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IMPROVEMENT IN RADIATION PROTECTION INFRASTRUCTURE FOR X-RAY FACILITIES IN BANGLADESH: THE ROLE OF THE EXECUTIVE REGULATORY AUTHORITY

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ABSTRACT

The national regulatory body in the state regulates the source of ionizing radiation, to optimize exposure for occupational radiation workers and public. The Bangladesh Atomic Energy Regulatory Authority covers all radiological regulatory aspects of ionizing radiation, such as diagnostic X-ray facilities for all practices and intervention requirements. The study presents an assessment and analyses the degree of technical radiation protection requirements and the status of improvement in the national regulatory standards for 230 different facilities in the four particular districts in Bangladesh. The methods used included comprehensive on-site inspections, visual assessments of equipment, operational observations, staff interviews, and technical evaluations. Safety system tests were conducted, and compliance records, licensing, and training programs were reviewed. The main objective is to ensure all the regulatory requirements are being fulfilled by analyzing data on radiation protection matters. In the cases of public and radiation workers, approximately 77% and 56% of dose rates in the examined facilities, respectively, were following the radiological protection technical regulation. However, significant progress has been observed in the facilities in the last few years since the authority initiated the regulatory program.

Keywords: Ionizing Radiation, X-ray Facility, Regulatory Authority, Radiation Protection, Occupational Worker.

1. INTRODUCTION

Radiation may have a significant impact on health and disease, possibly with proper use and prevention of misuse or overuse. It has many beneficial applications, but, as in every single activity of human life, when risks are associated with its use, specific actions need to be put in place to protect the people and environment. Although ionizing radiation has many benefits, it can also be detrimental (1). It can come from various sources, including cosmic rays and natural radionuclides in air, food, and water (2). The rationale for using radiation for diagnosis and treatment is developing, and hence the need that this practice be promoted and perfected (3). Protection from radiation risks needs to be improved (4). Therefore, appropriate justification is needed before using radiation.

The Basic Safety Standard (BSS 115) of International Atomic Energy Agency (IAEA) has outlined basic steps for creating a legislative and regulatory framework to guarantee a secure and safe working environment in radiation installations (5). First of all, BSS 115 categorizes the radiation exposure into the three categories such as occupational, medical and public exposures. Occupational exposure is defined as the exposure that is incurred while at work and mostly as a result of work. The public exposures include all other exposures, while the medical exposures, which are mostly exposures of patients, are obtained during diagnosis or treatment.

Moreover, this medical exposure is the largest man-made source of radiation exposure, accounting for more than 95% of total radiation exposure (6). According to IAEA and national standard, the requirements of fundamental radiation protection principle are desired to be followed during working with any sort of radioactive materials or radiation generating equipment (such as X-ray machines, CT scanners, Dental, Mammography, C-arms etc.) (7).

In order to reduce radiation destructive impacts, the International Committee on Radiological Protection (ICRP) developed dose limits for usage in the workplace and by the general public in 1960. Nevertheless, there is still no exposure limit for patients; instead, advisory levels are offered for them (8). Therefore, it is very important to know about radiation mechanisms, the dose from regularly used radiation generating equipment, the magnitude or limit, and type of risks (9,10). Generally, society accepts radiation risk on the conditional basis as benefit to be gained from the use of radiation generating equipment or radioactive sources. However, the risks should be limited and complied against the application of radiation safety standards developed by national and international organizations (11).

In Bangladesh, radiological diagnostic facilities having radiation generating X-ray units are consistently increasing day by day from city to rural areas, for establishing the public health demand. It has been determined that in order to ensure effective, efficient, and uniform regulatory control in medical X-ray equipment and installations, the radiation protection infrastructure of every X-ray unit in the nation needs to be specifically analyzed. Since the late 1990s, Bangladesh has prioritized radiation safety and protection. The national regulatory body has implemented a program to evaluate the infrastructure by conducting regular inspections and radiation surveys of all radiation-generating machinery. The objective is to improve the regulatory framework, update the inventory of equipment, and enhance awareness about radiation safety among stakeholders. The situation gradually started improving and regulatory inspections were performed from time to time in order to update the inventory and make the concerned people alert towards the radiation safety, which has been reflected in the post regulated scenarios of the radiation protection infrastructure of the facilities.

In this report some inspections were carried out to collect and investigate the regulatory data on such radiation generating equipment in four different districts in Bangladesh (Feni, Jhalokati, Rajshahi, and Cox`s Bazar) as a part of the regulatory program. This study's outcomes are expected to guide future regulatory efforts, helping to strengthen radiation safety and protection infrastructure in the surveyed districts and potentially across the entire country.

2. STATUS OF RADIATION SAFETY AND PROTECTION INFRASTRUCTURE DEVELOPMENT

2.1 Legislative framework and international legal instruments

People have the fundamental right to get health treatment, and the government shall regard the improvement of public health as among its primary duties, as stated in the constitution of Bangladesh. In the 1990s, the Bangladesh Atomic Energy Commission (BAEC) took the initiative to develop a legal framework for controlling radiation-related activities. On the basis of this effort Bangladesh government promulgated Nuclear Safety and Radiation Control (NSRC) act in 1993 and the corresponding NSRC rules in 1997 where the basic radiation safety requirements of BSS 115 have been incorporated (12,13). For betterment of peaceful atomic activity and to ensure nuclear and radiation safety in a superior way as well as to establish an independent regulatory authority, named as Bangladesh Atomic Energy Regulatory Authority (BAERA) (11). The nuclear and radiation safety legislation and regulation are shown in Fig. 1 in a hierarchical order. BAER Act-2012 is the comprehensive legal framework for the regulation and monitoring of peaceful applications of atomic energy and radiation, which covers the issues of safety and radiation protection, environmental protection, control of the operation, emergency preparedness, and response, transport of nuclear and radioactive material etc. It can be mentioned here that the 'NSRC Act-1993' is repealed now, as BAER Act-2012 is promulgated. Bangladesh does not have a distinct legislation pertaining to radiation safety aside from these Acts.

