depths in the target, they suffer varying amounts of attenuation in the target. There is greater attenuation for x-rays coming from greater depths than those from near the surface of the target. Thus the intensity of the x-ray beam decreases from the cathode to the anode direction of the beam. The variation across the x-ray beam is called the heel effect. The effect is particularly pronounced in diagnostic tubes because of the low x-ray energy and steep target angles. The problem can be reduced by using a compensating filter to provide differential attenuation across the beam in order to compensate for the heel effect and improve the uniformity of the beam.

The cathode assembly in a modern x-ray tube consists of a wire filament, a circuit to provide filament current, and a negatively charged focusing cup. The function of the cathode cup is to direct the electrons toward the anode to strike the target of the focal spot. Since size of focal spot depends on filament size, the diagnostic tubes usually have two separate filaments to provide one small and one large focal spot. The material of the filament is tungsten, chosen because of its high melting point.

2.3. Physics of X-ray Production

There are two different mechanisms by which x-rays are produced. One gives rise to bremsstrahlung x-rays and the other characteristic x-rays. The process of bremsstrahlung (braking radiation) is the result of radiative collision (interaction) between a high-speed electron and a nucleus. The electron while passing near a nucleus may be deflected from its path by the action of Coulomb forces of attraction and lose energy as bremsstrahlung, a phenomenon predicted by Maxwell's general theory of electromagnetic radiation. According to this theory, energy is propagated through space by electromagnetic fields. As the electron

with its associated electromagnetic field, passes in the vicinity of a nucleus, it suffers a sudden deflection and acceleration. As a result, a part or all of its energy is dissociated from it and propagates in space as electromagnetic radiation.

Since an electron may have one or more bremsstrahlung interactions in the material and an interaction may result in partial or complete loss of electron energy, the resulting bremsstrahlung photon may have any energy up to the initial energy of the electron. Also, the direction of emission of bremsstrahlung photons depends on the energy of the incident electrons. At electron energies below about 100 keV, x-rays are emitted more or less equally in all directions. As the kinetic energy of the electrons increases, the direction of x-ray emission becomes increasingly forward.

Electrons incident on the target also produce characteristic x-rays. An electron, with kinetic energy E_0, may interact with the atoms of the target by ejecting an orbital electron in K, L, or M orbits leaving the atom ionized. The original electron will recede from the collision with energy E_0 - E, where E is the energy given to the orbital electron. A portion of E is spent in overcoming the binding energy of the electron and the rest is carried by the ejected electron. When a vacancy is created in an orbit, an outer orbital electron will fall down to fill that vacancy. Consequently, the energy is radiated in the form of electromagnetic radiation. This is called characteristic radiation of the atoms in the target and of the shells between which the transitions took place. With higher atomic number targets and the transitions involving inner shells such as K, L, M, and N, the characteristic radiations emitted are of high enough energies to be considered in the x-ray part of the electromagnetic spectrum.

2.4. Radiation

In physics, radiation is an electromagnetic beam, charged particles and neutron beams in which energetic particles or waves travel through a medium or space. There are two distinct types of radiation; ionizing and non-ionizing. The word radiation is commonly used in reference to ionizing radiation only but it may also refer to non-ionizing. The energy radiates from its source and this naturally leads to a system of measurements and physical units that are equally applicable to all types of radiation. Both ionizing and non-ionizing radiation can be harmful to organisms and can result in changes to the natural environment.

There are different types of ionizing radiation that penetrate solid matter. They include alpha particles (α) (stopped by a sheet of paper), beta particles (β) (stopped by an aluminium plate) and Gamma radiation (γ)(attenuated when it penetrates matter). Radiation with sufficiently high energy can ionize atoms, and this occurs when an electron is knocked out from an electron shell, leaving the atom with a net positive charge. Because cells and more importantly the DNA can be damaged, this ionization can result in an increased chance of cancer. An individual cell is made of trillions of atoms. [5] The probability of ionizing radiation causing cancer is dependent upon the dose rate of the radiation and the sensitivity of the organism being irradiated. [8] Roughly speaking, photons and particles with energies above a few electron volts (eV) are ionizing. Alpha particles, beta particles, gamma rays, X-ray radiation, and neutrons may all carry energy high enough to ionize atoms. This energy is usually higher than about 40eV.The ability of an electromagnetic wave (photons) to ionize an atom or ~~molecule~~ depends on its frequency. Radiation on the short-wavelength end of the electromagnetic spectrum such as high frequency ultraviolet, X-rays, and gamma rays are ionizing. Ionizing radiation comes from radioactive materials, X-ray tubes, particle

accelerators, and is present in the environment. It is invisible and not directly detectable by human senses, so instruments such as Geiger counters are usually required to detect its presence. In some cases, it may lead to secondary emission of visible light upon interaction with matter, as in Cherenkov radiation and radiolumnescence.

Ionizing radiation has many practical uses in medicine, research, construction, and other areas, but presents a health hazard if used improperly. Exposure to radiation causes damage to living tissue, resulting in skin burns, radiation sickness and death at high doses and cancer, tumours and genetic damage at low doses. [9]

Electromagnetic radiation takes the form of self-propagating waves in a vacuum or in matter. EM radiation has an electric and magnetic field component which oscillate in phase perpendicular to each other and to the direction of energy propagation. Electromagnetic radiation is grouped into types according to the frequency of the wave, in order of increasing frequency the EM spectrum is: radio waves, microwaves, terahertz radiation, infrared radiation, visible light, ultraviolet radiation, X-rays and gamma rays. Of these, radio waves have the longest wavelengths and gamma rays have the shortest. A small window of frequencies, called visible spectrum or light, is sensed by the eye of various organisms. Ionizing electromagnetic radiation is that for which the photons making up the radiation have energies larger than about two electron volts (an energy of about 3.2×10^{-19} joules), which is a typical binding energy of an outer electron to an atom or organic molecule. This corresponds with a frequency of 4.8×10^{14} Hz, and a wavelength of 620 nm.

2.5. Occupational Limits

The National Council on Radiation Protection and Measurements (NCRP) states that the total lifetime detriment incurred each year from radiation by a worker exposed near the limits over his or her lifetime should not be greater than the annual *risk* of accidental death in a "safe" industry [10]. The annual rate of fatal accidents in 1991 varied from about 0.2×10^{-4} to 5×10^{-4}, being lowest for trade, manufacturing, and service industries and highest for mining and agriculture. The Council cites the 1980 average annual dose equivalent of 2.1 mSv for monitored radiation workers with measurable exposures. Using the total probability coefficient for workers, one finds for the average total detriment incurred by a worker $(2.1\times10^{-3}\ \text{Sv}\ \text{y}^{-1})\ (5.6\times10^{-2}\ \text{Sv}^{-1}) = 1.2\times10^{-4}\ \text{y}^{-1}$. [10] This level is in the range of the average annual risk for accidental death for all industries. This recommendation is made by the NCRP for lifetime occupational exposure to radiation: The Council recommends that the numerical value of the individual worker's lifetime effective dose in tens of mSv be limited to the value of his or her age in years excluding medical and natural background exposure. To control the distribution of exposure over a working career, the Council recommends that the annual occupational effective dose be limited to 50 mSv without medical and background exposure. It is stipulated, further, that the annual effective-dose limit is to be applied to the sum of the relevant effective doses from external radiation in the specified time period. Under a worst-case scenario, workers near the end of their careers at age 64 with an accumulated occupational effective dose of 640 mSv would not technically have exceeded the lifetime limit just stated. Their lifetime total detriment, would be $(0.64\ \text{Sv})\ (5.6\times10^{-2}\ \text{Sv}^{-1}) = 3.6\times10^{-2}$. The worst-case scenario for their lifetime risk of a fatal accident in 50 y of working in industry is about $(50\ \text{y})\ (5\times10^{-4}\ \text{y}^{-1}) = 2.5\times10^{-2}$, comparable with the estimate for radiation. The

International Commission on Radiological Protection (ICRP) recommends the same occupational annual effective-dose limit of 50 mSv. However, its cumulative limit is different, being simply 100 mSv in any consecutive 5-y period. Over a 50-y working career, the International Commission on Radiological Protection (ICRP) lifetime limit would be 1000 mSv, compared with 700 mSv at age 70 y for the NCRP [10]. The NCRP recommendations allow somewhat greater flexibility, but require maintaining cumulative lifetime exposure records for an individual. Technically, the ICRP recommendations require exposure records only over 5-y periods. For preventing deterministic effects, both the NCRP and ICRP recommend the following annual occupational equivalent-dose limits: 150 mSv for the crystalline lens of the eye and 500 mSv for localized areas of the skin, the hands, and feet [10]. The limits for deterministic effects apply irrespective of whether one or several areas or tissues are exposed. Exposure of the embryo-foetus entails special risks thus the NCRP recommends a monthly equivalent dose limit of 0.5 mSv to the embryo-foetus excluding medical and natural background radiation once the pregnancy is known.

2.6. Non Occupational Limits

Exposure limits have been established for the members of the public. Historically, limits for non occupational exposures have been one-tenth those for occupational exposures. The NCRP makes the following recommendations for the exposure of an individual to man-made sources excluding natural background and medical exposures: For continuous exposure, it is recommended that the annual effective dose not to exceed 1 mSv while a maximum annual effective dose limit of 5 mSv is recommended to provide for infrequent annual exposures. For

deterministic effects, the NCRP recommends an annual equivalent dose limit of 50mSv for the hands, feet, and skin and 15 mSv for the lens of the eye [10]

2.7. Relative Biological Effectiveness

In radiology, the relative biological effectiveness (RBE) is a number that expresses the relative amount of damage that a fixed amount of ionizing radiation of a given type can inflict on biological tissues. The higher that number, the more damaging is that type of radiation, for the same amount of absorbed energy [11]. The relative biological effectiveness for radiation of type R on a tissue of type T is traditionally defined as the ratio

$$W_R = \frac{D_X}{D_R}$$

where D_X is a reference absorbed dose of radiation of a standard type X, and D_R is the absorbed dose of radiation of type R that causes the same amount of biological damage [11]. Both doses are quantified by the amount of energy absorbed in the cells. Different types of radiation have different effectiveness mainly because they transfer their energy to the tissue in different ways. Photons and beta particles have a low linear energy transfer coefficient, meaning that they ionize atoms in the tissue that are spaced by several thousand angstroms apart along their path. In contrast, alpha particles and neutrons leave a denser trail of ionized atoms in their wake, spaced about one angstrom apart. The relative biological effectiveness is the radiation weighting factor that enters in the conversion of units of absorbed energy (such as rads and grays) to units of biological equivalent dose for radiation exposure (such as rems and sieverts, respectively). The concept is relevant in medicine, such as in radiology and radiotherapy, and to the evaluation of risks and consequences of radioactive contamination in

various contexts, such as nuclear power plant operation, nuclear fuel disposal and reprocessing, nuclear weapons, uranium mining, and laboratory safety.

