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Status and Trend of Occupational Radiation Exposure in Radiotherapy and Diagnostic X-ray Practices in Bangladesh

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ABSTRACT

Introduction: The evaluation of occupational exposure and related trends due to external ionizing radiation in diagnostic and therapeutic purposes has become crucial to understanding the implementation of regulatory acts and technological advancement. This study describes the status of occupational radiation exposure in the radiotherapy (RT) and diagnostic X-ray (DR) sector and the comparison with related research.

Material and Methods: Overall, 12141 radiation workers were monitored using thermoluminescent dosimeters (TLDs) read-out by Harshaw TLD Reader (Model 4500) on a quarterly basis. Several parameters such as annual collective effective dose, average annual effective dose, collective and individual dose distribution, and the probability of cancer risk were analyzed.

Results: The number of monitored workers increased by around 35%, whereas the number of radiation workers who received a measurable amount of doses decreased by around 37% during 2014-2018. The annual average effective doses in RT and DR were in the range of 0.017-0.1112 and 0.076-0.1702 mSv, respectively. The results indicate that more than 94% of the total collective dose was for the non-physician group. Among exposed radiation workers, almost 78% received doses below 1mSv and <1% received doses over 15mSv. The annual average effective dose is five times lower than the worldwide average value. Depending on the average occupational dose, the expected number of radiation-induced cancer cases among the monitored workers is below 1.

Conclusion: Dose distribution tends to move towards lower levels and reveals that the majority of the organizations maintain adequate radiation protection.

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Introduction

The application of ionizing radiation in medical practices upholds the benefits rather than its hazardous effects. Thus the probability of long-term exposure due to low dose radiation and related adverse biological effects viz., by changing the metabolic characteristics of tissue and cells, adverse effect in the respiratory system, change the characteristics of blood parameters, etc. [1-4] on the human body cannot be excluded. Consequently, this has taken the attention of researchers [5-16] to study the dose level of occupational radiation exposure to understand proper utilization of radiation protection in respective fields. The exercise of ionizing radiation for diagnostic and therapeutic purposes provides immense convenience to human health, which creates an inevitable part of a risk to the workers, and they are forming one-fifth of collective effective dose in the world, as reported by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) from artificial radiation [17]. Researchers provided evidence on the biological effect for high and moderate doses (higher than 100mSv); however, the discussion is still going on for the effect of low doses (less than 100mSv) [12, 16, 18].

Occupational exposure refers to those exposures which are taken during work and the worker means the person who is subjected to individual radiation dose assessment [13]. With the vision of providing adequate information on the effective dose which may be within the dose limits imposed by International Organizations and National Regulation, Health Physics Division of Atomic Energy Centre Dhaka (HPDAEC) of Bangladesh Atomic Energy Commission (BAEC) is providing individual monitoring service over the whole country as per as Nuclear Safety and Radiation Control (NSRC) Rules-1997 of Bangladesh, International Commission on Radiological Protection (ICRP) 2007, and International Atomic Energy Agency (IAEA) General Safety Requirements (GSR) part-3 since 2000 [19-21]. According to these provisions, the annual effective dose should be within on average 20mSv for 5 consecutive years and should not exceed 50mSv in a single year.

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Over the past few years, several researchers studied occupational radiation exposure in medical practices. Wu et al. [5] carried out research in Chinese medical sectors and found that with the increase in monitored workers, the annual average effective dose decreased. In western China, few workers received doses over 15mSv. Colgan et al. [7] found in the investigation that collective doses declined over the studied period. In Ireland, Bosnia, Tanzania, and Ghana, workers in the radiology department received most of the individual doses over 1mSv [7-10]. They concluded that in Ireland, sources of natural radioactivity account for > 90% of all occupational exposure. In Lithuania, Samerdokiene et al. [11] studied the overall status of medical radiation exposure for 53 years and found that 78% of radiation workers received doses below 5 mSv. Al-Abdulsalam in Kuwait found a very low calculated risk of radiation-induced cancer among hospital workers [12]. In Bangladesh, occupational exposure assessment was done among the workers of interventional cardiology and nuclear medicine department. Studies showed that annual average effective dose was below worldwide average value and recommended value [13, 14].

