

ANNUAL AVERAGE EFFECTIVE DOSE (AAED) DISTRIBUTION AND ANALYSIS OF LIFETIME FATAL AND LIFETIME NONFATAL CANCER RISKS AMONG PAKISTANI MEDICAL STAFF

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Abstract

Diagnostic and therapeutic ionizing radiations are in extensive use to treat various diseases cancers. We assessed the exposed radiation doses for medical workers during 2010-2014 at INMOL (mention abbreviation here), Hospital followed by evaluating lifetime cancer risks. The workers of nuclear medicine (NM), radiotherapy (RT) and diagnostic radiology (DR) departments were screened for exposed whole-body radiation doses by using the film badge dosimetry (FBD). We used the 'nominal probability coefficients' for stochastic effects and lifetime risk of death from fatal and nonfatal cancers were evaluated by adopting ICRP (International Commission on Radiological Protection) and UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) dose-effect assessment methods. The NM workers' were having more lifetime fatal and a lifetime non-fatal cancer risks as compared to RT and DR workers. The lifetime non-fatal cancer risks were found lesser than the lifetime fatal cancer risks for all departments: NM, RT and DR. It is observed as the AAED dose is reduced each year from 2010 to 2014; both lifetime fatal and lifetime nonfatal cancer risks were also decreasing for all three departments' radiation workers. The annual average effective doses (AAEDs) in medical workers were found quite below the permissible limit (20 mSv). This is an indication of proper radiation protection and safety practices at INMOL, Hospital, Lahore Pakistan.

Introduction

Diagnostic as well as therapeutic radiations around the globe are long in extensive use for the diagnosis and treating various diseases. The 'Institute of Nuclear Medicine and Oncology'-INMOL, Lahore, admits and treats a large number of cancer from patients across the country for radiotherapy treatments for the cancer patients. The institute follows guidelines given by 'International Atomic Energy Agency'-IAEA and 'Pakistan Atomic Energy Commission'-PAEC to maintain the required standard of medical care for both patients and entire staff. We keep monitoring the ionizing radiation (IR) exposure from following: Nuclear Medicine (NM) department, Radiotherapy (RT) department and Diagnostic Radiology (DR) department. The INMOL hospital's radiation oncology and nuclear medicine unit comprised of the following equipment: diagnostic X-ray machines, radioimmunoassay counters, SPECT gamma cameras, mammography units, USG machine, automated systems and cell separators and radio-pharmacy etc. The ⁶⁰Co unit, linear accelerator (06-15 MV X-rays) and electron beam unit (09 to 21 MeV), deep X-ray therapy units, ¹⁹²Ir high dose rate brachytherapy units and computerized treatment management facilities are also available (Coursey, 1998).

The objective of this research was based on the assessment and analysis of the occupationally cumulatively exposed radiations (ILO, 1987) medical staff during 2010-2014 at INMOL. The 'International Atomic Energy Agency'-IAEA and the 'United Nations Scientific Committee on the Effects of Atomic Radiation'-UNSCEAR safety standards were taken into consideration (IAEA, 1994; ICRP, 1990; Masood *et al.*, 2013). According to IAEA and UNSCEAR guidelines, the exposure of occupational personnel should not exceed 20mSv/y (averaged over a period of five consecutive years). The whole-body radiation exposed doses of 124 medical staff working in mentioned departments were derived by using the 'Film Badge Dosimetry' (FBD) technique. We have mentioned the annual average effective doses (AAEDs) in the occupationally exposed medical staff and their results have been presented in the current study. Owing radiobiological epidemiological knowledge, the UNSCEAR and 'International Commission on Radiological Protection'-ICRP have established stochastic radiation induced dose-effect relationships methods (Masood *et al.*, 2013; Lochard, 2003). Therefore, we adopted the procedure described by ICRP (Publication 60) (Masood *et al.*, 2013; ICRP, 1990) and complied by UNSCEAR for the assessment of lifetime risk of fatal and nonfatal cancers from exposed personnel from the departments: Nuclear Medicine, Radiotherapy and Diagnostic Radiology. The ICRP has also set radiation dose

limits of 20 mSv/year (averaged over any 5-year period), for an occupational exposure (Masood *et al.*, 2013; Al-Abdulsalam and Brindhaban, 2014). The UNSCEAR has reported that the worldwide average annual occupational dose in nuclear medicine and diagnostic radiology departments is below 2 mSv (Masood *et al.*, 2013; UNSCEAR, 2010).