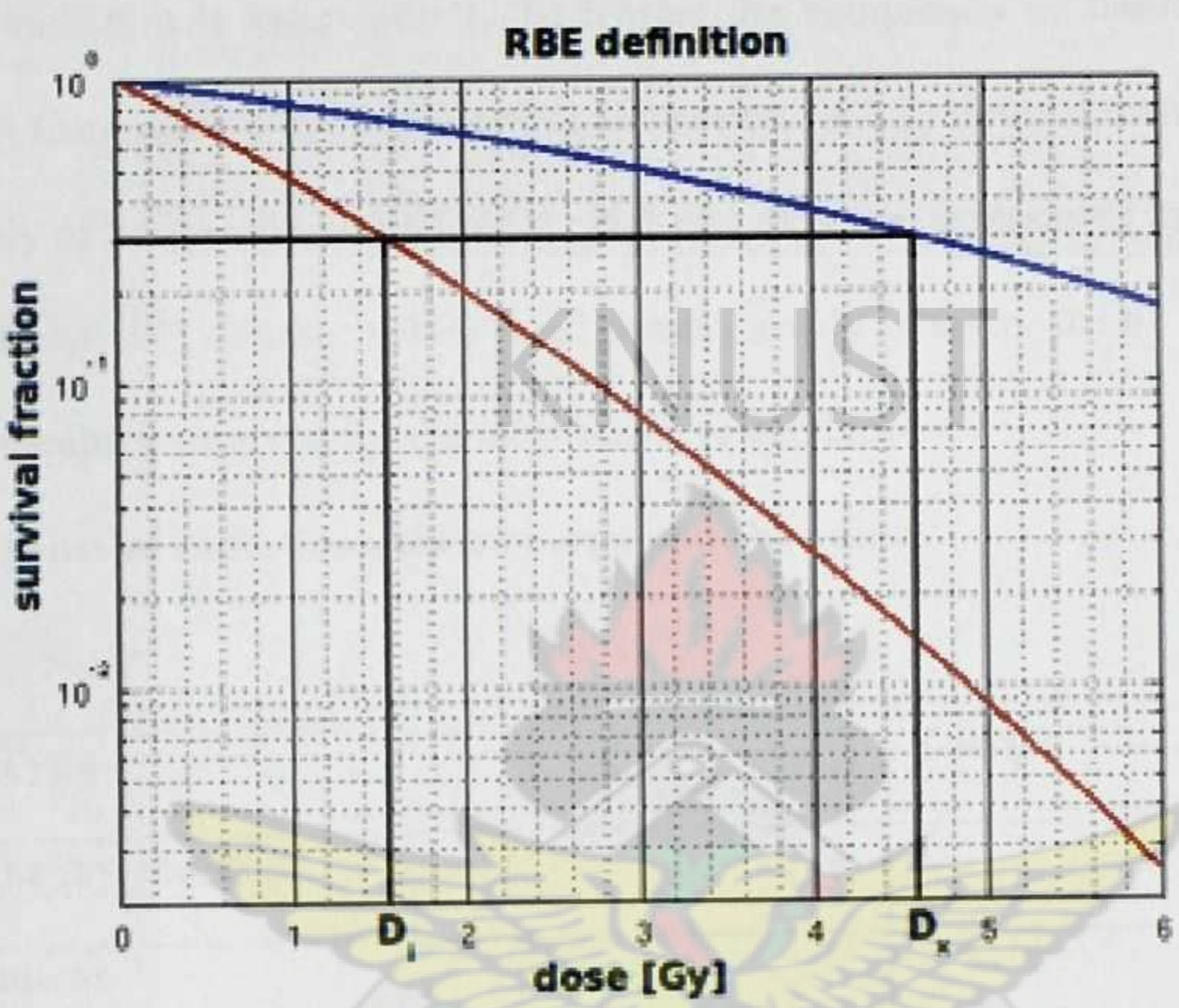


Figure 2.1: LD-50 limit for CHO-K1 cell line irradiated by photons (blue curve) and by carbon ions (red curve). [11]

Typically the evaluation of relative biological effectiveness is done on various types of living cells grown in culture medium, including prokaryotic cells such as bacteria, simple eukaryotic cells such as single celled plants, and advanced eukaryotic cells derived from organisms such as rats. The doses are adjusted to the LD-50 point; that is, to the amount that will cause 50% of the cells become unable to undergo mitotic division thus being effectively sterilized — even if they can still carry out other cellular functions. The types *R* of ionizing radiation most considered in RBE evaluation are X-rays and gamma radiation, alpha radiations (helium-4 nuclei), beta radiation, neutron radiation, and heavy nuclei, including the fragments of nuclear fission. For some kinds of radiation, the RBE is strongly dependent on the energy of the

individual particles. It was found that X-rays, gamma radiation, and beta radiation were essentially equivalent for all cell types. Therefore, the standard radiation type *X* is generally an X-ray beam with 250 keV photons. As a result, the relative biological effectiveness of beta and photon radiation is essentially 1. To bypass the complexity of tissue dependence, the International Commission on Radiological Protection (ICRP) defined standard RBE values, independently of tissue type, to be used for risk and exposure assessment in radiology and the nuclear industry [11]. These values are conservatively chosen to be greater than the experimental values observed for the most sensitive cell types.

Table 2.1: Types of radiations, their energy and W_R values

Radiation Type	Energy	W_R
x-ray, gamma ray, electrons		1
Positrons, muons	<10keV	5
neutrons	10keV-100keV	10
	100keV-2MeV	20
	2MeV-20MeV	10
	>20MeV	5
Protons	>2MeV	2
alpha particles, nuclear fission products, heavy nuclei		20

Thus, for example, a given amount of energy absorbed in the form of 15 keV neutrons should be assumed to produce 10 times the damage caused by an equal amount of energy absorbed as X-rays or gamma rays.

2.8. Dosimetric Quantities

2.8.1. Equivalent Dose

The equivalent dose, $H_{T,R}$, in a tissue or organ T due to radiation R, is defined as the product of the average absorbed dose, $D_{T,R}$, in T from R and a dimensionless radiation weighting factor, w_R, for each radiation:

$$H_{T,R} = w_R D_{T,R}.$$

When the radiation consists of components with different w_R, then the equivalent dose in T is given by summing all contributions:

$$H_T = \sum w_R D_{T,R},$$

with $D_{T,R}$ expressed in Gy (1 Gy = 1 Jkg^{-1}), $H_{T,R}$ and H_T are in Sv (1 Sv = 1 Jkg^{-1}).

The equivalent dose replaces the dose equivalent for a tissue or organ, the two are conceptually different. Whereas dose equivalent in an organ is defined as a point function in terms of the absorbed dose weighted by a quality factor everywhere, equivalent dose in the organ is given simply by the average absorbed dose weighted by the factor w_R [3].For radiation types and energies, the ICRP and NCRP give a prescription for calculating an approximate value of w_R as an average quality factor, Q. For this purpose, the quality factor Q is defined in terms of the linear energy transfer L.

2.8.2. Effective Dose

Since different tissues of the body respond differently to radiation, the probability for stochastic effects that result from a given equivalent dose will generally depend upon the particular tissue or organ irradiated. To take such differences into account, the ICRP and NCRP have assigned dimensionless tissue weighting factors w_T, which add to unity when summed over all tissues. The equivalent dose H_T in a given tissue, weighted by w_T, gives a quantity that is intended to compare with the overall detriment to an individual, independently of T. The detriment includes the different mortality and morbidity risks for cancers, severe genetic effects, and the associated length of life lost. The equivalent dose of 1mSv to the lung entails the same overall detriment for stochastic effects as an equivalent dose to the thyroid of $(0.12/0.05) \times (1\ \text{mSv}) = 2.4\ \text{mSv}$. In the definition of effective dose, they apply to workers, to the whole population, and to either sex. The w_T are based on rounded values of the organ's contribution to the total detriment. The risk for all stochastic effects for an irradiated individual is represented by the effective dose, E, defined as the sum of the weighted equivalent doses over all tissues:

$$E = \sum_T w_T H_T.$$

Like H_T, E is expressed in Sv. The risk for all stochastic effects is dependent only on the value of the effective dose, whether or not the body is irradiated uniformly. In the case of uniform, whole-body irradiation, H_T is the same throughout the body.

Then, since the tissue weighting factors sum to unity,

$$E = \sum_T w_T H_T = H_T \sum w_T = H_T,$$

The effective dose replaces the earlier effective dose equivalent. The latter quantity was defined the same way as E in the above equation with H_T being the organ or tissue dose equivalent. It should be understood that the procedures embodied in this equation have been set up for use in radiological protection. The values of w_T are simplified and rounded for a reference population of equal numbers of males and females over a wide range of ages. As stated in NCRP Report No. 116 they "should not be used to obtain specific estimates of potential health effects for a given individual." [10]

2.8.3. Absorbed Dose, Deep Dose and Skin Dose

The absorbed dose indicates the total radiation energy absorbed by the irradiated matter in gray (Gy). Fundamental dose variables in radiation protection are "organ dose" and "effective dose". The expression "body dose" is used as a collective term for organ dose and effective dose. The last two are protective variables in radiation protection, including risk assessment. They form a basis for the assessment of the probability of stochastic radiation effects for absorbed doses far below the thresholds for deterministic radiation damage. The unit of these dose values is sievert (Sv).The Radiological Protection Ordinance requires measurement of the personal dose for the determination of body dose which cannot be measured directly. Personal dose is the dose equivalent measured in the measuring variables of depth dose and skin dose at an area of the body surface representative of radiation exposure. [12] The depth dose $Hp(10)$ in this case is an estimated value for the effective dose for whole body exposure with penetrating radiation and the organ doses of deep organs and the skin dose $Hp(0,07)$ an estimated value for the skin dose.[12]

2.9 Interaction of Ionising Radiation

When an x-ray passes through a medium, Photoelectric and Compton inelastic scattering interactions occur between photons and matter, with the results that energy is transferred to the medium. The initial step in the energy transfer involves the ejection of electrons from the atoms of the absorbing medium. These high-speed electrons transfer their energy by producing ionization and excitation of the atoms along their paths. If the absorbing medium consists of body tissues, sufficient energy may be deposited within the cells, destroying their reproductive capacity. However, most of the absorbed energy is converted into heat, producing no biologic effect

2.9.1. Ionization

The process by which a neutral atom acquires a positive or a negative charge is known as ionization. Removal of an orbital electron leaves the atom positively charged, resulting in an ion pair. The stripped electron, in this case, is the negative ion and the residual atom is the positive ion. In some cases, an electron may be acquired by a neutral atom and the negatively charged atom then becomes the negative ion. Charged particles such as electrons, protons and beta particles are known as directly ionizing radiation provided they have sufficient kinetic energy to produce ionization by collision as they penetrate matter. [8] The energy of the incident particle is lost in a large number of small increments along the ionization track in the medium, with an occasional interaction in which the ejected electron receives sufficient energy to produce a secondary track of its own, known as a gamma ray. If, on the other hand, the energy lost by the incident particle is not sufficient to eject an electron from the atom but is used to raise the electrons to higher energy levels, the process is termed excitation.