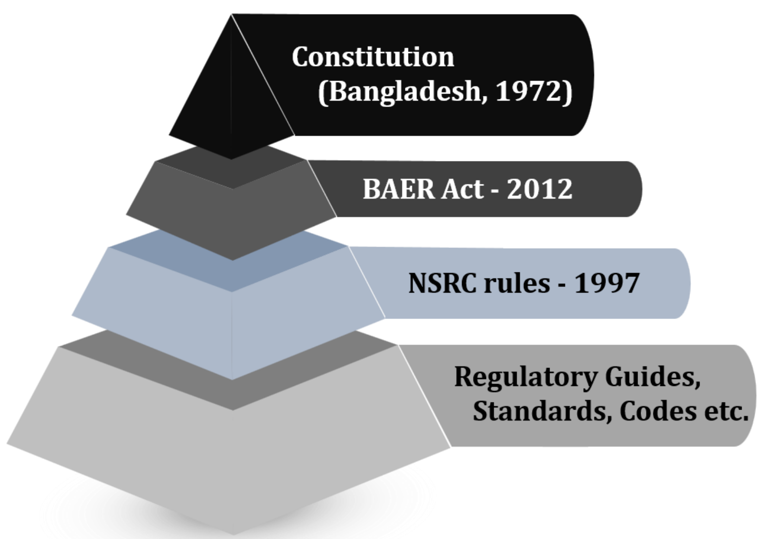


Fig. 1 Hierarchy of legislative framework for radiation safety

2.2 Regulatory framework

The regulatory framework is based on the BAER Act-2012 and the subordinate legislation i.e. bylaw-the NSRC rules-1997, which is still enforced (13). As shown in Fig. 1, radiation safety regulations, safety guides, standards, and codes for design, construction, inspections, licensing reviews, and enforcement activities are yet to be developed. Establishment of the regulatory authority, office premises, constitution, tenure of chairman and members, and responsibilities and functions of the authority is stated in Section 4, 5, 6, 7, and 11 of the BAER Act-2012. The prime responsibility of the regulatory authority is to regulate the radiation safety through authorization, inspection, and enforcement under the provision of Section 11 of the BAER Act-2012 and the nuclear safety and radiation control (NSRC) rules-1997. Within the existing structure of the government, as shown in Fig. 2, BAERA operates as an autonomous body under the MoST. BAERA has five divisions. Among them, the nuclear safety, security & safeguard division is responsible for safety of nuclear activities while the radiation, transport & waste safety division is overseeing the safety of nuclear and radiological activities. The decision-making body of the regulatory authority consists of four members and a chairman. The chairman is the chief executive who works under the secretary and minister of the Ministry of Science and Technology (MoST). To create any regulatory documents such as regulations, rules, standards, guides, codes, etc., the regulatory authority has to take the proper initiative following the BAER Act-2012 and BAERA's administrative MoST is the responsible organization to approve them.

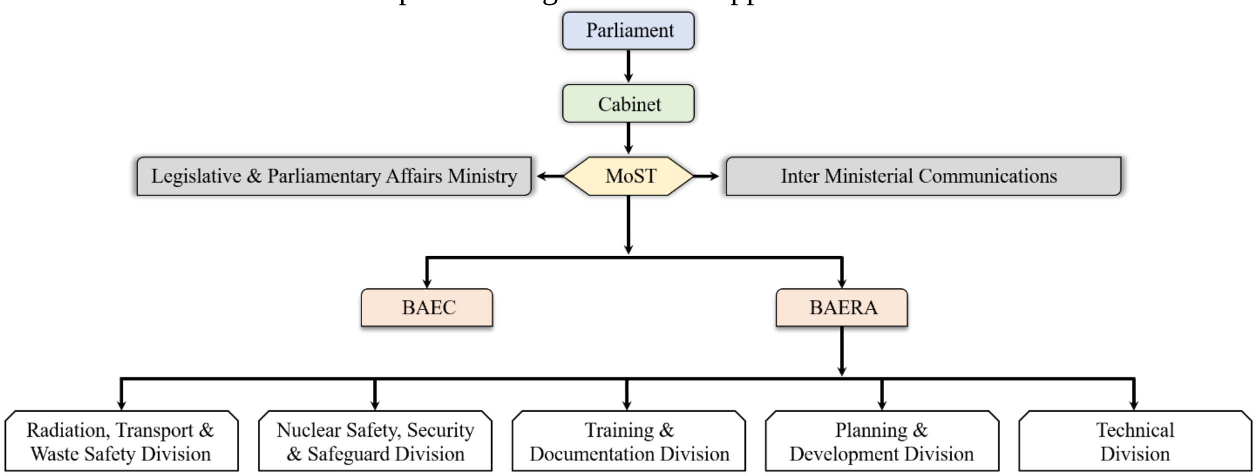


Fig. 2 Structure of national framework of regulatory for radiation safety

If a new Act/law is to be developed or the amendment of BAER Act-2012 or NSRC rules-1997 is required, it will go to the concerned law ministry, cabinet, and then to the parliament for final approval. To acquire a license, the licensee should apply to the regulatory authority in filling out all prescribed forms by the regulatory requirements.

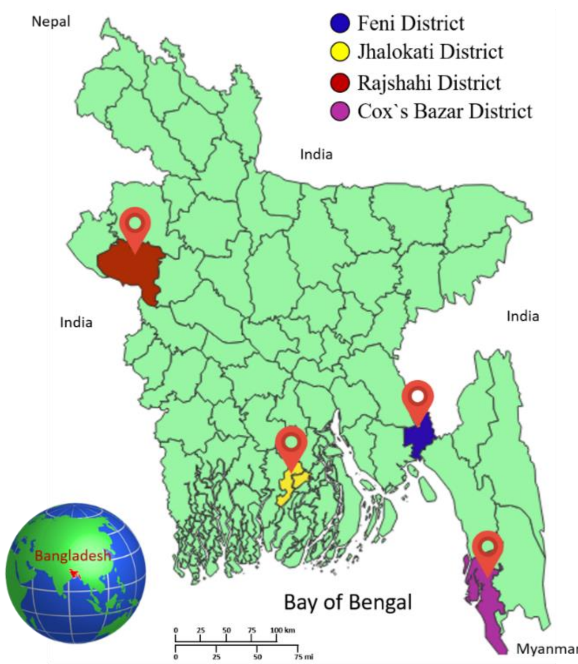
2.3 Regulatory body inspection and responsibilities

The inspection checklist is one of the most crucial inspection tools for the regulatory body to properly conduct the inspection procedure. The prime activity of the regulatory body is the so-called planned inspections. The inspection may take place either announced or unannounced. Unannounced inspections force the regulatory agency to investigate the facility's actual condition. This makes this kind of inspection the preferable one over the others. The other type of inspection is the announced inspection, which enables the inspectors to actively interview users or RCOs (Radiation Control Officers) and cover a wide range of topics with them. For computed tomography (CT), interventional radiology (IR), fluoroscopy, and mammography X-ray facilities, the recommended minimum range of inspection frequencies is 3 years, but the corresponding number for conventional X-ray is 5 years (14,15). The ability to regularly apply for the quality control program, as outlined in the international guideline; the positioning of the X-ray machine and the layout of the X-ray room with regard to occupancy and neighboring room. The inspector should choose radiation measurement instruments at random, such as portable survey equipment or stationary monitoring equipment, and assess them to ensure their effectiveness (15).

The following items will be examined by the regulator: (i) The managing organization's users are equipped with a system to guarantee that medical exposures are covered by an approved method and handled by occupational radiation workers in accordance with the ALARA concept (as low as reasonably achievable). (ii) The duty of protecting patients was delegated in a way that is appropriate for a trained medical expert, such as a radiologist. (iii) The calibration of the user equipment, such as clinical dosimetry, imaging tools, and quality control, was created for a skilled specialist, like a medical physicist. (iv) All radiation workers possess valid credentials and enough training in radiation protection and legal requirements. (v) The absorbed dose provided to the patient must be optimized, and a program for quality control test procedures for X-ray machines, including dose measurements, must be frequently carried out at the facility (15, 16).