Ionizing radiation (IR) is a known environmental agent promoting DNA-damaging effects. Various primary lesions are produced due to physicochemical interaction with cellular DNA, such as alkali-labile sites, single-strand or double-strand breaks etc. (Masood *et al.*, 2013; Al-Abdulsalam and Brindhaban, 2014; Natarajan, 1993; Kruszewski *et al.*, 1998; Chaubey *et al.*, 2001; Garaj-Vrhovac *et al.*, 2006). Low level exposure to IR, affects a large number of people, including medical radiation workers who are exposed to radiations being used while delivering health care to humans (Masood *et al.*, 2013; Garaj-Vrhovac *et al.*, 2006). Ionizing radiation is a non-threshold carcinogen. There is an uncertainty in devising a method for calculating the risk of low radiation exposure (Masood *et al.*, 2013; Mullenders *et al.*, 2009). High dose radiations affect human body significantly, which can result in cancerous disease. Moreover, now the effect of low dose radiations to induce cancer is also evident. Brenner *et al.*, (2003) had analyzed the difficulties while calculating the risks of low dose radiation through two points. There is a widespread research in progress related to radiologists and other radiation technologists, because these occupational groups have been found most exposed to the therapeutic as well as diagnostic radiations. In 1902, radiation induced skin cancer was observed (Masood *et al.*, 2013; Yoshinaga *et al.*, 2004; Henshaw *et al.*, 1944; Ulrich, 1946), and such concerns have led many studies to evaluate risk. The studies on radiologists, conducted in United Kingdom (Masood *et al.*, 2013; Yoshinaga *et al.*, 2004; Brown and Doll, 1958) and in the United States (Masood *et al.*, 2013; Yoshinaga *et al.*, 2004; Seltser and Sartwell, 1965) were conducted. It is necessary to monitor the potential health risks of these radiations to ensure protection. The risk of radiation induced cancers have been calculated and well documented. Among such studies, a follow-up study of the atomic bomb blasts Japanese survivors is most informative quantitatively and qualitatively to derive other radiation related reports (UNSCEAR, 2000; Pierce *et al.*, 1996; Cardis *et al.*, 1995). The atomic bomb data reflect the exposure of single episode of the large amount of radiations however, in medical radiations; the workers are exposed to low radiations, directed to different parts of the body, on multiple occasions (Masood *et al.*, 2013; Yoshinaga *et al.*, 2004).

In the past, several cohort studies have been presented to point out radiation impacts inducing cancer risk for medical radiation workers. In the cohort study of Chinese X-ray workers, the incident cancers were verified by analyzing hospital data during years 1950-1995. The radiation doses were estimated (14%) of this cohort (Masood *et al.*, 2013; Yoshinaga *et al.*, 2004; Wang *et al.*, 1988; Wang *et al.*, 1990; Wang, 2002). A Danish cohort study conducted on miscellaneous radiation exposed radiotherapy workers. The incident cancers had been identified through a link between Danish Cancer Registry during 1968-1985. The data concerning related to radiation exposed doses had been accessible from film dosimeters after 1954 in this cohort (Yoshinaga *et al.*, 2004; Anderson and Futamura, 1976). A Japanese cohort of radiological workers reported mortality from 1969 to 1993 via. the 'Japanese National Registry' system (Yoshinaga *et al.*, 2004; Aoyama *et al.*, 1983). A Canadian cohort also conducted for medical radiation workers (Yoshinaga *et al.*, 2004; Ashmore *et al.*, 1998). The radiation dose record related to the individual monitoring had been achieved from the link of the National Dose registry and cancer incidence was estimated through the nationwide cancer reporting system that is, Canadian Mortality Data Base for the workers between 1969 to 1983 (Yoshinaga *et al.*, 2004; Sont *et al.*, 2001). Another previous study had reviewed the occupational exposure dose in the range 2-6 mSv (mili-Sieveret) in Kuwait hospitals and non-medical industries from 1980 to 1983 (Al-Abdulsalam and Brindhaban, 2014; Mustafa *et al.*, 1985).