The aim of this study is to evaluate the level of exposure due to ionizing radiation among the workers of diagnostic X-ray (DR) and radiotherapy (RT) practices based on the employment category during 2014-2018, and study the related trends to understand the present condition of radiation protection. This study also describes the factors responsible for the risk of cancer induction associated with effective dose.

Materials and Methods

Materials and Equipment

In order to monitor the whole-body occupational exposure of radiation worker in the department of RT & DR, thermoluminescent dosimeter (TLD), LiF:Mg,Ti (TLD-100), was used throughout the country as the effective atomic number of thermoluminescence material is nearly equivalent to human body soft tissue (accounts for 8.2) that HPDAEC, Bangladesh, provided. To measure elemental correction co-efficient (ECC), each TLD was exposed by 2mSv dose for personal dose equivalent (Hp (10)) through X-ray Unit from the Secondary Standard Dosimetry Laboratory (SSDL) of BAEC before the TLD badge (TLD card and holder) was supplied to radiation workers. The overall performance of BAEC SSDL is maintained in line with the necessities of the International Atomic Energy Agency (IAEA)/World Health Organization (WHO). As a result, the evaluated dose is perceptible to the International Measurement System (IMS). HPDAEC always participates in the programs of inter-laboratory dose comparison organized by IAEA, and according to the standard trumpet curve criteria [22, 23], satisfactory performance was achieved in the recent comparison.

Radiation workers were issued TLD badges quarterly. The workers were instructed to wear the TLD during working time on the torso, which was returned to HPDAEC after using it for the dose measurement. The assessment of dose is done by Harshaw TLD reader (Model: 4500, Country: United States of America (USA), Company: Thermo Fisher Scientific) [24] in which a stream of hot gas (nitrogen) is used by the gas heating system to heat TL element at properly controlled way and linearly raise the temperature to a maximum of 400^0C, and the superior electronic design and the heating by hot gas under closed-loop feedback control produces repeatable glow curves. After annealing, TLD is issued again along with dose report for the next quarter cycle to the relevant worker.

Dose Evaluation Procedure

For dose evaluation, 11 (872) organizations and 169 (1853) workers were monitored in the year 2014, and these numbers increased by 2 (253) and 36 (679) for organizations and workers, respectively, at the end of 2018 in RT (DR) practices as shown in Table 1. This is a clear indication of an increase in the number of workers with the economic growth and development in the country's medical facilities. The dose report is always provided in terms of personal dose equivalent, Hp (10), considered a whole-body effective dose. After subtraction of the background radiation dose, the minimum detectable limit (MDL) is considered as 0.05mSv for three months, dependent on the dosimeter's physical characteristics [7]. The effective dose below MDL is reported as below the detection limit (BDL). The evaluated dose above MDL is recorded in the database as an actual dose of individuals (radiation workers). For precise evaluation, workers were grouped into two categories: Physician and Non-Physician (technician, technologist, experimental officers, lab assistants, and others). The number of workers based on these categories is given in the following as table:

Table 1. Number of organizations and workers monitored using TLDs in radiotherapy and diagnostic X-ray sector from 2014 to 2018

Department		Year				
		2014	2015	2016	2017	2018
Radiotherapy	No. of organizations	11	12	12	12	13
	No. of Physicians	66	67	67	66	74
	No. of Non-Physicians	103	108	107	111	131
Diagnostic X-Ray	No. of organizations	872	962	1010	1121	1125
	No. of Physicians	55	76	88	86	91
	No. of Non-Physicians	1798	2031	2136	2439	2441

Data Analysis

In this study, we analyze five parameters such as annual collective effective dose (S_E), average annual effective dose ($\overline{E_a}$), annual collective dose distribution ratio (SR_E), individual dose distribution ratio (NR_E), and lifetime fatal cancer risk (LFTR) for the given five years period to ensure a harmless work environment for radiation workers following the recommended guideline. The figures (Figure 1-3) were drawn by using Microsoft Excel.

