06.30.2024 JOURNAL OF

Systematic and Modern Science Research (JSMSR) Vol. 4 No.9

ASSESSMENT OF ANNUAL EFFECTIVE DOSES, DISTRIBUTION PATTERNS, AND CUMULATIVE DOSES IN RADIOTHERAPY STAFF AT USMAN DANFODIYO UNIVERSITY TEACHING HOSPITAL, SOKOTO, NIGERIA

[1] AHMADU IBRAHIM, [2]ZAYYANU SHEHU AND [3]IBRAHIM ABUBAKAR MADAWAKI

[1]Department of Physics Usman Danfodiyo University Sokoto. [2]Department of Physics, Shehu Shagari University of Education Sokoto. [3]Department of Physics, Shehu Shagari University of Education Sokoto.

Corresponding Author: ahmedmubi9113@gmail.com

ABSTRACT

The use of ionizing radiation in medicine has grown significantly worldwide, including in Nigeria. This study assessed occupational radiation exposure of personnel in the Radiotherapy department at Usmanu Danfodiyo University Teaching Hospital, Sokoto, Nigeria.To evaluate annual effective doses, individual distribution patterns, and collective effective doses among personnel.A retrospective study using Thermoluminescent Dosimetry (TLD) records from the past five years evaluated whole-body occupational exposure. The study covered personnel working with ionizing radiation in the Radiotherapy department. TLDs were read quarterly using a Harshaw dual-4500 TLD reader. Annual effective doses ranged from 0.25 mSv to 2.75 mSv for Administrative staff and Medical Physicists, respectively. Collective effective doses ranged from 8.58 man mSv to 90.09 man mSv. No Radiotherapist exceeded the 5 mSv or 10 mSv annual dose limit. No Radiologist received an annual effective dose

Introduction

Background

Ionizing radiation, known for its short wavelength and high energy, has varied applications in medicine, industry, research, and the military (Del Solfernandez, 2017). When it interacts with matter, it produces free radicals (ions) by removing electrons from atoms, leading to ionization (Del Solfernandez, 2017). This type of radiation includes particles such as alpha, beta, and gamma, as well as energetic electromagnetic waves like X-rays and gamma rays. These can cause significant biological damage when absorbed by tissues (Hall & Amato, 2006). Exposure to high doses is associated with mutations, cancer, radiation sickness, and

E-ISSN 3027-2939 P-ISSN 3026-8397

exceeding the 20 mSv recommended by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR).

Keywords: Dose, Ionization, Collective, Equivalent Dose, and Effective Dose.

even death (EPA, 2009).

Dosimetry and Dose Measurement

Regardless of the application, measuring the energy deposited per unit mass during radiation interaction is essential. This measurement, quantified as the absorbed dose in Gray (Gy), is a fundamental goal in radiation studies (RSSC, 2011). Dosimeters are vital in radiation protection and therapy, as they measure various radiation-related risks, including dose equivalent, individual dose distribution, annual effective dose, and collective annual effective dose, either directly or indirectly (Short, 2014).

These devices assess exposure quantities such as Kerma (Kinetic Energy Released in Matter), absorbed dose, and equivalent dose (Cember, 1996). The International Commission on Radiation Units and Measurements (ICRU) sets the recommended dose ranges for personal dosimeters (0.01-1 mSv), X-ray diagnosis (0.1-100 mSv), and radiotherapy (up to 5 Sv) (Masood et al., 2015).

Biological Effects of Ionizing Radiation

Early health effects of ionizing radiation include extensive cell death/damage, manifesting as skin burns, hair loss, and impaired fertility (Agu, B.N.C. 1965). These effects exhibit a threshold; surpassing this level within a short period triggers the impact, with severity increasing with dose Peter (Gainsford. 1995). Acute doses exceeding 50 Gy can severely damage the central nervous system, leading to death within days [8]. Even lower doses (>8 Gy) can induce symptoms of radiation sickness (acute radiation syndrome) like nausea, vomiting, diarrhea, and fatigue (Masood, K et al., 2015). These effects are considered "acute" as they occur immediately after exposure. Exposed individuals might initially survive but succumb later due to gastrointestinal damage [9]. Lower doses may cause delayed sickness and milder symptoms (Masood, K. et al., 2015).

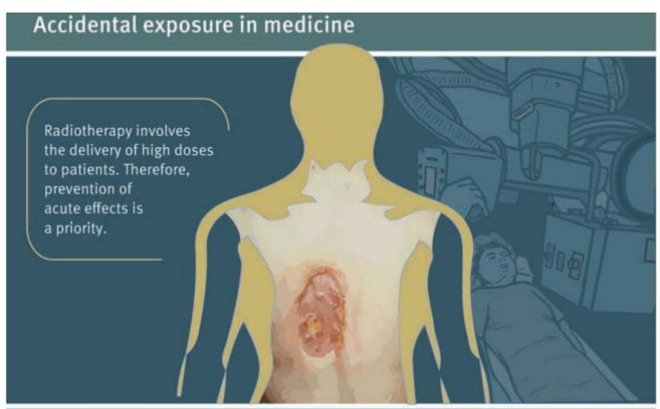

Fig 1. Accidental exposure in medicine.

Fortunately, the red bone marrow and blood-forming system exhibit remarkable regenerative capacity. Doses below 1 Gy allow for full recovery, although there's an increased risk of leukemia in later years (Gratsky & Covens (2004).When only a portion of the body is irradiated, enough undamaged bone marrow remains to replace damaged cells. Animal studies suggest a near 100% survival rate with even just 10% of active bone marrow spared from irradiation (Harshaw 4500 2007). This knowledge of radiation's effect on cellular DNA is harnessed in cancer treatment through radiotherapy (Le Haron, et al., 2010).