3. METHODOLOGY

A comprehensive inspection/re-inspection was carried out and a detail radiation safety assessment has been performed in the 230 private and government diagnostic facilities containing with X-ray units, which are located in at four different districts in Bangladesh. For this current investigation, we choose Feni (South-eastern), Jhalokati (Southern), Rajshahi (Mid-western), and Cox`s Bazar (South-eastern) district in Bangladesh. The selection of the specific districts for this study based on a combination of factors aimed at providing a representative assessment of radiation protection standards across diverse regions in Bangladesh.



The above map shows the locations of the medical or diagnostic facilities in Bangladesh where the inspections and re-inspections were ethically performed.

3.1 Inspection parameters and instruments

This study used a quantitative, non-experimental, descriptive method to gather data on radiation protection and safety measures. At first, a full fledge regulatory inspection checklist/questionnaire was prepared including various regulatory information from the construction design and layout of the X-ray facility for the field survey. The checklist consisted of a combination of 17 closed and open-ended regulatory requirements. The dimensions of the room, including its length and width, wall thickness, door and control panel shielding condition, and thickness, were used to design the layout of the radiation-generating X-ray machine room. The layout also included the locations of the X-ray machine, chest stand, control panel, dark room, computed radiography room, and surrounding areas.

In this inspection the radiation exposure levels were measured using two portable Geiger Muller (GM) and scintillation micro-Roentgen survey meter (LUDLUM, Model: 3 and 26) and pressurized ion-chamber (LUDLUM, Model: 9DP) type of radiation dose rate meters. For GM or scintillation based micro-Roentgen survey meter, the reading in μR/h were converted to μSv/h using the conversion factor (from the definition of Roentgen). The dose rate was then assessed at various points within the X-ray room, including the control panel (CP), entrance door (ED), dark room (DR), computed radiography (CR) room, as well as any extra doors. Year of putting in of the X-ray machine, type of the X-ray machine, including model, serial number, manufacturer, maximum tube potential (kV), maximum tube current (mA), light beam diaphragm, and total tube filtration, as well as the number of radiation workers involved, including the technologist and technician, were also noted during the inspection. The investigation found that personal monitoring data are kept and retained, adequate personal protective equipment is available, and occupational worker wear personal dosimetry devices on the proper part of their bodies. It was determined whether or not the persons around and the general public were exposed to radiation by observing the areas around the X-ray room. Also, it is evaluated to determine whether facility staff members are abiding by the rules and effectively carrying out their normal duties. The existence of a radiation sign and a warning signal at the X-ray room's appearance point was also evaluated.

An inspection report was created after compiling a variety of regulatory data, and it contained recommendations for enhancing the radiation safety status. Subsequently, a re-inspection was carried out to determine whether any changes had been made to the facilities with regard to the radiation protection issue. In this study, findings also include an analysis of the current regulatory data in comparison to previous inspection data which have been presented in the different tables.

3.2 Statistical analysis

The regulatory data where cumulatively collected and analyzed using tables, charts, and graphs to determine the safety culture that deal with radiation in the above X-ray facilities where the equipment and the checklist was used. All the results are reported as an arithmetic mean value and the spread of the data is given by standard error. Data were processed and visualized using Microsoft Excel (Microsoft Office 2019, Ver. 16.0.10730.20102) and OriginPro 2019b (OriginLab Corporation, Ver. 9.6.5.169).

4. RESULTS

The investigation was done for X-ray units and their corresponding radiation workers in the field of medical or diagnostic radiography. A total of 230 facilities out of 350 were analyzed in four different districts in several region of Bangladesh, where almost 281 radiation generating machines were carefully inspected. Among all the machines, the most fixed type X-ray machines were found. In Table 1, the number of monitored medical or diagnostic facilities in the corresponding year is depicted, and an increasing tendency is observed in the number of facilities as well as X-ray units, whether they are authorized or not.

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Table 1. Comparison of radiological infrastructure before and after regulatory inspections across four districts in Bangladesh

District`s Name	Location in Bangladesh	Total Facility, *N*		Authorized X-ray Facility, *N* (%)		Duration of Both Inspection (New Licenced), *N* (%)	Facility Not Licenced (At 2018), *N* (%)	New Issue (After Last Inspection), *N* (%)	Before 2023 Not Licenced, *N* (%)
		Before 2018	At 2022	Before 2018	At 2022				
Feni	South-eastern	43	77	35 (81%)	47 (61%)	12 (29%)	08 (19%)	06 (20%)	24 (80%)
Jhalokati	Southern	13	27	11 (85%)	16 (59%)	05 (31%)	02 (15%)	04 (36%)	07 (64%)
Rajshahi	Mid-western	14	58	12 (86%)	21 (36%)	08 (17%)	02 (14%)	06 (16%)	32 (84%)
Cox`s Bazar	South-eastern	30	68	22 (73%)	39 (57%)	17 (37%)	08 (27%)	07 (24%)	22 (76%)

Table 2. Summary of facility`s radiation-monitoring findings by dosage levels for public and occupational workers

District`s Name	Total Facility, *N*	Total Machin, *N*	X-ray Facility Considering Dose Level for Public				X-ray Facility Considering Dose Level for Worker			
			Normal Dose Rate (≤5 µSv/h)		Unsatisfactory Dose Rate (>5 µSv/h)		Normal Dose Rate (≤5 µSv/h)		Unsatisfactory Dose Rate (>5 µSv/h)	
			N (%)	Mean ± SE	*N* (%)	Mean ± SE	*N* (%)	Mean ± SE	*N* (%)	Mean ± SE
Feni	77	93	68 (88%)	(73 ± 7) %	9 (12%)	(27 ± 7) %	56 (73%)	(56 ± 10) %	21 (27%)	(44 ± 10) %
Jhalokati	27	30	16 (59%)		11 (41%)		16 (59%)		11 (41%)	
Rajshahi	58	69	41 (71%)		17 (29%)		18 (31%)		40 (69%)	
Cox`s Bazar	68	89	50 (74%)		18 (26%)		42 (62%)		26 (38%)	

**N* is the number of counts, '%' is the percentage, and 'SE' is the standard error.

Table 1 illustrates the impact of regulatory interventions on facility licensing and compliance over time. Less than half of all radiological facilities for each district were found in the areas where re-inspection was performed. After statistically normalizing the data, the majority of the column in Table 1 shows the value of the count and percentage. During the midterm period of both inspections, more than 73% to 86% of the registered (data from the previous inspection done in 2017-2018) radiological facilities in four distinct districts in Bangladesh were authorized by the competent regulatory authority. On the other hand, we discovered that, 6–10 months after the last surveys, which were conducted in 2022, almost 36% to 61% of facilities had already received their authorizations. Actually, the total number of X-ray facilities is increasing from 100 to 230, which is more than double the number reported in both inspections. Numerous radiological facilities have attempted to obtain licenses following the inspections in 2017–2018 and 2022; in this instance, we calculated that 17% to 37% and 16% to 36% of new facilities, respectively, had applied for authorization. The results indicate a significant issue regarding unauthorized radiological facilities operating without regulatory approval. Specifically, we found that between 14% to 27% of the assessed facilities had not yet submitted licensing applications, highlighting the presence of facilities potentially operating without regulatory oversight. In actuality, the majority of unlicensed radiological facility operators were ignorant of regulatory authorization because of a lack of knowledge or purposefully postponed obtaining licenses. This situation underscores the need for continued and enhanced regulatory efforts to ensure all radiological facilities comply with safety standards and obtain the necessary approvals to operate legally.