The above mentioned studies and alike are beneficial in honing the standard protocols for various radiological procedures and their adequacies. Such protocols and practices are not only useful for patients but they should also provide protection measures for the radiological workers. Data obtained through epidemiologic studies of medical radiation workers on duty before 1950, have shown the excess risk of skin, breast and skin cancers, but there is little data to support the evidence of cancer risk in later years. It is a need of time to update and upgrade the knowledge on the radiation dose exposure to assess lifetime death risks from any type of cancer in physicians and technologist performing for example, the interventional procedures. These studies will help to outline proper and adequate protection measures and protocol of cancer screening in radiologists and other assistants (Linet *et al.*, 2010). It has been observed that overall, however, the time trend effective dose data for radiologists and radiologic technologists are generally showing that occupational exposures of radiation exposed workers are declining over the time, regardless observing increase medical radiation procedures specifically during the past 30 years (Linet *et al.*, 2010; NCRP, 2009). The UNSCEAR has reported that the worldwide average annual occupational dose in nuclear medicine and diagnostic radiology departments is below 2 mSv (Al-Abdulsalam and Brindhaban, 2014; UNSCEAR, 2010).

Materials and Methods

The Collection of Data and FBD Technique:

The present study encloses the level of radiation protection measures and safety of medical staff during years 2010–2014. The occupational exposure doses of medical staff were measured, analyzed and collated by employing the FBD (Film Batch Dosimetry) technique. The collected data was processed by the ‘Radiation Dosimetry Group’ (RDG) for further assessment and analysis. RDG system is responsible for furnishing personal dosimetry services concerning measurement of occupational exposure to medical personnel working in the radiation departments. The exposed medical workers (n=124) from Nuclear Medicine, Radiotherapy and Diagnostic Radiology departments, has been monitored. The annual average effective (AAED) doses of medical staff with a maximum annual permissible limit of 20 mSv is always averaged over a period of 5 consecutive years for estimation of risk involved due to external radiation. The measurement technique FBD provides a permanent dose record in the processed films (Cember, 1969; William, 1994). The technique can accomplish the registering radiation doses between ‘0.1 mSv to 18 Sv’ with the detectable exposure range of ‘0.10 mSv to 0.20 mSv’ (Masood *et al.*, 2013; Holm and Berry, 1971; Martin *et al.*, 2012).

Record of Measured Doses:

A software ‘RADLAB’ was used to record the measured doses both in soft and hard copies. The ‘Secondary Standard Dosimetry Laboratory’ (SSDL) was used for the calibration of the films using an X-ray generator (5, 39-40). The determination of the ‘whole-body’ effective doses was performed by ‘dose assessment algorithm’ (5, 39-40). Table 1 shows the number of occupationally exposed medical workers and the AAEDs (mSv) in all departments. The Table 2 represents the distribution of exposed medical workers in the mentioned effective dose intervals and their AAEDs (mSv) for all radiation exposed departments.

**Table 1. The number of occupationally exposed medical staff and their AAED (mSv) in NM, RT and DR along with the calculation of lifetime fatal and non-fatal cancer risks (2010–2014).
AAED: Annual Average Effective Dose**

Year	NM				RT				DR			
	Workers	AAED	FC-LTR	NFC-LTR	Workers	AAED	FC-LTR	NFC-LTR	Workers	AAED	FC-LTR	NFC-LTR
2010	20	1.36 ₁	1.9×10 ⁻³	3.8×10 ⁻⁴	23	0.99 ₃	1.4×10 ⁻³	2.8×10 ⁻⁴	7	0.502	7×10 ⁻⁴	1.4×10 ⁻⁴
2011	36	0.71 ₂	9.9×10 ⁻⁴	1.9×10 ⁻⁴	36	0.50 ₂	7×10 ⁻⁴	1.4×10 ⁻⁴	8	0.372	5.2×10 ⁻⁴	1×10 ⁻⁴
2012	41	0.51 ₀	7.1×10 ⁻⁴	1.4×10 ⁻⁴	40	0.50 ₃	7×10 ⁻⁴	1.4×10 ⁻⁴	8	0.291	4.1×10 ⁻⁴	8.1×10 ⁻⁵
2013	43	0.45 ₃	6.3×10 ⁻⁴	1.3×10 ⁻⁴	42	0.44 ₁	6.2×10 ⁻⁴	1.2×10 ⁻⁴	9	0.263	3.7×10 ⁻⁴	7.3×10 ⁻⁵
2014	45	0.41 ₉	5.8×10 ⁻⁴	1.2×10 ⁻⁴	43	0.41 ₃	5.8×10 ⁻⁴	1.2×10 ⁻⁴	10	0.238	3.3×10 ⁻⁴	6.6×10 ⁻⁵

