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Assessment of Occupational Radiation Exposure for Radiotherapy Healthcare Workers at Kenyatta National Hospital Using Thermoluminescence Dosimeter LiF:Mg,Ti

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Abstract

Kenyatta National Hospital (KNH) is the largest public referral hospital with a comprehensive cancer treatment facility in East and Central Africa. Occupational radiation monitoring is a significant technique for demonstrating compliance of radiation regulatory limits. The objective of the study was to carry out assessment of occupational radiation exposure among radiotherapy personnel at KNH using thermoluminescence dosimeter, TLD. KNH staff were monitored using dosimeter type TLD-100 made of LiF:Mg,Ti, on monthly basis. The reader system used for analysis was Harshaw 8800. The measurement established the average monthly accumulated occupational personnel dose for KNH to be 0.21 mSv and 0.29 mSv for Hp (10) and Hp (0.07) respectively. The accumulated dose results were within the maximum acceptable dose of 1.67 mSv/month and 41.6 mSv/month for Hp (10) and Hp (0.07) respectively. The investigation results were higher than the acceptable public limit of 0.08 mSv/month. Moreover, incidences were noted where the fetus dose limit 0.42 was also exceeded. Evaluation of statistical dose exposure among doctors, nurses and radiographers' measurement results were within ±0.02 mSv. The study established the average KNH occupational radiation exposure levels for both Hp (10) and Hp (0.07) were within the ICRU recommendation, validating radiation protection safe practice. Data analysis of healthcare workers did not indicate exposure trend biased to any healthcare profession. Hence radiation risk cut across all professional categories. It is recommended that Radiation Monitoring program be reviewed to include non-clinical staff who access the facility. Radiation reporting should not be limited to one facility, but reflect cases where workers are involved in multiple multiple jobs.

Keywords

Occupational Monitoring, Exposure, Thermoluminescence Dosimeter and Radiotherapy

1. Introduction

The East African region has significantly experienced increase of radiotherapy facilities for treatment of cancer (Ndonye & Tagoe, 2022). Kenyatta National Hospital (KNH) is the largest public referral hospital in East and Central Africa with comprehensive cancer treatment facilities. More than 100 cancer patients access radiotherapy treatment per day at the facility.

The LINAC radiotherapy technique involves delivery of high radiation dose to the tumor, between 4 to 25 MeV (IAEA, 2000). Medical radiation staff are at risk of possible exposure during treatment (Salama et al., 2016). Globally, it is estimated that half of the exposed population to ionizing radiation are medical radiation workers (Bhatt & Ween 2008). The objective of this study is to carry out assessment of occupational radiation exposure of radiotherapy healthcare workers at KNH. TLD audit carried out by IAEA and WHO for Co-60 and high energy X-ray between 1969-2016, found out that 5% of the radiotherapy center's results were out of tolerance limits. Dosimetry audit carried out for radiotherapy centers in Malaysia by Fadzil et al., 2022, revealed that 20% were out of tolerance limit of ±5%.

For most radiation application, occupational radiation exposure is inevitable and therefore carries an inherent health risk if adequate efforts are not made for radiation protection (UNSCEAR, 2000). Several studies have found out that healthcare workers are at increased risk of cancer, including skin, blood, and solid tumors by Azizova et al., 2018; Berrington de Gonzalez et al., 2012; Gilbert et al., 2013; Kuznetsova et al., 2016; and Sokolnikov et al., 2015. However, the relationship is not clear for healthcare workers who are exposed to low-level radiation (Chartier et al., 2020). Furthermore, radiotherapy has undergone significant technological advancement and innovation over the past few years that need to be investigated to ascertain level of exposure (Mettler et al., 2020; Brenner & Hall, 2007).

Occupational radiation dose monitoring is significant in protecting workers from the effect of radiation, establishing of radiation risks, ensuring radiation protection measures, and demonstrating compliance to regulator authority (IAEA, 2000). Investigation on occupational dose assessment results have been used to influence radiation regulation, reviewing of policy and changing of work practices (UNSCEAR, 2000). Study done by Salama et al., 2016 in Saudi Arabia, found out that many hospitals lack adequate radiation protection measures and protective equipment including lack of lead shields, lead glasses, and low utilization safety measures. Moreover, poor radiation practice in hospital has been reported to contribute to occupational exposure by Valuckiene et al., 2016. Study to determine dose distribution in hospital staff among radiologist, radiologic technologist, nurses, and other workers in Japan by Almasri et al., 2014, found out that occupational dose was skewed with radiologic technologist receiving the highest exposure compared to other categories. Therefore, mitigation of radiation risk can be achieved through compliance with safety measures and radiation protection practices (Eze et al., 2013).

