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Assessment of Occupational Exposure to External Radiation among Workers at the Institute of Radiotherapy and Nuclear Medicine, Pakistan (2009-2016)

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ABSTRACT

Introduction: Assessment of occupational exposure to external radiation and the analysis of associated trends are imperative to observe changes that have taken place over time due to regulatory operations or technological advancements. Herein, we describe the occupational radiation exposure to workers employed in Nuclear Medicine (NM), Radiotherapy (RT), and Diagnostic Radiology (DR) departments at the Institute of Radiotherapy and Nuclear Medicine, Peshawar, Pakistan, and to evaluate the related trends during 2009-2016.

Materials and Methods: A retrospective analysis of the dose records of 4320 film dosimeters was performed during 2009-2016. The analyzed quantities included annual collective effective dose, annual average effective dose, distribution of workers, and their annual average effective doses in various effective dose intervals, as well as the maximum and minimum annual individual effective doses.

Results: The annual average effective doses in RT, NM, and DR were within the ranges of 1.07-1.45, 1.25-1.55, and 1.03-1.60 mSv, respectively. The majority (90%) of the workers received effective doses in the interval of 1-4.99 mSv, while 10% of the workers received doses within the range of the minimum detectable level-0.99 mSv. The minimum and maximum annual individual effective doses were 0.30 mSv and 3.96 mSv as recorded in RT and NM, respectively. The annual average effective doses measured for NM, RT, and DR were 1.39, 1.23, and 1.30 mSv, respectively. These values are comparable with the worldwide annual average effective doses.

Conclusion: All the workers received doses below the annual dose limit. The status and trends of doses showed that radiation protection conditions were adequate.

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Introduction

Ionizing radiation is being used extensively in medical practices. Globally, it is estimated that half of the exposed population to ionizing radiation consist of medical radiation workers [1]. The exposure to ionizing radiation during the course of work termed as 'occupational exposure' is inevitable, and hence, carries an inherent health risk if adequate efforts are not made for protection [2,3]. Considering the importance of this issue, international agencies like International Commission on Radiological Protection (ICRP) and International Atomic Energy Agency (IAEA) have published various series of papers periodically, in which the results of ongoing studies have been reported [4-9]. One of the most important aspects of radiation protection is individual monitoring. The occupational radiation exposure is usually determined by individual monitoring to comply with the dose limits required by the national regulations and international recommendations and standards [10].

In Pakistan, the national radiation safety infrastructure has been in place since 1965. However, after signing the international convention on nuclear safety in 1994, Pakistan Nuclear Regulatory Board (PNRB) was established under the umbrella of Pakistan Atomic Energy Commission (PAEC). In 2001, the Pakistan Nuclear Regulatory Authority Ordinance No.III was promulgated, which resulted in the establishment of Pakistan Nuclear Regulatory Authority (PNRA) [11]. PNRA is an independent body

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that regulates nuclear safety and radiation protection in the country. All of these are serious initiatives taken by the government of Pakistan to regulate, safeguard, and monitor the ionizing radiation activities. PNRA has adopted the occupational dose limit in accordance with the recommendations of IAEA and ICRP. In this perspective, the annual effective dose to the occupationally exposed workers should not surpass 20 mSv averaged over a five-year period, with a stipulation that the individual dose does not exceed 50 mSv in any single year [12].

Institute of Radiotherapy and Nuclear Medicine (IRNUM) is one of the cancer institutes working under the umbrella of PAEC since 1975. Located at the Peshawar University Campus, it provides medical services in the field of Nuclear Medicine (NM), Radiotherapy (RT), and Diagnostic Radiology (DR) to patients all over Khyber Pakhtunkhwa Province and a major bulk of patients from Afghanistan, as well. There is an established radiation protection committee in the institute headed by the radiation protection officer to monitor the use of ionizing radiation in hospital according to the requirements of PNRA.

Regular assessment of occupational radiation exposures and the analysis of associated trends are imperative to observe changes that have taken place over time due to regulatory operations or technological improvements [13]. The objectives of this study were to reveal and describe the occupational radiation exposure of workers employed in NM, RT, and DR departments at IRNUM Peshawar, Pakistan, and to evaluate the related trends during 2009-2016.