The uncharged particles such as neutrons and photons are indirectly ionizing radiation because they liberate directly ionizing particles from matter when they interact with matter. Ionizing photons interact with the atoms of a material or absorber to produce high-speed electrons by three major processes: photoelectric effect, Compton Effect, and pair production. [8]

2.10 Classification of Radiations in Radiobiology

For use in radiobiology and radiation protection the physical quantity that is useful for defining the quality of an ionizing radiation beam is the linear energy transfer (LET), an approximation of stopping power, which focuses attention on the energy loss by an energetic charged particle moving through a medium. The LET also focuses attention on the linear rate of energy absorption by the absorbing medium as the charged particle traverses the medium. The International Commission on Radiological Protection (ICRP) defines the LET as follows: "LET of charged particles in a medium is the quotient dE/dl, where dE is the average energy locally imparted to the medium by a charged particle of specified energy in traversing a distance of dl."[13] Both stopping power and LET have typical unit of MeV/cm / keV/μm. The energy average is obtained by dividing the particle track into equal energy increments and averaging the length of track over which these energy increments are deposited. Typical LET value for commonly used for X ray radiations of 250 kVp X ray is 2 keV/μm. X rays and gamma rays are considered low LET (sparsely ionizing) radiations, while energetic neutrons, protons and heavy charged particles are high LET (densely ionizing) radiations.

2.11. Type of Radiation Damage

2.11.1 Direct Action in Cell Damage by Radiation

In direct action the radiation interacts directly with the critical target in the cell. The atoms of the target itself may be ionized or excited through Coulomb interactions, leading to the chain of physical and chemical events that eventually produce the biological damage. Direct action is the dominant process in the interaction of high LET particles with biological material.

2.11.2 Indirect Action in Cell Damage by Radiation

In indirect action the radiation interacts with other molecules and atoms (mainly water, since about 80% of a cell is composed of water) within the cell to produce free radicals, which can, through diffusion in the cell, damage the critical target within the cell. In interactions of radiation with water, short lived yet extremely reactive free radicals such as H_2O^+ (water ion) and OH• (hydroxyl radical) are produced. The free radicals in turn can cause damage to the target within the cell. The free radicals that break the chemical bonds and produce chemical changes that lead to biological damage are highly reactive molecules because they have an unpaired valence electron. About two thirds of the biological damage by low LET radiations such as X rays or electrons is due to indirect action.[13] Indirect action can be modified by chemical sensitizers or radiation protector .The steps involved in producing biological damage by the indirect action of X rays are as follows:

- Step 1: Primary photon interaction such as photoelectric effect, Compton Effect and pair production produces a high energy electron
- Step 2: The high energy electron in moving through tissue produces free radicals in water.
- Step 3: The free radicals may produce changes in DNA from breakage of chemical bonds.

- Step 4: The changes in chemical bonds result in biological effects.

2.11.3 Fate of Irradiated Cells

Irradiation of a cell will result in one of the following nine possible outcomes:

- No effect.
- Division delay: The cell is delayed from going through division.
- Apoptosis: The cell dies before it can divide or afterwards by fragmentation into smaller bodies, which are taken up by neighbouring cells
- Reproductive failure: The cell dies when attempting the first or subsequent mitosis.
- Genomic instability: There is a delayed form of reproductive failure as a result of induced genomic instability.
- Mutation: The cell survives but contains a mutation.
- Transformation: The cell survives but the mutation leads to a transformed phenotype and possibly carcinogenesis.
- Bystander effects: An irradiated cell can send signals to neighbouring unirradiated cells and induce genetic damage in them.
- Adaptive responses: The irradiated cell is stimulated to react and become more resistant to subsequent irradiation.

2.11.4 Timescale

The timescale involved between the breakage of chemical bonds and the biological effect may be hours to years, depending on the type of damage. If cell dies as a result, it may happen in hours to days, when the damaged cell attempts to divide. This can result in early tissue

reaction if many cells died. If the damage is oncogenic (cancer induction), then its effects may be delayed for years. Ionizing radiation has been proven to cause leukaemia and has lead to the development of many other cancers in tissues such as bone, lung, skin, thyroid and breast. Delayed effects of radiation may cause delayed tissue reactions such as fibrosis and other reactions mediated by vascular deficiencies; life span shortening; genetic damage; and potential effects to the foetus.

Usually, changes in many genes are required to transform a normal cell into a cancer cell.[14] Radiation can cause cancer in most parts of the body, and at any age, although radiation-induced solid tumours usually take 10–15 years, and can take up to 40 years, to become clinically manifest, and radiation-induced leukaemia typically require 2–10 years to appear. [15] Unlike chemical or physical triggers for cancer, ionizing radiation hits molecules within cells randomly. If it happens to strike a chromosome, it can break the chromosome, result in an abnormal number of chromosomes, inactivate one or move genes in the part of the chromosome that it hit, delete parts of the DNA sequence, cause chromosome translocations, or cause other types of chromosome abnormalities.[15] Major damage normally results in the cell dying, but smaller damage may leave a stable, partly functional cell that may be capable of proliferating and developing into cancer, especially if tumor suppressor genes were damaged by the radiation.[15] Three independent stages appear to be involved in the creation of cancer with ionizing radiation: morphological changes to the cell, acquiring cellular immortality (losing normal, life-limiting cell regulatory processes), and adaptations that favour formation of a tumor.[15] Even if the radiation particle does not strike the DNA directly, it triggers responses from cells that indirectly increase the likelihood of mutations.[15]

2.11.5 Classification of Radiation Damage

Radiation damage to mammalian cells is divided into three categories:

- Lethal damage, which is irreversible, irreparable and leads to cell death;
- Sub lethal damage, which can be repaired in hours unless additional sub lethal damage is added that eventually leads to lethal damage;
- Potentially lethal damage, which can be manipulated by repair when cells are allowed to remain in a non-dividing state.

2.12. Radiation Effects

2.12.1 Somatic and Genetic Effects

The effects of radiation on the human population can be classified as either somatic or genetic:

- Somatic effects are harm that exposed individuals suffer during their lifetime, such as radiation induced cancers (carcinogenesis), sterility, opacification of the eye lens and life shortening.
- Genetic or hereditary effects are radiation induced mutations to an individual's genes and DNA that can contribute to the birth of defective descendants. Carcinogenesis expresses itself as a late somatic effect in the form of acute or chronic myeloid leukaemia or some solid tumours, for example in the skin, bone, lung, thyroid or breast. Human data on carcinogenesis have been collected from the following sources:
  - Low level occupational exposure;
  - Atomic bomb survivors in Hiroshima and Nagasaki;
  - Medical radiation exposure of patients and staff

2.12.2 Stochastic and Deterministic (non-stochastic) Effects

The harmful effects of radiation may be classified into two general categories: stochastic and deterministic. The NCRP defines these effects as follows:

- A stochastic effect is one in which the probability of occurrence increases with increasing dose but the severity in affected individuals does not depend on the dose. There is no threshold dose for effects that are truly stochastic, because these effects arise in single cells and it is assumed that there is always some small probability of the event occurring even at very small doses.
- A deterministic effect (tissue reaction) is one that increases in severity with increasing dose, usually above a threshold dose, in affected individuals. These are events caused by damage to populations of cells, hence the presence of a threshold dose.

2.12.3 Acute Versus Late Tissue or Organ Effects

An organ or tissue response to radiation damage can either be an acute effect or as a late (chronic) effect. Acute effects manifest themselves soon after exposure to radiation and are characterized by inflammation, edema, denudation of epithelia and haemopoietic tissue, and haemorrhage. Late effects are delayed and are, for example, fibrosis, atrophy, ulceration, stenosis or obstruction of the intestine. Late effects may be generic and caused by absorption of radiation directly in the target tissue, or consequential to acute damage in overlying tissues such as mucosa or the epidermis.

2.13 Individual Monitoring and Exposure Assessment

The reason for monitoring and exposure assessment is to collect information on the actual exposure of workers and to confirm good working practices contributing to reassurance and

motivation. The Basic Safety Standards (BSS) requires individual monitoring for any worker who is normally employed in a controlled area and who may receive a significant occupational exposure. Those radiotherapy professionals who need individual monitoring are radiation oncologists, qualified experts in radiotherapy physics, radiation protection officers, radiotherapy technologists, source handlers, maintenance staff and any nursing or other staff who must spend time with patients who contain radioactive sources. Monitoring includes measuring and determining the equivalent dose and also interpretation and assessment. Individual external doses can be determined by using individual monitoring devices such as thermoluminescent dosimeters (TLDs) or film badges, which are usually worn on the front of the upper trunk .In a radiotherapy department the personal dosimeters should be exchanged at regular intervals not exceeding three months. Moreover, the reports on read dosimeters should become available as soon as possible but not later than within three months after the exchange. Delays in the evaluation of a dosimeter can result in the loss of the stored information. If an individual's dosimeter is lost, the licensee shall perform and document an assessment of the dose the individual received and add it to the worker's dose record. Often the most reliable method for estimating an individual's dose is to use his or her recent dose history, provided that nothing unusual occurred in the period. Individual monitoring devices are to be calibrated, and this calibration shall be traceable to a standards dosimetric laboratory.

2.14 External Radiation Protection

2.14.1 Distance, Time, and Shielding

In principle, one's dose in the vicinity of an external radiation source can be reduced by increasing the distance from the source, by minimizing the time of exposure, and by the use of

shielding. Distance is often employed simply and effectively. For example, tongs are used to handle radioactive sources in order to minimize the dose to the hands as well as the rest of the body. Limiting the duration of an exposure significantly is not always feasible, because a certain amount of time is usually required to perform a given task. Sometimes, though, practice runs beforehand without the source can reduce exposure times when an actual job is carried out. While distance and time factors can be employed advantageously in external radiation protection, shielding provides a more reliable way of limiting personnel exposure by limiting the dose rate. In principle, shielding alone can be used to reduce dose rates to desired levels. In practice, however, the amount of shielding employed will depend on a balancing of practical necessities such as cost and the benefit expected.