The total radiation dose in radiotherapy varies based on the cancer type and stage. Typical doses for solid tumors range from 20 to 80 Gy, delivered to the tumor but posing a threat if administered as a single dose (Masood, K. et.al. 2015). Therefore, radiotherapy uses repeated fractions with each not exceeding 2 Gy. This fractionation allows healthy tissues to recover while selectively eliminating tumor cells, which have lower repair efficiency (Beganovic, A. 2010).

Thermoluminescence Dosimetry (TLD) in Personnel Monitoring

Personnel dosimetry at Usmanu Danfodiyo Teaching Hospital (UDUTH) Sokoto primarily employs Thermoluminescence Dosimeters (TLDs) to assess radiation exposure in radiology, radiotherapy, and dental departments. These small radiation detectors, worn by personnel or patients, monitor external exposures (Faulkner, A. 1999). The fundamental principle of TL dosimetry relies on the direct proportionality between the TL output and the radiation dose received by the phosphor, allowing for estimation of unknown radiation levels (Krohmer, J. S. 1969).

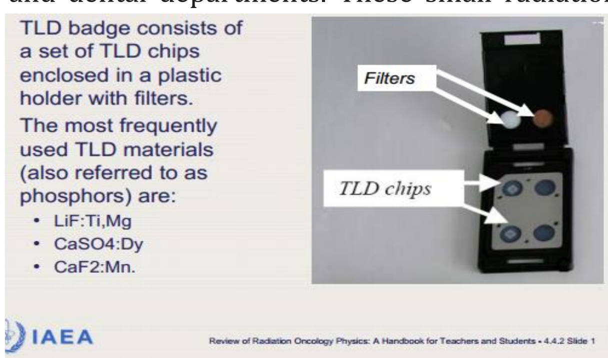

Fig 2. Harshaw Manual 4500 TLD Card Reader.

METHODOLOGY

Data Source and Ethical Considerations

This study utilized anonymized data from the Radiotherapy Department at Usman Danfodiyo University Teaching Hospital, Sokoto, Nigeria. The data consisted of quarterly dosage measurements for personnel working in the department from 2014 to 2018.

Data Collection and Participant Confidentiality

Data collection adhered to the principles of the Health Research Ethics Board (HREB) by ensuring participant anonymity. Each participant received a unique Thermoluminescence Dosimeter (TLD) code to maintain confidentiality (Faulkner, A., & John J. Fletcher 2015).

Data Analysis

The anonymized and coded records included quarterly whole-body and extremity doses. These were used to calculate annual cumulative doses using a published equation (Masood, K. et al., 2015).

$$D = \frac{HT}{WR} \quad (1)$$

Where D = Absorbed dose

H_T = Equivalent dose

W_R = Radiation weighing factor

Skin dose: Hp(0.07) = [(1.2958Rskin) + 0.0097] Msv 2

Deep dose: Hp(10)= [(1.3772Rdeep) + 0.0566]mSv 3

$$H_T = W_R \times D \quad (4)$$

W_R: Radiation weighing factor.

Individual average annual effective dose

Risk related parameter, taking relative radio sensitivity of each organ or tissue into account.

$$E_i(Sv) = \sum_T W_T \times H_T \quad \text{(EPA 2009)} \quad (5)$$

W_T: tissue weighing factor for organ T

H_T: equivalent dose received by organ or tissue T

$$S = \sum_i E_i \times N_i \quad (6)$$

E_i: is the annual effective dose received by the worker

N_i : Is the total number of workers monitored

Individual annual effective dose

Risk related parameter, taking relative radio sensitivity of each organ or tissue into account (ICRP 60 1990).

$$E_i(Sv) = \sum_T W_T \times H_T \quad \text{(EPA 2009)} \quad (7)$$

W_T: tissue weighing factor for organ T

H_T: equivalent dose received by organ or tissue T

The individual dose distribution

The individual dose distribution ratio is giving by relation

$$NR_E = \frac{N(>E)}{N} \quad (8)$$

N (>E): is the number of workers receiving annual dose exceeding E mSv in this research, NR_E was analyzed for values of E of 15, 10, 5 and 1 msV as per UNSCEAR Protocol. The parameter provides an indication of the fraction of workers exposed to higher levels of individual doses (NNRA 2006).

RESULTS AND DISCUSSION

RESULTS

This research investigated occupational radiation exposure among personnel working in the Radiotherapy Department at Usman Danfodiyo University Teaching Hospital, Sokoto, Nigeria (West Africa) (Abu-Jarad F. 2008). The study period spanned five years, from 2014 to 2018, during which ionizing radiation sources were actively used (Abu-Jarad F. 2008).

The assessment focused on several key parameters:

- Annual effective dose (AED) for individual workers (Abu-Jarad F. 2008).
- Collective annual effective dose for the entire department (Abu-Jarad F. 2008).
- Individual distribution patterns of annual effective dose (Abu-Jarad F. 2008).
- Cancer risk for the 33 Radiotherapists involved (Abu-Jarad F. 2008).

The findings related to Annual Effective Dose (AED) for Radiotherapists are presented in tables (not included here). These tables detail the mean, standard deviation, minimum, and maximum annual doses in millisieverts (mSv) for various staff positions within the department (Aborisade Caleb, M.I., and T.B. Ibrahim.2019). The assumed annual effective dose for Radiotherapists was set at 1.31 mSv.

Table 1 Radiotherapy Cadres AED (mSv) (SPSS.20).

