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Assessment of whole-body occupational radiation exposure in industrial radiography practices in Bangladesh during 2010-2014

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ABSTRACT

Presently, ten industrial radiography facilities are operating in Bangladesh using X-ray or gamma-ray sources. During the last 5-year, 14 industrial radiography facilities were received individual monitoring service using thermoluminescent dosimeters (TLDs) from the Health Physics Division (HPD), Atomic Energy Centre, Dhaka under Bangladesh Atomic Energy Commission. HPD is the only individual monitoring service provider in Bangladesh due to external sources of ionizing radiation. The number of monitored industrial radiography facilities ranged from 7 to 14 while the number of worker ranged from 72 to 133 during the study period. The annual average effective doses received from external radiation in industrial radiography workers and the distributions of the annual effective doses by dose intervals are presented. The distribution of the occupational doses shows that the majority (about 75 %) of workers received doses below 1 mSv for the last 5-years. Even though, very few workers (about 1%) received doses higher than average annual dose limit (20 mSv), but no workers received doses higher than 100 mSv in 5 consecutive years. The average annual effective dose of industrial radiography workers in Bangladesh is higher than the corresponding values in Tanzania, Greece, Poland, Australia, UK and lower than in Bosnia and Herzegovina, USA and Canada. However, the average annual effective dose is comparable to the corresponding values in China, Brazil, Germany and India. The status and trends in occupational doses show that radiation protection situation at the majority of the workplace were satisfactory. In spite of that, additional measures are required due to big differences observed in the maximum individual doses over the last 5-year.

Keywords: industrial radiography, thermoluminescent dosimeter, effective dose.

1. INTRODUCTION

Industrial radiography work is often carried out under difficult working conditions, such as in confined spaces, in extreme cold or heat, or during the night. Working under such adverse conditions might results in operational situations in which occupational radiation protection may be compromised. Gamma radiography equipment utilizes a high activity sealed source housed in a shielded exposure device. Improper management of high-activity sources can have severe deterministic effects on individuals [1-7]. Based on the potential hazards of radioactive sources, a system of categorization has been developed by the International Atomic Energy Agency (IAEA) [8, 9]. Industrial radiography is one of the most common non-destructive testing (NDT) methods worldwide and must be managed very safely and securely. Industrial radiographers are considered one of the most critical group of radiation workers. The annual average effective dose received by industrial radiographers is higher than that of other radiation workers [10]. With regard to this fact and according to the Bangladesh Atomic Energy Regulatory (BAER) Act-2012 [11], any activity in this field shall be performed only after obtaining a proper licence. All applicants must submit the necessary documents to the Bangladesh Atomic Energy Regulatory Authority (BAERA) and ensure that they have the competence to carry out all activities with the proper administrative and technical measures.

Any individual radiation monitoring program has at least two main aims. The first aim is to provide information on the adequacy of protection measures which is a key input for operational decisions related to the optimization principle [12, 13]. Secondly, the individual monitoring programs aim is to demonstrate compliance with the relevant dose limits as required by the national regulations [14] and recommendations of International Organizations [12, 13, 15]. In this context, the annual effective dose to the occupationally exposed workers should not exceed 20 mSv averaged over five consecutive years (100 mSv in 5-years), with a provision that the individual dose does not exceed 50 mSv in any single year. Regular assessment of occupational radiation exposures and the analysis of related trends are vital to examine changes that have taken place over time due to regulatory operations or technological improvements. The objectives of this paper were to present the occupational radiation exposure of workers in industrial radiography practices in Bangladesh and to evaluate the related trends over a period of 2010-2014.