2.14.2 Shielding in X-Ray Installations

X-ray machines have three principal uses—as diagnostic, therapeutic, and nonmedical radiographic devices. An X-ray tube is frequently housed in a heavy lead casing with an opening through which the primary beam emerges. In general, the beam passes through metal filters to eliminate unwanted, less penetrating radiation and is then collimated to reduce its width. The housing, supplied by the manufacturer, must conform to certain specifications in order to limit the leakage radiation that emerges from it during operation. For diagnostic X-ray tubes, regulations require that manufacturers limit the leakage exposure rate at a distance of 1 m from the target of the tube to 0.1 R h^{-1} when operated continuously at its maximum rated current and potential difference.[13] The shielding provided by the X-ray housing is referred to as source shielding. Additional protection is obtained by the use of structural shielding in an X-ray facility. A primary protective barrier, such as a lead-lined wall, is fixed in place in any

direction in which the useful beam can be pointed. This shield reduces the exposure rate outside the X-ray area in the direction of the primary beam. Locations not in the direct path of the beam are also exposed to photons in two ways. The leakage radiation escapes from the housing in all directions. In addition, photons are scattered from exposed objects in the primary beam and from walls, ceilings, and other structures. Secondary protective barriers are required to lessen exposure rates outside the X-ray area from both leakage and scattered radiation. Sometimes existing structures, such as concrete walls, provide sufficient secondary barriers; otherwise, additional shielding, such as lead sheets, must be added to them. Usually, structural shielding has been designed in a way consistent with limiting the effective dose to an individual outside the X-ray room to 1 mSv wk^{-1} in controlled areas and to 0.1 mSv wk^{-1} in uncontrolled areas. A controlled area is one in which access and occupancy is regulated in conjunction with operation of the facility. Persons working there have special training in radiation protection, and radiation exposures are monitored. In contrast, individuals are free to come and go in uncontrolled areas. These design goals adhere to the annual limits of 50 mSv and 5 mSv for occupational and non occupational radiation. Since many instruments used to monitor X radiation are calibrated to measure exposure in roentgen (R), the shielding design objectives that have usually been employed are expressed as 0.1 Rwk^{-1} and 0.01 Rwk^{-1}. Numerically, an exposure of 1 R produces an absorbed dose of 8.76 mGy in air. On the other hand, a 1-mGy absorbed dose in air corresponds to 0.114 R. In 2004 the National Council on Radiation Protection and Measurements (NCRP) issued Report No. 147, Structural Shielding Design for Medical X-Ray Imaging Facilities, in which the Council recommends that air kerma, k, be the quantity used for making X-ray shielding calculations. [13] It specifies that an instrument reading in R can be divided by 114 to obtain the air kerma in Gy. The suggested

design goal for occupational exposure is also revised. The cumulative effective-dose limit implies an average annual limit of 10 mSv. In the design of new facilities, the Council recommends one-half this value, or 5 mSv y^{-1}, and a weekly design goal of P = 0.1 mGy air kerma. Using one-half also accomplishes adherence to a monthly equivalent-dose limit of 0.5 mSv to a worker's embryo or foetus.

2.15 Risk Estimates for Radiation Protection

Risk estimates for cancer and genetic effects from radiation were studied by Organizations such as the ICRP, NCRP, the Radiation Effects Research Foundation, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the National Radiological Protection Board of the United Kingdom and the National Academy of Sciences–National Research Council in the United States. From these studies, the ICRP and the NCRP have concluded that it is proper to use for the nominal lifetime fatal cancer risks for low-dose and low-dose-rate exposure the values 4.0×10^{-2} Sv^{-1} for an adult worker population and 5.0×10^{-2} Sv^{-1} for a population of all ages. These numbers reflect risk estimates that are lower by about a factor of 2 compared with data from high doses and high dose rates. The detriment from radiation exposure must include other deleterious effects in addition to fatal cancer. The detriments from nonfatal cancers were estimated by the ICRP and NCRP to be 0.8×10^{-2} Sv^{-1} for workers and 1.0×10^{-2} Sv^{-1} for the whole population. Those for severe genetic effects were, respectively, 0.8×10^{-2} Sv^{-1} and 1.3×10^{-2} Sv^{-1}. The total detriments (equivalent fatal cancer risks) were then 5.6×10^{-2} Sv^{-1} for a working population and 7.3×10^{-2} Sv^{-1} for a population of all ages. The ICRP and NCRP referred to these quantities as "probability coefficients," preferring to employ the term "risk" for the abstract

concept rather than a numerical value of the quantity. They reflect cancer incidence, adjusted for lethality, and heritable effects. Subsequent studies by the ICRP have led to some revision in the totals given in the last line of Table 2.2 to values of 4.9×10^{-2} Sv^{-1} and 6.5×10^{-2} Sv^{-1}, respectively, for workers and for the general population, in place of 5.6×10^{-2} Sv^{-1} and 7.3×10^{-2} Sv^{-1} [13]. The overall estimated probability coefficients for workers and for the public are thus about 10% lower than before.

Table 2.2 Probability Coefficients for Stochastic Effects (per Sv effective dose)

Detriment	Adult workers ($10^{-2}Sv^{-1}$)	Whole population($10^{-2}Sv^{-1}$)
Fatal cancer	4.0	5.0
Nonfatal cancer	0.8	1.0
Severe genetic effect	0.8	1.3
Total	5.6	7.3

Source: ICRP Publication 60 and NCRP Report No. 116.

2.16 Current Exposure Limits of the NCRP and ICRP

The exposure limits of the NCRP and ICRP embrace the following philosophy, as stated in NCRP Report No. 116 (p. 9):

The specific objectives of radiation protection are:

1. to prevent the occurrence of clinically significant radiation-induced deterministic effects by adhering to dose limits that are below the apparent threshold levels and
2. to limit the risk of stochastic effects, cancer and genetic effects, to a reasonable level in relation to societal needs, values, benefits gained and economic factors.

The Council goes on to include the principle of As Low As Reasonably Achievable (ALARA) in its philosophy. It states, further, that for radiation-protection purposes, the risk of stochastic effects is assumed to be proportional to dose without threshold throughout the dose range of relevance in routine radiation protection.

2.17 Probability of Causation

As we have pointed out several times, it is difficult, if not impossible, to attribute a given malignancy in a person to his or her past radiation history. Diseases induced by radiation, from either natural or man-made sources, also occur spontaneously. The concept *of probability of causation* has been introduced to provide an estimate of the probability that a given cancer in a specific tissue or organ was caused by previous exposure to a carcinogen, such as radiation. Although not a part of limits setting, the concept is closely related to the health effects and risk estimates that we have been discussing here. If R denotes the excess relative risk for the cancer that results from a given radiation dose, then the probability of causation P is defined as:

$$P = \frac{R}{1+R}$$

This concept does not take other factors into account, such as uncertainties in dose and in the models used to determine R.[13] In the United States, the Congress mandated the use of the probability of causation to evaluate claims of radiation injury from nuclear weapons testing, fallout, and uranium mining.

2.18 Thermoluminiscence

In thermoluminescent dosimeters (TLDs), the crystal material and impurities are chosen so that the electrons and holes remain trapped at the activator sites at room temperature. When in a radiation field, a TLD crystal serves as a passive integrating detector, in which the amount of trapped electrons and holes depends on its radiation exposure history. After exposure, the TLD material is heated and increased temperature causes trapped electrons and holes to migrate and combine, with the accompanying emission of photons with energies of a few eV. Some of the photons enter a photomultiplier tube and produce an electronic signal. The sample is commonly processed in a TLD reader, which automatically heats the material, measures the light yield as a function of temperature, and records the information in the form of a glow curve. Typically, several peaks occur as traps at different energy levels are emptied. The total light output or the area under the glow curve can be compared with that from calibrated TLDs to infer radiation dose. All traps can be emptied by heating to sufficiently high temperature, and the crystal reused.

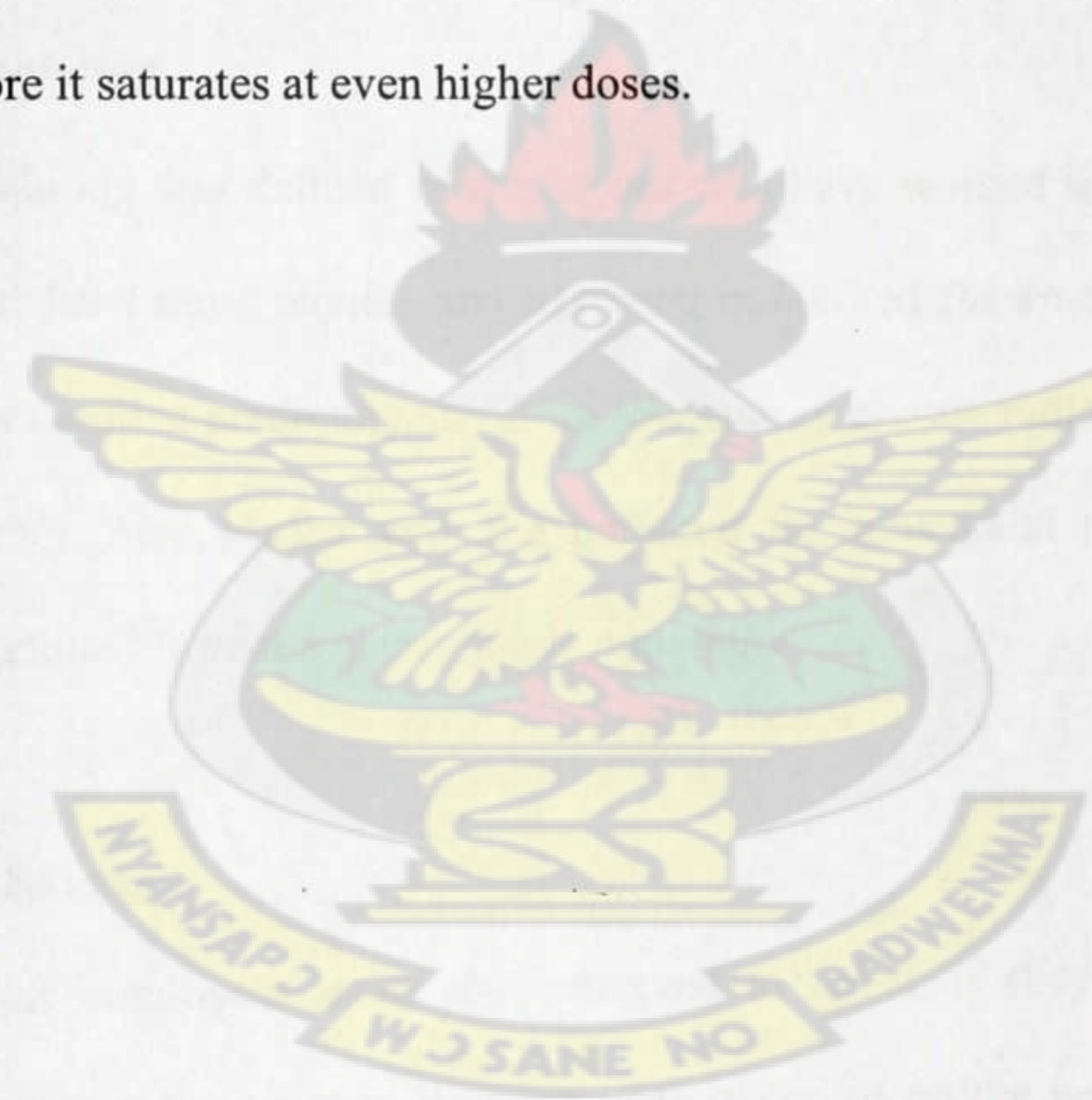
Some common TLD materials are Manganese-activated calcium sulphate ($CaSO_4$): Mn is sensitive enough to measure doses of a few tens of μrad. Another popular TLD crystal is LiF, which has inherent defects and impurities and needs no added activator. It is resistant to fading and is close to tissue in atomic composition. It can be used to measure gamma-ray doses in the range of about 0.01–1000 rad. Other TLD materials include CaF_2: Mn, CaF_2: Dy, $Li_2B_4O_7$: Mn, LiF: Mg, Ti, LiF: Mg, Cu, P and $Li_2B_4O_7$: Mn, because of their tissue equivalence. Other TLDs, used because of their high sensitivity, are $CaSO_4$: Dy, Al_2O_3: C [13]