Annual Collective Effective Dose

According to the recommendation of UNSCEAR 2000, the following equation was used to obtain the annual collective effective dose (S_E), provides the estimate of the impact of a particular practice in a given time [25]:

$$S_E = \sum_{j=1}^{N} E_j, \qquad (1)$$

here, E_j is annual effective dose which was received by j^{th} workers and N is the total number of monitored workers.

Average annual effective dose

The average annual effective dose (AAED), denoted as $\overline{E_a}$, was obtained from the ratio of S_E/N and is important to organize a dose distribution database.

The annual collective dose distribution ratio

The annual collective dose (ACD) distribution ratio (SR) represents the indication of the fraction of collective dose received by exposed workers to a higher level of individual dose [9, 14]. As stated in UNSCEAR 2000, we can obtain SR from the following equation [25];

$$SR = \frac{S_E(>E)}{S_E}, \qquad (2)$$

where S_E (>E) is the ACD at a given individual effective dose in a year exceeding E mSv, and in this study, we numerically calculated the value of SR for E value of 15, 10, 5, and 1 mSv.

The individual dose distribution ratio

Portion of the exposed workers to higher levels of individual doses is expressed as the individual dose (IND) distribution ratio (NR) which describes the number of the workforce working in the particular workplace or field. Based on the UNSCEAR 2000, we can write

$$NR = \frac{N_E(>E)}{N} \qquad (3)$$

Prediction of lifetime fatal cancer risk

According to ICRP 60 [26] recommendation and UNSCEAR guidelines, the measurement of the risk of fatal cancer induction due to an external source of ionizing radiation have been done by using 'probability coefficients' of 500×10^{-4} per Sv for stochastic effect for the workers exposed by low doses in the medical sectors. Lochard in his publication [27] described radiation risk in various workplaces and compared it with other workplaces of United States of America, Japan, and France. Based on the literature [12, 27, 28], the fatal cancer risk [FTR] probability was calculated as the equation below:

Probability of fatal cancer risk = AAED × Probability Coefficient (4)

Based on this equation, for the recommended annual average dose limit of 20 mSv, the probability of developing fatal cancer is 1000 per million.

The dose-effect relationship is linear with effective dose as well as with exposure time; therefore, without exposure time, the annual risk of fatal cancer can be evaluated and for evaluating lifetime fatal cancer risk, the exposure time should be multiplied.

Results

During 2014-2018, dose records were evaluated for the radiation workers in the field of RT and DR. Several trends were found during the evaluation of annual collective effective dose, average annual effective dose, and dose range. Overall, 12141 workers were monitored in which 11405 (736) belonged to non-physician (physician) group during the five years period in the above-mentioned areas. The assessment of the annual collective effective dose is shown in Table 2. The total collective dose was 57.374 man.mSv and 1016.894 man.mSv for RT and DR department, respectively in 5 years. Among all the years, in RT (DR) sector, 29.66% (21.43%) of the total collective dose was evaluated in the year 2014 (2015), which was found as highest, and in both areas, majority of the contribution in total collective dose was for non-physician group. Table 2 also shows that the annual average effective dose with standard deviation varies between 0.0170 ± 0.028 mSv and 0.1702 ± 0.086 mSv, and both lowest and highest average effective dose belong to the physician group both areas.

Figure 1 represents the maximum dose received by any individuals and compares the received maximum dose between physician and non-physician in both occupational sectors. Among all categories of workers, the maximum dose received by the non-physician group is between 2.39 mSv and 19.90 mSv, and for the physician group, it is between 0.76 mSv and 5.60 mSv. Figure 2 illustrates the number of workers in percentage received doses below the minimum detection limit (MDL). Among 12141 number of monitored radiation workers, 11172 number of workers received doses below MDL that accounts for 92.01%.