2. MATERIALS AND METHODS

2.1 Description of TLDs and readout process

The thermoluminescent dosimeters (TLD) consists of LiF:Mg,Ti (TLD-100); phosphor has the effective atomic number of 8.2, approximately equivalent to that of the soft tissue of a human body. TLD chips 3 mm (1/8 inch) square encapsulated between two sheets of Teflon 0.003 inches (10 mg/cm^2) thick and mounted on an aluminum substrate. In this study, two-chip TLD cards kept in a holder are issued for quarterly (3 months) basis to the radiation workers working in industrial radiography facility (IRF). The worker wears the TLD on torso at the working time. After using the cards of the stipulated time, IRF send back those used TLDs to the Health Physics Division (HPD), Atomic Energy Centre, Dhaka (AECD) under Bangladesh Atomic Energy Commission (BAEC). The Harshaw TLD reader (model 4500) is used for measurement of TLD dose of a wide varity of thermolumincence (TL) materials in many forms and sizes [16]. It has two photomultiplier tube (PMT) in a sliding housing for manual reading of TLD cards and TL chips for whole body, extremity and environmental dose monitoring purposes. Dual PMTs and associated electronics enable it to read cards in two positions simultaneously. PMT consists of photocathode that has the ability to convert the incident light into amplified current to give measured output which is proportional to the number of generated photons and as a result proportional to the absorbed dose. The Harshaw automatic TLD reader (model 6600 plus) has two heating methods such as hot nitrogen gas and dry air [17]. The doses of the received TLDs are measured in the TLD Reader by using hot nitrogen gas flow. The gas heating system uses a stream of hot nitrogen at precisely controlled, linearly ramped temperatures to a maximum of 300°C. The hot gas heating under closed loop feedback control and the superior electronic design produces consistent and repeatable glow curves. The annealed TLD again issue along with the dose report to the relevant worker for use of next quarter cycle.

2.2 Equipments and dose evaluation procedures

The operational dose quantity used for the estimation of doses from external radiation is the personal dose equivalent $H_p(10)$. Monitoring of radiation workers by the HPD, AECD under BAEC using TLDs begin immediately after a facility is licensed to operate. HPD, AECD is the only institute that provides dosimetry service for facilities that employ the use of ionizing radiation in Bangladesh. LiF:Mg, Ti (TLD-100) dosimeters have been used throughout the period 2010-2014. In the same period, two thermoluminescent dosimetry systems have been employed to readout the TLDs. They are Harshaw Manual TLD Reader, Model 4500 [16] (from 2000 and still running) and Automatic TLD Reader, Model 6600 Plus [17] (from June 2014) with manual system of data transfer. Harshaw 6600 plus Automatic TLD Reader which is one of the most technically advanced dosimetry systems for whole body, extremity, neutron and environmental monitoring, is being used by the HPD, AECD. The system offers 'one dosimetry solution' by its ability to monitor whole body (beta, photon and neutron), extremity and environmental exposure with a single dosimeter. It can take up to 200 dosimeters per cycle and also saves significant time by virtue of its automatic calibration capabilities. It has a flat panel display and touch-screen operation service and it exceeds International Electrotechnical Commission (IEC), International Organization for Standardization (ISO) and American National Standards Institute Performance requirements. The Harshaw TLD Readers are connected to an external personal computer (PC) and are operated through installed menu-driven WinREMS software.

The Secondary Standard Dosimetry Laboratory (SSDL) has been available at BAEC since 1991, which is traceable to the Primary Standard Dosimetry Laboratory (PSDL) of National Physical Laboratory (NPL), UK. Prior to use, each TLD is exposed with 2 mSv dose from SSDL of BAEC with respect to H_p (10), using a ^{137}Cs beam incident on a slab phantom of PMMA for measurement of elemental correction coefficient (ECC). SSDL of BAEC has X-ray Unit (30 kV-225 kV) for calibration of TLDs. The performance of BAEC SSDL is maintained according to the requirements of the International Atomic Energy Agency (IAEA)/World Health Organization (WHO) network of SSDLs. Therefore, the evaluated doses are traceable to the international measurement system. Furthermore, the personal monitoring laboratory regularly participates in inter-laboratory dose comparison programmes as organized by IAEA. In the latest comparison, adequate performance was achieved according to the standards trumpet curve criteria [18, 19].