2.18.1. Thermoluminescent dosimeter systems

- TLDs are available in various forms e.g. powder, chips, rods and ribbons.
- Before they are used, TLDs need to be annealed to erase the residual signal. Well established and reproducible annealing cycles, including the heating and cooling rates, should be used.

  A basic TLD reader system consists of a planchet for placing and heating the TLD, a PMT to detect the thermoluminiscence light emission and convert it into an electrical signal linearly proportional to the detected photon fluence and an electrometer for recording the PMT signal as a charge or current.
- The thermoluminiscence intensity emission is a function of the TLD temperature T. Keeping the heating rate constant makes the temperature T proportional to time t, and so the thermoluminiscence intensity can be plotted as a function of t if a recorder output is available with the TLD measuring system. The resulting curve is called the TLD glow curve. In general, if the emitted light is plotted against the crystal temperature one obtains a thermoluminiscence thermogram.
- The peaks in the glow curve may be correlated with trap depths responsible for thermoluminiscence emission.
- The main dosimetric peak of the LiF: Mg, Ti glow curve between 180°C and 260°C is used for dosimetry.[13] The peak temperature is high enough so as not to be affected by room temperature and still low enough so as not to interfere with black body emission from the heating planchet.
- The total thermoluminiscence signal emitted (i.e. the area under the appropriate portion of the glow curve) can be correlated to dose through proper calibration.

- Good reproducibility of heating cycles during the readout is important for accurate dosimetry.
- The thermoluminiscence signal decreases in time after the irradiation due to spontaneous emission of light at room temperature. This process is called fading. Typically, for LiF: Mg, Ti, the fading of the dosimetric peak does not exceed a few per cent in the months after irradiation.[13]
- The thermoluminiscence dose response is linear over a wide range of doses used in radiotherapy, although it increases in the higher dose region, exhibiting supralinear behaviour before it saturates at even higher doses.



CHAPTER THREE

3.0 Materials and Methods

Information was collected on 36 workers from 10 hospitals in parts of Volta, Eastern and Greater Accra Regions of Ghana. To be eligible for inclusion in the study, a subject had to satisfy a number of defined criteria including availability of the individual in X ray units for at least three months as an employee, and availability of information on monitoring policies and practices over time.

3.1 Main Sample Population

The main sample population was defined as employees who have worked in an x ray unit of selected hospital for at least three months and has been monitored for an external radiation exposure, whose doses resulted predominantly from low energy photon radiation (x ray in the range 83 kV to110 kV). Any worker with the potential for substantial doses from other radiation types was excluded from the main sample population.

3.2 Observation and Survey

The safety practices of employees were also observed to check if they followed safety procedures as they carry out their duties. Workers were observed on the issue of wearing of thermoluminescent dosimeters (TLD) badges and lead aprons. Also, interviews in the form of questionnaire surveys also formed part of this research methodology. These questionnaires were distributed to each person to fill and after one week were collected. Some notable components included the age of subject, daily number of patient attendant among others. Each hospital was visited at least three times to enable the researcher carry out his observation. The

first observation was done at the time the TLD badges questionnaires were being distributed, the second when the questionnaires were being collected and the final one at the time the badges were being collected. The employees were not made aware of the observation since the researcher wanted to use it to confirm some of the information provided on the questionnaires.

3.3 Dosimetry

For each worker monitored for external radiation exposure, a dosimetric record was reconstructed using recorded photon doses from individual facilities. The TLD badges were collected from the physics department of Kwame Nkrumah University of Science and Technology (KNUST) which were sent to the facilities and then distributed to the employees. These badges were worn by the employees for a period of one month. These were then collected and sent to the laboratory for reading to determine the absorbed dose employees received for the period. This was then repeated for another two months to determine three month cumulative dose from which the averages were calculated. Each worker was assigned TLDs (TLD-100) with a facility and a personal identification number (PIN) for traceability. Via hospital management, radiation safety officers were provided with dosimeter user instructions that included strict adherence to wearing of TLD badges on the upper torso, between the neck and waist, and outside protective gear when undertaking exposure-related activities. Compared to photographic film dosimeters (film badges), TLD's are more sensitive, reusable, often more nearly tissue-equivalent, cover a wider range of doses, allows measurement of deep and shallow doses, and most TLD materials are less subject to fading. [16] Regulations require that workers occupationally exposed to ionizing radiation should wear devices called dosimeters so that accumulated doses can be monitored over a period of time.

Thermoluminiscent dosimeters contain material which when exposed to ionizing radiation, absorbs the energies and stores it. When heated, a small part of the deposited energy is released as light. [16] The process is called the thermoluminiscence. The amount of released light (under given heating conditions) is proportional to the energy deposited.[16]The TLD-100 is fabricated from lithium fluoride elements assembled in bar-coded cards encapsulated in Teflon (Harshaw Model 0110).The TLD-100 has a radiation dose measurement range of 0.05 mSv - 10 Sv. For penetrating external ionising radiation, personal deep dose equivalent (which is scientifically recommended for operational deep dose quantity) was adopted in this study. The LiF (TLD-100) used was given special annealing to minimize sensitivity. The holder is of HPA design and comprises a polypropylene case with a thick filter of PTFE and polypropylene which covers the thick TLD element for the assessment of Hp (10). [17] A circular open window is positioned over the thin TLD element which is only covered by the retaining layer of PTFE and the thin wrapper, for the assessment of Hp (0.07). [17] For the TLD to achieve best performance as dosimeters they were subjected to uniform, reproducible, and optimal heat treatment before and after use. This is to enable them have small enough leakage for practical room-temperature dosimetry having a half-life of trapped charge carriers in months or years.

3.4 The TLD Reader

The instrument used to heat a TLD phosphor, and to measure the resulting TL light emitted is simply called a "TLD reader". The TLD phosphor to be measured is placed in the heater pan at room temperature, and heated while the emitted light is measured with a photomultiplier.

Heating of the sample was done by means of preheated N_2 gas. Its design principle is shown schematically in the fig 3.1 below.