Table 2 demonstrates the facilities (count and percentage) in accordance with their radiation-monitoring findings. Regarding the dosage levels, we separated the public dose (maximum value) for radiation at the X-ray room's entrance door or other external areas and the dose (maximum value) for occupational workers who are in close proximity to radiation-generating equipment, which is a major concern from the regulatory point of view. We also distinguished the radiation dose level as normal (less than equal 5 µSv/hr for public) and unsatisfactory because the dose rate exceeded the regulatory limit (greater than 5 µSv/hr for occupational worker) and the shielding in the entrance door and control panel was inadequate. This level is based on the graded approach taken by regulatory bodies, which aim to limit radiation exposure to a level that is considered negligible in terms of health risks over extended periods of exposure. We found that the average normal dose rate for public is about (73 ± 7) % facilities of the four districts while (27 ± 7) % facilities hold the average unsatisfactory dose rate. Where, the Feni and Jhalokati district are engendered the maximum average dose rate for public with normal and unsatisfactory cases, respectively. Furthermore, we discovered that the average normal dose rate for occupational workers in the four districts is approximately (56 ± 10) %, while the average unsatisfactory dose rate is (44 ± 10) %. Thus, the Feni and Rajshahi districts have the highest average daily dose rates for occupational workers with normal and unsatisfactory cases, respectively.

We measured and analyzed the dose rate at different location and recorded the instant highest radiation exposure dose rate in the medical or diagnostic facility. The histograms of maximum values of measured dose rate for both, public and occupational worker with corresponding number of facilities are presented in Fig. 3. The peak of the histogram shifted in the right direction with dose rate (Fig. 3 (A-D)), which can be clearly shown by comparing Fig. 3(A) and Fig. 3(B). The histograms were fitted by the well-known lognormal distribution (17,18). The probability density function for dose rate is as follows:

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$$f(D_r) = \frac{1}{D_r}\frac{1}{\sigma\sqrt{2\pi}}\exp\left[-\frac{\{\ln(D_r)-\mu\}^2}{2\sigma^2}\right] \quad (1)$$

where, D_r is the value of the dose rate for each facility, μ is mean and σ is standard deviation. The values of μ and σ were obtained from the fitted curve. The lognormal distribution of the given equation is a skew distribution in which the mean is usually larger than the mode. It is typically used in the description of the distribution along with other phenomena having large data range. So, the lognormal distribution is important in this study because it accurately models the skewed, non-negative, and multiplicative nature of radiation dose rate data, providing a more realistic representation and better statistical handling of the data.

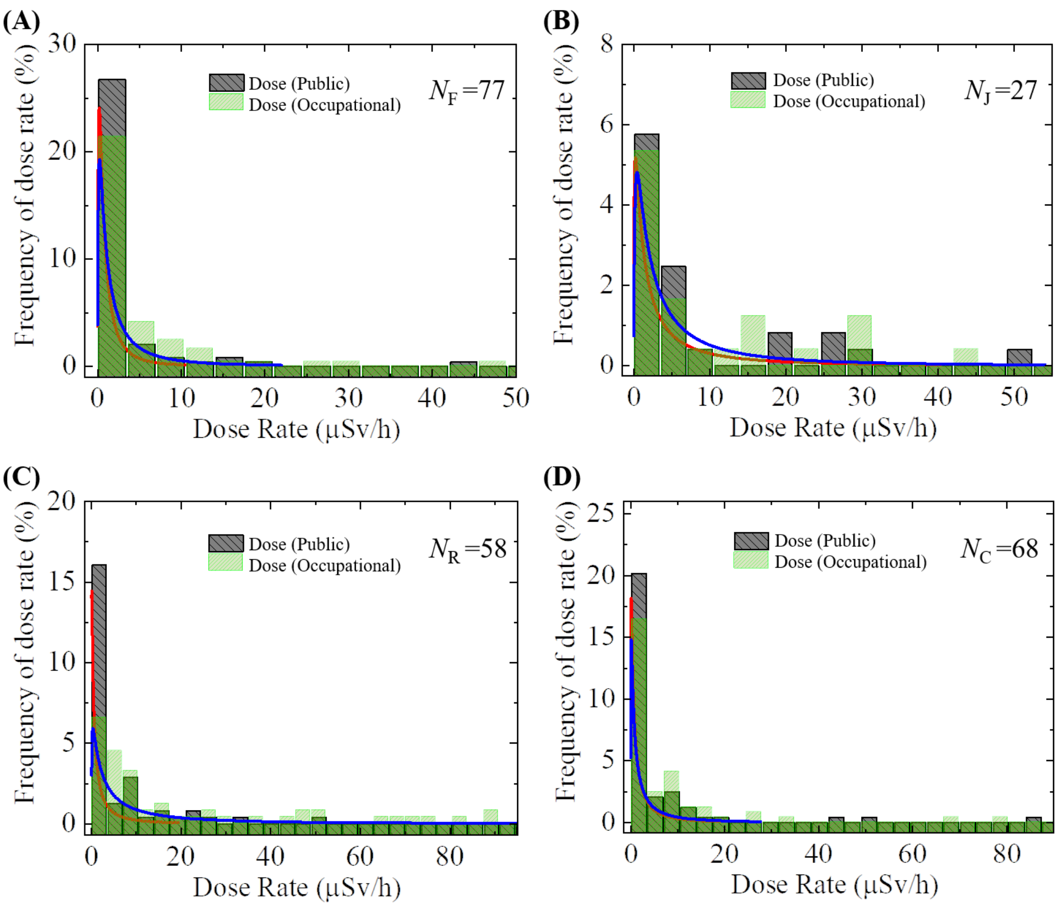

Fig. 3 Dose rate distribution histograms for public (■) and occupational workers (■) of all the inspected facilities in the four districts. (A) Feni (B) Jhalokati (C) Rajshahi, and (D) Cox`s Bazar. *N* indicates the number of facilities in the four distinguished districts, where $N_F$, $N_J$, $N_R$, and $N_C$ refer the total facility number investigated in Feni, Jhalokati, Rajshahi, and Cox`s Bazar, respectively. The best fitting theoretical curves (blue and red lines) for measured dose rate of both, public and occupational worker corresponding to Eq (1).