To minimize the risks of stochastic and non-stochastic radiation effects, International Commission on Radiological Protection (ICRP) and International Atomic Energy Agency (IAEA) have established radiation dose limits, for both the workers and the general public. Radiation application (ICRP, 2012) requires concise system of safe practice including (IAEA, 2000) protection, prevention techniques and dose limits. The annual effective occupational dose limit for whole body dose is 20 mSv average over 5 consecutive years, 500 mSv for skin dose and 150 mSv for lens of the eye (ICRP, 2012; IAEA, 1996). The public acceptance of the risks associated with radiation is conditional on the benefits to be gained from the use of radiation. Nonetheless, the risk must be restricted by subjecting application to radiation safety standards to protect occupational exposure.

2. Materials and Methods

LINAC radiotherapy facility at Kenyatta National Hospital (KNH)

The study was carried out at KNH, a public health institution in Kenya offering radiotherapy treatment to cancer patients using linear accelerator of Elekta Sinergy. The Cancer Treatment Center (CTC) consists of diagnostic, radiotherapy, and nuclear medicine departments. The treatment modalities include external-beam therapy, brachytherapy, and chemotherapy.

Radiotherapy is executed by multidisciplinary practitioners from different background including oncologist, radiologists, technologists, radiographers, medical physicist, biomedical engineers, dietitians, psychologists, and nurses. The team have access to the treatment bunker, which houses linear accelerator system and accessories. The treatment bunker is controlled and restricted area from members of the public and built with concrete walls for radiation shielding, as shown in **Figure 1**. Facility safety features include warning lights, lead door, emergency button and lead aprons.

Data collection

A total of 170 KNH healthcare workers were identified and monitored during the study. The workers were issued with TLD badges at the beginning of the month and collected at the end of the month, for the entire period of measurement. Ethical approval of research work, data collection and publication were obtained from a joint KNH and University of Nairobi (UoN) Ethics and Research Committee (ERC).

The healthcare workers were instructed to wear the TLD during working hours at the radiation facility on the torso, between the neck and waist, with the window facing outside. Further recommendations included not to exchangeable

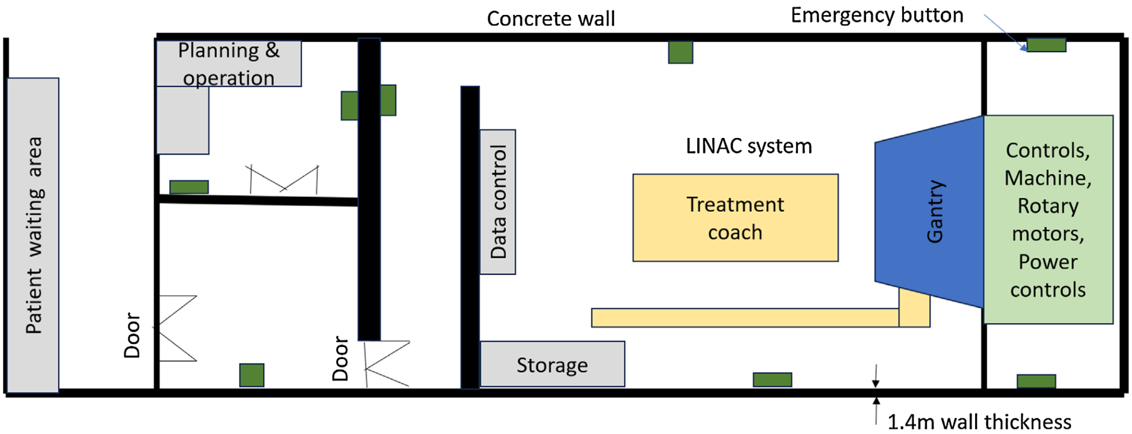

Figure 1. Radiotherapy facility at KNH.

