Estimation of annual occupational effective doses from external ionising radiation at medical institutions in Kenya

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Abstract

This study details the distribution and trends of doses from occupational radiation exposure among radiation workers from participating medical institutions in Kenya, where monthly dose measurements were collected for a period of one year (January to December 2007) using thermoluminescent dosimeters. A total of 367 medical radiation workers were monitored, comprising 27% radiologists, 2% oncologists, 4% dentists, 5% physicists, 45% technologists, 4% nurses, 3% film processor technicians, 4% auxiliary staff, and 5% radiology office staff. The average annual effective dose for all subjects ranged from 1.19 to 2.52 mSv. Among these workers, technologists received the largest annual effective dose. The study forms the initiation stage of wider, comprehensive and more frequent monitoring of occupational radiation exposures and long-term investigations into its accumulation patterns, which could form the basis of future records on the detrimental effects of radiation, characteristic of workers in the medical sector, and other co-factors in a developing country such as Kenya.

Introduction

The discovery of X-rays in 1895 by Wilhelm Conrad Röntgen (for which he won the Nobel Prize in Physics in 1901) wrought a revolution in medicine and medical care. Diagnostic and experimental radiation exposures in the early 1900s revealed the deterministic effects of radiation such as skin erythema and radiation burns. Owing to this recognised harmful effect of radiation on patients and experimental subjects, significant modifications took place in the design of X-ray machines and patient positioning. Other researchers who used radiation also suffered deterministic effects. In 1905, guidelines on the safety of workers handling patients for diagnostic X-ray were introduced for the first time.[1] X-ray equipment was first installed in Kenya in 1936 at the current grounds of the Kenya Medical Training College within the Kenyatta National Hospital grounds. It was housed in a wooden structure; radiation safety and protection was not considered at that time.

Kenya is a developing nation, with about 1 000 radiation-producing facilities country-wide of which 80% are for medical applications. There are around 500 large X-ray machines for diagnostic radiology, 150 for dental imaging, 27 for CT scans, 18 for mammography and bone densitometer units, 3 cobalt radiotherapy units, 3 Linac accelerators for radiotherapy, over 100 fluoroscopy units, 5 interventional units, 2 brachytherapy units, and 3 gamma cameras. There are less than 10 airport security cargo scanners, and a few dozen radioactive sources are estimated to be used in agriculture, as well as in industrial gamma radiography. A few sources with low activities are found at the *in vitro* biomedical research and teaching institutions. Medical use accounts for the largest proportion of ionising radiation use in Kenya. It is on this basis that the present study focused on occupational exposure in the medical sector.

The legal framework for radiation protection in Kenya is based on laws governing radiation protection;[2] subsequent regulations are being revised to ensure compliance with current international practices and safety standards.[3] The regulations that govern the radiation protection of persons working in radiation areas is covered internationally under the prescribed dose limits derived from quantitative estimates of human studies on the effects of acute high doses, such as the Hiroshima and Nagasaki nuclear bomb survivors, who have demonstrated increased deaths from circulatory, respiratory and digestive diseases associated with radiation exposure.[4] However, current regulations in Kenya do not classify radiation workers according to recognised occupational dose limits criteria. The Type A radiation worker conditions allow the possibility of receiving in excess of 30% of the annual effective dose limit, and require a mandatory medical examination each year as well as individual monitoring of exposure levels. Type B radiation workers are highly unlikely to receive more than 30% of the annual effective dose limit and therefore do not undergo mandatory medical examination or have individual exposure monitoring requirements.[5,6] Personnel radiation monitoring in the USA is required for workers who are likely to receive more than 10% of the occupational dose limits.[7] Overall, the Kenyan regulatory requirements subject all radiation workers to the same medical examination, and require occupationally exposed persons to incorporate the sum of external and, where relevant, internal radiation exposures into the dose limitation criteria. However, assessment of internal radiation exposures is not yet well established in Kenya.