Method of Assessment of Dose-Effect Relationship

We adopted the procedure described by ICRP (Publication 60) and complied by UNSCEAR for the assessment of annual risk of fatal and non-fatal cancers from radiation exposed dose by using ‘nominal probability coefficients’ for stochastic effects for INMOL radiation departments. The UNSCEAR guidelines were considered for the upper value of the tolerable risk. According to ICRP (Publication 60) (1990), the ‘nominal probability coefficient’ for stochastic effects (for adult workers for medical field) is fatal cancer is 4.0×10^{-2} (detriment per Sievert) and for non-fatal cancer is 0.8×10^{-2} (detriment per Sievert). These values are rounded off. It is described in this publication that for fatal cancer, the detriment is equivalent to the ‘probability coefficient’ (Lochard, 2003). The calculations for the estimation of lifetime risk linked an occupational medical radiation exposure suffered over 35 years at the average value. The lifetime risk is calculated by multiplying the level of mean annual exposure by 35 years and by the coefficient $4.0 \times 10^{-2}/\text{Sv}$ lifetime for fatal cancer risk and $0.8 \times 10^{-2}/\text{Sv}$ for lifetime non-fatal cancer risk (Lochard, 2003; ICRP, 1990). Table 1 also shows the corresponding department’s workers’ lifetime fatal and non-fatal lifetime cancer risk for each year.

Results

Annual Average Effective Doses Assessment:

The processing of total 7440 film dosimeters was carried out to measure the radiation exposure of INMOL's radiation departments. The AAED is a signal of the trend of occupational radiation exposure in a certain categorical radiation work per year. Table 1 presents the AAED in (mSv) for the years (2010–2014). AAED remained in the range of 0.42–1.36 (mSv), 0.41–0.99 (mSv) and 0.24–0.50 (mSv) for the Nuclear Medicine, Radiotherapy and Diagnostic Radiology departments respectively.

Table 2. The distribution of occupationally exposed medical staff in various effective dose intervals and their annual average effective dose (mSv) for Nuclear Medicine, Radiotherapy and Diagnostic Radiology (2010–2014).

Years	Nuclear Medicine			Radiotherapy			Diagnostic Radiology		
	≤0.99	1.0–4.99	5.0–9.99	≤0.99	1.0–4.99	5.0–9.99	≤0.99	1.0–4.99	5.0–9.99
The number of workers in effective dose intervals									
2010	12	8	–	21	1	1	7	1	–
2011	27	9	–	34	2	–	8	–	–
2012	38	3	–	40	–	–	8	–	–
2013	36	7	–	42	–	–	9	–	–
2014	37	8	–	43	–	–	10	–	–
The average effective exposure dose received by medical staff and their effective dose intervals (mSv)									
2010	0.681	2.380	–	0.684	1.292	7.420	0.498	1.914	–
2011	0.390	1.651	–	0.434	1.131	–	0.372	–	–
2012	0.404	1.813	–	0.503	–	–	0.291	–	–
2013	0.362	1.534	–	0.441	–	–	0.263	–	–
2014	0.348	1.421	–	0.413	–	–	0.238	–	–

Table 2 exhibits the distribution of number of exposed medical worker in various effective dose intervals (mSv) related to the areas of NM, RT and DR for the years 2010–2014. Up to 99.9%, 98.5% and 99.9 % of the total workers in NM, RT and DR, respectively, fall in the 'dose-interval' from a minimum detectable limit to '4.99 mSv'. Occupationally exposed medical worker falling in the effective dose interval '5.0 mSv to 9.99 mSv' has received radiation exposure only in RT during the year 2010. In NM and DR, no worker exceeded the dose value of 5 mSv throughout the assessment period. Similarly, in RT, only one worker exceeded the dose value of 5 mSv. The AAED values measured for Nuclear Medicine, Radiotherapy and Diagnostic Radiology departments were found to be 0.69 mSv, 0.57 mSv and 0.33mSv, respectively, as presented in Figure 1. The obtained annual average exposure dose values are comparable to those of the UNSCEAR report (41–43) recommended safest dose range. Three categorized ranges of AAED along with a corresponding representation for NM, RT and DR groups are shown for comparison in Figure 2.