Table 2. Annual collective effective dose and annual average effective dose with standard deviation in RT and DR departments during 2014-2018 in Bangladesh using TLD (based on occupational category)

	Occupational Category		2014	2015	2016	2017	2018
RT	Physician	Annual Collective Effective Dose (man.mSv)	5.618	4.473	1.844	1.119	1.342
		Annual average effective dose (mSv) ± SD*	0.085 ± 0.095	0.067 ± 0.1	0.0275 ± 0.056	0.017 ± 0.028	0.0181 ± 0.02
	Non-Physician	Annual Collective Effective Dose (man.mSv)	11.401	12.018	11.252	3.609	4.698
		Annual average effective dose (mSv) ± SD	0.1106 ± 0.04	0.1112 ± 0.033	0.1051 ± 0.021	0.0325 ± 0.014	0.0359 ± 0.059
DR	Physician	Annual Collective Effective Dose (man.mSv)	9.36	11.39	10.21	8.98	8.19
		Annual average effective dose (mSv) ± SD	0.1702 ± 0.086	0.1499 ± 0.195	0.116 ± 0.11	0.1044 ± 0.089	0.09 ± 0.012
	Non-Physician	Annual Collective Effective Dose (man.mSv)	187.153	206.486	200.16	189.375	185.59
		Annual average effective dose (mSv) ± SD	0.1041 ± 0.025	0.1017 ± 0.048	0.0937 ± 0.045	0.0776 ± 0.038	0.076 ± 0.026

*SD = Standard Deviation

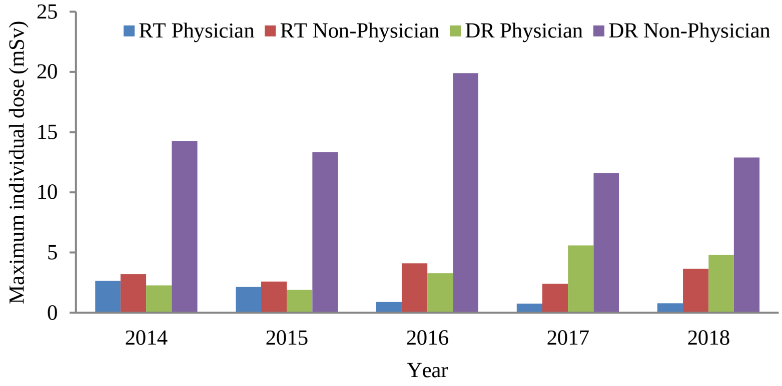

Figure 1. Maximum individual dose per year received by the radiation workers during 2014 -2018 based on the category of occupation.

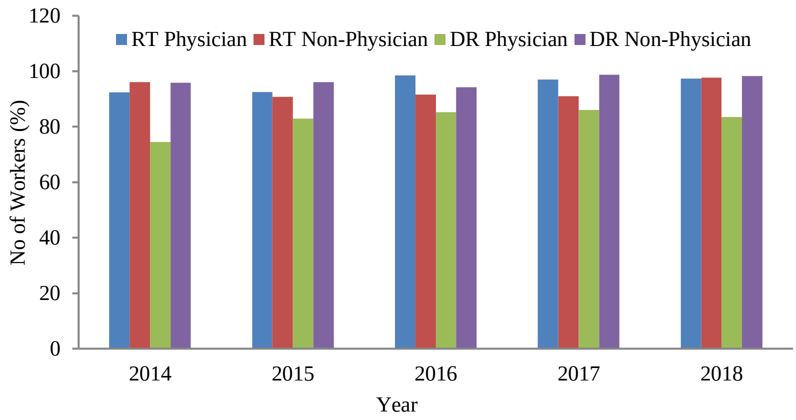

Figure 2. Percentage of workers received dose below the minimum detection limit (MDL) in both RT and DR sectors during 2014- 2018 based on employment category

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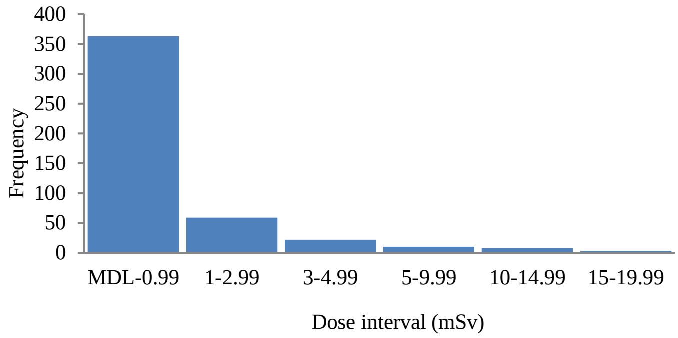

Figure 3. Frequency of observation of annual average effective dose intervals of exposed workers irrespective of departments and job category during 2014 to 2018.