There are indications from epidemiological studies that radiologists and other medical X-ray workers may experience increased mortality from cancer and leukaemia.[8] Cytogenetic studies of hospital workers occupationally exposed to low doses of ionising radiation have revealed enhanced baseline levels of chromosomal aberrations, compared with the control populations.[9] Cytogenetic monitoring of persons who accidentally had large exposures is of special value in biodosimetry, and the measurement technique may be extended to personnel in hospitals as well as workers in the nuclear and radiopharmaceutical industries. Without proper calibration references for personal dosimeters, individual monitoring of radiation exposure may result in underestimation of the actual occupational exposure. Thermoluminescence dosemeters (TLDs) are easy to calibrate and give reliable dose measurements, and have been the basis of many important studies, including national dose surveys in Sweden[10] and the UK.[11]

A radiation safety programme should lend support to all radiation users by promoting radiation safety at the equipment performance level and a safe working environment. The programme objectives require accurate and reliable monitoring of radiation workers to effectively manage radiation protection and quality assurance. The use of TLDs in dose measurements offers several advantages in radiation protection monitoring programmes. TLDs are small, robust dosimeters, allowing accurate positioning and reasonable spatial detail in dose measurement, and they are suitable for wide ranges of dose and dose rate values. Some TLD materials, especially $Li_2B_40_7$, have nearly the same effective atomic numbers as soft tissue, and their energy responses to absorbed radiation show little variation over wide ranges of photon energy. The energy stored in TLD crystals following exposure can be retained over long periods of time before read-out. TLD cards can be re-used after suitable thermal treatment, making them cost-effective and viable in the long term.

In Kenya, there is no recorded evidence in the literature of studies on occupational radiation exposure, and personnel monitoring programmes are not yet fully established, except during this study. The aim of the study was to evaluate the dose delivered to the various groups of radiation workers as a result of external exposure to ionising radiation and to compare the results with dose limits stated by international safety standards.[5,6]

Materials and methods

This study was carried out over one year by monitoring occupationally exposed individuals working at medical institutions that agreed to participate in the International Atomic Energy Agency (IAEA) Project RAF/9/033 on Medical Exposure Control.[12] A list of medical radiation workers indicating job group and age was submitted by each participating hospital. Each worker was assigned 2 pairs of individual 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. Hospital management assigned one person to deliver the dosimeters for monthly reading and collection of newly annealed TLD badges. Natural background radiation levels from control TLD samples were used to correct for the actual individual dose received by each worker.

The TLD-100 is fabricated from lithium fluoride elements assembled in bar-coded cards encapsulated in Teflon (Harshaw Model 0110); units were provided with the Harshaw Model 8814 card holder to each radiologist, oncologist, dentist, physicist, technologist, nurse, film processor, auxillary staff (cleaners in the department) and radiology office staff in participating medical institutions. A TLD reader (Harshaw Model 4500 operating under WinREMS software) was used to process the TLD signals. The TLD-100 has a radiation dose measurement range of 0.05 mSv - 10 Sv. The calibration factor RCF used was 0.024 nC/μSv for the radiation to which workers in the medical sector were exposed, as determined using the manufacturer's instruction manual and recommendations in the IAEA Standard.[12]

Dosimeter read-outs were done at the National Radiation Protection Laboratories on the Kenyatta National Hospital grounds. Accumulated dose from TLD cards not submitted on time for reading was excluded and an appropriate value of the individual measured monthly mean dose was assigned instead. For penetrating external ionising radiation, personal deep dose equivalent (which is scientifically recommended for operational deep dose quantity) was adopted in this study. The measured dose and details of the data collected were entered into an Excel spreadsheet for analysis. The collective effective dose was

Table I. Annual radiation exposure dose measured with TLDs worn by occupationally exposed personnel in the medical sector