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From the fitted curves (blue and red solid lines), we got the values of μ and σ. Using these values, it was calculated the mean values of dose rate for normal and unsatisfactory radiation exposure of the distribution. As we mentioned above, the mean values with standard error of radiation exposure from the X-ray generating equipment for district wise medical or diagnostic facilities are shown in Fig. 4. For both, public and occupation worker`s mean dose date is illustrated in Fig. 4(A) and Fig.4(B), respectively. We investigated that the normal dose rate for both public and occupational workers of all districts are very much similar to each other. The mean radiation dose rate for public at Cox`s Bazar is higher than other three districts. Again, we measured that the mean radiation dose rate for occupational worker at Rajshahi district more than others. With regards to the dose levels, the patient entrance door and waiting place areas are major source of concern from the regulatory perspective. All the values of mean dose rate with standard error for both public and radiation workers of all facilities in each district are provided in SM1.

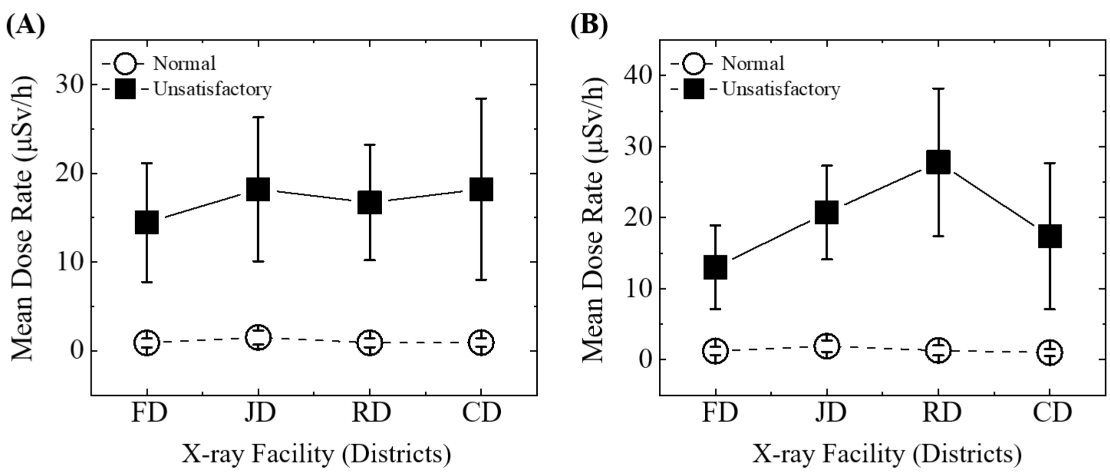

Fig. 4 Mean dose rate for normal (**O**) and unsatisfactory (■) radiation exposure from all the corresponding inspected facilities in the four districts. (A) Public dose record (B) Occupational worker`s dose record. FD, JD, RD, and CD indicate the district of Feni, Jhalokati, Rajshahi, and Cox`s Bazar, respectively.

Fig. 5 shows the assessment of radiation safety equipment available in all the observed facilities of the four districts. According to the figure, some progress has been made in respect to the availability of accessories especially lead apron, lead thyroid collar, and lead equivalent eye goggles in case of radiation protective equipment, lead hand gloves are not available in any of the facilities. As per national act or regulations and international safety standards these tools are obligatory for the medical and diagnostic practices.

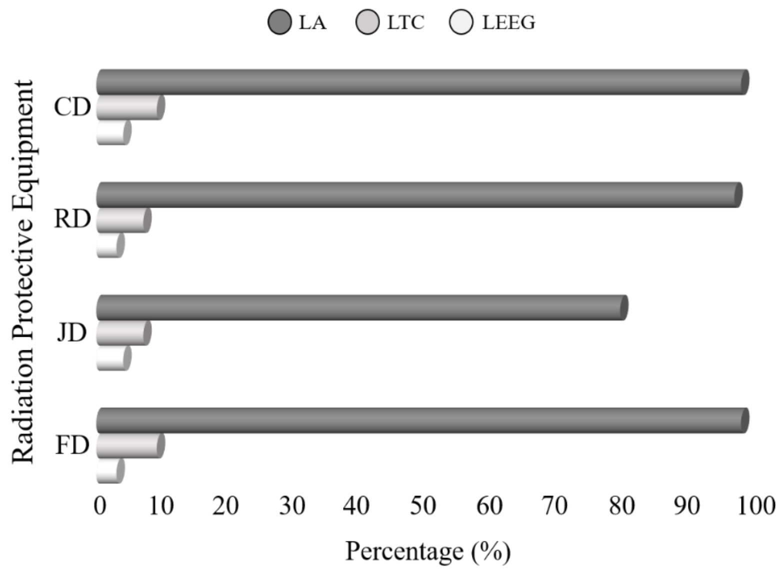

Fig. 5 Assessment of radiation protective equipment in the four districts (FD, JD, RD, and CD indicate the district of Feni, Jhalokati, Rajshahi, and Cox`s Bazar, respectively). LA, LTC, and LEEG indicate Lead Apron, Lead Thyroid Collar, and Lead Equivalent Eye Goggles, respectively. We calculated that almost 96% of facilities, excluding Jhalokati district, have the lead apron, whether they use it or not. However, the findings in the case of lead thyroid collar and lead equivalent eye goggles availability are diametrically opposed. All the data that belongs to radiation safety equipment are provided in SM2.

Now, Fig. 6 illustrates the assessment of radiation shielding availability in all the observed facilities of the four districts. Among the shielding systems for radiation protection, the availability of entrance door shielding, control panel: lead equivalent barriers/mobile lead shields, window shielding, etc. are carefully evaluated. So far, we found that most of the facilities in the four districts have a good percentage of entrance door shielding availability, with Feni showing the highest recognition. However, the medical or diagnostic facilities in the Jhalokati district have a very low number of the entrance door shielding for radiation protection.