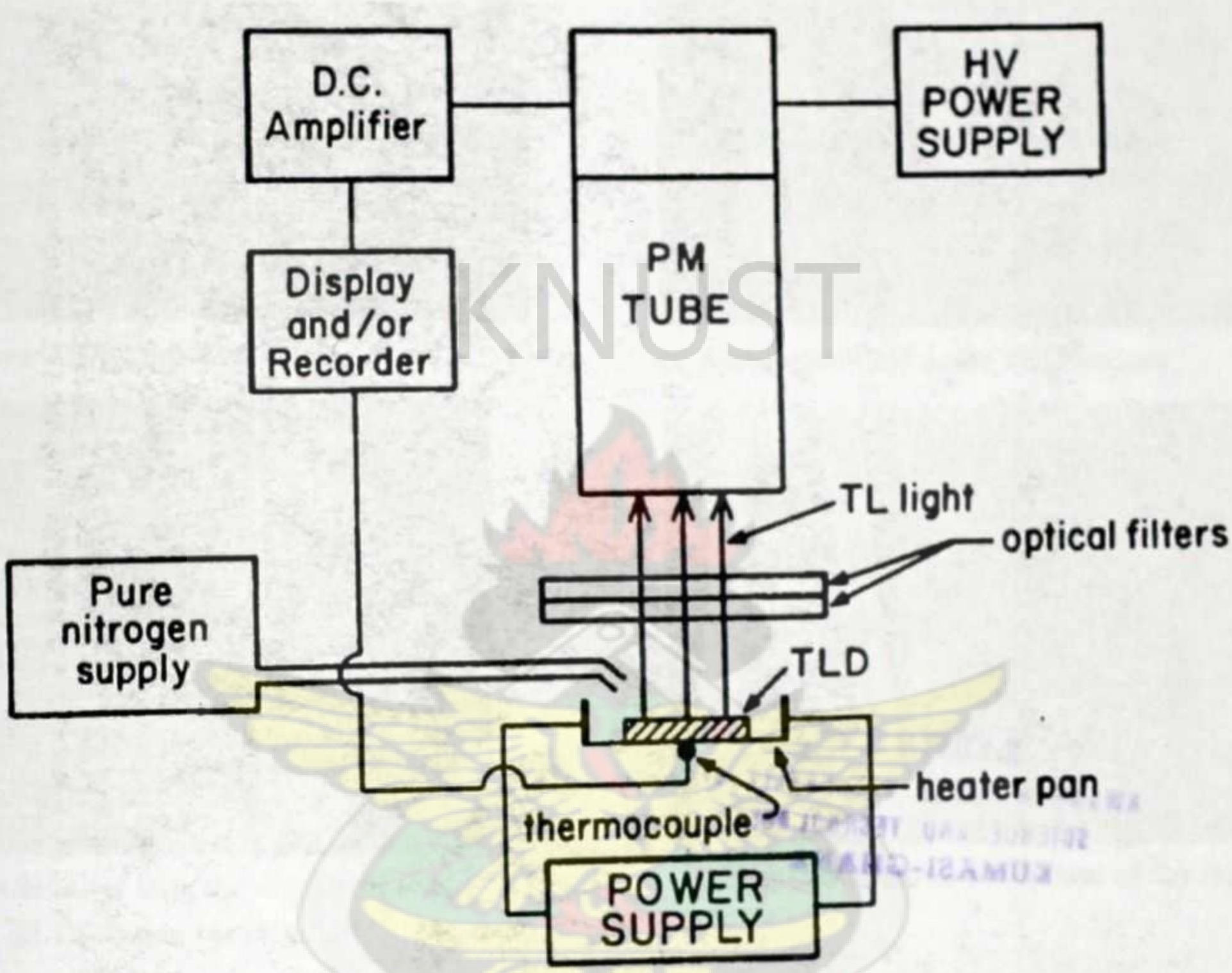


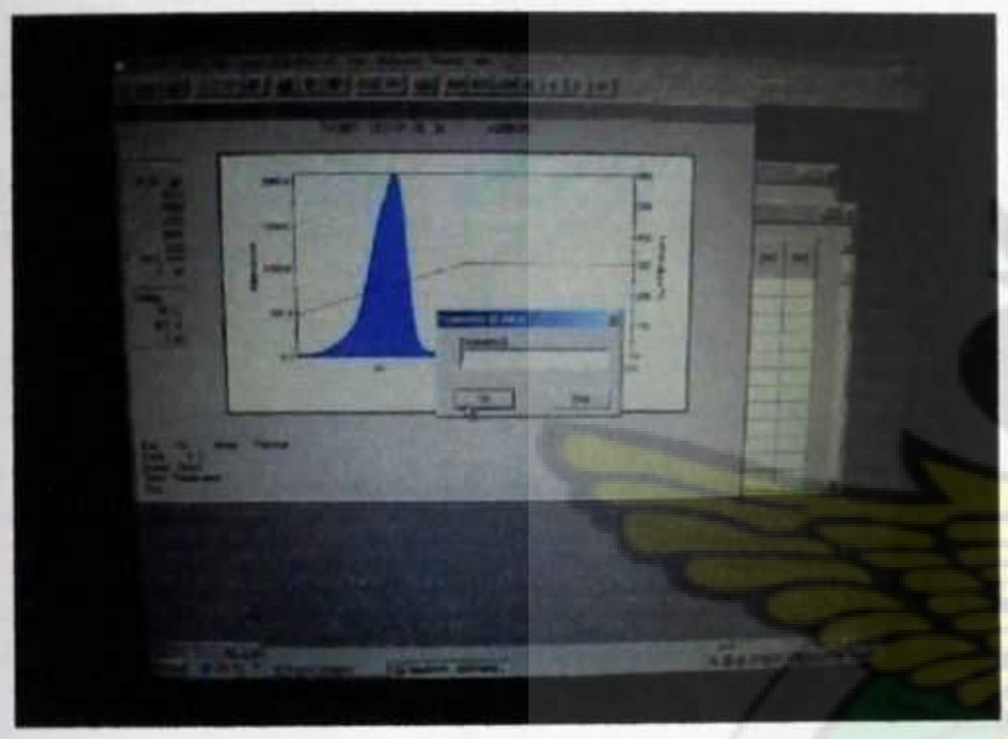
Figure 3 1: Schematic diagram of TLD Reader

Source: 30-integrating Dosimeter 1 a presentation by Michael Hale

TLD reader (Harshaw Model 4500 operating under WinREMS software) was used to process the TLD signals. The Oven and the Reader were connected to a dedicated personal computer that used WinREMS software for initiating the annealing and reading programs respectively.

Harshaw 4500 model reader

System unit and some TLD badges



Computer monitor with the display of read out from TLDs during reading

Blower which blows hot air out of the reader

Front view of nitrogen gas generator

Side view of nitrogen gas generator

Fig 3.2: Equipment used the researcher to carry out the measurement of TLDs

3.5 Cumulative Dose Calculation

For each worker, cumulative dose was estimated over time from the first month to the third month and then average monthly dose determined. There was no information on employee's history as a secondary data so this calculation was done on an assumption. It was assumed that, the average monthly dose received by each worker in the three months external exposure monitoring is the same and then used to estimate the annual dose. This was to reduce probable uncertainties of using just one month dose value. Other types of radiation dose such as medical and background radiation exposures were ignored, assuming monthly doses were distributed uniformly for the rest of the year. To allow for a possible latent period between an exposure and its consequences, cumulative doses were lagged by 2 years for leukaemia and 10 years for all other causes of death, as in most previous nuclear worker studies [18].

3.6 Statistical Analysis

Using the regression analysis, the researcher wants to establish a relationship between the average dose received by an employee and the estimated number of patients radiographed in a month. It was anticipated that the higher the number of the patients attendance rate the higher the dose received by an employee. Using the t distribution, the population mean was determined from the sample mean. The t distribution formula uses at specific confidence interval for the sample mean (X) when population standard deviation(σ) is unknown and sample size (n) less than 30 is given by $\mathbf{X-t_{\alpha/2}(s/\sqrt{n})<\mu<X+t_{\alpha/2}(s/\sqrt{n})}$,where (s) is the sample standard deviation and (μ) the population mean.

3.7 Risk Estimation Models

As a result of extra years of follow-up in the Japanese bomb survivors, it became clear that the relative risk model fitted the solid cancer data much better than the absolute risk model. [18] For this reason ICRP and most other scientific committees tend to use the relative risk model rather than the absolute risk model for projecting solid cancer risks to the end of life. [18] For ease of PC calculations the generalised relative risk model is preferred since it does not require knowledge of baseline cancer mortality and incidence rates.[18] In calculating the *PC* relating to a particular occurrence the individual characteristics (other than age and sex) of a person are ignored. The probability of causation is still a useful concept that can be understood as the likelihood that a particular cancer was induced by radiation.

3.7.1 Leukaemia Models

Biological Effects of Ionizing Radiation (BEIR V) used a linear-quadratic relative risk model obtained by fits to the Japanese Life Span Study (LSS) leukaemia mortality data (ICD9 204-207). [18] Under this model, the leukaemia mortality rate following a dose of *D* Sv is:

$r_0(a, s)\,[1 + (\alpha_2 D + \alpha_3 D^2)\exp\beta_1)]$ if $e \leq 20, t \leq 15$

$r_0(a, s)\,[1 + (\alpha_2 D + \alpha_3 D^2)\exp(\beta_2)]$ if $e \leq 20, 15 < t \leq 25$

$r_0(a, s)\,[1 + (\alpha_2 D + \alpha_3 D^2)]$ if $e \leq 20, t > 25$

$r_0(a, s)\,[1 + (\alpha_2 D + \alpha_3 D^2)\exp(\beta_3)]$ if $e > 20, t \leq 25$

$r_0(a, s)\,[1 + (\alpha_2 D + \alpha_3 D^2)\exp(\beta_4)]$ if $e > 20, 25 < t \leq 30$

$r_0(a, s)\,[1 + (\alpha_2 D + \alpha_3 D^2)]$ if $e > 20, t > 30$

where $r_0(a, s)$ is the baseline mortality rate, e = age at exposure, t = time since exposure and where $\alpha_2 = 0.243\ Sv^{-1}$, $\alpha_3 = 0.271\ Sv^{-2}$ $\beta_1 = 4.885$, $\beta_2 = 2.380$, $\beta_3 = 2.367$, $\beta_4 = 1.638$. [18]

3.7.2 Digestive cancer models

BEIR V used a linear relative risk model obtained by fits to the Japanese LSS mortality data for the group of "all digestive cancers" (ICD9 150-159) (with <4 Sv stomach dose). Under this model the digestive cancer mortality rate following a dose D (Sv) is:

$r_0(a, s)[1 + \alpha_1 D)]$	if s = male, e ≤ 25
$r_0(a, s)[1 + \alpha_1 \exp(\beta 2 (a - 25))]$	if s = male, 25 < e ≤ 35
$r_0(a, s)[1 + \alpha_1 D \exp(10\beta 2)]$	if s = male, 35 < e
$r_0(a, s)[1 + \alpha_1 D \exp(\beta_1)]$	if s = female, e ≤ 25
$r_0(a, s)[1 + \alpha_1 D \exp(\beta_1 + \beta_2 (a - 25))]$	if s = female, 25 < e ≤ 35
$r_0(a, s)[1 + \alpha_1 D \exp(\beta_1 + 10\ \beta 2)$	if s = female, 35 < e

(α_1=0.809 Sv^{-1}, β_1 = 0.553, $\beta 2$=-0.198[18]

All the above models were fitted using the relative biological effectiveness (RBE) = 20 for neutron radiation. This called for some modification to the above models since different types of radiations have different RBEs. The researcher therefore decided to divide all parameters such as α's and β's used to fit the data for the models by RBE= 20 because the X-ray used in this study has RBE =1

CHAPTER FOUR

4.0 Result, Discussion, Conclusion and Recommendation

4.1 Results

Assessment of radiation risk involves the comprehensive analysis of issues affecting the safety of employees. Table 4.1 outlines the basis for analysis:

Table 4.1 Issues that Affect Employees safety

Description	Number	Percentage
Those who wear TLD always	15	41.7
Those who do not wear TLD always	21	58 .3
Those who have their TLD replaced soon after they are sent for reading	12	33.3
Those who have their TLD not replaced soon after they are sent for reading	24	66.7
Employees who wear apron	26	72.2
Employees who do not wear apron	9	27.8
Those who ever experience radiation accident	3	8.3
Those who never experience radiation accident	33	91.7
Those who have medical physicist in their hospital	14	38.9
Those who have no medical physicist in their hospital	22	61.1
Those who have formal training	28	77.8
Those who do not have formal training	8	22.2
Those who ever got pregnant	3	33.3
Those who never got pregnant	6	66.7
Female employee who are aware that their foetus is at risk at early stages	3	33.3
Female employee who are not aware that their foetus is at risk at early stages	6	66.7

Table 1 indicates the distribution of issues that affect employees safety in the various hospitals visited. These issues try to identify risk behaviour or otherwise of the employees and that of their employers. Several issues or factors that borders on employee safety were addressed. From the Table, the following findings were established. It was indentified that 41.7% employees interviewed wear their TLD always while the 58.3% did not. Those who have their TLD's replaced soon after collection were only 33.3% whilst the rest 66.7% either have theirs replaced at time or not at all. Out of the total number of employees surveyed 72.2% said they always wear apron any time the need arises while 28.8% did not .Only 8.3% had ever had radiation accident in the course of their duty but 91.7% never had accident. When employees were asked as to whether they have medical physist in their hospitals, only 38.9% of the total said they have medical physicist in their hospital. As can be seen from the Table 4.1,33.3% of respondents claim their badges are replaced soon after they are sent for reading and 66.7% did not have theirs immediately replaced. Regarding those who had some formal training, 77.8% had some formal training and the rest, 22.2% have not undergone formal training. Out of the six female employees interviewed, only 33.3% had ever gotten pregnant as an employee. Regarding those who had any knowledge of risk of radiation to their foetus in early stages pregnancy, only 33.3% answered in the affirmative whilst 66.7% did not.