Materials and Methods

A retrospective analysis was conducted on the occupational radiation doses of all the radiation workers employed in RT, NM, and DR departments at IRNUM, Peshawar, KPK, Pakistan, for a block of eight years (2009-2016). All the radiation workers were issued a film badge with inimitable code, depicting the information about the period of use, worker's identity, and his/her establishment. The workers were instructed to wear the film badge at the upper torso just under the lead apron during working hours to provide a picture of the whole body exposure. In Pakistan, Radiation Dosimetry Laboratory (RDL) is responsible for providing personnel dosimetry services for the measurement of occupational radiation exposure [14]. The radiation workers registry of IRNUM contains dose information of 360 workers during 2009-2016.

All the workers in the present study were monitored on a monthly basis. Film dosimeters were obtained from RDL, Islamabad, at the end of every month, and they were replaced for all radiation workers on the first working day of every calendar month. The used dosimeters were sent back to RDL for analysis and report. The Minimum Detectable Level (MDL) of film badge dosimetry is 0.1 mSv. The results of film badges communicated by RDL were kept as records for evaluating the radiation dose history of the workers.

Importantly, the action level of our institute is 50% of the regulatory annual dose limit (i.e., 10 mSv). Specifically, individual annual doses greater than 10 mSv are investigated by the radiation protection committee of the institute to document and record the reasons. In addition, individual annual doses greater than 20 mSv are investigated by the national regulatory body (i.e., PNRA) to probe the cause of high dose and to substantiate whether the dose is factual or otherwise. If the factualness is not confirmed, the recorded dose will be omitted from the dose record. The quantities analyzed during this study include annual collective effective dose, annual average effective dose, distribution of the workers, and their annual average effective dose in various effective dose intervals, as well as the maximum and minimum values of the annual individual effective doses.

Results

A dose record of 4320 film dosimeters of the radiation workers employed in NM, RT, and DR during 2009-2016 was retrieved from the radiation worker's dose registry of IRNUM and used in the present study. The number of occupationally exposed workers, their annual collective effective dose (person-mSv), and annual average effective dose (mSv) during 2009-2016 are presented in Table 1. During the study period, the annual average effective dose remained within the ranges of 1.07-1.45, 1.25-1.55, and 1.03-1.60 mSv for RT, NM, and DR, respectively. Table 2 depicts the range of individual doses for all the three occupational groups, the results are shown with their standard deviation (SD).

Table 3 demonstrates the annual average effective dose of the workers in various effective dose intervals along with the distribution of the workers over the investigated period. All the radiation workers had received annual average effective doses less than 5 mSv, with the majority of workers falling within the range of 1-4.99 mSv effective dose interval. The overall summary of occupational exposure dose data in a block of eight years (2009-2016) is exhibited in Table 4.

Table 1. Number of occupationally exposed workers, their annual collective effective dose and annual average effective dose in nuclear medicine, radiotherapy, and diagnostic radiology at the institute of Radiotherapy and Nuclear Medicine during 2009-2016

		2009	2010	2011	2012	2013	2014	2015	2016
RT	No. of workers	27	28	22	22	20	20	19	22
	Annual collective effective dose (person-mSv)	39.25	35.55	23.47	25.32	23.56	23.14	23.38	27.6
	Annual average effective dose (mSv)	1.45	1.27	1.07	1.15	1.18	1.16	1.23	1.25
NM	No. of workers	21	19	20	19	19	17	16	16
	Annual collective effective dose (person-mSv)	30.63	25.44	26.47	26.78	26.51	24.19	24.76	19.95
	Annual average effective dose (mSv)	1.46	1.34	1.32	1.41	1.39	1.42	1.55	1.25
DR	No. of workers	5	5	5	5	4	3	3	3
	Annual collective effective dose (person-mSv)	8.02	6.66	5.15	5.52	4.86	4.66	4.35	3.69
	Annual average effective dose (mSv)	1.60	1.33	1.03	1.10	1.22	1.55	1.45	1.23