Table 3. The individual dose distribution ratio during 2014-2018

Annual individual dose exceeding (mSv)	Individual Dose Distribution Ratio				
	2014	2015	2016	2017	2018
15	0	0	0.0013	0	0
10	0.0005	0.0008	0.0004	0.0011	0.0003
5	0.001	0.0004	0.0013	0.0006	0.0007
1	0.006	0.0062	0.009	0.006	0.007

Table 4. The collective dose distribution ratio during 2014-2018

Annual individual dose exceeding (mSv)	Collective Dose Distribution Ratio				
	2014	2015	2016	2017	2018
15	0	0	0.234	0	0
10	0.067	0.11	0.047	0.16	0.065
5	0.06	0.033	0.102	0.07	0.07
1	0.153	0.136	0.232	0.142	0.306

Figure 3 describes the dose distribution among the exposed workers and it shows that the majority (around 78%) of them received doses below 1 mSv. Table 3 and 4 represent the individual dose distribution ratio and collective dose distribution ratio above the doses of 1, 5, 10, and 15 mSv with respect to the different year. It can be highlighted that in 2016 workers received dose above 15 mSv and in the subsequent years, no workers received the dose over 15 mSv though the number of workers increased in those years. This indicates that there was an appropriate distribution of workloads among the radiation workers.

Using equation 4, the occurrence of fatal cancer risk was predicted to understand the present status of occupational exposure. Based on the calculated annual average effective dose of radiation workers in RT sector, the probability of developing cancer reduced from 5 to 1 per million of workers between the year 2014 and 2018, and for DR sector, it reduced from 5 to 4 per million of exposed workers for the same period. These are very low compared to the risk of cancer induction for 20 mSv per year of recommended dose limit, accounting for 1000 per million radiation workers. Between these two sectors, workers in the field of DR are more likely to be at risk of developing cancer than the workers of RT.

Discussion

In order to ensure the safety of the radiation worker, assessment of occupational exposure dose by TLDs plays a vital role, and to ensure proper utilization and distribution of TLDs, HPDAEC has been selected as the central institute for individual monitoring service in Bangladesh. During the study period, there was a significant proportion (around 35%) of the increase in the number of workers (see Table 1) the majority of them belong to the diagnostic X-ray department. Based on the employment category, non-physicians (almost 94%) were in the leading position.

During five years period, no specific trend was followed by annual collective effective dose. In the case of DR, which accounts for about 95%, the annual collective effective dose was more than RT sector which constitutes 5%. This may be due to the use of advanced device in RT departments for treatment that uses an external beam from highly protected Cobalt-60 source or linear accelerator (LINAC) and workers can operate the device from the outside of treatment room. Based on occupational responsibility, the collective effective dose which is received by non-physicians is much higher in comparison with physicians (see in Table 2). As per the Table 2, the relation of the annual collective effective dose was inversely proportional with the number of workers except for some situation; therefore, the average annual effective dose follows a slightly decreasing trend for both departments. The highest value of the average annual effective dose was observed for DR sector, which was 0.1702 mSv with standard deviation of 0.086 in 2014 and for the same group of workers it became 0.09 ± 0.012 mSv in the end of 2018. The lowest average annual effective dose was 0.017 ± 0.028 mSv that belongs to the physician group of RT sector. Overall, the annual average individual effective dose for monitored workers was 0.088 mSv which is approximately five times lower than world average value (0.48 mSv) for the year between 2000 and 2002 [17]. In the Table 5, the annual average effective dose of exposed workers is compared with other studies. This implies that proper safety measure was maintained and under the BAER Act-2012 [29], the Bangladesh Atomic Energy Regulatory Authority (BAERA) regulation was suitably followed. However in DR sector, as in comparison with non-physician group, physicians should decrease workloads or take necessary steps to minimize the effective dose.

