Original Article :

Occupational Radiation Exposure to Fingers Using Thermoluminescent Ring Dosimeters in Healthcare Personnel at AEMCK

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Abstract

Background and Aims:
This study at Atomic Energy Medical Center Karachi (AEMCK) marks the first-ever implementation of ring thermoluminescent dosimeters (TLDs) in 2020 for extremity dose monitoring of Nuclear Medicine employees. It aimed to assess finger doses during radiopharmaceutical preparation/ administration and evaluate compliance with radiation protection standards.

Methods:
Five Nuclear Medicine technologists (two workers from the Hot Laboratory, two from the Gamma Camera, and one from the Stress Laboratory) wore ring TLDs on the dominant hand's index/ ring finger base for monthly cycles over the period (2020–2021). Doses measured skin equivalent at Hp(0.07). TLDs calibrated with Cs-137 in a Secondary Standard Dosimetry Laboratory at KANUPP-1. Statistical analysis used Microsoft Excel and the t-test distribution.

Result:
Hot Laboratory staff showed higher mean finger doses (58.79 ± 30.48 mrem) than Gamma/Stress Laboratory staff (18.19 ± 7.30 mrem), with a significant difference ($p = 0.000238$). The maximum monthly dose was 110 mrem. All doses remained well below the 50,000 mrem/year (500 mSv/year) extremity limit.

Conclusion:
The study highlights the importance of continuous extremity dose monitoring in nuclear medicine practice. All measured doses across different areas were within permissible limits; adopting protective measures such as syringe shields, short-tubing butterfly cannulas, staff rotation, and simulated training can further optimize safety. Regular extremity monitoring is strongly recommended across Atomic Energy Cancer Hospitals (AECHs).

Keywords:
Occupational radiation exposure, Extremity dose monitoring, Ring thermoluminescent dosimeter (TLD), Nuclear medicine personnel, Finger dose, Radiation protection

Introduction:

Occupational exposure to ionizing radiation in nuclear medicine (NM) is a concern due to handling unsealed radiopharmaceuticals such as technetium-99m (^{99m}Tc) and iodine-131 (^{131}I)[1]. While whole-body monitoring with film badges has been routine at AEMCK for over a decade, extremity (finger) monitoring was absent until 2020.

In NM, staff frequently handle high-activity radiopharmaceuticals, such as technetium-99m (99mTc) and Iodine-131 (^{131}I), during patient preparation and administration. These procedures often involve direct finger contact with unshielded vials and syringes. Therefore, the fingers often receive higher doses than the torso during direct handling of vials/syringes[2]. Placing the extremities at elevated risk of radiation exposure. Recent studies confirm that extremity doses can significantly exceed whole-body doses without proper shielding or monitoring [3, 4].

To comply with PNRA regulations and IAEA recommendations[5], AEMCK introduced ring TLDs for Hp(0.07) measurement. This first local implementation provides data on dose variation by job role (Hot Lab vs. Gamma/ Stress Lab), supporting work practice optimization and alignment with the ICRP extremity limit (500 mSv/year)[6].

Materials and Methods:

Study Design and Settings: Observational study at AEMCK NM Department, conducted over four monthly monitoring cycles (Nov–Dec 2020, Jan–Feb 2021, Sep–Oct 2021, Nov–Dec 2021).

Study Participants: Five occupationally exposed NM workers:

Group 1(RW1/2): Two staff members from the Hot Laboratory (Hot Lab)

Group 2(RW3/4/5): Two Tech operating gamma cameras, and one from the Stress Lab

These participants regularly handled technetium-99m (^{99m}Tc) and iodine-131 (^{131}I) for diagnostic and therapeutic procedures.

Dosimetry and Dosimeter Description

To monitor extremity dose, TLDs were used:

Ring Design: Ring TLDs (TLD-100 chips in custom plastic holders) worn on the dominant hand's index/ring finger base. Control TLD was stored in a low-background area for background subtraction. Calibration used a Cs-137 source (1 mGy) in KANUPP SSDL, traceable to IAEA standards. Readout via a RADOS RE-2000 reader under nitrogen, with annealing and

element-correction coefficients. Doses were recorded in mrem (Hp(0.07)). Gloves were worn over rings to prevent contamination. No syringe shields were used during the study (though recommended).

TLD Calibration and Readout

A RADOS TLD reader model RE-2000 at KANUPP-1 was used to process exposed TLDs. This service provided by KANUPP-1. For calibration, a known dose of 1 mGy was delivered to a batch of TLDs using a Cs-137 source. This dose level was chosen to represent the typical range of occupational exposures and falls within the linear response range of the dosimeters. The resulting glow curve data were used to construct calibration curves for dose-to-light-output conversion.