	Occupational classification	Age range	Quartile dose mSv Q1	Q2	Q3	Max. annual dose (mSv)	Annual average dose (mSv)	Number monitored (N)	Person-Sv
1.	Radiologists	37 - 70	1.15	2.01	2.73	5.9	2.18	99	0.22
2.	Oncologists	40 - 68	1.58	1.63	2.00	2.1	1.55	6	0.01
3.	Dentists	30 - 71	1.88	2.27	2.54	3.6	2.04	16	0.03
4.	Physicist	26 -55	1.63	2.00	2.63	6.8	2.33	20	0.05
5.	Technologists	22 - 59	1.37	2.28	3.21	7.4	2.52	166	0.42
6.	Nurses	24 - 53	0.95	1.76	2.27	3.4	1.77	14	0.02
7.	Film processors	45- 54	1.13	1.29	1.73	1.9	1.26	10	0.01
8.	Auxillary	28 - 50	0.62	1.19	1.69	2.2	1.19	16	0.02
9.	Radiology office staff	28 - 55	0.92	1.08	1.25	2.3	1.21	20	0.02

estimated from the number of persons multiplied by the average effective dose. An analysis of the average annual effective doses received for medical radiation workers according to gender was also determined.

Results

Table I indicates the distribution of age and annual occupational dose for different groups of medical radiation workers in Kenya in 2007. The measured natural radiation background was 0.10 mSv, and the measurement range for annual absorbed dose was 0.32 mSv to 6.78 mSv. The largest to the smallest radiation exposure was observed in the following worker groups respectively: technologists, physicists, radiologists, dentists, nurses, oncologists, film processors, auxillary staff, and radiology office staff. The annual collective effective dose from occupational exposure in the medical sector was estimated as 0.8 person-Sv.

Fig. 1 indicates the trends over time for the individual worker groups. The monthly percentage range was 1 - 4%, with an average of 2%. The spread was less than 5% for each worker group. A standard deviation of 34% indicates the variation in exposure among the different groups of workers involved in the medical sector.

Fig. 2 indicates the distribution of occupational dose among the 29% female and 71% male radiation workers. The female mean annual dose was 2.16 mSv, the male 2.14 mSv. The level of mean annual dose for female radiation workers was higher than the fetal dose limit of 1 mSv per year, and a study is therefore necessary to ensure that the working environment is safe for pregnant workers.

Fig. 3 indicates the distribution of annual personal dose; 17% were below 1 mSv and 81% between 1 mSv and 5 mSv. For all the subjects monitored, the doses were well below the internationally recommended limit of 20 mSv per year.[5,6] In all the individual doses received by the radiation workers, none of the workers qualified to be classified as type A. Only 4% of the workers received more than 10% (5 mSv) of the annual occupational dose limits.

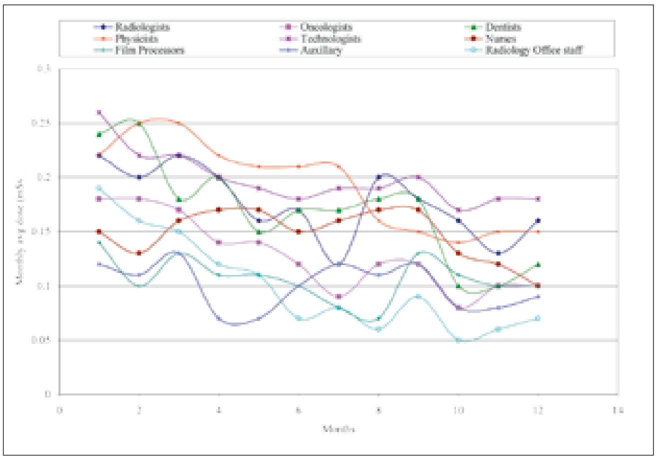

Fig. 1. Distribution of monthly average dose according to work group.

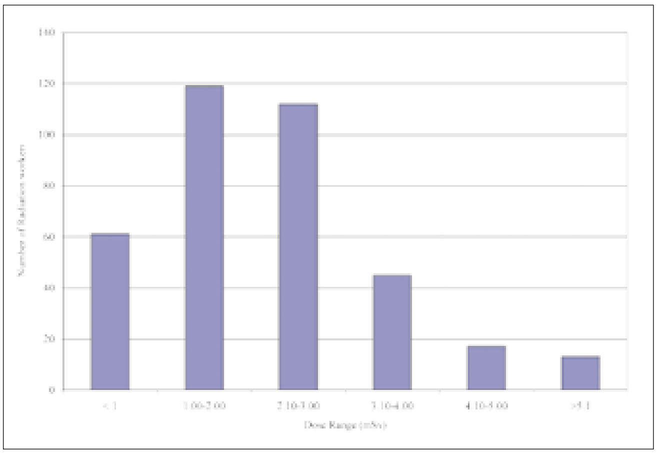

Fig. 2. Percentage distribution of radiation workers by gender in relation to quartile dose in mSv.

