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Measurement and Modeling of Radiation dose Levels versus Activity used in the Working Areas of the Nuclear Medicine Unit of Mulago National Referral and Teaching Hospital

Peter Opio [a*], Akisophel Kisolo [b] and Zeridah Muyinda [c]

[a] Department of Physical Sciences, Faculty of Science, Technology and Innovation, Mountains of the Moon University, P.O. Box-837, Fortportal, Uganda.
[b] Department of Physics, College of Natural Science, Makerere University, P.O. Box-7062, Kampala, Uganda.
[c] Department of Radiology and Radiotherapy, College of Health Sciences, Mulago National Referral and Teaching, P.O. Box-7272, Kampala, Uganda.

Authors' contributions

This work was carried out in collaboration among all authors. Author PO designed the study, performed the statistical analysis, wrote the protocol, managed the literature searches and wrote the first draft of the manuscript. Authors AK and ZM managed the analyses of the study. All authors read and approved the final manuscript.

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ABSTRACT

Radiation dose levels in nuclear medicine working areas have attracted the attention of many researchers. An extensive survey of radiation doses versus activity used in the working areas of the nuclear medicine unit of Mulago national Referral and teaching hospital has been carried out. This survey was done using two chip LiF TLD-100 dosimeter badges. The TLD badges and reader were calibrated using a standard 90-Strontium radiation source.

The mean monthly effective radiation dose levels for the working areas ranged from 0.09 ± 0.05 mSv/month in the staff room to 1.23 ± 0.05 mSv/month in the waste collection room while as annual effective radiation dose levels ranged from 1.03 mSv/year, which was the least to 14.77 mSv/year, which was the highest, in the staff room and waste collection room respectively. Monthly Radiation dose level versus activity used followed power distribution on statistical analysis using MatLab. The

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**Corresponding author: Email: opiopeter99@gmail.com;*

measured radiation dose levels were found to be below the recommended safety levels as provided by international agencies such as the International Commission on Radiological Protection (ICRP) and International Atomic Energy Agency (IAEA).

Keywords: Nuclear medicine; radiation dose level; working areas; Mulago National Referral and Teaching Hospital.

1. INTRODUCTION

Technetium-99m and iodine-131 have out competed other radionuclides in many Nuclear Medicine facilities for diagnostic and therapeutic applications [1-3]. In order to use them, they are tagged to pharmaceuticals forming radiopharmaceuticals which deliver the radionuclides to specific; organs, tissues or cells for any required diagnostic or therapeutic purpose [4].

For efficient carrying out of any diagnostic or therapeutic nuclear medicine activity, any nuclear medicine unit/ department should have designated working areas for the different nuclear medicine procedures in order to guard the safety of the workers, patients and patient care takers from risks associated with radiation. Working areas in Nuclear medicine are classified as supervised and controlled in order to restrict unnecessary access for purposes of radiation monitoring [5].

If the effective dose exceeds 1 mSv in a certain area, the equivalent dose to an eye of 15 mSv or the equivalent dose to hands, feet or skin of 50 mSv per year, the area shall be defined as a supervised area [6-8]. In these working areas, workers are provided with instructions on working, use of radiation sources and radiological hazards associated with the sources. Radiological conditions of the supervised area, outlines of the area and adequacy of the protective measures shall be verified with regular inspections. These include, imaging rooms, patient radionuclide administration room and data acquisition room.

Working areas where a 40 hour weekly stay may cause an internal radiation dose exceeding 1 mSv/y, is classified as a controlled working area [8,9]. In the Nuclear medicine Unit, controlled areas include the hot laboratory and the wastes collection room. Access to these areas is more restricted and persons entering these areas should have personal badges and dose meters with audible alerts for identification and accessing individual radiation exposures and sources. If the individual radiation dose received in a workplace exceeds 0.5 mSv per week, a dosimeter enabling real-time dose monitoring shall be additionally used. An alarming dosimeter (preferably with a dose rate alarm) shall be used if the dose rate exceeds 1 mSv per hour.

Application of nuclear medicine procedures in the nuclear medicine unit at Mulago national referral and teaching hospital are governed by the regulations issued by the Atomic Energy Council [10], the national regulator. These regulations are in line with the requirements of nuclear medicine practicing IAEA member states.

Due to increased nuclear medicine applications at the nuclear medicine unit of Mulago national referral and teaching hospital, the staff in the unit, the patient, the patient care taker and the general public, would want to know the radiation dose levels in the different working areas of the unit. We report a survey of the radiation dose levels, radiation dose levels versus the activity used in the different working areas of the Nuclear Medicine Unit of Mulago Hospital while using $^{99m}T_C$ as the main radionuclide.