Even though most of them claimed to have worn TLD always, only few were observed to practice what they said. Regarding apron use, since it does not have to be worn at all times but during specific operation, there was observation. The reason was that, at the time those specific operations were carried out; the observer had either left or had not yet arrived at the hospitals visited. Employees were questioned about the correct way of wearing TLD with the

protective apron and most of them said under the apron while few said on or under protective apron.

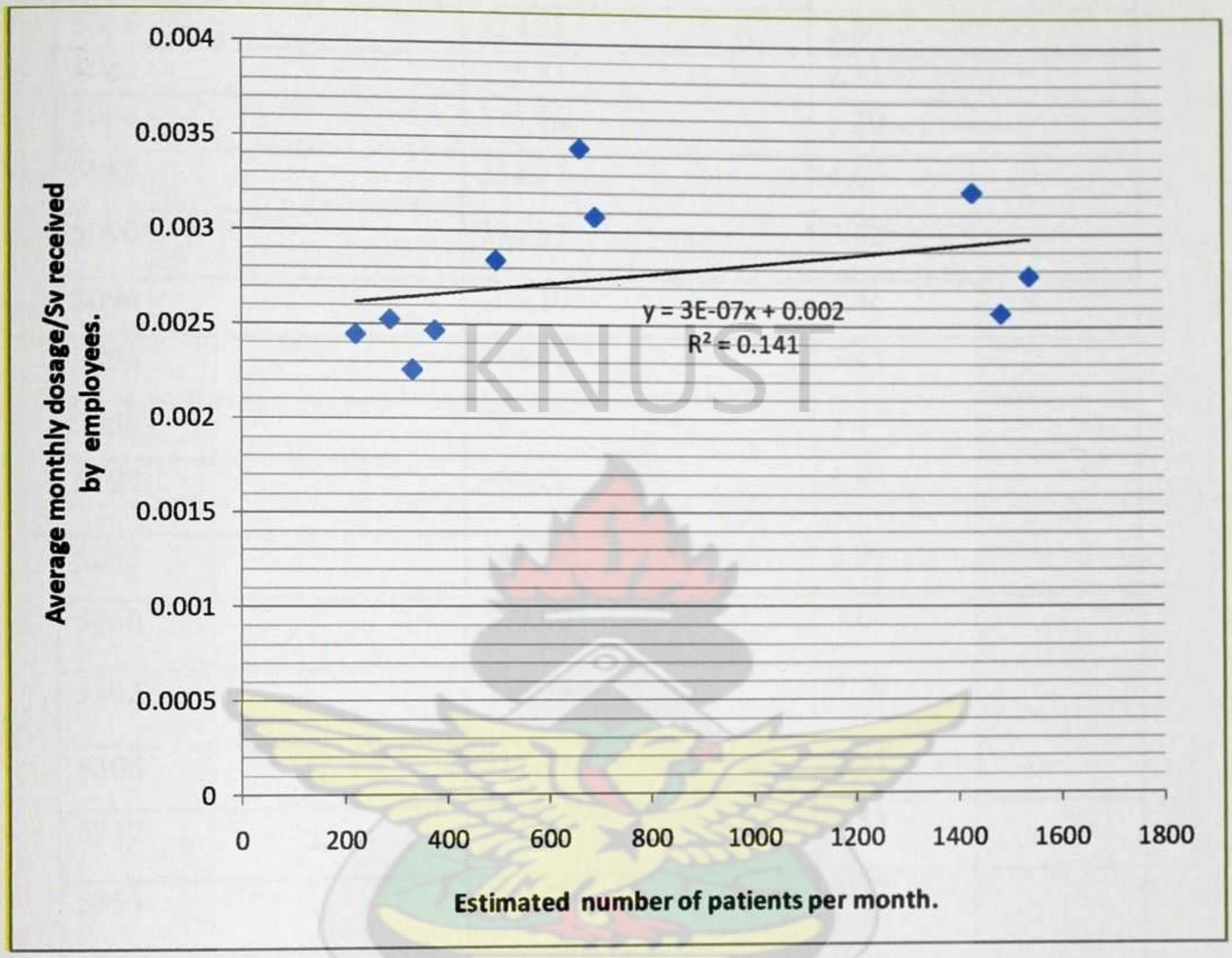


Figure 4.1 Graph of average dose versus number of patients that visited the department

Fig 4.1 shows the relationship between average dose received by employees in an X-ray department and the estimated number of patients that visited their respective department in a month. Scatter diagram was used to obtain a line of best fit to establish the kind of relationship between the variables. The graph produced a positive correlation with R^2=0.1416 which indicates a rather weak relationship between the variables, hence the significance that dose received depends on patients attendance is very low.

Table 4.2: Table of Employee ID, Average Monthly dose and estimated annual dose

Employee ID	Average Monthly dose/μSv	Estimated annual dose/mSv
5058	279.85	3.36
5082	175.51	2.11
5084	275.16	3.30
5085	334.77	4.05
5090	276.37	3.32
5094	205.10	2.46
5096	286.66	3.44
5098	281.17	3.37
5199	403.22	4.84
5242	241.54	2.90
5250	299.80	3.60
5302	358.44	4.30
5306	317.44	3.81
5332	293.82	3.53
5353	280.66	3.37
5360	199.86	2.40
5364	282.85	3.39
5368	251.22	3.01
5561	273.27	3.28
5582	208.67	2.50

Results obtained from dose measurement of employees are shown on Table 4.2.These results were obtained as average values from individual dose measurements. From these measurements, 10% of the subjects monitored have their monthly dose received below 0.2 mSv, 70% between 0.21 mSv-0.30 mSv and 20% between 0.31-0.40mSv.The highest monthly

dose was 575.36 μSv while the lowest monthly dose was 80.77 μSv. For all employees monitored the average monthly doses were below internationally recommended limits.

Table 4.3 Employee ID Sex Age Values of Cumulative dose, PCs for Lukaemia and Digestive cancers

Employee ID	Sex	Age	Three month cumulative dose(D)/μSv	Dx10^{-4}/Sv	(PC for Lukaemia) X10^{-5}%	(PC for digestive cancer)x10^{-5}%
5242	F	20	724.62	7.246	0.88	3.02
5306	F	25	952.32	9.523	1.16	3.97
5332	F	25	881.46	8.814		
5561	F	21	819.81	8.198	1.00	3.41
5058	M	30	839.55	8.396	1.02	3.24
5082	M	44	526.33	5.263	0.64	1.93
5084	M	26	825.48	8.255	1.00	3.31
5085	M	24	1004.31	10.043	1.22	4.07
5090	M	45	829.11	8.291	1.01	3.04
5094	M	48	615.30	6.153	0.75	2.26
5096	M	30	859.98	8.600	1.05	3.31
5098	M	28	843.51	8.435	1.03	2.54
5199	M	23	1209.66	12.097	1.47	4.90
5250	M	36	899.40	8.994	1.09	3.30
5302	M	29	1075.32	10.753	1.31	4.19
5364	M	58	848.55	8.486	1.11	3.11
5353	M	37	841.98	8.420	1.02	3.09
5360	M	52	599.58	5.996	0.72	2.20
5368	M	55	753.66	7.537	0.92	2.76
5582	M	31	626.01	6.260	0.76	2.40

Table 3 shows employees ID, age and a three month cumulative dose. The names of employees and their hospitals are omitted from the table for reasons of confidentiality. Also on this table are the values of probability of causation (PC) for leukaemia and those of digestive cancers of subjects monitored, determined from the cumulative dose. The values for leukaemia ranged (0.64-1.47) $x10^{-5}$ % and those of digestive cancers in the range of (1.93-4.9) $x10^{-5}$ % which were calculated based on the three month cumulative dose. The PC values for leukaemia is found to be dose dependent as it increases with the absorbed dose a subject monitored received. This is however not the case for digestive cancers which is more dependent on the age at exposure than dose received. Another determinant for these cancers is the sex of the exposed individual, since females with relatively small doses have higher PC values than their male counterparts.

4.2 Discussion

The dose received by personnel and the corresponding estimated patient attendant have been shown to be weakly correlated with coefficient of determination being 0.142.This means that only 14.6% of the changes in dose can be attributed to variation in patient attendant rate. The trend in graph could be attributable to the fact that most of the subjects monitored failed to wear their badges always. This is supported by the fact that only 41.7% of the respondents wore badges all the times and even the observation of the researcher reveals worst than this claim. Those who failed to wear badges always did so for the following reasons; the general claim was that they do not have the badges while few also blamed it on the delay in bringing it back from reading institution. The subjects surveyed said it takes between few days to as long

as six months. It was discovered in most of the cases that badges were not replaced soon after they are sent for replacement to be effected.

Out of the proportion of female employees that ever got pregnant as employee, two stopped working in machine room and one did not take any action. Children who were exposed to high doses of radiation prior to birth (as an embryo/foetus) have shown an increased risk of mental retardation and other congenital malformations.[19] All women of childbearing age have responsibility of declaring their pregnancy to their supervisors, even though this is not mandatory. Other studies such as "Colorado Rules and Regulations Pertaining to Radiation Control", suggest that an association exists between exposure to diagnostic x-rays before birth and carcinogenic effects in childhood and in adult life however, scientists are uncertain about the magnitude of the risk. [19] Some studies show the embryo/foetus to be more sensitive to radiation-induced cancer than adults. In recognition of the possibility of increased radiation sensitivity, and because dose to the embryo/foetus is involuntary on the part of the embryo/ foetus, a more restrictive dose limit has been established for the embryo/foetus of a declared pregnant radiation worker. For the protection of the embryo/foetus of a declared pregnant woman, the dose limit is 0.5rem (5mSv) during the entire pregnancy. [19] All women monitored for external exposure in this work have their estimated annual dose received below this limit.