CADRES		@2014	@2015	@2017	@2016	@2018
ADM	Mean	.4800	.7300	2.6600	.0000	.0000
	% of Total Sum	1.7%	2.5%	9.3%	0.0%	0.0%
	Minimum	.48	.73	2.66	.00	.00
	Maximum	.48	.73	2.66	.00	.00
	Sum	.48	.73	2.66	.00	.00
CLN	Mean	1.9300	1.2700	.8000	1.5400	.2600
	% of Total Sum	6.9%	4.4%	2.8%	5.0%	1.0%
	Minimum	1.93	1.27	.80	1.54	.26
	Maximum	1.93	1.27	.80	1.54	.26
	Sum	1.93	1.27	.80	1.54	.26
ENGR.	Mean	1.2200	.8900	.9800	1.7600	.9400
	% of Total Sum	4.4%	3.1%	3.4%	5.7%	3.5%
	Minimum	1.22	.89	.98	1.76	.94
	Maximum	1.22	.89	.98	1.76	.94
	Sum	1.22	.89	.98	1.76	.94
M.P	Mean	1.6900	1.6700	2.7300	2.1500	2.1600

	% of Total Sum	6.0%	5.8%	9.5%	6.9%	8.2%
	Minimum	1.69	1.67	2.73	2.15	2.16
	Maximum	1.69	1.67	2.73	2.15	2.16
	Sum	1.69	1.67	2.73	2.15	2.16
NUR	Mean	1.2500	1.2200	.4800	1.4100	.9100
	% of Total Sum	4.5%	4.2%	1.7%	4.6%	3.4%
	Minimum	1.25	1.22	.48	1.41	.91
	Maximum	1.25	1.22	.48	1.41	.91
	Sum	1.25	1.22	.48	1.41	.91
ONC.	Mean	.0000	1.9200	.0000	1.9900	1.5000
	% of Total Sum	0.0%	6.6%	0.0%	6.4%	5.7%
	Minimum	.00	1.92	.00	1.99	1.50
	Maximum	.00	1.92	.00	1.99	1.50
	Sum	.00	1.92	.00	1.99	1.50
RG	Mean	1.3900	1.3400	1.0600	2.1100	.7100
	% of Total Sum	5.0%	4.6%	3.7%	6.8%	2.7%
	Minimum	1.39	1.34	1.06	2.11	.71
	Maximum	1.39	1.34	1.06	2.11	.71
	Sum	1.39	1.34	1.06	2.11	.71
UNSCEAR	Mean	20.0000	20.0000	20.0000	20.0000	20.0000
	% of Total Sum	71.5%	68.9%	69.7%	64.6%	75.5%
	Minimum	20.00	20.00	20.00	20.00	20.00
	Maximum	20.00	20.00	20.00	20.00	20.00
	Sum	20.00	20.00	20.00	20.00	20.00
Total	Mean	3.4950	3.6300	3.5888	3.8700	3.3100
	Std. Deviation	6.69834	6.62551	6.70234	6.55392	6.77759
	Kurtosis	7.793	7.920	7.494	7.742	7.761
	% of Total Sum	100.0%	100.0%	100.0%	100.0%	100.0%
	Minimum	.00	.73	.00	.00	.00
	Maximum	20.00	20.00	20.00	20.00	20.00
	Sum	27.96	29.04	28.71	30.96	26.48

Journal of Systematic and Modern Science Research

Table 1 displays the collective annual effective dose, which amounted to around 1424 man mSv. The assumed mean collective dose was 17.16 man mSv, contributed by Radiotherapy cadres over the five-year period.

Table2 Radiotherapy CAED (mSv)

CADRES		@2014	@2015	@2016	@2017	@2018
ADM	Mean	15.8400	24.0800	.0000	87.7800	.0000
	N	1	1	1	1	1
	Minimum	15.84	24.08	.00	87.78	.00
	Maximum	15.84	24.08	.00	87.78	.00
	Sum	15.84	24.08	.00	87.78	.00
	% of Total Sum	6.0%	8.1%	0.0%	30.5%	0.0%
CLN	Mean	63.6900	41.9100	50.8200	26.4000	8.5800
	N	1	1	1	1	1
	Minimum	63.69	41.91	50.82	26.40	8.58
	Maximum	63.69	41.91	50.82	26.40	8.58
	Sum	63.69	41.91	50.82	26.40	8.58
	% of Total Sum	24.2%	14.0%	14.1%	9.2%	4.0%
ENGR.	Mean	40.2600	29.3700	58.0800	32.3400	31.0200
	N	1	1	1	1	1
	Std. Error of Kurtosis	.	.	.	.	.
	Minimum	40.26	29.37	58.08	32.34	31.02
	Maximum	40.26	29.37	58.08	32.34	31.02
	Sum	40.26	29.37	58.08	32.34	31.02
	% of Total Sum	15.3%	9.8%	16.1%	11.3%	14.5%
M.P	Mean	55.7700	55.1100	70.9500	90.0900	71.2800
	N	1	1	1	1	1
	Minimum	55.77	55.11	70.95	90.09	71.28
	Maximum	55.77	55.11	70.95	90.09	71.28
	Sum	55.77	55.11	70.95	90.09	71.28
	% of Total Sum	21.2%	18.5%	19.6%	31.3%	33.3%
NUR	Mean	41.2500	40.2600	46.5300	15.8400	30.0300
	N	1	1	1	1	1
	Minimum	41.25	40.26	46.53	15.84	30.03
	Maximum	41.25	40.26	46.53	15.84	30.03
	Sum	41.25	40.26	46.53	15.84	30.03
	% of Total Sum	15.7%	13.5%	12.9%	5.5%	14.0%