Table 2. Minimum and Maximum annual individual doses in mSv and their standard deviation in nuclear medicine, radiotherapy, and diagnostic radiology for the years 2009-2016

	Radiotherapy			Nuclear medicine			Diagnostic radiology		
Year	Min	Max	SD	Min	Max	SD	Min	Max	SD
2009	0.66	2.45	0.37	0.61	3.04	0.517	1.44	1.80	0.136
2010	0.42	1.60	0.274	1.16	1.49	0.095	1.25	1.46	0.082
2011	0.34	1.50	0.199	0.96	2.88	0.577	0.74	1.38	0.234
2012	0.31	1.63	0.295	0.81	3.96	0.722	0.65	1.36	0.269
2013	0.70	1.31	0.145	0.43	3.16	0.677	0.8	1.55	0.312
2014	0.37	1.50	0.273	0.8	2.93	0.277	1.22	2.16	0.526
2015	0.30	1.50	0.299	1.24	2.87	0.426	1.39	1.49	0.053
2016	1.0	2.67	0.339	1.0	1.93	0.221	1.18	1.31	0.07

Table 3. Annual average effective dose of workers in various effective dose intervals (mSv) for nuclear medicine, radiotherapy, and diagnostic radiology along with the distribution of workers enclosed in parenthesis

Year	Radiotherapy			Nuclear medicine			Diagnostic radiology		
	MDL- 0.99	1-4.99	≥ 5	MDL-0.99	1-4.99	≥ 5	MDL-0.99	1-4.99	≥ 5
2009	0.68 (3)	1.55 (24)	---	0.75 (4)	1.63 (17)	---	---	1.60 (5)	---
2010	0.47 (2)	1.33 (26)	---	---	1.34 (19)	---	---	1.33 (5)	---
2011	0.78 (3)	1.11 (19)	---	0.97 (4)	1.41 (16)	---	0.84 (2)	1.16 (3)	---
2012	0.64 (4)	1.27 (18)	---	0.83 (2)	1.48 (17)	---	0.65 (1)	1.22 (4)	---
2013	0.84 (2)	1.22 (18)	---	---	1.40 (19)	---	0.80 (1)	1.35 (3)	---
2014	0.56 (3)	1.26 (17)	---	0.80 (1)	1.46 (16)	---	---	1.55 (3)	---
2015	0.41 (2)	1.33 (17)	---	---	1.55 (16)	---	---	1.45 (3)	---
2016	---	1.25 (22)	---	---	1.25 (16)	---	---	1.23 (3)	---

Table 4. The overall summary of occupational exposure dose data in a block of eight years (2009-216).

	Annual individual dose (mSv)		Total collective dose (person-mSv)	No. of workers	Annual average effective dose (mSv)
	Min	Max			
Radiotherapy	0.30	2.67	221.27	180	1.23
Nuclear medicine	0.61	3.96	204.73	147	1.39
Diagnostic radiology	0.65	2.16	42.91	33	1.30
All the departments	0.30	3.96	468.91	360	1.30

Discussion

Annual average effective dose and annual collective effective dose are the two basic quantities used to describe the overall trend of occupational radiation exposure. The highest values of annual average effective doses of 1.45 mSv for RT in 2009, 1.60 mSv for DR in 2009, and 1.55 mSv for NM in 2015 were observed as shown in Table 1.

Results of the annual collective effective doses and annual average effective doses are schematically depicted in Figures 1 and 2, respectively. Overall, the results showed a slight decreasing trend in the annual collective effective dose,as well as in NM, RT, and DR, except for RT in 2016 (Figure 1).