It is assumed that all personnels who perform x-ray activities can potentially receive doses sufficiently large, require personnel dosimetry policies to be in place for all. All employers are required to provide a dosimeter to all employees who have a likelihood of receiving doses as large as 10% of the applicable legal limit for monitoring whole-body dose. [19] All employees

are required to wear their dosimeters as the employer has to make sure that these rules are followed. Regulations are to be put in place to allow for the determination of effective dose equivalent so personnel are able to stay within regulatory limits without shirking. No excuses are acceptable as it is reasonable for a facility not to allow an employee to spend any time in a radiation area unless a dosimeter is worn properly. Any contrary action puts both the employer and the employee at risk. From the work done so far most employees and employers have shown little or no compliance to this policy. Badges have to be replaced soon after they are taken for reading. This has to be done so that the dosimetric record of personnel's will be adequate. The 66.7% of the subjects monitored failed to wear badges always and could therefore lose appreciable amount of records concerning their dosimetric record. There is the need for personnel to wear protective apron anytime they work in areas other than behind the shield provided. The proportion of 72.2% compliance to this safety act is rather commendable on the part of personnel. Radiation accident is usually chacterised by the emission of large amount of radiation, hence increasing the dosage to a worker possibly above the recommended limits. In the case of X ray, such accidents can occur from leakages from the source which normally has to be detected by a specialist. It has been revealed that any dose accumulation as a result of such incidents will, to a large extent, be minimal because only 8.3% had some form of such accidents. There is the need for specialist like the medical physicist to perform routine checks on the machine to ensure that leakages and any other problem are avoided in the machine room. Lack of these specialists in any hospital is an issue that should be treated as a matter of urgency.

The research has revealed that 77.8% of subject surveyed had some form of formal training. This proportion is encouraging as this fraction of employees will be familiar with characteristics of radiation and the associated health risks. If a worker receives a dose in excess of any of the annual dose limits, the regulations prohibit any occupational exposure during the remainder of the year in which the limit is exceeded. The licensee is also required to file an overexposure report with the Department and provide a copy to the individual who received the dose. Radiation protection limits do not define safe or unsafe levels of radiation exposure. Exceeding a limit does not mean that you will get cancer. For radiation protection purposes, it is assumed that risks are related to the size of the radiation dose. Therefore, when your dose is higher your risk is also considered to be higher. Monthly average occupational dose values for this study have been found to be (0.274 mSv 98%CI 0.257, 0.295) which is comparable to 0.179 mSv obtained in Kenya in 2007 and, 0.30 mSv and 0.39 mSv obtained in Nigeria in 1999 and 2000 respectively. [20] The final readings were greater than the earlier ones because there is some kind of feedback for them that arouse their interest in knowing how much dose they receive. The personal monitoring effort therefore made radiation workers more aware, and led to improvement, of some of their radiation protection practices. The study showed that providing each worker with the measured monthly dose can have a positive influence on improving radiation safety measures. However, the individual monthly averages for each employee monitored even when converted into an annual dose will be below the recommended annual dose limit of 50 mSv. Analysis of the data revealed that for cancers of the digestive system there is some evidence that relative risks which is main determinant of PC decrease with increasing time after exposure. The implication of this is that the younger personnel stand at lower risk than the older ones if they receive comparable amount of dose.

The PC values obtained on the whole for both leukaemia and the digestive cancers have been found to be extremely insignificant even if extrapolated over the entire working life of the employees, on the assumption that the cumulative doses they received is near constant. For categories of NRC-regulated industries with larger doses, the average measurable occupational dose in 1993 was 0.31 rem (0.0031 Sv).[19] A simple calculation based on the article by "Cohen and Lee", shows that 0.3 rem (0.003 Sv) per year from age 18 to 65 results in an average loss of 15 days.[19] These estimates indicate that the health risks from occupational radiation exposure are smaller than the risks associated with many other events or activities we encounter and accept in normal day-to-day activities.[19]Putting the above finding in the context of this study there are insignificant risks to subjects monitored since close to 85% have their estimated annual dose comparable to the dose of 0.003 Sv. According to the Committee on the Biological Effects of Ionizing Radiations (BEIR) V report, approximately one in five adults normally will die from cancer from all possible causes such as smoking, food, alcohol, drugs, air pollutants, natural background radiation, and inherited traits. Thus, in any group of 10,000 workers, we can estimate that about 2,000 (20%) will die from cancer without any occupational radiation exposure. [19] The report further added that a 1-rem (0.01 Sv) dose may increase an individual worker's chances of dying from cancer from 20 percent to 20.04 percent. Again all subjects monitored, will to very large extent, fall below the risk of 20.04 percent since none of them will have estimated annual dose up to 10 mSv.

4.3 Conclusion

This work examined the effect of ionising radiation on employee in X-ray Units of ten hospitals in south-eastern part of Ghana. This employed the use of radiation protection

approaches to assess whether personnel are of any risk of radiation effects. A survey conducted in this work indicated that radiation safety practices in general have not been carried out in satisfactory manner. For instance the policy that ensures safety practices such as mandatory wearing of TLD badges and their prompt replacement when sent for reading among others were not strictly followed in most of the institutions covered in the work. A rather low positive correlation was established between employee dosages received as against the number of patient radio- graphed in a given month. The monthly average dose obtained is 0.274 mSv (98% CI 0.257, 0.295) which is comparable with works done earlier when converted to estimate annual dose.[20] These results have been found to be far below internationally recommended limit of 50 mSv when projected into annual dose. Probability of causation (PC) for leukaemia and digestive cancers obtained in orders of 10^{-5} % are extremely low to pose any radiation induced health risk to any of the subjects monitored.

4.4 Recommendation

Through the data collection, observation and interviews undertaken during this study, the following suggestions were therefore put forward. First of all, this kind of work should be done on large scale covering possibly the entire country. In fact there is a perception that radiation departments are danger zones resulting in the refusal of certain nurses to send patients who need treatment in these departments, meanwhile the outcome of this study has proved otherwise. For employees to know their true dosimetric records they should try and wear badges always. Also employers should endevour to make monitoring devices available to their employees and enforce their safety policies to the fullest. There should also be some

feedback for employees on their dose received on regular basis as this will raise their interest in knowing more about what they receive.

REFERENCES

1. Occupational Safety and Health-Wikipedia free encyclopedia available online at http//www.en.wikipedia.org/wiki/health_and_safety_at_work_etc_act_1974 .(Accessed 12:04:2012)

2. Occupational Safety and Health-Wikipedia free encyclopedia available online at http//www.en.wikipedia.org/wiki/health_and_safety_at work.(Accessed 27:07:2011)

3. Obiri-Danso K. (2010) Occupational Health and Hazards, idl KNUST, Kumasi, Ghana, p 30

4. Irigaray P, Newby JA, Clapp R (2007). Lifestyle-related factors and environmental agents causing cancer: an overview. *Biomed. Pharmacother.* pp 640–658

5. World Health Organization (2007). "WHO calls for prevention of cancer through healthy workplaces". Press release. http://www.who.int/mediacentre/news/notes/2007/np19/en/index.html. (Accessed 27:07:2011)

6. National Institute for Occupational Safety and Health- Occupational Cancer. United States National Institute for Occupational Safety and Health. http://www.cdc.gov/niosh/topics/cancer.(Accessed 27:07:2011).

7. Kunnumakara A .B, Anand P. (2008). Cancer is a preventable disease that requires major lifestyle changes. *Pharm. Res,* vol. 9, p 116.

8. Faiz M. Khan (2003) Physics of Radiation Therapy, Third Edition, Lippincott Williams & Wilkins, pp 60-61

9. Winters-TH, Franza-JR,(1982). Radioactivity in Cigarette Smoke. *New England Journal of Medicine*, pp 364–365

10. James E. Turner (2007) Atoms Radiation, and Radiation Protection,wiley-vch Verlag GmbH & Co.KGaA, Weinheim,USA ,pp 453-478

11. ICRP Publication 92 (2003). Relative Biological Effectiveness (RBE), ISBN 10: 0-08-044311-7, Elsevier, p 80.

12. Dose variables used in radiation protection in more detail.
http//www.euronuclear.org/info/encyclopedia/d//dose.htm (Accessed 12:06:2012)

13. E.B. Podgorsak (2005) Radiation oncology physics: a handbook for teachers and student, IAEA, Vienna, Austria, pp 482-494

14. Knudson AG (2000). "Two genetic hits (more or less) to cancer. *Nature reviews. Cancer* **1** (2):http://www.en.wikipedia.org/wiki/Cancer. (Accessed 27:07:2011)

15. Little, John B (2000). In Bast RC, Kufe DW, Pollock RE, B.C. Decker. Holland- Frei Cancer Medicine.http://www.ncbi.nlm.nih.gov/books/NBK20793/. Accessed: 31:01: 2011.

16. Users manual on thermoluminiscence dosimetry services.www.pnri.dost.gov.ph/TLD manual.doc (Accessed 29:06:2011).

17. Body thermoluminiscence dosemeter (TLD)-Health protection agency www.hpa.org.uk/webc/HPAwebFile/HPAweb_C/1194947386284 (Accessed 12:06:2012).

18. International Atomic Energy Agency (1996). Methods for estimating the probability of cancer from occupational radiation exposure. Vienna, pp 15,43-45.

19. Radiation risk from occupational exposure:
www.colorado.gov/cs/satellite?c=Page&childpage name=CDPHE-HM% (Accessed 06:08:2012).

20. 20 J. S. Wambani, G K Korir, I K Korir, (2011): Estimation of annual occupational effective dose from external ionising radiation at medical institutions in Kenya.www.ajol.info/index.php/sajr/article/viewFile/73476/62391 (Accessed04:08:2012).

APPENDIX

QUESTIONNAIRE

TOPIC: Risk analysis of the effect of ionizing radiation exposure on employees and the possible health implications: A case study in radiological or X-Ray departments in some selected health facilities.

This questionnaire designed to ascertain whether employees and management undertake requisite radiation safety practices as regards personnel monitoring.

1 How old are you? .....

2 How long have you been working as a radiographer? .....

3 How many patients come here in a day? .....

4 Do you wear TLD all the times while on duty? .....

5 If no, why? .....

.....

.....

6 How often do you send the TLD for reading? .....

7 Are they replaced soon after they are sent for reading?.....

8 Do you wear protective clothing when working in areas other than behind the Shield? .....

9 Have you ever experienced any radiation accident before? .....

10 If yes, how many times? .....

11 Do you have medical physicist in your hospital? .....

12 Have undergone any formal training on the use of the machine? .....

For female employees only

13 Have you ever been pregnant while working as a radiographer? .....

14 Are you aware that at early stages of your pregnancy the foetus is at higher risk? .....

15 If yes what action did you take? .....

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