ONC.	Mean	.0000	63.3600	65.6700	.0000	49.5000
	N	1	1	1	1	1
	Minimum	.00	63.36	65.67	.00	49.50
	Maximum	.00	63.36	65.67	.00	49.50
	Sum	.00	63.36	65.67	.00	49.50
	% of Total Sum	0.0%	21.2%	18.2%	0.0%	23.1%
RG	Mean	45.8700	44.2200	69.6300	34.9800	23.4300
	N	1	1	1	1	1
	Minimum	45.87	44.22	69.63	34.98	23.43
	Maximum	45.87	44.22	69.63	34.98	23.43
	Sum	45.87	44.22	69.63	34.98	23.43
	% of Total Sum	17.5%	14.8%	19.3%	12.2%	11.0%
Total	Mean	37.5257	42.6157	51.6686	41.0614	30.5486
	N	7	7	7	7	7
	Std. Deviation	22.31161	13.62642	24.59098	34.72893	24.10119
	Kurtosis	-.149	-.549	4.056	-.959	.116
	Std. Error of Kurtosis	1.587	1.587	1.587	1.587	1.587
	Minimum	.00	24.08	.00	.00	.00
	Maximum	63.69	63.36	70.95	90.09	71.28
	Sum	262.68	298.31	361.68	287.43	213.84
	% of Total Sum	100.0%	100.0%	100.0%	100.0%	100.0%

Table 3 below showed the individual annual effective dose distribution ratios for five years period of Radiotherapy cadres.

Table 3 Radiotherapy cadres (IAEDDR)NR_E

	NRE	Mean	Std. Deviation	N
@2014	NR1	.1515	.	1
	NR10	.0000	.	1
	NR15	.0000	.	1
	NR5	.0000	.	1
	Total	.0379	.07575	4
@2015	NR1	.1515	.	1
	NR10	.0000	.	1
	NR15	.0000	.	1
	NR5	.0000	.	1
	Total	.0379	.07575	4
@2016	NR1	.1818	.	1

	NR10	.0000	.	1
	NR15	.0000	.	1
	NR5	.0000	.	1
	Total	.0455	.09090	4
@20172018	NR1	.0909	.	1
	NR10	.0000	.	1
	NR15	.0000	.	1
	NR5	.0000	.	1
	Total	.0227	.04545	4

Table 4 below showed the individual collective annual effective dose for each of Radiotherapist for the period of five years.

Table 4 Radiotherapy cadres ICAEDDR (Man mSv) SR_E

	SRE	Mean	Std. Deviation	N
@2014	SR1	.1734	.	1
	SR10	.0000	.	1
	SR15	.0000	.	1
	SR5	.0000	.	1
	Total	.0434	.08670	4
@2015	SR1	.1720	.	1
	SR10	.0000	.	1
	SR15	.0000	.	1
	SR5	.0000	.	1
	Total	.0430	.08600	4
@2016	SR1	.2540	.	1
	SR10	.0000	.	1
	SR15	.0000	.	1
	SR5	.0000	.	1
	Total	.0635	.12700	4
@2017	SR1	.1450	.	1
	SR10	.0000	.	1
	SR15	.0000	.	1
	SR5	.0000	.	1
	Total	.0363	.07250	4
@2018	SR1	.0848	.	1
	SR10	.0000	.	1
	SR15	.0000	.	1
	SR5	.0000	.	1

DISCUSSION

The outcomes derived from the monitoring of 33 Radiotherapists, with the results of 2018 serving as the baseline year, are discussed in the figures below. Figure 1.3, derived from table 1.0, illustrates seven distinct cadres within the Radiotherapy department, including 5 Radiographers, 6 Medical Physicists, 2 Oncologists, 4 Engineers, 6 Nurses, 8 Cleaners, and 2 Administrators (CNSC 2012).

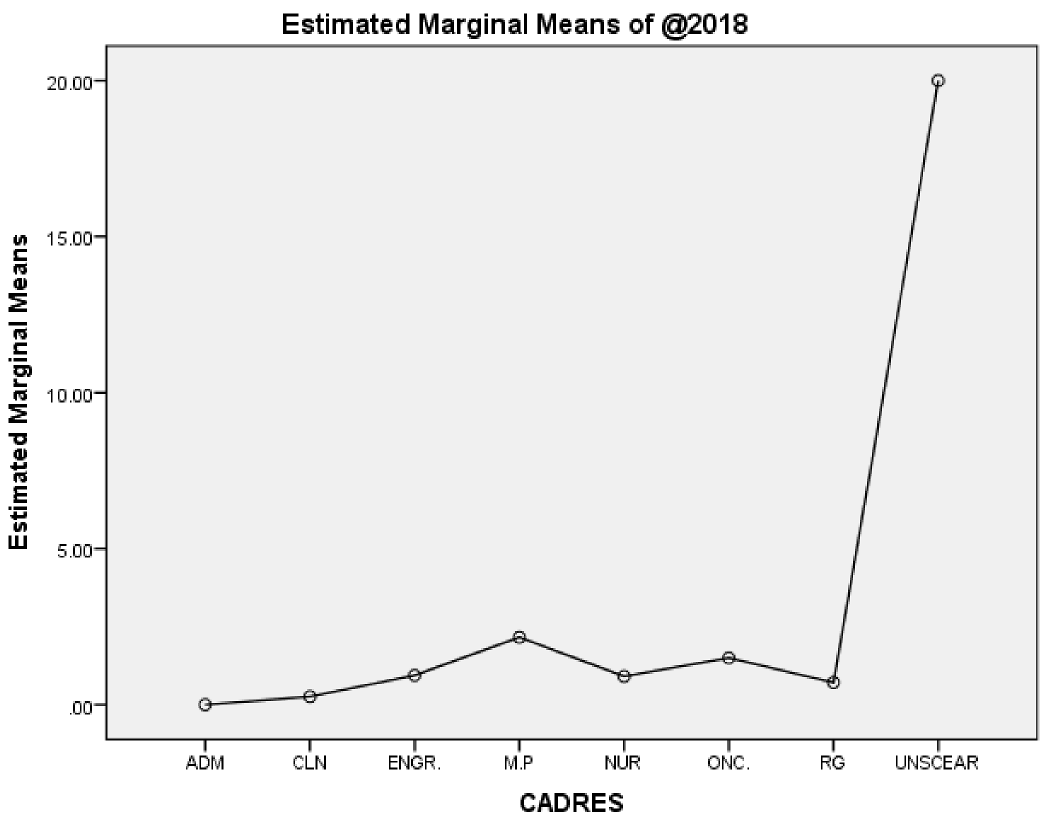

Figure 3 Radiotherapy Cadres Annual Effective Dose (mSV)