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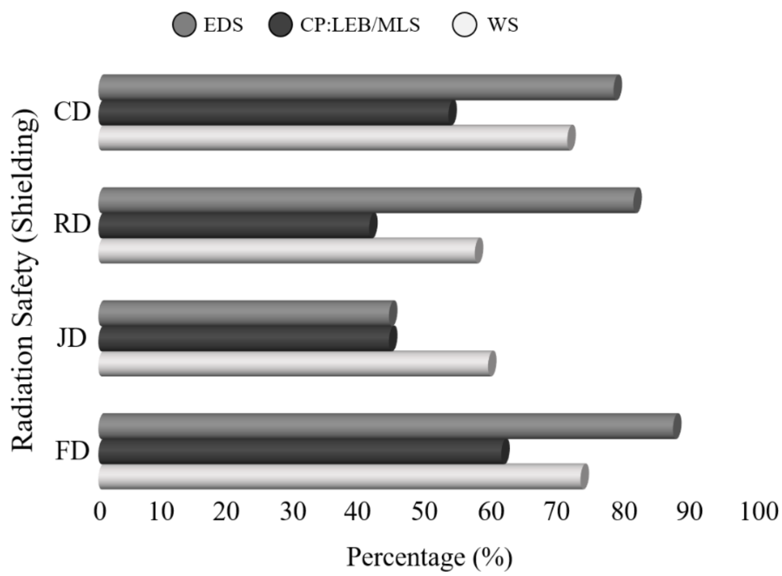

Fig. 6 Radiation shielding assessment in the four districts (FD, JD, RD, and CD indicate the district of Feni, Jhalokati, Rajshahi, and Cox`s Bazar, respectively). EDS, CP: LEB/MILS, and WS indicate Entrance Door Shielding, Control Panel: Lead Equivalent Barrier/Mobile Lead Shield, and Window Shielding, respectively.

We also observed that the shielding scheme for the control panel and window of the X-ray units for radiation safety, the facilities in Feni districts carried higher numbers than others. All the data related to the shielding system for radiation protection are provided in SM2.

In the present study, the availability of some essential radiation safety parameters, such as X-ray room size, warning signal, and wall condition, is inspected. Fig. 7 demonstrates the assessment of the radiation safety parameters. Most of the facilities in all the targeted districts contained a very low number of standard-sized rooms (225 ft^2). Approximately, 75% facilities are below standard, indicating that a significant improvement is required to meet regulatory demands (19). Almost 90% of all X-ray rooms feature a 10-inch brick wall that achieves regulatory requirements and effectually protects against radiation. In Fig. 7, a significant advance is observed in area classification by putting up radiation warning signs, which was not convincing at all before the start of the regulatory process. All the data related to the radiation safety parameters are provided in SM3.

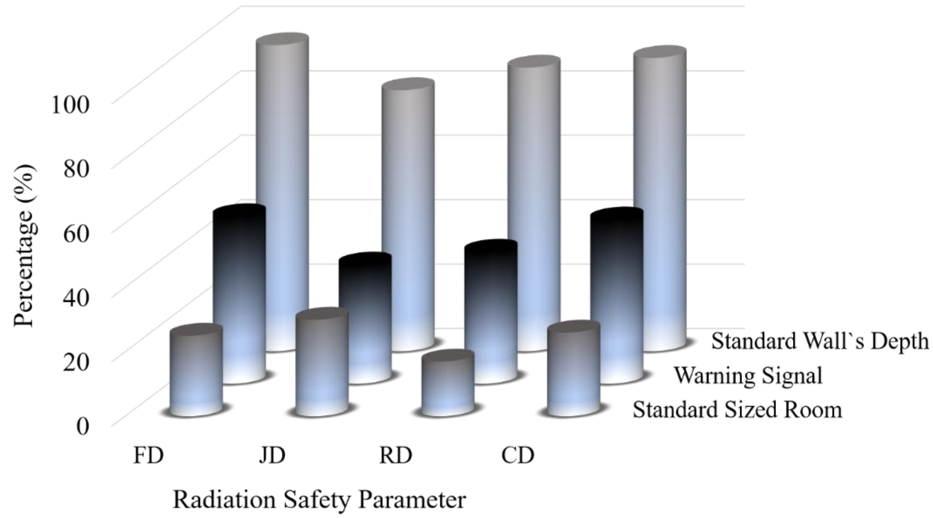

Fig. 7 Indispensable parameters for radiation safety in the four districts (FD, JD, RD, and CD indicate the district of Feni, Jhalokati, Rajshahi, and Cox`s Bazar, respectively).

The status of the radiation monitoring dosimeter and individuals with knowledge of radiation control activities are shown in Fig. 8. TLD badge is a radiation dose measuring device, that enables us to know whether we are working within the safe dose limits prescribed in NSRC rules-1997. We found that about 52 facilities had the TLD badge out of 77 in the Feni district, which was the maximum percentage (33%) of availability of all the other three districts, where Rajshahi exhibits a very low quantity, as shown in Fig. 8(A).

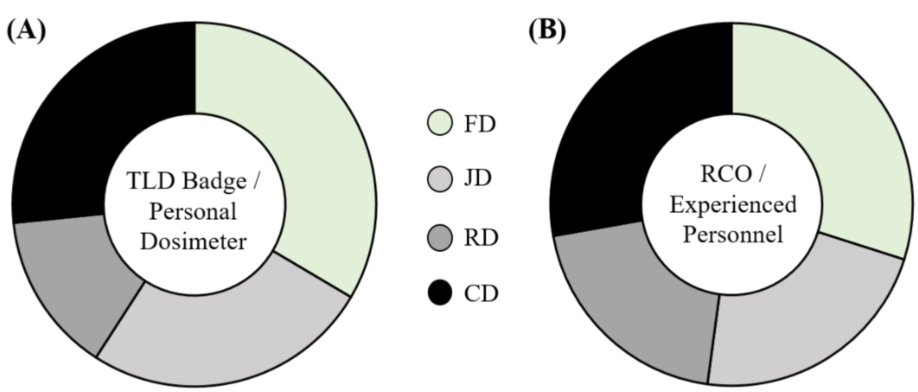

Fig. 8 Status of radiation monitoring equipment and personnel in the four districts (FD, JD, RD, and CD indicate the district of Feni, Jhalokati, Rajshahi, and Cox`s Bazar, respectively). (A) Availability of thermoluminescent dosimeter badge (TLD) or any personal radiation dosimeter (B) Availability of radiation controlling personnel.

We also calculated the availability of the radiation control officer (RCO), who is the central point of reference for radiation protection matters within a medical or diagnostic facility (20), as shown in Fig. 8(B). Feni and Cox`s Bazar districts accounted for 70% and 65% of the availability of such experienced radiation control personnel, respectively. All the data related to the radiation dose storing equipment (TLD) and experienced executive personnel are provided in SM3.