Annual collective dose in RT, NM, and DR decreased from 39.25 to 27.6, 30.63 to 19.95, and 8.02 to 3.69 person-mSv, which shows ~30%, ~35%, and ~54% reduction in the annual collective doses, respectively, from 2009 to 2016. One of the factors contributing to the downward trend was the reduction in the number of workers. Other factors include awareness regarding radiation protection practices and the use of better equipment and technologies in the field. Moreover, regulatory pressures, technological advances, and a global approach to work consistent with ALARA contributed to this shift. In 2009, 2010, and 2016, RT made a prominent contribution to the overall annual collective effective dose followed by NM and DR, while during 2011-2015, NM was the major contributor followed by RT and DR.

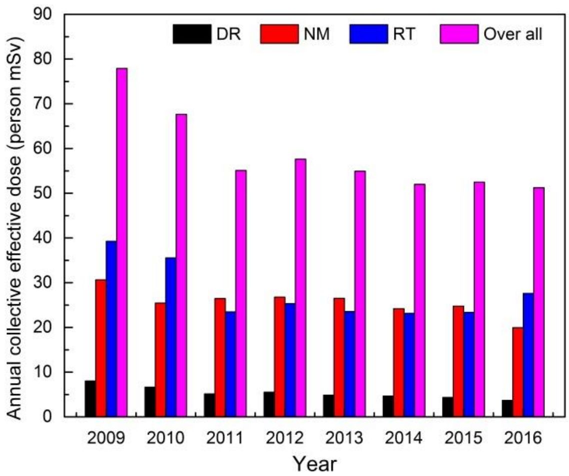

Figure 1. The annual collective effective doses in diagnostic radiology, nuclear medicine, and radiotherapy; the total collective dose for all the three groups is indicated as “Overall”

The annual average effective dose did not follow a particular trend during the eight-year study period. Comparison revealed a relatively high value in NM, except in 2009 and 2014, when DR corresponded to the higher value (Figure 2).

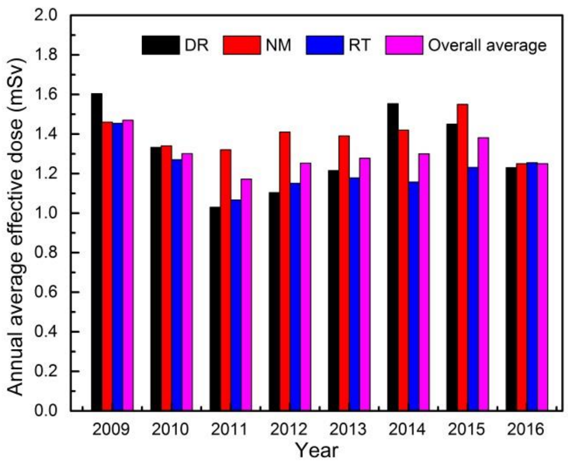

Figure 2. The annual average effective dose in diagnostic radiology, nuclear medicine, and radiotherapy; the overall average annual dose for all the three groups is indicated as "Overall average"

Workers in NM are usually involved in the preparation of radiopharmaceuticals and injecting the patients and remain in close contact with patients during the whole process of imaging, which makes somewhat the greatest contribution to occupational exposure.

Occupational exposures in RT are relatively low since treatments are usually carried out using the external beam either from linear accelerator or highly protected Co-60 teletherapy sealed source. Brachytherapy treatments are also provided with Cs-137 source, but using a remote afterloading the machine. During the irradiation process, the staff remains outside the treatment room, therefore, diminishing the occupational exposure values. The same was concluded by other researchers worldwide [14-17].

The ranges of annual individual doses for the three occupational groups over the study period revealed that the doses were quite below the recommended dose limit (Table 2). We have setup an action level of 10 mSv, 50% of the annual dose limit at our institute. If an individual receives an annual dose greater than 10 mSv, the radiation protection committee at the center will investigate the cause of high dose and document the reason for record.

For more precise and clear illustrations, the number of workers in NM, RT, and DR along with their annual average effective doses were divided into three effective dose intervals. The defined effective dose intervals are MDL-0.99 mSv, 1-4.99 mSv, and ≥5 mSv. The analysis of data showed that all the radiation workers received annual average effective doses less than 5 mSv (Table 3). The percentages of workers falling in the effective dose interval of 1-4.99 mSv were ~88%, ~93%, and ~89% for DR, NM, and RT, respectively. This situation is illustrated schematically in Figure 3.