A breakdown of radiation exposure for healthcare workers in 2018 showed most were radiographers (75.5%). Medical physicists (8.2%) and radiographers (75.5%) received the highest radiation doses (2.16 mSv and 2.11 mSv respectively), exceeding the average yearly dose (1.31 mSv). This variation is likely due to workload differences. Although both professions exceeded the average dose, neither exceeded the recommended safety limit of 20 mSv (UNSCEAR, 2008). Workers in administrative roles (1%) received the lowest dose (0.26 mSv). The presented results highlight a crucial aspect of radiation safety in healthcare settings: the varying degrees of occupational exposure among different professions. As expected, medical physicists and radiographers, due to the nature of their work, receive the highest annual effective doses (2.16 mSv and 2.11 mSv respectively) exceeding the assumed average annual effective dose (1.31 mSv). This aligns with findings from (Bello, . 2017), who reported radiographers having the highest mean annual dose among healthcare workers in their study. The current study attributes this variation to workload fluctuations, suggesting a potential link between optimized work practices and radiation safety.

The figure above illustrates the distribution of monitored workers in 2018, with 1% in Admin, 3.5% in Cleaners, 8.2% in Medical Physicists, 5.7% in Nurses, 2.7% in Oncologists, and the majority, 75.5%, in Radiographers. Among these, Medical Radiographers recorded the highest percentage with an annual effective dose of 2.11 mSv. Medical Physicists, constituting 8.2%, recorded the highest annual effective dose of 2.16 mSv, which falls below the recommended limit of 20 mSv by UNSCEAR (2008) but exceeds the assumed mean annual effective dose of 1.31 mSv by 0.85 mSv. Admin, with the lowest percentage of 0%, had the lowest annual effective dose at 0.26 mSv. The variation in absorbed doses was attributed to fluctuations in workload. The Lepto-kurtic-curve (LKC) for this analysis was 7.920 mSv, and the Plate-kurtic-curve (PKC) was 7.494 mSv, both of which are below the 20 mSv recommended by UNSCEAR (2008).

Figure 2, derived from table 2, and indicates a contribution of 1424 man mSv to the global cumulative annual effective dose.

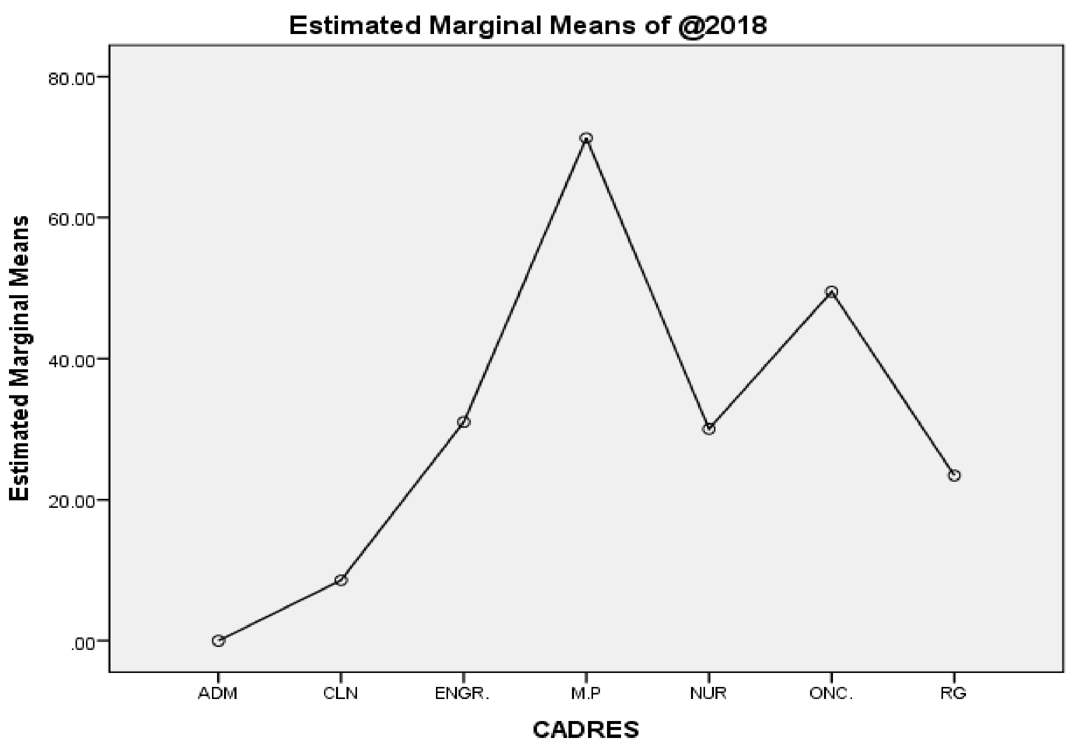

Figure 4 Radiotherapy Cadres Collective Annual Effective (man mSv)

E-ISSN 3027-2939 P-ISSN 3026-8397

The data shows a significant variation in radiation exposure across different healthcare jobs. Medical physicists (M.P) had the highest overall contribution (33.3% or 71.28 man mSv) likely due to increased workloads and working with higher energy radiation sources. Admin staff received the lowest collective dose (4% or 8.58 man mSv). The standard deviation for the data was 24.10, and a specific curve metric (LKC) indicated a value of 0.116 (Al-Abdulsalam, A., & Brindhaban. 2016).