It can be seen from Figure 1 that the maximum individual dose received by a worker belongs to a non-physician, to be a more specific technician, of DR department, which accounts for 19.90 mSv in 2016. According to the policy of HPDAEC, after investigation, it was found that during that monitoring period, that particular technician was new and didn't follow the instruction of radiation protection. As a result, the radiation control officer (RCO) gave the technician less workload, which was helpful to keep the dose level below-average annual dose limit of 20mSv in consecutive years. During the studied period, non-physicians received maximum dose in compared to physicians. This might be due to less awareness about the radiation protection field, improper training on radiation protection, less technological advances, and not having proper infrastructures. However, these cases of receiving maximum doses were very low and could not impact the annual average effective dose, which leads to decline the doses as low as reasonably achievable (ALARA).

From Figure 3 and Table 3 it can be observed that the distribution of individual doses tended to lower levels as the distribution pattern reported by UNSCEAR [30]. , The number of Physicians from RT and DR who received doses below MDL were in the range of around 92-97% and 74-86%, respectively in which highest number was in the year 2016. In the case of non-physicians, a number of workers from RT was about 90-97% and from DR was approximately 94-98% and the highest number was in the year 2018. The result of the collective dose distribution ratio suggests that around 5% of collective doses were contributed above 15 mSv by individual exposure doses.

The study shows [12, 27, 28] probability of cancer risk increases with the increase of dose. The risk of cancer induction in Bangladesh accounts for 4 per million exposed workers, was 10 times lower than the risk of cancer induction in Kuwait (40 per million) [12], which means the predicted number of radiation among the monitored 12141 worker induced cancer cases is below 1. Thus it clearly demonstrates the improvement of the radiation protection protocols. Although long-term exposure may increase the risk of cancer, this assessment can build confidence among radiation workers. Another important thing is that the probability of lifetime FTR is in a linear relationship with exposure time; as a result, if anyone gets overexposed, the risk of cancer induction can be minimized by reducing workload. Despite the fact that there is insufficient evidence of cancer risk due to low doses, this kind of assessment will help to distribute the workload.

There are some limitations in the measurement of occupational exposure properly. Though this study is conducted by considering the employment category, workers need to be grouped based on the nature of exposure and shielding effect to understand the difference in occupational exposure. Besides, for lifetime fatal cancer risk measurement, exposure time is very crucial. So, it is recommended for future studies to take into account these factors, and for the prediction of cancer risk, workers group according to age and gender should be taken into consideration.

Table 5. Comparison of annual average effective dose for occupationally exposed workers with other studies of various countries

Country	Period	Average annual effective dose (mSv) of occupationally exposed workers in different practices		
		DR	RT	All medical
China [5]	1986-1990	2.20	1.50	2.20
	1991-1995	1.50	1.00	1.50
	1996-2000	1.50	0.90	1.40
Ireland [7]	1996-2000	-	-	0.28
	2001-2005	-	-	0.32
Bosnia and Herzegovina [8]	1999-2003	1.60	1.20	-
	2004-2008	1.60	1.60	-
Tanzania [9]	1996-2010	1.02	0.91	-
Ghana [10]	2000-2009	1.05	0.14	0.69
Lithuania [11]	1991-2003	1.60	1.60	-
Pakistan [15]	2009-2016	1.30	1.23	1.30
This study	2014-2018	1.10	1.15	-
Worldwide [17]	2000-2002	1.34	1.33	1.24

Conclusion

The radiation workers, who received doses during dealing with ionizing radiation in the field of RT and DR, were monitored by using TLD, which HPDAEC evaluated in 05 consecutive years. This study implies that the dose received by workers in RT & DR is less than similar studies in other countries. Although the annual average effective dose of radiation workers is less than the recommended limit, continuous evaluation of the trends of occupational exposure is recommended to pursue proper radiation protection practices necessary to create safe working conditions.

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