Figure 2. TLD card.

dosimeters among themselves, TLD not to be used outside KNH facility, dosimeter to be returned promptly on monthly basis and lost or damaged dosimeter to be reported immediately. The TLD's ware identified with serial number and equated to each staff member.

Thermoluminescent Dosimeter TLD

TLD dosimeter used in investigation consists of TLD card containing two elements of TLD-100 chips of lithium fluoride, doped with Mg and Ti, as shown in **Figure 2**, mounted on an aluminum sheet. The cards are enclosed in a plastic holder with filters to protect it from environmental and mechanical damages. The standard filters facilitate different radiation absorption and estimation of Hp (10) and Hp (0.07). The TLD preferred for occupational monitoring investigation was LiF:Mg,Ti because of its effective atomic number which is closer to soft tissue and air (IAEA, 2005). This ensure the amount of energy absorbed by LiF is approximately the same or close to the amount absorbed by equal mass of soft tissue or air (Hendee & Ritenour, 2002). Moreover, it was preferred because of its availability, small size, re-usability, wide range 10 µGy to 1 Gy, and repeatability which is less than 2% variation (IAEA, 2000). However, it's main challenges are inability for instant readout and signal losses. Therefore, necessary precautions were taken to ensure correct readings of accumulated dose.

TLD reader system

The TLD reader was carried out by Harshaw TLD reader system, model 8800

Plus and manufactured by Thermo Fisher Scientific Inc of United States of America (USA), as shown in **Figure 3**. The system has a planchet for positioning and heating the TLD. A photo multiplier tube (PMT) for detection of thermoluminescence light emission and converting it to electrical signal. The emitted light is linearly proportional to the detected photon fluence (IAEA, 2005).

Figure 3. Harshaw 8800 TLD reader system.

Individual personnel doses were then analyzed using WinREMS software which is embedded in the reader system. The Reader System produces direct measurements by utilizing WinREMS and SQL database for data storage, analysis, display and reporting the exposure for each element. The aim of calibration is to ensure TLD provide the same response to radiation exposure, arising from natural variation in TL material and manufacturing defects.

To account for variations in signal response, Element Correction Factor (ECF) was tabulated for each individual chip using Equation (1)

$$\mathrm{ECF} = \frac{\bar{Q}}{Q} \quad (1)$$

where

$\bar{Q}$ is the mean signal (nC) from a TLD group;

Q is the individual TLD signal.

The TLDs was then calibrated using a uniform photon beam, from Cesium-137 source at KEBS SSDL, by exposing it to a known dose rate for a defined time duration, attached to a water phantom. The dosimetric peak of the LiF:Mg,Ti glow curve was utilised for dosimetric anaysis.

The dose measured from TLD reading (D) was calculated using the equation below:

$$\text{Individual radiation dose} = \frac{(\mathrm{ECC} \times \text{TL signal})}{\mathrm{RCF}} \quad (2)$$

where,

RCF is the Reader Calibration Factor;

ECC is the Element Correction Coefficient as defined in Equation (1).

The personal dose equivalent was assessed indirectly by use of a thin tissue-equivalent detector of radiation dosimeter, which is worn at the body's surface. The equivalent dose Hp (10) is regarded as absorbed dose received by tissue at a 10 mm depth from the skin surface and considered as whole-body dose. The Hp (0.07) on the other hand, is the dose received at a depth of 0.07 mm and considered as skin dose (ICRP, 1990).

3. Results and Discussion

Figure 4 shows the radiation exposure whole-body Hp (10) results of individual monitoring for KNH healthcare workers. The results indicate a variation of accumulated dose for each, and every individual monitored for 3 months. The variation was random in nature as it did not pick any pattern or trend. However, all the individual accumulated dose results were higher than the background radiation. This indicates that occupational radiation exposure is inevitable as long as one is in radiation environment and therefore carries an inherent health risk that must be addressed. Further to this, the results were above the public maximum limit of 0.083 mSv/month or 1 mSv/year. During the study, administrators and other non-clinical staff had access to radiotherapy facility yet they were not being monitored. There is need to review this practice so as to monitor both clinical and non-clinical staff that have access to the facility, since the result indicate that exposure within the facility is more than the acceptable public dose limit. The results of the individual dose were within the occupational maximum dose limit of 1.67 mSv/month or 20 mSv/year, as recommended by ICRU. The whole-body results therefore validate radiation protection safety measures and demonstrate confidence in safety of KNH healthcare worker.