Figure 5, derived from table 3, illustrates the individual annual distribution ratio of Radiotherapy Cadres surpassing 1, 5, 10, and 15 mSv (UNSCEAR 2008).

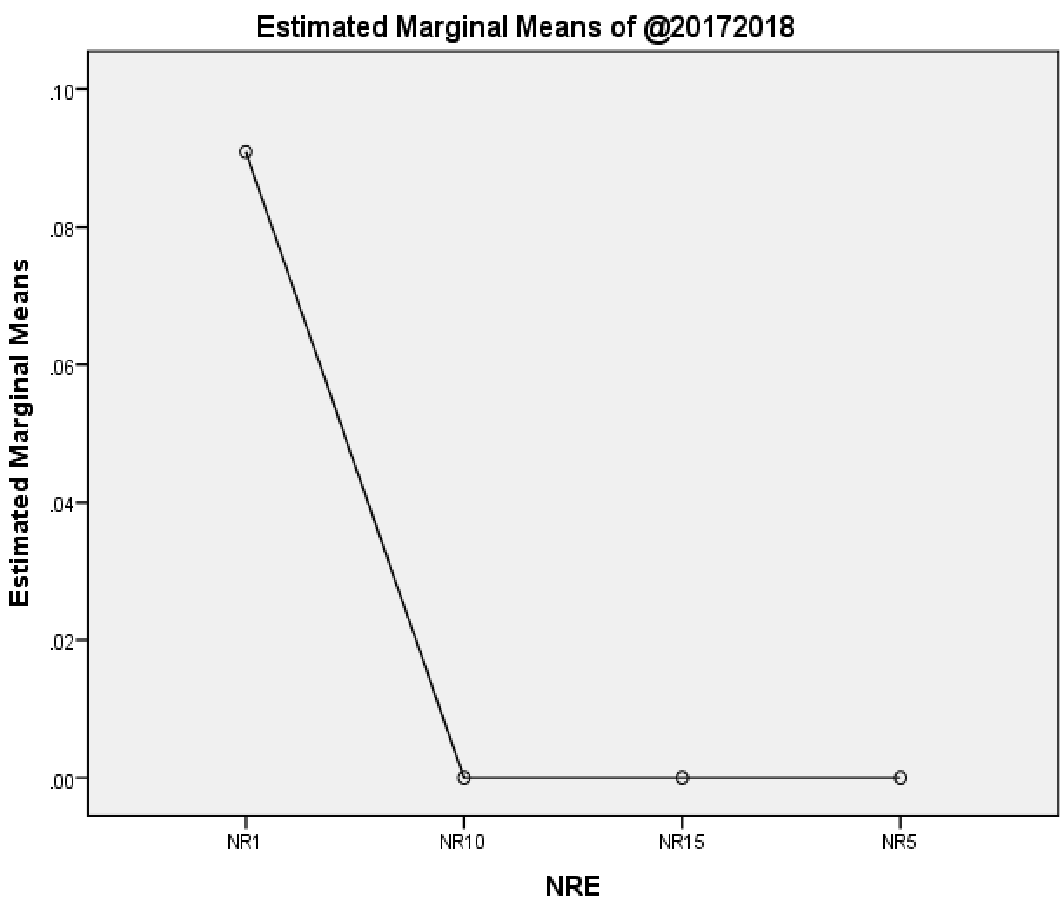

Figure 5 Radiotherapy Cadres Individual Annual Effective Distribution Ratio

Almost all radiotherapy staff (nearly 99%) had annual radiation doses exceeding 1 millisievert (mSv). This is important, but the good news is that no group went over the safety limits of 5 mSv, 10 mSv, or 15 mSv. The data also showed a very consistent distribution of doses across the staff (standard deviation of 0.045).

Figure 6 below illustrates the distribution of individual collective annual effective dose denoted by SRE for Radiotherapy Cadres.