Readout protocol: Pre-read annealing was conducted to eliminate low-temperature peaks. TLD glow curves were recorded under a nitrogen atmosphere. Light output was converted into dose using pre-established element correction coefficients (ECCs) and calibration factors. Doses were expressed in mrem, representing Hp(0.07); the operational quantity for skin dose equivalent at 0.07 mm tissue depth.

Work Procedures and Source Handling

Radioisotopes handled: ^{99m}Tc (from ^{99}Mo/^{99m}Tc generator) was used for routine SPECT imaging, ^{131}I was used for treatment of thyrotoxicosis and differentiated thyroid cancer

Tasks were performed by the NM Technician, which included:

i. Generator elution, radiopharmaceutical preparation, and labeling.
ii. Syringe loading and patient administration.
iii. Patient positioning and imaging (Gamma Camera and Stress Lab).

Dose Evaluation and Grouping

Workers were monitored over multiple monthly cycles. Doses were averaged across months and grouped based on role:

i. Group 1 (Hot Lab): Higher handling of unshielded radioactivity
ii. Group 2 (Gamma/Stress Lab): Indirect contact, occasional administration

All doses were compared with the annual dose limits recommended by the International Commission on Radiological Protection (ICRP) and the Pakistan Nuclear Regulatory Authority (PNRA)[5].

Statistical analysis:

Means ± SD were calculated per group (Group 1: 8 data points; Group 2: 12 data points). An unpaired two-tailed Welch's t-test was used to assess intergroup differences (Excel 2016; confirmed via a t-distribution calculator). Significance at p

< 0.05. Data collected from the ring TLDs worn by five nuclear medicine (NM) staff members over the specified period were statistically analyzed to evaluate differences in extremity radiation exposure across job roles. Descriptive and inferential statistics were used.

The Finger doses data were entered and statistically analyzed using Microsoft Excel 2016 (Microsoft Corp., USA) and validated using https://stattrek.com/online-calculator/t-distribution for statistical testing.

Descriptive statistics were calculated for Group 1 and Group 2 of staff members from the NM division; the mean (average) and standard deviation (SD) were calculated as follows:

i. Group 1 (Hot Lab): 2 workers × 4 months = 8 data points
ii. Group 2 (Gamma Camera/Stress Lab): 3 workers × 4 months = 12 data points

To assess the statistical significance (p<0.5) between two groups of staff members, an unpaired two-tailed t-test with unequal variances (Welch's t-test) was applied using the following formula:

$$t=\frac{X1+X2}{\sqrt{\frac{s1^2}{n1}+\frac{s2^2}{n2}}}$$

Where X1 and X2 represented sample means, s1 and s2 represented sample standard deviations, and n1 and n2 represented the sample sizes.

The degrees of freedom were calculated using the following Welch–Satterthwaite equation:

$$df=\frac{(\frac{s1^2}{n1}+\frac{s2^2}{n2})^2}{(\frac{s1/n1)^2}{n1-1}+\frac{(s2/n2)^2}{n2-1}}$$

The p-value was computed using the t-distribution with df ≈ 12, for a two-tailed test:

p = 2 \times P(T > |2.48|) \ approx. 0.038. This was confirmed using online t-distribution calculators.

Ethical Consideration: As this involved routine occupational dose monitoring without patient intervention or additional procedures, formal Institutional Review Board approval was not required. Informed verbal consent was obtained from all participants.

Results:

Overview of Measured Extremity Doses

In this study, extremity radiation doses measured with ring TLDs were recorded for five nuclear medicine (NM) radiation workers between 2020 and 2021. Table 1 presents the monthly ring dose values assigned to Group 1 (RW1 and RW2) and Group 2 (RW3, RW4, and RW5), assigned to the Gamma Camera and Stress Lab.

Table 1: Finger Doses for Group 1 & Group 2 Radiation Workers of Nuclear Medicine.

Radiation Worker	NM Area	Monthly Ring Dose (mRem) (mrem)				Dose Range	Mean± Standard Deviation	
		Nov-Dec 2020	Jan-Feb 2021	Sep-Oct 2021	Nov-Dec 2021	(mrem)	Mean	SD
RW1	Hot Lab	78	0	40	35	78	38.25	31.9
RW2	Hot Lab	100	19	51	54	81	56	33.3
RW3	Infinia	15	24	28	30	15	24.25	6.7
RW4	E-Cam	10	28	30	0	30	17	14.5
RW5	Stress Lab	10	15	15	17	7	14.25	3

Group 1 exhibited the highest extremity dose values, as expected due to direct handling of unshielded radiopharmaceuticals. The recorded doses for RW1 ranged from 0 to 78 mrem/month, and for RW2 from 19 to 110 mrem/month. The highest single dose was recorded for RW2 (100 mrem) during Jan–Feb 2021, indicating high exposure, possibly during ^{131}I handling. The lowest recorded dose (0 mrem) for RW1 suggests either non-participation or procedural variation during that period. The mean ± SD finger dose for Group 1 was 58.79 ± 30.48 mrem, highlighting both a high average and substantial dose variability. Group 2 workers with indirect-exposure roles received consistently lower doses. RW3's doses ranged from 15 to 28 mrem, RW4 from 10 to 30 mrem, and RW5 from 10 to 15 mrem. The highest dose in this group was 30 mrem. The mean ± SD for Group 2 was 18.19 ± 7.30 mrem, confirming their lower exposure profile as compared to Group 1.