Figure 5 shows occupational exposure monitoring results for skin Hp (0.07) for KNH healthcare workers. Results indicate dose variation for each individual for the entire period of investigation despite working in a common facility. This

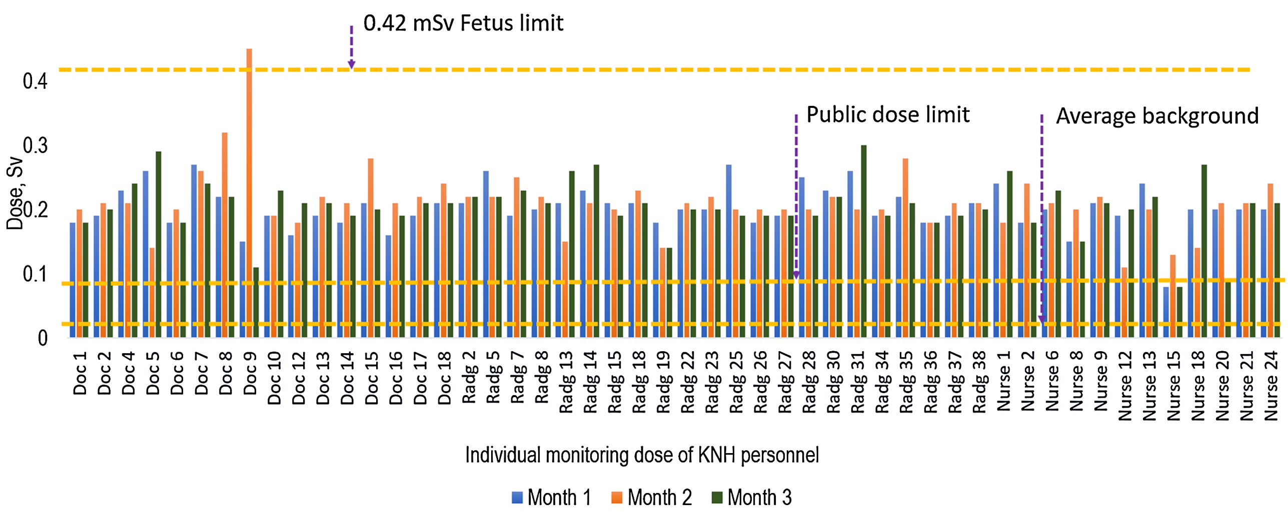

Figure 4. Radiation exposure of individual monitoring results for whole-body Hp (10) for KNH healthcare workers.