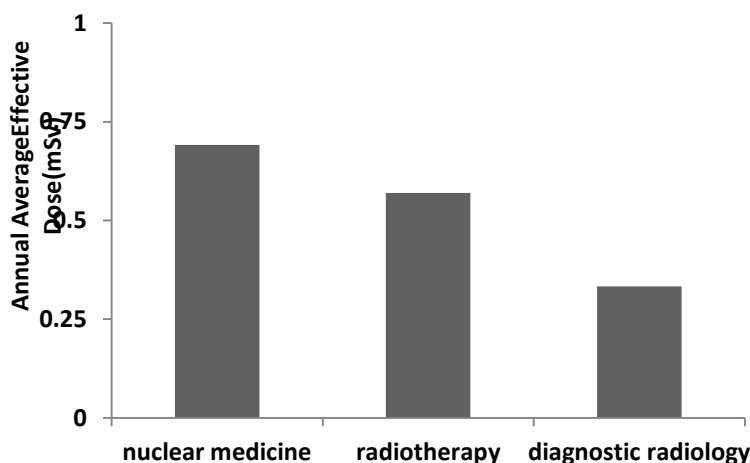


Fig.1. The annual average exposure dose values of medical staff in NM, RT and DR during the years (2010–2014).

Assessment of a Lifetime Fatal and a Nonfatal Cancer Risks

Table 1 describes the calculation concerning corresponding department's workers' fatal and nonfatal lifetime cancer risk for each year that is, from 2010 to 2014. It is observed as the AAED dose is reduced each year from 2010 to 2014, both lifetime fatal and lifetime nonfatal cancer risks were decreasing for all three departments: NM, RT and DR. In the RT, the lifetime fatal and lifetime non-fatal cancer risks were same that is, 7×10^{-4} for the years 2011 and 2012. The NM department workers' were having more lifetime fatal and lifetime nonfatal cancer risks as compared to RT and DR department's workers. The lifetime non-fatal cancer risks were found lesser than the lifetime fatal cancer risks for all departments: NM, RT and DR.

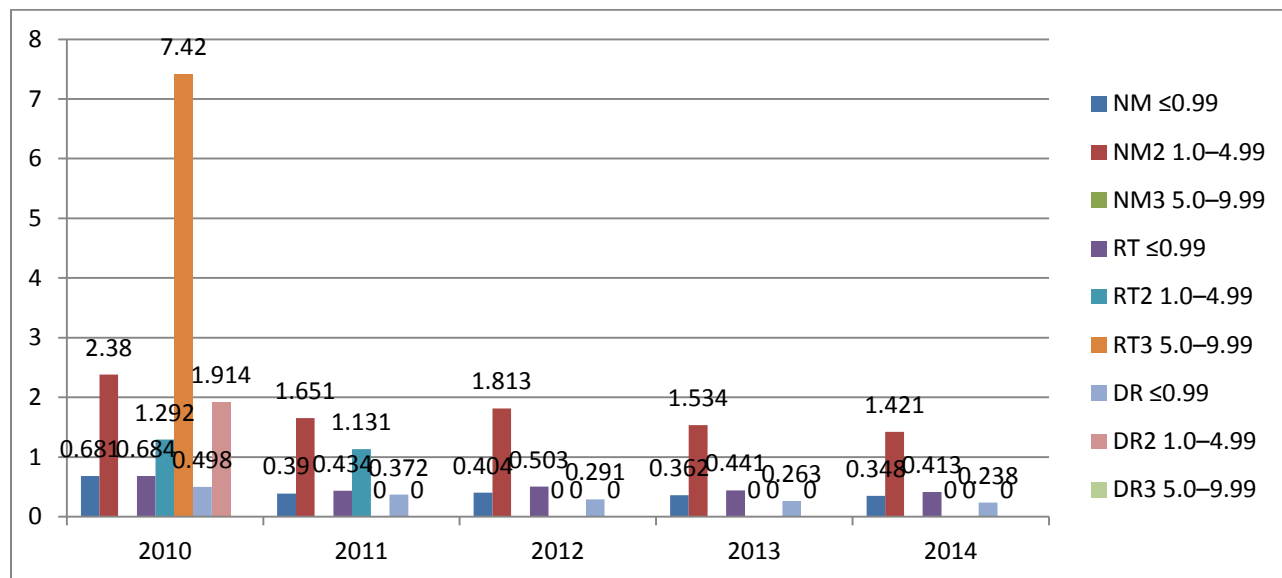


Figure 2: (Plot of Table 2) Three categorized ranges of AAED along with a corresponding representation for NM, RT and DR groups are shown for comparison for the years 2010-2014.