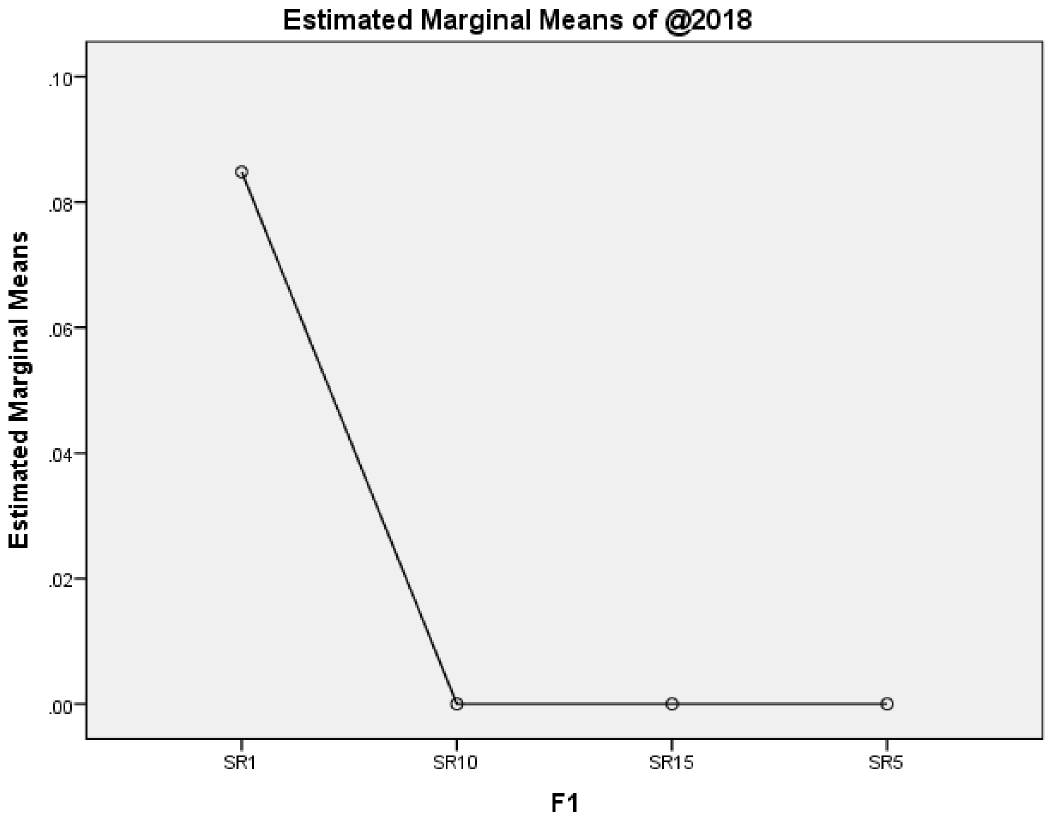

Figure 6 Radiotherapy Cadres Individual Collective Annual dose distribution ratios

Nearly all radiotherapy staff (almost 99%) had a combined annual radiation dose that, when adjusted for the total number of workers, exceeded 1 millisievert (mSv). This adjusted dose is called the collective annual effective dose ratio. There were variations in radiation exposure among staff members (standard deviation of 0.424). It's important to note that data is missing for 2017 and 2018. Interestingly, 2014 seems to be the year with the highest overall radiation exposure for radiotherapy personnel (UNEP 2016).

SUMMARY

This study assessed the occupational radiation exposures of medical radiation, workers at Usman Danfodiyo University Teaching Hospital. The average annual effective dose for Radiotherapy was determined to be 1.9132mSv, with a cumulative annual effective dose of 80.41 person mSv. The findings revealed that approximately 46.88% of Radiotherapy workers received an annual effective dose exceeding 1 mSv, while none of the workers exceeded the annual distribution ratio thresholds of 5, 10, and 15mSv in the Radiotherapy department. (Alves, J.,et al., 2007).

CONCLUSION

Relatively High Average Dose: The average annual effective dose for radiotherapy personnel was 1.9132 millisievert (mSv), which is higher than the 1 mSv level observed in some previous studies. This suggests potential areas for dose optimization.

Significant Collective Dose: The collective annual effective dose of 80.41 person mSv indicates a substantial cumulative radiation exposure for the entire radiotherapy department. This highlights the importance of implementing effective radiation safety protocols.

Exposure above 1 mSv but Below Limits: While nearly half (46.88%) of radiotherapy workers received annual doses exceeding 1 mSv, none surpassed the stricter regulatory limits of 5 mSv, 10 mSv, or 15 mSv. This adherence to safety standards is positive.

RECOMMENDATIONS FOR IMPROVED RADIATION SAFETY AND EXPOSURE ASSESSMENT

1. Enhanced Calibration Procedures: Implement a consistent calibration protocol for the Harshaw 4500 TLD reader using a 137Cs beam source before each use. This ensures accurate dose measurements for personnel monitoring.
2. Evaluation of Advanced TLD Technology: Conduct a comparative study utilizing the Harshaw 8800/6600 model TLD reader. Its high precision and accuracy could potentially improve the reliability of occupational radiation exposure assessments.
3. Comprehensive Cancer Risk Assessment Models: Develop or upgrade existing models to assess both Excess Relative Risk (ERR) and Excess Absolute Risk (EAR) for various cancers simultaneously. This provides a more complete picture of potential health risks.
4. Broadened Occupational Exposure Assessment: Extend the scope of future studies to include radiation exposure risks for a wider range of healthcare workers. This could include radiologists, dental professionals, and support staff like porters.
5. Workload Management Strategies: Implement measures to address workload pressures on radiation workers. This could involve exploring cost-effective scheduling strategies that minimize human errors associated with fatigue.
6. Advanced Cancer Detection Modeling: Invest in the development of models capable of detecting cancer across all radiosensitive organs. This would provide a more comprehensive approach to early cancer diagnosis.

7. Optimized TLD Reading Schedule: In locations with high temperatures like Sokoto, schedule TLD readings one month after exposure to minimize data loss due to thermoluminescent fading within the chips.
8. Increased Staffing Levels: Consider employing additional personnel within radiation departments to alleviate workload pressures and improve overall safety protocols.

REFERENCES

Abu-Jarad F. (2008). Evaluation of Radiation Source Applications in the Oil and Gas Industry and Challenges in Service Provision. International Symposium on the Peaceful Application of Nuclear Technology in GCC Countries, Jeddah 2008. Radioisotopes Applications, Session 10/No.3.

Aborisade Caleb, M.I., and T.B. Ibrahim. (2019). Estimation and Radiological Implications of Dose Distribution in Female Patients Undergoing Fluoroscopy Examinations at Ondo State Trauma and Surgical Center, South West Nigeria. Philippine Journal of Science, 12(1), 23-36.

Agu, B.N.C. (1965). Monitoring of Radioactive Fallout in Nigeria up to 1961. Nature, 205, 649-651.

Al-Abdulsalam, A., & Brindhaban. (2016). Occupational Radiation Exposure Among Staff in the Departments of Nuclear Medicine and Diagnostic Radiology in Kuwait. Medical Principles and Practice: International Journal of the Kuwait University, 23(2), 129–133, 2014.

Alves, J., Abrantes, J., Roda, A., Martins, M. (2007). Occupational Exposure in Nuclear Medicine in Portugal in the 1999–2003 Period. Radiation Protection Dosimetry, 125(1-4), 130–134.

Bello, G. (2017). Thesis on the Assessment of Occupational Exposure and Radiation at Ahmadu Bello University Zaria (kubanni.abu.edu.ng).