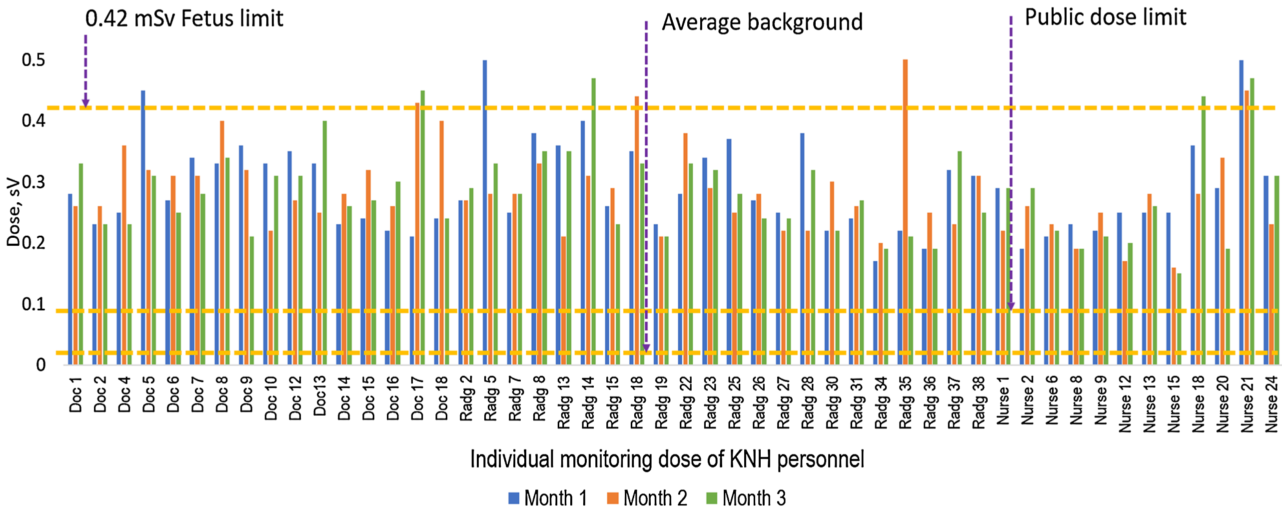

Figure 5. Radiation exposure monitoring results for skin dose Hp (0.07) for KNH healthcare workers.

is attributed to background radiation, occasioned by naturally occurring radioactive minerals in the ground or in air.

The individual doses results were above the public maximum acceptable dose limit of 0.083 mSv/month or 1 mSv/year. This highlight the fact that radiation dose exposure is inevitable for occupational workers. Several cases were noted where the results exceeded the maximum acceptable fetus dose limit of 0.42 mSv/month or 5 mSv/year, which is contrary to Hp (10) results as shown in Figure 4. This is considered acceptable since Hp (0.07) measurement is for skin dose covering extremities like arms below the elbow and legs below the knees. In this case, the location of the fetus falls under whole body category, Hp (10). All the individual accumulated radiation exposure results were within the maximum Hp (0.07) occupational dose limit of 41.7 mSv/month or 500 mSv/year. The Hp (0.07) results therefore validate radiation protection measures during radiotherapy treatment.

Figure 6 shows the exposure monitoring results for radiation professionals working at radiotherapy facility. The healthcare workers were divided into three groups, namely doctors, radiographers, and nurses. The professional accumulated dose results for Hp (10) and Hp (0.07) fluctuated on monthly basis without a clear trend and therefore providing little room for predictability. The dose variation was within ± 0.05, indicating that radiation risks cut across all professional categories. Lack of clear pattern or trend also indicates that no professional category was disadvantaged or skewed by radiation exposure. All the medical specialty within the radiotherapy department has equal opportunity of increased risk of radiation exposure. Radiation protection program should therefore cut across all healthcare practitioners. Further to this, it was observed that all the individual exposure were within the recommendation of ICRP of 20 mSv/year, in all of the professional categories.

The reported occupational exposure is limited to KNH and does not take consideration among common practice of healthcare professionals working for multiple