TLDs output read by Harshaw TLD reader is the charges produced by electrons due to the annealing process. To convert the output readings of TLDs from charge (nC) to absorbed dose (Gy); the following equations are used:

$$absorbed\ dose = \frac{equivalent\ dose}{quality\ \ factor} \qquad (1)$$

The time between irradiation and readout should be the same to keep same fading from one calibration to another for all TLDs. The calibration factor ($f_{calibration}$) is defined as follows:

$$f_{calibration} = \frac{D_{ionization\ \ chamber(mGy)}}{TLD_{reading(nC)}} \qquad (2)$$

Absorbed dose due to irradiation is obtained after background subtraction by the following equation:

$$D_{TLD} = D_{av} - BG \qquad (3)$$

Then absorbed dose is obtained for each TLD by the following equation:

$$D_{TLD}(mGy) = f_{cal}(\frac{mGy}{nC}) \times TLD_{reading}(nC) \qquad (4)$$

Dose reporting is performed on a quarterly basis. For all individual doses, the minimum detection level (MDL) is 0.05 mSv for 3 months for two TLD systems after background subtraction. This value (MDL) is taken as dose recording level. The workers who received doses less than MDL are regarded as non-exposed. All doses that exceed the level of 5 mSv in a monitoring period (3 months) are always investigated. The dose record is accordingly amended after receiving a written explanation with reasons of high dose received by the workers from the Radiation Protection Officer/Head of the Institution. The database, therefore, includes only actual doses received by the radiation workers. Table 1 shows the number of monitored workers for the years 2010-2014.

2.3 Monitored and exposed workers

The dosimetry service at HPD uses a personal dosimeter system with a MDL of 0.05 mSv for a three month monitoring period after subtracting background radiation. Exposed workers are workers who may be exposed to doses exceeding 0.05 mSv. The workers who have effective doses less than MDL are considered as non-exposed. Therefore, the doses less than MDL are recorded as zero. All values of $H_p(10)$ are recorded and reported as the effective dose.

Table 1: Number of monitored workers in industrial radiography practices for the years 2010-2014 (enclosed in the brackets in the column are the number of institutions).

Type of practice /Year	2010	2011	2012	2013	2014
Industrial radiography	72 (7)	84 (9)	129 (11)	133 (11)	130 (12)

2.4. Data Analysis

In this study, four quantities recommended by UNSCEAR [20] were used to analyze individual doses for the years 2010-2014. They include the annual collective effective dose, the average annual effective dose, the individual dose distribution ratio and the annual collective effective dose distribution ratio. In addition, the minimum and the maximum values of the annual individual effective doses were analyzed to complement the average annual effective doses.

2.4.1. Annual collective effective dose (S)

The annual collective effective dose (S) was obtained according to the following equation given by UNSCEAR [20]:

$$S = \sum_{i=1}^{N} E_i \qquad (5)$$

Where E_i is the annual effective dose received by the i^{th} worker and N is the total number of workers monitored. The parameter S, gives an estimate of the impact of particular practice on the population in given time frame.

2.4.2. Average annual effective dose

The average annual effective dose, $\bar{E}$ was obtained from the ratio S/N, where the meaning of symbols are the same as in equation (5).

2.4.3. The individual dose distribution ratio

The individual dose distribution ratio, NR_E was obtained according to the following equation [20]:

$$NR_E = \frac{N(>E)}{N} \qquad (6)$$

Where N(>E) is the number of workers receiving annual dose exceeding E mSv. In this study, NR_E was analysed for values of E of 1, 5, 10 and 15 mSv. The parameter NR_E provides an indication of the fraction of workers exposed to higher levels of individual doses.

2.4.4. The annual collective dose distribution ratio

The annual collective dose distribution ratio, SR_E was obtained according to the following equation [20]:

$$SR_E = \frac{S(>E)}{S} \qquad (7)$$

Where S (>E) is the annual collective dose delivered at an annual dose exceeding E mSv. In this study, SR_E was analysed for values of E of 1, 5, 10 and 15 mSv. The parameter SR_E, provides an indication of the fraction of the collective dose received by workers exposed to higher levels of individual doses.