LEGENDS:

NM: Nuclear Medicine group with dose range: ≤ 0.99
 NM2: Nuclear Medicine group with dose range: 1.0–4.99
 NM3: Nuclear Medicine group 3 with dose range: 5.0–9.99

RT: Radiotherapy group with dose range: ≤ 0.99
 RT2: Radiotherapy group with dose range: 1.0–4.99
 RT3: Radiotherapy group with dose range: 5.0–9.99

DR: Diagnostic Radiology group: ≤ 0.99
 DR2: Diagnostic Radiology group: 1.0–4.99
 DR3: Diagnostic Radiology group: 5.0–9.99

Discussion

It has been found that over the globe, the number of medical radiation workers and the number of advanced radiological imaging technology procedures have been increased. The risks from long term-low dose radiation exposures for nuclear medicine or diagnostic radiology workers are evident and have been found associated with the biological hazards because evidences are available related to reversible and non-reversible genotoxic effects (Masood *et al.*, 2013; Lochard, 2003; Sahin *et al.*, 2009). Therefore, the concern related to the measurement of exposed radiation doses to the workers of the nuclear medicine department as well as therapeutic and diagnostic radiation department is having a great weightage worldwide. Moreover, the biological risks owing moderate to high exposed doses are well known, but still there is a worldwide debate concerning effects due to low-level dose exposures (Masood *et al.*, 2013; Al-Abdulsalam and Brindhaban, 2014; Linet *et al.*, 2010; Sahin *et al.*, 2009; Pauwels and Bourguignon, 2012; Covens *et al.*, 2012; Leuraud *et al.*, 2015).

It is evident from Table 1 that these AAEDs during 2010–2014 are quite below the allowable annual dose limit of 20mSv/y. The AAED values are at a minimum for the recent year 2014. The comparison of AAED values for all exposed departments, mentions that the greatest value is reported in Nuclear Medicine department, followed by Radiotherapy department and then the Diagnostic Radiology department. This peculiarity is due to the fact that medical staff in Nuclear Medicine department is exposed to radionuclide generators which includes handling lots of radioactive pharmaceuticals for example, during 'injection transfusions' or during 'camera imaging' management (Masood *et al.*, 2013). In Radiotherapy department, the occupational exposure is mainly due to the use of external beam therapy (EBT) units. The analysis indicates (Table 2) that up to 99.9%, 98.5% and 99.9 % of the total workers in NM, RT and DR departments, respectively, fall in the dose interval from a minimum detectable limit to '4.99mSv'. The exposed medical worker lying in the effective dose interval 5.0mSv to 9.99mSv has received radiation exposure only in Radiotherapy department during the year 2010. In Nuclear Medicine and Diagnostic Radiology departments, no worker was exceeded the dose value of 5mSv throughout the assessment duration except one worker. It is concluded that no exposed workers has exceeded the maximum permissible annual dose value of 20mSv during 2010–2014. We concluded that INMOL is strictly satisfying with IAEA, UNSCEAR and PNRA radiation protection and safety rules and regulations (Masood *et al.*, 2013; IAEA, 2007; PNRA, 2004; PNRA, 2008; PNRA, 2007; PNRA, 2009). The AAED values measured for all departments were found to be 0.69mSv (NM), 0.57mSv(RT) and 0.33mSv (DR) illustrated in Figure 1. The present observational report has provided proper and careful information on the FBD program at the institute INMOL, Lahore. Previously, in the same institute, the declining trend was also observed in the AAED values during years 2007–2011. This is an omen of alleviated medical ionizing radiation protection system at INMOL, Pakistan (Masood *et al.*, 2013).