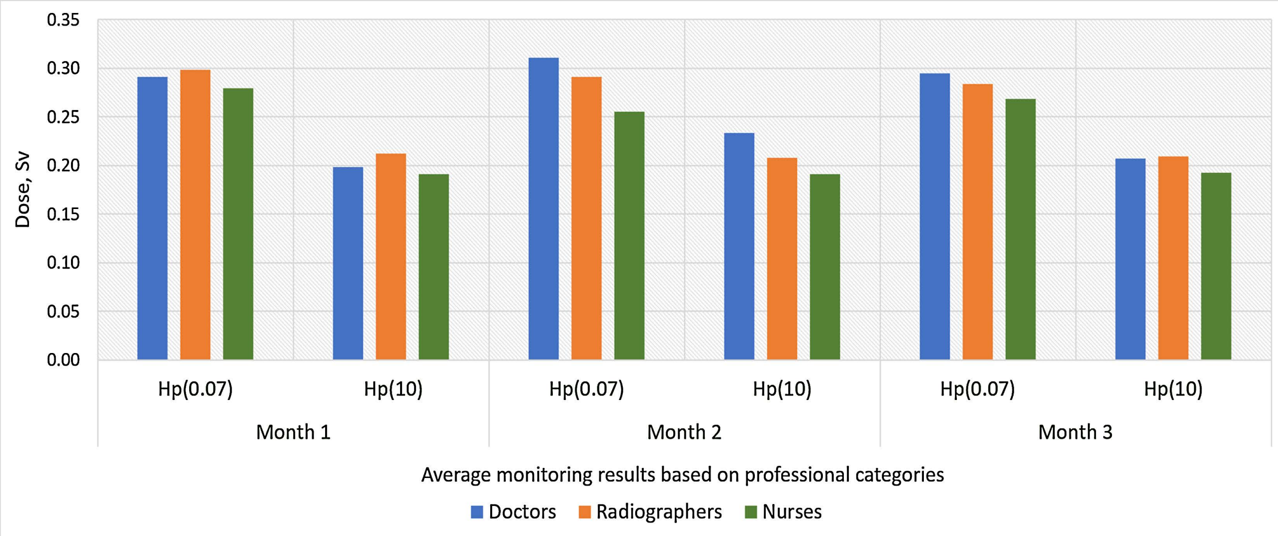

Figure 6. Radiation exposure individual monitoring results for different healthcare professional categories among KNH staff.

facilities. Despite the occupational level within the ICRP (1990) recommended limit, there was no universal mechanism to track and record exposure for individuals working in more than one hospital. Radiation regulation policy needs to be reviewed to accommodate the scenario where workers are rendering services for multiple institutions.

Remarks

The measurement established average monthly occupational baseline dose for KNH as 0.21 mSv and 0.29 mSv for Hp (10) and Hp (0.07) respectively. The occupational dose was within the ICRU recommendation of 1.67 mSv and 41.6 mSv monthly maximum dose, indicating sound radiation protection practice. The investigation results were within the study's findings of 0.227 mSv Hp (10) and 0.222 mSv Hp (0.07) done in UAE by Abuzaid et al., 2024. Similarly, the results were comparable finding of accumulated dose of 1.23 mSv of study done Kuwait by Misbah et al., 2017 and result of 0.28 mSv of a study done by Nassef Kinsara, 2017 in Saudi Arabia.

However, the investigation results were higher than the acceptable public limit of 0.08 mSv/month. Hence, it is recommended that radiation protection practice be reviewed to cover non-clinical staff who access radiotherapy facility.

The investigation did not reveal any incidence of occupational dose exceeding the annual regulatory limits of 20 mSv/year. This demonstrates confidence of radiation protection measures and safe working environment with minimal risks to radiation.

Occupational measurements were carried out for different radiotherapy practitioners, and the results did not indicate a skewed or trend correlation biased to specific category of staff profession. Evaluation of statistical dose exposure among doctors, nurses and radiographers' measurement results were within ± 0.05 mSv. The results are contrary to study by Almasri et al., 2014 indicating technologist receiving the highest exposure compared to nurses and doctors.

It is significant that the finding of occupational radiation exposure be within the recommended ICRP recommendation. The harm of radiation exposure has been demonstrated by its potential for detrimental health effects including induction of malignancies and damage to genetic material (IAEA, 2005). In addition, health effects are likely to occur in infants because of exposure of the embryo or foetus to radiation. These effects increase likelihood of leukaemia and severe mental retardation and congenital malformations, ICRP Publication 84.

Based on KNH investigation, radiation exposure level among healthcare workers can be improved by enhancing capacity building on radiation protection, use of radiation protection protocol or procedure during practice, restricting access the facility, warning signs, lead shielding, concrete wall, maintenance of radiotherapy equipment's, safety culture, quality control, emergency button, emergency plans and use of safety standards.

4. Conclusion

The study established occupational individual monitoring baseline dose for both Hp (10) and Hp (0.07) for KNH. The average accumulated dose was within the maximum acceptable dose as recommended by ICRU, validating radiation protection safe practice. However, the occupational dose results exceeded the public maximum limit, highlighting the need for review of monitoring program policy to include non-clinical staff that have access to the facility. Occupational result did not indicate exposure trend biased to any healthcare profession, emphasizing the fact that radiation risks cut across all professional categories. In as much as the accumulated dose was within maximum acceptable dose, the results were on limited to KNH facility. Therefore, regulation on reporting of individual occupational dose needs review of policy to have mechanism for tracking and recording exposure of workers involved in multiple jobs, contrary to current practice.

Data Availability Statement

All data related to this study can be found within the manuscript and can be provided upon reasonable request.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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