3. RESULTS AND DISCUSSION

3.1. Annual average effective dose and collective effective dose

The annual average effective dose and annual collective effective dose did not follow a particular trend between the 5-year periods. The annual average doses of the monitored workers were ranged 1.12-1.74 mSv during the period 2010-2014 as shown in Figure 1. The average annual effective dose of the monitored workers for the last 5-year period was 1.40 mSv which is comparable to the worldwide average annual effective dose of 1.50 mSv during 1995-1999, 2000-2002 periods [21]. The lowest annual average effective dose was 1.12 mSv in 2011. The observation may be due to decrease in workload or adherence to proper radiation protection protocols in 2011. The sudden rise in annual average effective dose in 2012 and 2013 could be due to improper radiation protection measures resulting in unintended over exposure of certain TLDs [22]. The decrease in average annual effective dose after 2013 is probably due to the formulation of independent regulatory Authority (BAERA) under the BAER Act-2012 [11] and proper regulatory control of the industrial radiography facilities. The annual maximum individual effective doses were 23.65, 21.71, 54.14, 55.37 and 12.49 mSv in 2010, 2011, 2012, 2013 and 2014 respectively as shown in Figure 2. It is the policy of HPD, BAEC dosimetry service to write to employers if any recorded dose exceeds 5 mSv for a monitoring period of 3 months. The employer is informed immediately of the dose and is requested to investigate the incident and to report the findings of such investigation to the HPD, BAEC. It is found that most of these exposures were due to prolonged working with radioactive sources at on-sites or mistakes by radiation workers. X-rays and gamma-ray sources such as ^{192}Ir are widely used for industrial radiography in Bangladesh. Most of these workers might not have proper training on radiation protection and their high exposure dose is thought to be the result of improper handling of the radioactive sources during their daily work. As can be seen from Figure 3, the majority of workers (75%) received doses less than 1 mSv during the entire study period. This means that the distributions are left skewed towards low doses in accordance with the distribution pattern described by UNSCEAR [23], the implication of which is that most occupationally exposed workers received very low doses with only a small number receiving high doses. During the period 2010-2014, two workers received doses higher than 50 mSv (54.14 mSv in 2012 and 55.37 mSv in 2013), while 4 workers received doses higher than annual average permissible dose limit (20 mSv) (23.65 mSv in 2010, 21.71 mSv in 2011, 36.44 mSv in 2012 and 36.58 mSv in 2013). Currivan and Koczynski [24, 25] investigated that industrial radiography workers received higher doses than their counterparts in the medical group is a common phenomenon. Based on this observation, as in most countries, industrial workers are the ones at risk and therefore rigorous surveillance has to be maintained in order to reduce the doses to this group of workers. The surveillance programme should include an analysis of worker dose records to determine whether the same set of workers always receives the higher doses.

Figure 1: *Trends of annual collective dose and average dose of the workers in industrial radiography practices.*