Began, A., R.K. Khan, and Schelur Rahman. (2016). Thesis on the Assessment of Whole-Body Occupational Radiation Exposure in Nuclear Medicine Practices of Bangladesh (2010-2014).

Beganovic, A. (2010). Ten Years of Monitoring Occupational Radiation Exposure in Bosnia and Herzegovina. 139(1.3), 400-2.

Benard, O., & Williams, K. (2015). Personal Radiation Monitoring of Occupationally Exposed Radiographers in the Largest Tertiary Referral Hospital in Ghana (https://doi.org/10.1186/S40886-015-009-Y).

CNSC (2012). Introduction to Radiation (http://nuclearsafety.gc.ca). ISSN: 1700-8042.

Cember, H. (1996). Introduction to Health Physics, McGraw-Hill, Davis, New York.

Covens, P., Berus, D., Buls, N., Clerinx, P., Vanhavere, F. (2007). Personal Dose Monitoring in Hospital Globe Assessment: Critical Application and Future Needs. Radiation Prot Dosimetry, 124, 250-9.

Del Solfernandez, S. (2017). Environmental Monitoring Intervention Radiology, Conference Paper. Conference: 2017 J. Phys: Ser. 792012085.

EPA (2009). External Exposure to Radionuclides in Air, Water, and Soil. Federal Guidance Report NO: 12 EPA.402-R-93.

EPA (2015). Radiation Protection and Safety of Radiation Sources. ISSN 1020-52X NO. GRS parts, ISBN 978-92-0-135310-8.

Eric, J.H., & Amato J.G. (2006). Radiobiology for the Radiologist, 6th edition, Philadelphia, USA: Lippincott Williams and Wilkins.

Faulkner, A. (1999). Determination of Entrance Skin Dose from Diagnostic X-ray in Humans (https://www.ajol.info>viewfile PDF).

Faulkner, A., & John J. Fletcher (2015). Occupational Radiation Dose to Eyes from Interventional Radiology Procedures in Light of the New Eye Lens Dose Limit from the International Commission. Journal of Radiology, 88(1049), 210140627.

Gratsky and Covens (2004). Introduction to Radiation. ISBN.978-1-100-215.

Greenlee, C., Burmeister, L.A., Butler, R.S., Edinboro, C.H., Morrison, S.M., Milas, M. (2011). Current Safety Practices Relating to I-131 Administered for Diseases of the Thyroid: A Survey of Physicians and Allied Practitioners. Thyroid, 21, 51-160.

Gilbert and Dr. Ben. Occupational Radiation Exposure, Biological Effects of Ionizing Radiation Report (2007).

Harshaw 4500 (2007). Dual TLD Reader and Workstation Operator's Manual (JRT Associates 5 Nepperhan Avenue, Suite 2B, Elmsford, NY) (Pub.No.10523800-221-011).

Hasford F., Owusu-Banahene I., Amoako JK. (2011). Assessment of Annual Whole-Body Occupational Radiation Exposure in Education and Industrial Sectors in Ghana (2000-2009). Radiat Prot Dosim. doi:10.1093/rpd/ncr404.

IAEA. Occupational Radiation Protection: Safety Guide. The International Atomic Energy Agency and the International Labor Office, Vienna, 3rd edition, 7, 1999.

IAEA (2015). Protection of Public against Exposure Indoor due to Radon. ISBN: 978-92-0-102514-2 ISSN: 1020-525X.

IAEA (2002); No.RS-G-1.5 Safety Guide; Radiological Protection for Medical Exposure to Ionizing Radiation Vienna; p 76.

IAEA (2014). Radiation Protection and Safety of Radiation Sources. ISBN: 978-92-0-135310-8. ISSN: 1020-525X no.GSR.parts.

ICRP 60 (1990). Recommendations of the International Commission on Radiological Protection, Publication 60, Pergamon Press, Oxford, and New York.

ICRP 103 (2007). Recommendations of the International Commission on Radiological Protection, Publication 103, Elsevier, Amsterdam.

Krohmer, J. S. (1969). Introduction to Health Physics. https://doi.org/co.1148193.3.618.

Kinsara A Nassef, M. (Year not provided). Occupational Radiation Dose for Medical Workers at University Hospital. Journal of Taibah University for Science, 11(6).

Le Haron, Getrude C., Joseph K. (2010). European Journal 76(1):20-3 on Radiation Protection of Medical Staff.

Lagarde, C. S. Al-Haj, A. N. (Year not provided). Statistical Analysis of Historical Occupational Dose Records at a Large Medical Center. Health Physics, 83(6).

Masood, K., Zafar, J., Zafar, T. (2015). Assessment of Personal Occupational Radiation Exposures Received by Nuclear Medicine and Oncology Staff in Punjab (2003-2012). Australasian Physical Engineering Sciences in Medicine, 38(3), 473–478.

Maduemezia (2008). Thesis on Assessment of Occupational Radiation Protection in Some Selected Well Logging and Industrial Radiography Facilities in Nigeria (www.modishproject.com>occupational radiation).

NNRA (2006). Nigeria Transportation of Radioactive Source Regulations 2006, Federal Republic of Nigeria S.I 59 of 2006. B511-521.

Peter Gainsford. (1995). Recommendations for Limiting Exposure to Ionizing Radiation. Guidance note. National Medical and Health Research Council, Australia, Australia.

RSSC (2011). Fundamental Radiation Concept 072011. 2-1.

Short (2014). Iranian Journal of Public Health, 42(4), 428 on Alterations of Visual Reaction Time and Short Memory in Military Radar Personnel.

UNSCEAR (2008). Sources and Effects of Ionizing Radiation Report to the General Assembly of the United Nations with Scientific Annexes, New York. United Nations Sales Publication. E.10.X1.3.

UNEP (2016) Sources and Effects of Ionizing Radiation. New York E.10.X1.3.