2. MATERIALS AND METHODS

2.1 Classification of the Working Areas

During the period of this study, a total activity of 21328 ± 15 mCi of technetium-99m was administered to six hundred thirty patients for the different nuclear medicine diagnostic procedures. The Unit works five days a week (Monday to Friday) and during these days, all the working areas of the unit are in use.

The unit has classified, the Hot laboratory, the wastes storage/collection room, the imaging room and patients radiopharmaceutical administering room as supervised working areas, whereas, the patients reception room, the data acquisition room and the staff room have been classified as controlled working areas.

These working areas were labeled as H (Hot laboratory), W (wastes collection/storage room), I_R (patients radiopharmaceutical administration room), R_E (Patient's Reception room), D_A (Data Acquisition room), I_R (Imaging room) and S_R (Staff room).

2.2 Experimental Design

TLD-100(LiF) dosimeters were used to measure the radiation doses in the working areas. The Harshaw Bicron TLD Reader (Model 4500) (Harshaw Bicron 1996) was used to read the badges. A standard 90-Strontium Irradiator (Model 2000) was used to calibrate the badges and the reader [11]. Seven badges, each with a Room Identification Number (RIN), H, W, I_R, R_E, D_A, I_R and S_R, for traceability, were fixed at a height of 1 meter above the floor of every working area to determine the monthly average radiation dose level in each of the working areas. The badges were unfixed after a month and on the day they were unfixed, new set of badges was fixed. The unfixed badges were collected and taken to the Radiation Laboratory of the Physics Department of Makerere University for reading.

The projected annual radiation doses received by staff were estimated by projecting the monthly average effective radiation dose levels in each working area according to equation one.

$$\text{Annual radiation dose level} = \left\{\frac{\text{measured radiation dose level}}{\text{duration of monitoring in months}}\right\} \text{x12 months} \qquad (1)$$

3. RESULTS AND DISCUSSION

The radiation dose levels in the working areas are presented in Table 1 after subtracting off 0.05 mSv/month, the Units monthly background radiation dose level. This background radiation dose level was monitored for two months, when the unit took a period of three months without getting the $^{99m}T_C$ Generator.

The hot laboratory and the wastes collection/storage rooms had the highest radiation dose levels. The wastes collection room radiation dose levels are higher than those of the hot laboratory because the room contained wastes from day one of the working week of the Unit up to the last day when the wastes were being taken away for discharge.

Similarly, the imaging room had higher radiation dose levels than the injecting room because patients always spent more time in the imaging room (a maximum of thirty minutes) than in the injecting room (a maximum of five minutes).

Table 2 shows one of the monthly daily $^{99m}T_C$ generator activity used in relation to the number of daily procedures carried out in the unit.

For the period of this study, the staff room had both the lowest monthly and annual radiation dose levels because the staff members always occupied this room at lunch break and it had no radioactive sources in it. However, its annual radiation dose level was greater than for any public place because it was always receiving radiation doses from other working areas.

Table 1. Radiation Dose Levels in the Working areas

Working Area	Monthly (mSv/month)					Mean monthly (mSv/month)	Projected annual (mSv/yr)
	1	2	3	4	5		
H	1.09	0.94	0.77	0.58	0.86	0.85	10.19
W	1.48	1.20	1.18	0.94	1.35	1.23	14.77
I_N	0.47	0.39	0.21	0.19	0.23	0.30	3.58
R_E	0.45	0.35	0.17	0.08	0.28	0.27	3.21
S_R	0.16	0.09	0.06	0.03	0.09	0.09	1.03
D_A	0.47	0.32	0.27	0.08	0.18	0.27	3.18
I_R	0.85	0.72	0.28	0.15	0.52	0.50	6.03
Activity used (mCi)	7003.86	4142.29	3348.39	2894.93	3938.14		

Table 2. Daily eluted activity from the $^{99m}T_C$ generator and daily nuclear medicine procedures done in the unit

Date of storage	Activity dispensed from the $^{99m}T_C$ Generator ± 0.1 mCi	Number of procedures
14/01/2022	495.3	15
15/01/2022	359.6	12
16/01/2022	301.1	9
17/01/2022	239.3	9
18/01/2022	183.4	7
21/01/2022	126.4	6
22/01/2022	83.00	5
23/01/2022	57.0	6
24/01/2022	36.4	3
25/01/2022	19.6	2
28/01/2022	544.0	13
29/01/2022	382.4	10
30/01/2022	327.0	10
31/01/2022	269.3	8
1/02/2022	209.0	6
4/02/2022	113.8	6
5/02/2022	83.0	4
6/02/2022	54.8	2
7/02/2022	33.2	2
8/02/2022	14.7	1
11/02/2022	503.0	10
12/02/2022	328.1	10
13/02/2022	305.4	7
14/02/2022	234.9	6

It is observed that the projected annual radiation dose levels of working areas ranged between 1.03 mSv/yr to 14.77 mSv/yr with the supervised working areas having the highest radiation dose levels ranging between 3.58 mSv/yr to 14.77 mSv/yr. These higher radiation dose levels are attributed to the fact that these working areas always contained radiation sources. The controlled working areas had the lowest projected annual radiation dose levels ranging between 1.03 mSv/yr to 3.21 mSv/yr.