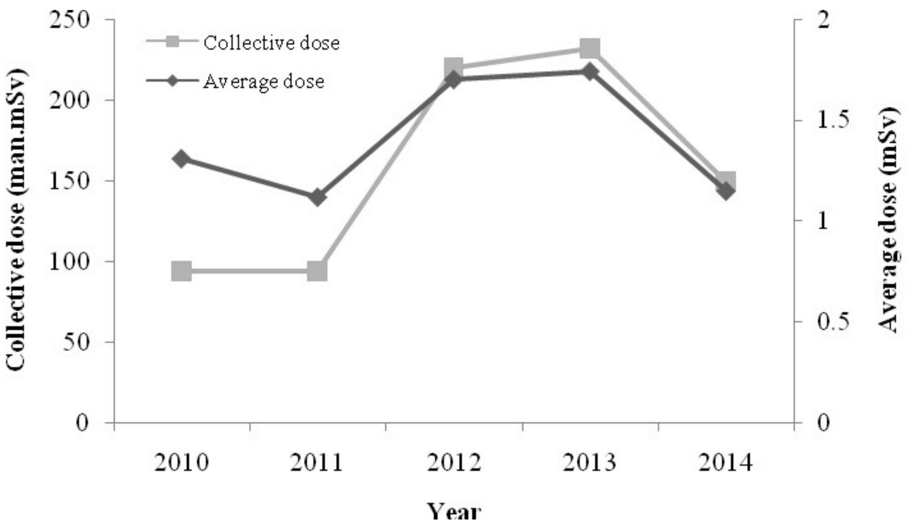


Figure 2: *Maximum individual annual effective dose from 2010 to 2014.*

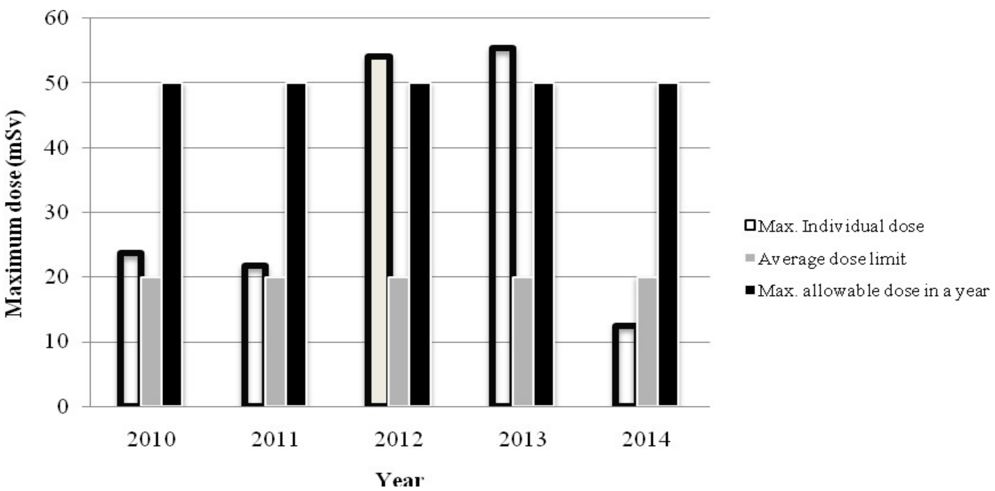
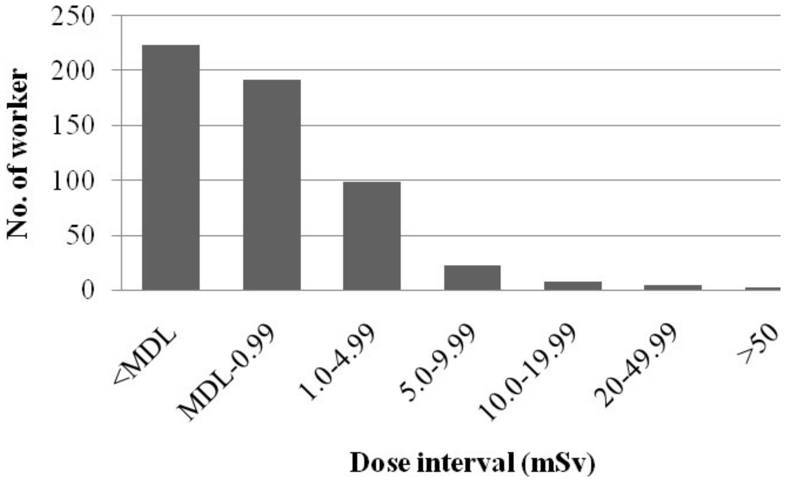


Figure 3: *Number of workers average annual effective doses interval in industrial radiography practices during the period 2010-2014.*



The comparisons with other countries data (Table-4) in literature show varying results. For example, in Tanzania, average annual effective dose for the years 1996-2010 was 0.59 mSv. In Greece, the average annual effective dose for the years 1996-2003 was 0.56 mSv, while in China, average annual effective dose for the years 1996-2000 was 1.18 mSv. In Bosnia and Herzegovina, average annual effective dose for the years 2004-2008 was 3.4 mSv, while in USA, average annual effective dose for the years 2000-2002 was 5.36 mSv. Therefore the average annual occupational exposure in Bangladesh is largely within the ranges of exposure situations that are found in other countries.

Considering the global condition, the worldwide average effective dose for monitored workers is 1.50 mSv during 1995-1999 and 2000-2002 [21]. The results from this work show that for the years 2010-2014, the average annual effective dose for monitored workers was 1.40 mSv. Therefore the average annual effective dose for industrial radiography workers in Bangladesh is higher than the corresponding values in Tanzania, Greece, Poland, Australia, UK and lower than in Bosnia and Herzegovina, USA and Canada. The average annual effective dose for industrial radiography workers in Bangladesh is comparable to the corresponding values in China, Brazil, Germany and India [30, 20]. It is to be noted that the doses for these countries correspond to different time periods. The variations can be accounted for by the differences in the workloads of practices, the state of the technology or the understanding level on radiation protection.