5. DISCUSSIONS

More than 73% of the list of the examined facilities in the four districts were authorized by state`s regulatory authority and accepted based on the national regulations and matched with the standards regulations. The operator of each facility should be familiar with the guidance and documents related to the radiation protection program. The shielding design for the walls and the areas around the entrance to the X-ray room were found to be around 80%, except for Jhalokati district`s facilities. The shielding requirements for the operator console to prevent unnecessary radiation exposure were not sufficient for all facilities. In addition, other protective tool at each facility such as lead glass for window shielding are almost available. The lead apron holder was present in the majority of the facilities that were inspected, but it wasn't always used. Each facility's mobile X-ray machine storage and security were verified to be in good working order. It's critical to note that none of the facilities we inspected had gonad shields or leaded screens as protective barriers. Overall, the examined facilities show moderately good and sufficient shielding conditions based on radiation the NSRC rules-1997 and safety standards (13, 14, 21). In the present report indicated that about 55% of the inspected facilities except Rajshahi district do not have any personal radiation dosimeter such as a thermoluminescent dosimeter (TLD) and most of those facilities do not keep a record for the personal dosimeter reading at their facilities. Only 17-30% of the inspected facilities in the four districts have standard sized room for radiological operations. For the purpose of performing radiation safety and maintenance at those facilities, approximately 55% of the facilities under inspection have radiation control personnel on hand. The majority of technologists are trained through their professional work. For some of them, basic radiation protection training has been offered by the Bangladesh Atomic Energy Regulatory Authority (BAERA). Finally, more than 50% of the examined facilities do not have any warning sign or alarm warning light at their entrance to the room. Despite being present at certain sites, radiation-warning signs were not used by the bulk of the facilities. Following the previous inspections, the radiation technicians or operators in all X-ray facilities generally shown a good awareness of the fundamental guidelines and safety directives in the medical and diagnostic area. According to the data analysis, about one-third of the facilities meet the required radiological safety standards.

6. CONCERNS ON RADIATION PROTECTION AND RECOMMENDATIONS

The primary duty and responsibility of the regulatory body are to conduct inspections for nuclear and radiation-related activities, including the radiological facility in the state (15). According to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), 4.2 billion diagnostic radiographs are produced annually by the X-ray machines that are inspected globally, which makes the radiological survey essential for the inspection of diagnostic radiology equipment (22).

The majority (more than 95%) of the radiation dosage that humans are exposed to comes from medical exposures. Radiation protection is a crucial element of good medical practice. The three radiation protection principles of justification, optimization and dose limitation are enshrined in the IAEA Fundamental Safety Principles (SF-1) and apply to all medical and radiological facilities and activities that give rise to radiation risks (14, 23, 24). The foundations of radiation safety practice are an understanding of external radiation protection measures as well as technical aspects of operating the X-ray system. The three fundamentals of radiation safety to an operator include i.

time, ii. distance, and iii. shielding and dosimeter monitoring (21, 25). Radiation exposure can be accumulated over the time of exposure. The physician must improve his interventional skills, and the radiographer must verify the X-ray at the proper site and time without smudged images in order to reduce the usage time. Operators must maximize their distance from the X-ray source as radiation intensity follows the inverse square law: if an operator maintains a distance twice as far from the source as necessary, they can minimize their radiation exposure not to half but to one-fourth (21, 26). Shielding can be applied externally, personally, or both. The degree of lead equivalence in each form determines how much radiation protection it provides. A lead apron with or without shoulder coverings for breast shielding, lead glasses, thyroid protectors, radiation-reducing gloves, and caps are all examples of personal shielding. Attenuating 95–96% of the scatter radiation, the lead apron should be at least 0.35 mm thick (21, 27). The key principles of protection systems and fundamentals radiation safety for human exposure are summarized in the illustration, as shown in Fig. 9.

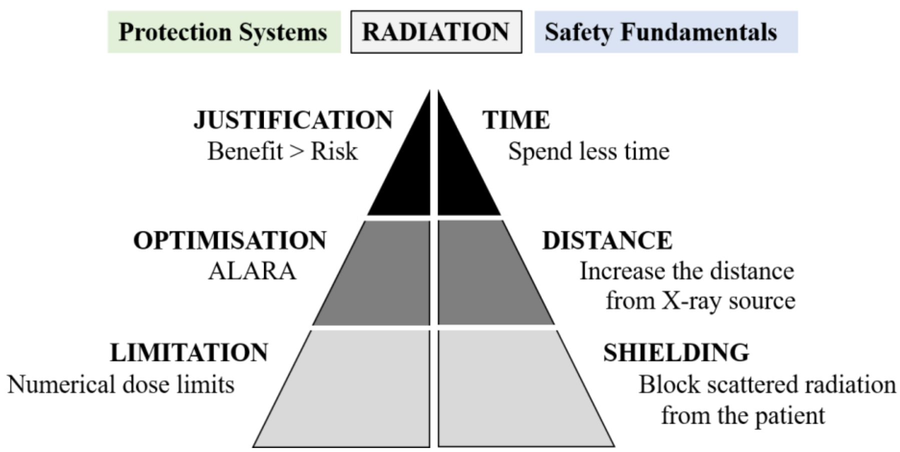

Fig. 9 Illustration of the systems of radiological protection and fundamental rules of radiation safety.

To maintain optimal diagnostic image quality with the least amount of risks and discomfort to patients, every diagnostic X-ray facility is required to have a basic quality assurance (QA) program in place. The executive authority should regularly review this program to evaluate the outcomes of each QA action. Also, it is advisable to identify and include in the quality control (QC) manual all of the various significant components of the monitoring and maintenance tasks.

The medical and diagnostic facilities, with assistance from the Ministry of Health or Directorate General of Health Services (DGHS), Bangladesh, should work with BAERA to ensure complete compliance. Following the complete implementation of the regulations governing radiation protection, a follow-up study should be conducted to evaluate regulatory compliance and the different stakeholders' (administrators, clinicians and other healthcare staff, and the public) awareness of radiation protection and safety. A study that will evaluate room design and the installation of equipment to meet required radiation safety standards is recommended. The provision of additional training opportunities for radiologists or technicians through RCO trainings and workshops run by BAERA should also be taken into account, so they can adequately comprehend the regulations.

7. LIMITATIONS

Out of a possible 350 facilities in the inspected districts, only 230 were visited by the BAERA regulators, making it impossible to confirm the veracity of all respondents' claims regarding the availability of tools and resources. The technologists or technicians could have been biased when reflecting on radiation safety and placing blame on management of the facility. More thorough investigation of the management of the facilities and the maintenance of X-ray generating equipment could be beneficial for future guidelines on the implementation of radiation safety in the radiological facilities.

8. SIGNIFICANCE OF THE RESULTS AND IMPLICATIONS FOR FUTURE WORK

The findings of this study highlight the progress and ongoing challenges in radiation protection within radiological facilities in Bangladesh. The significant reduction in leakage radiation dose rates demonstrates the effectiveness of regulatory inspections and the adoption of safe practices. However, the persistent gap in compliance with licensing requirements underscores the need for more stringent enforcement and greater awareness among stakeholders.

Future directions:

Future work should focus on several key areas to strengthen radiation safety further:

- **Regular inspections:** Increasing the frequency and thoroughness of inspections to ensure continuous compliance and address any emerging safety issues promptly.
- **Enhanced training programs:** Regular, mandatory training sessions for all personnel involved in radiological practices to reinforce the principles of radiation protection and ensure adherence to safety protocols.
- **Technological upgrades:** Investment in modern, safer radiological equipment with better shielding and automated safety features.
- **Public awareness campaigns:** Educating the general public about radiation safety to ensure community support and compliance with safety measures.
- **Policy development:** Revisiting and updating national policies to incorporate the latest international guidelines and best practices in radiation safety.