3.1 Statistical Analysis and Modeling

The measured data was processed and statistically analyzed using MatLab to obtain a model for radiation dose level distributions in the working areas of the unit. Measured data was fitted to the, Exponential, Linear Polynomial and Power. The Power fit Root Mean Square Error (RMSE) was preferred to other fits to be the most suitable model to radiation dose level distribution versus activity used in the nuclear medicine unit. This model yielded the lowest Root Mean Square Error (RMSE) value of 0.333, compared to 0.368 and 0.351 of Exponential and Linear Polynomial, respectively.

The lower value of RMSE indicates better fit for the data.

$$\mathrm{D(x) = ax^{b}} \tag{2}$$

Where D is the radiation dose level in the working area, x is the activity used, a and b are constants for the different working areas. Equation 2, shows the variation of the activity used in the unit with respect to the radiation dose levels in the respective working areas. Results in Table 3, clearly shows that the waste collection/storage area had the highest radiation dose in each month relative to the activity used, when the respective values of a and $b$are put in the equation.

Fig. 1 shows the best fit with the power RMSE.

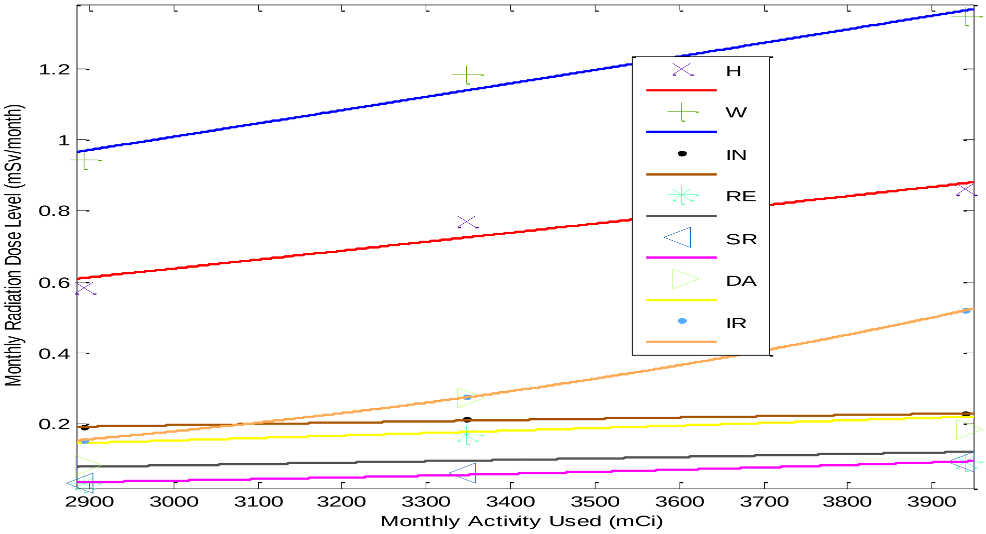

Fig. 1. RMSE of radiation dose levels with monthly activity used for a power fit

Table 3. Constants; a and b for the different working areas

Working area	**Constant**	
	a	***b***
H	5.1920 x10^{-5}	1.176
W	0.0001	1.111
I_N	0.0019	0.581
R_E	1.171x10^{-6}	1.394
S_R	2.766 x10^{-13}	3.206
D_A	3.506 x10^{-6}	1.334
I_R	3.892 x10^{-15}	3.929

There was a big difference in the activity (7003.681mCi) used in the first month compared to the rest of the other months (4000mCi and below) making the radiation dose levels in the first month in all the working areas be higher than for the corresponding months. For Fig. 1, the plot for the activity used in the first month was not included because its inclusion would not produce a good fitting for the graph.

On studying the effect of activity used on the constants a and b . Statistical analysis showed that, a ranges from 3.892 x10^{-15} to 0.0001 and b ranges from 0.581 to 3.929 for the different working areas, as shown in Table 3.

4. CONCLUSION

Statistical modeling of radiation dose levels in the working area versus activity used in the nuclear medicine unit of Mulago National Referral and teaching Hospital follows a power distribution. The monthly radiation dose levels in the working areas depended on the monthly activity used and are far well below the established IAEA and ICIRP standards.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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