3.2. Individual and collective dose distribution ratio

The individual dose distribution ratios for the period 2010-2014 were presented in Table 2. It is seen that very few individuals were exposed to doses exceeding 10 and 15 mSv. Furthermore, less than 3 % of the monitored workers received doses above 10 mSv. Table 3 presents the results of the collective dose distribution ratio for the period 2010-2014.

Table 2: The individual dose distribution ratio for the period 2010-2014.

Annual individual dose exceeding (mSv)	**Individual dose distribution ratio**				
	2010	**2011**	**2012**	**2013**	**2014**
1	0.208	0.167	0.232	0.256	0.307
5	0.069	0.071	0.054	0.060	0.069
10	0.027	0.024	0.023	0.030	0.015
15	0.014	0.012	0.023	0.022	0.00

Table 3: Collective dose distribution ratio for the period 2010-2014.

Annual individual dose exceeding (mSv)	**Collective dose distribution ratio**				
	2010	**2011**	**2012**	**2013**	**2014**
1	0.629	0.701	0.688	0.718	0.667
5	0.522	0.594	0.583	0.605	0.425
10	0.363	0.381	0.492	0.510	0.151
15	0.251	0.231	0.492	0.464	0.00

Table 4: Comparison of annual average effective dose of monitored and exposed workers with other countries.

Country	Annual average effective dose (mSv)			
	Period	Monitored Worker	Exposed Worker	Reference
Tanzania	1996-2010	0.59	-	MUHOGORA, W. E. et al [26]
Greece	1996-2003	0.56	-	Economides, S. et al [27]
Turkey	1995-1999	0.30	-	Gunduz, H. et al [28]
	2003	1.35	-	Zeyrek, C.T. et al [29]
China	1986-1990	1.92	-	TIAN, Y. et al [30]
	1991-1995	1.43	-	
	1996-2000	1.18	-	
Bosnia	1999-2003	3.0	5.8	BASIC, B. et al [31]
And Herzego-vina	2004-2008	3.4	4.1	
Poland	1999	0.80	-	KOCZYNSKI, A. et al [25]
	2011	0.48	-	WASEK, M. et al [32]
USA	1995-1999	4.13	5.51	UNSCEAR 2008 [21]
	2000-2002	5.36	6.40	
Argentina	1990-1994	0.83	2.90	UNSCEAR 2000 [20]
Australia	1990-1994	0.19	0.46	UNSCEAR 2000 [20]
Brazil	1990-1994	1.40	3.13	UNSCEAR 2000 [20]
Bulgaria	1990-1994	0.87	1.63	UNSCEAR 2000 [20]
Canada	1990-1994	3.39	5.82	UNSCEAR 2000 [20]
Germany	1990-1994	1.41	4.29	UNSCEAR 2000 [20]
India	1990-1994	1.84	3.49	UNSCEAR 2000 [20]
Japan	1990-1994	0.83	2.57	UNSCEAR 2000 [20]
UK	1990-1994	0.76	1.55	UNSCEAR 2000 [20]
Bangladesh	2010-2014	1.40	2.43	This study
Worldwide average	1995-1999	1.50	-	UNSCEAR 2008 [21]
	2000-2002	1.50	-	

4. CONCLUSION

The average annual effective dose is comparable to the worldwide average annual effective dose as quoted in the literature. Even though majority of workers received very low doses, but a very few workers received doses above annual average dose limit. Therefore, a close monitoring and control of the activities of this group of workers must be ensured. The following may be some of the reasons for high doses in any industrial radiography institution.

(1) Employ of workers who are not qualified or trained. Such workers may not know the implication of exposing themselves to unnecessary high radiation doses.

(2) Inadequate performance of radiation generating equipments due to ageing and lack of maintenance.

(3) Insufficient number of workers in the different institutions leading to workers high workload.

From this observation, it can be concluded that courses in radiation protection particularly the safe operation of the radiation generating equipments and radioactive sources are strongly recommended to those workers who have lack of proper training. Finally, workers should pay more attention to radiation protection procedures and guidelines in every exposure to keep the doses below the annual average permissible limit rather than maximum allowable dose in a year.

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