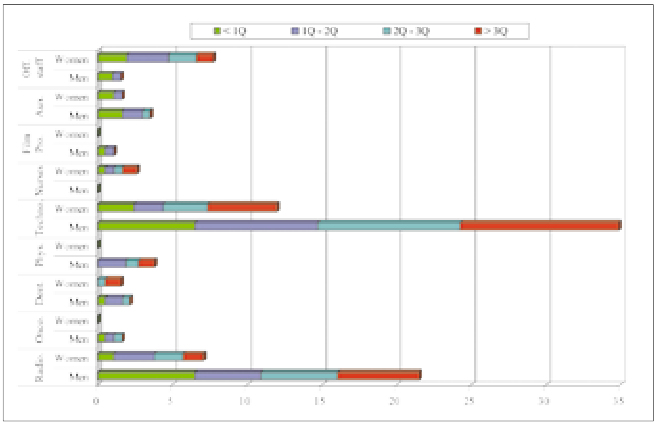

Fig. 3. Distribution of annual dose among medical radiation workers by dose range.

Discussion

Annual average occupational dose values in Kenya are higher than those reported among South Korean medical radiation workers.[13] The former country's average annual effective dose was found to be 2.15 mSv, which was larger than the average annual dose of 0.80 mSv for equivalent radiation workers in South Korea for 2006. The Korean means also were smaller than those of 3.6 mSv, 4.7 mSv and 7.7 mSv reported for radiation workers in Nigeria for 1999, 2000 and 2001, respectively.[14] The distribution of annual dose, however, was similar to that reported for Portugal (1986 - 1988), which showed that 97.8% of the personnel monitored received doses below 5 mSv.[15] The average dose to all radiation workers, corrected for the natural radiation exposure, was 4 times larger than the 2000 - 2002 estimated value of 0.5 mSv.[16] The technologist group exhibited the larger amount of radiation exposure owing to increased patient workload as well as the lack of physical or engineering radiation safety measures in the working environment. The technologist sample size produced consistent dose trends and the least spread among the group studied. The results of this study will consequently form the baseline for optimisation of radiation protection.

The monthly dose trend indicates a reduction of average dose over the study period. 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. Radiation workers who, like physicists, have fundamental understanding and knowledge of radiation safety, can derive the most benefit from these studies because their measured monthly dose showed the largest spread in distribution. The trend also indicates that working behaviour changed when radiation workers realised that they would be subjected to detailed analysis of their monthly exposure.

The level of mean annual dose to female radiation workers exceeded the fetal dose limit of 1 mSv per year; the working environment therefore did not comply with regulations for pregnant radiation workers. Additional radiation safety measures were necessary for this category of worker. Seventeen per cent of radiation workers (comprising radiologists and technologists) worked in 2 medical facilities and consequently received twice-larger doses than the annual average doses for the respective groups. About 17% of the workers monitored (mainly radiology office staff) had doses within the permissible limits. However, some of the occupational doses for this group were above the third quartile value obtained in the study, which emphasises the importance of radiation safety training for all workers in medical irradiating facilities.

Conclusion

A representative sample of occupationally exposed workers was surveyed in an effort to determine levels of radiation exposure in the medical industry in Kenya. The study found that annual exposure levels ranged from 0.32 - 6.98 mSv with a skewed annual distribution showing a median value of 1.5 mSv. Technologists were in the upper quartile in this radiation exposure distribution, therefore being the largest exposed group in the medical sector. The study also found shortcomings in various regulations governing radiation exposure of workers, wherein additional safety measures for pregnant radiation workers was lacking. Lastly, this study will form the basis for a national database of exposures for radiation workers that can be used to assess potential adverse radiation effects.

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