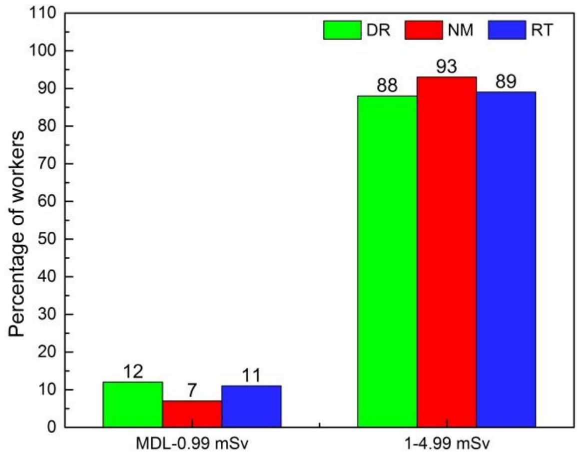

Figure 3. Percentage of workers in diagnostic radiology, nuclear medicine, and radiotherapy in different effective dose intervals

During the eight-year study period covered in the present work, there was no incidence of a dose exceeding the annual regulatory limit of 20 mSv or the action level of 10 mSv adopted at the institute level, which reflects the proper radiation protection protocol and compliance with PNRA and IAEA radiation safety and protection guidelines at IRNUM, Peshawar, Pakistan. The overall summary of occupational dose data in a block of eight years (2009-2016) showed the overall collective dose of 468.91 person-mSv, and the corresponding annual average effective dose due to the accumulated impact of all the three occupational groups was 1.30 mSv as presented in Table 4. The minimum and maximum annual individual effective doses during the investigated period were 0.30 mSv and 3.96 mSv as recorded in RT and NM, respectively. The annual average effective dose values measured for NM, RT, and DR averaged over a block of eight years were found to be 1.39, 1.23 and 1.30 mSv, respectively. This situation is demonstrated in Figure 4. The results of our work are comparable to the report by United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). Globally, UNSCEAR values for the annual average effective doses were 1.4, 1.3, and 1.3 mSv for NM, RT, and DR, respectively, for the period of 2000-2002 [18].

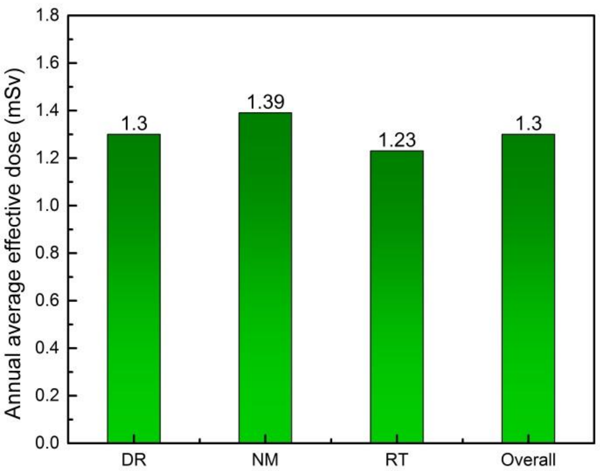

Figure 4. The annual average effective doses in a block of eight years (2009–2016) in diagnostic radiology, nuclear medicine, and radiotherapy. The overall annual average dose for all the three groups is indicated as "Overall"

Conclusion

During 2009-2016, all the workers received doses below the annual dose limit. Dose distribution is skewed towards low dose range, which is in accordance with the ALARA principle. Further, 90% of the workers received doses within the range of 1-4.99 mSv, and 10% received doses within the range of MDL-0.99 mSv. Among the three occupational groups, workers in NM received relatively higher annual average effective doses due to the nature of their work. The values of average annual effective doses are good indicators of radiation safety practices at IRNUM, Pakistan. The establishment of PNRA, as an independent regulatory body, provided fruitful outcomes as reflected by the status and trends of occupational exposure in the present study and indicated that the doses could be further abridged in the succeeding years.

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