By addressing these areas, Bangladesh can significantly enhance its radiation safety infrastructure, ensuring the protection of both the public and radiation workers while maintaining the benefits of ionizing radiation in various fields.

9. CONCLUSION

Ionizing radiation, such as X-ray has many beneficial applications in medicine, diagnosis, research, etc. With the increased use of ionizing radiation, safe use policies and practices are required. The lower percentage of leakage radiation dose rate in the examined facilities in the current study indicates comprehension of the concept of justification. A solid understanding of the ALARA principle is indicated by the higher percentage of personnel who maintain the advised safe distance from the radiation generating machine to them. Together with the routine control and inspection carried out by the executive regulatory authority, radiation protection in this context should also be strengthened by ongoing training, educational procedures, and pertinent information. The majority of medical and diagnostic facilities are currently authorized by BAERA, however despite repeated reminders from the regulatory body to the stakeholders, compliance levels fall short of the standards for license renewal. The radiation safety conditions of the facilities were found to be below the level demanded by national and international standards at the beginning of regulatory functions. If the BAER Act-2012 and the NSRC rules-1997 are correctly put into practice, it will be able to enhance the radiation protection infrastructure in X-ray facilities in the future. These studies provide valuable insights and guidance to enhance radiation safety regulations, ultimately ensuring safer practices and better protection for both the public and occupational workers in medical and diagnostic environments.

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AVAILABILITY OF DATA AND MATERIALS

The datasets generated and/or analyzed during the current study are not publicly available because they contain materials from unpublished manuscripts but are available from the corresponding authors upon reasonable request.

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES:

Burgio, E., Piscitelli, P. and Migliore, L., (2018), Ionizing Radiation and Human Health: Reviewing Models of Exposure and Mechanisms of Cellular Damage. An Epigenetic Perspective, *Int. J. Environ. Res. Public. Health*, vol. 15(9):1971.

Chang, Y. J., Kim, A. N., Oh, I. S., Woo, N. S., Kim, H. K. and Kim, J. H., (2014) The Radiation Exposure of Radiographer Related to the Location in C-arm Fluoroscopy-guided Pain Interventions, *Korean J. Pain.* 27(2):162-167.

Chalkia, M., Arkoudis, N. A., Maragkoudakis, E., Rallis, S., Tremi, I., Georgakilas, A. G., Kouloulias, V., Efstathopoulos, E. and Platoni, K., (2022), The Role of Ionizing Radiation for Diagnosis and Treatment against COVID-19: Evidence and Considerations, *Cells*. 11(3), 467.

Crow, E. L. and Shimizu, Eds., K., (1987), *Lognormal Distributions: Theory and Applications* (1st ed.) New York: CRC Press.

Do, K. H., (2016), General Principles of Radiation Protection in Fields of Diagnostic Medical Exposure, *J. Korean Med. Sci*. 31(1):S6-S9.

Engel-Hills, P., (2006), Radiation protection in medical imaging, *Radiography* (London 1995), 12(2), 153-160.

Heidbuchel, H., Wittkampf, F. H., Vano, E., Ernst, S., Schilling, R., Picano, E., Mont, L., Jais, P., de Bono, J., Piorkowski, C., Saad, E. and Femenia, F., (2014), Practical ways to reduce radiation dose for patients and staff during device implantations and electrophysiological procedures, *EP Eur*. 16(7):946–964.

IAEA, (1996), *International Basic Safety Standards for Protection Against Ionizing Radiation and For The Safety of Radiation Sources*. Saf. Ser. No. 115, Vienna, Austria.

IAEA, (2001), *Radiological Protection of Patients in Diagnostic and Interventional Radiology, Nuclear Medicine and Radiotherapy*. Proceedings Series, Vienna, Austria.

IAEA, (2014), *Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards*. IAEA Safety Standards Series No. GSR Part 3, Vienna, Austria.

IAEA, (2004), *Regulatory Control of Radiation Sources*. IAEA Safety Standards Series No. GS-G-1.5, Vienna, Austria.

IAEA, (2014), *Diagnostic Radiology Physics: A Handbook for Teachers and Students.* Non-serial Publications, Vienna, Austria.

IAEA, (2018), *Establishing the Infrastructure for Radiation Safety*. IAEA Safety Standards Series No. SSG-44, Vienna, Austria.

IAEA, (2018), *Occupational Radiation Protection.* IAEA Safety Standards Series No. GSG-7, Vienna, Austria.

IAEA, (2006), *Fundamental Safety Principles*. IAEA Safety Standards Series No. SF-1, Vienna, Austria.

IAEA, (2018*), Radiation Protection and Safety in Medical Uses of Ionizing Radiation*. IAEA Safety Standards Series No. SSG-46, Vienna, Austria.

IARC Working Group on the Evaluation of Carcinogenic Risks to Humans and World Health Organization and International Agency for Research on Cancer, (2000), *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans.* Ionizing radiation. Part 1, X- and gamma (γ)-radiation, and neutrons, IARC 1999:75 Lyon, France.

ICRP, (1991), *1990 Recommendations of the International Commission on Radiological Protection*. Ann. ICRP, 21(1-3):1-201.

Khamtuikrua, C. and Suksompong, S., (2020) Awareness about radiation hazards and knowledge about radiation protection among healthcare personnel: A quaternary care academic center–based study, *SAGE Open Med.* 8:2050312120901733.

Kim, J. H., (2018), Three principles for radiation safety: time, distance, and shielding, *Korean J. Pain.* 31(3):145–146.

McColl, N., Auvinen, A., Kesminiene, A., Espina, C., Erdmann, F., de Vries, E., Greinert, R., Harrison, J. and Schüz, J., (2015), European Code against Cancer 4th Edition: Ionising and non-ionising radiation and cancer, *Cancer Epidemiol*. 39(1): S93–S100.

Reed, W. J. and Jorgensen, M., (2004), The Double Pareto-Lognormal Distribution—A New Parametric Model for Size Distributions, *Commun. Stat. - Theory Methods*, 33(8):1733–1753.

Republic of Bangladesh Government. Bangladesh Atomic Energy Regulatory Act 2012 No. 19 Bangladesh Gazette (2012).

Republic of Bangladesh Government. Nuclear Safety and Radiation Control Act 1993 No. 21. Bangladesh Gazette (1993).

Republic of Bangladesh Government. Nuclear Safety and Radiation Control Rules-1997 (SRO No. 205-Law/97). Bangladesh Gazette (1997).

Ryu, J. S., Baek, S. W., Jung, C. H., Cho, S. J., Jung, E. G., Kim, H. K. and Kim, J. H., (2013) The Survey about the Degree of Damage of Radiation-Protective Shields in Operation Room, *Korean J. Pain.* 26(2):142-147.

United Nation Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), (2021) *Sources Effects of Ionizing Radiation: Report to the General Assembly*, with Scientific Annexes; United Nation Publications, (A/76/46), 1.