It is observed as the AAED dose reduced each year from 2010 to 2014, both lifetime fatal and lifetime nonfatal cancer risks were decreasing for all three radiation exposed departments. The NM department workers' were having more lifetime fatal and a lifetime nonfatal cancer risks as compared to RT and DR department's workers. According to the UNSCEAR (2000) Report data, with the average medical radiation exposure (0.33 mSv/a) the lifetime risk estimated is mentioned as 4.6×10^{-4} for fatal cancer related to 35 years of occupational exposure to IR (Masood *et al.*, 2013). It was found in a recent study that the high energy gamma rays used in PET-Positron Emission Tomography imaging pose higher radiation exposure for the workers as compared to the technetium-99m gamma rays used in different imaging procedures (Al-Abdulsalam and Brindhaban, 2014). A similar study conducted by Al-Abdulsalam and Brindhaban (2014) had investigated the exposed radiation dose of Kuwait hospital staff of nuclear medicine and diagnostic radiology departments from 2008 to 2009. They compared the annual exposed dose with the safe dose limit restricted by ICRP. This study (Al-Abdulsalam and Brindhaban, 2014) showed that the mean annual exposure dose of workers was less than 1.07 mSv/y concluded as a safer limit complying with ICRP standard following low calculated radiation-induced cancer risk (Al-Abdulsalam and Brindhaban, 2014). Another study had quantified associations between long term, low-dose exposures and monitored leukemia, lymphoma, and multiple myeloma mortality among radiation exposed workers in the U.S.A, U.K and France. This study provided a profound confirmation of positive associations between elongated low-dose radiation exposure and leukemia (Leuraud *et al.*, 2015). Another recent study, which was carried out at the Nuclear Institute of Medicine and Radiotherapy (NIMRA) Jamshoro, Pakistan to evaluate radiation doses by film badges. According to Memon *et al.*, (2013), only eight workers found with high radiation exposure among 35 workers in 2012 and the rest of the workers' exposed doses were in the range of 1.21 to 7.78 mSv (Memon *et al.*, 2013). In 2009, Muirhead *et al.*, evaluated mortality and cancer incidences of the data take from the National Registry for Radiation Workers by Standardized Mortality Ratios (SMR) method. Muirhead *et al.*, (2009) reported in this cohort that, mortality and incidence from both leukemia excluding CLL (Chronic Lymphocytic Leukemia) and the grouping of all malignant neoplasms excluding leukemia increased significantly (statistically) with increasing radiation dose.

Comparison of lifetime fatal and nonfatal cancer risks from ionizing radiations from other carcinogens as mentioned by Lochard (2003). According to the data of dose-effect relationship and risk coefficients are provided by WHO and ICRP for other chemical carcinogen exposures as well. Lochard (2003) has mentioned the values of 'lifetime risks for occupational exposure over 35 years' for following carcinogen agents are as follows: for Nickel exposure it is 4.4×10^{-2} , for Arsenic exposure it is 3.3×10^{-2} , for ionizing radiation it is 2.8×10^{-2} , for Benzene it is 1×10^{-2} and for Asbestos it is $\times 10^{-2}$. These 'lifetime risks for occupational exposure over 35 years' was calculated on the basis of a daily eight hours work. It was also observed that the lifetime risk of fatal and non-fatal cancer incidences are linked with the other occupational chemical exposures and it was found in the range of: 0.2×10^{-2} and 4.4×10^{-2} over a period of 35 years. The lifetime fatal cancer risk was from occupational radiations were found with the range described with its value equal to 2.8×10^{-2} (Lochard 2003). Lochard (2003) concluded that the amount of safety from cancer causing chemical substances and from ionizing radiations is not disparate as is usually thought (Lochard 2003). In current study, all measured lifetime fatal and lifetime non fatal cancer risks values were lesser than the previously risk values for all radiation workers of

INMOL (Table 1). Moreover, all risk values in INMOL's occupational radiation workers were lesser than the other carcinogens' (Nickel, Arsenic, Benzene, and Asbestos) lifetime occupational cancer risks.

Conclusion and Recommendations

It is observed as the AAED dose reduced each year from 2010 to 2014, both lifetime fatal and lifetime nonfatal cancer risks were decreasing for all three departments: NM, RT and DR. The NM department workers' were having more lifetime fatal and a lifetime non-fatal cancer risks as compared to RT and DR department's workers. The declining trends observed in the AAED values during years 2010–2014, is a manifestation of mitigated radiation protection and safety systems at INMOL, Pakistan. The present work would be useful to keep evaluating the aspects which presented here for workers' radiation safety, the development of further improved protocols to operate and handle X-ray and γ -ray equipments etc. There should be more radiation equipment handling trainings for occupational management. It is suggested that radiation workers' duty should not be continuing on radiation units through the year; rather it would be more appropriate to swap their duties with other non-radiation departments as well. There should be different medical tests conduction to keep monitoring their entire health per year. We recommend that lifetime cancer risks must also be evaluated in the exposure of other chemical substance. Life of expectancy along with cancer risks must also be evaluated.

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