The t-test showed that the difference in mean doses between Group 1 and Group 2 was statistically significant ($p = 0.000238$, $t = 4.89$). Since $p < 0.0001$, the difference between groups is statistically highly significant. This validated that Hot Lab workers (Group 1) were receiving significantly higher finger doses than those of Group 2, as shown in Table 2.

Table 2: Inferential statistics between Groups 1 & 2.

Group	n	Mean Dose (mrem)	Standard Deviation (mrem)
Group 1 (Hot Lab)	14	58.79	30.48
Group 2 (Gamma/Stress Lab)	21	18.19	7.3
Degree of Freedom (df)			14
t-value			4.89
Two-tailed p-value		<0.0001	0.000238

As shown in Figure 1, the comparative extremity doses for Group 1 and Group 2 indicated that Group 1 showed greater fluctuation, dose variance, and overall exposure. Group 2 showed tighter clustering and shorter bars, consistent with their controlled, indirect handling of radiopharmaceuticals. The nature of the task (i.e., direct vs indirect handling of unsealed sources) influenced extremity dose.

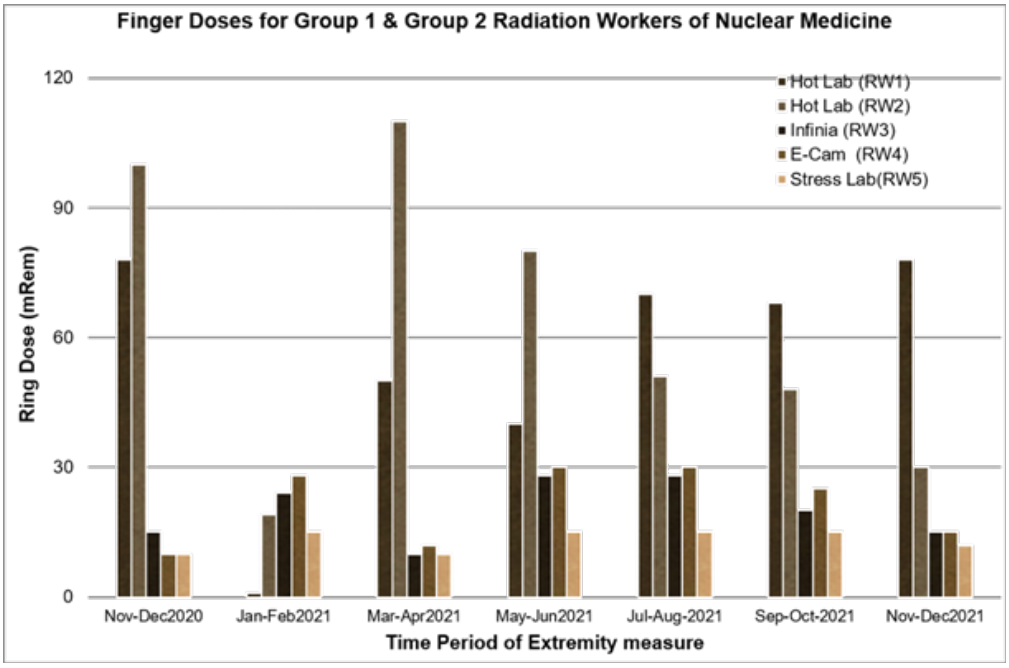


Figure1: Extremity Dose of Group1 and Group2 RW

As observed, in Group 1, none of the workers exceeded the annual dose limit of 500 mSv/year (50,000 mrem/year) for the extremities, as set by the ICRP and the PNRA. The maximum monthly dose (100 mrem) observed in RW2 remains well below the permissible threshold when annualized.

Table 3 shows the trade names and origins of the materials used in the research.

Table 3: Trade Names and Origins of Materials and Equipment Use.

Item/Material	Trade Name/Model	Purpose/Use
Thermoluminescent Dosimeter (TLD) Chips	TLD-100 (LiF:Mg,Ti)	Extremity dose at (Hp(0.07))
TLD Ring Holders	Custom Plastic Adjustable Rings	Placement of TLD on finger. Fabricated Locally
TLD Reader	RADOS RE-2000	Reading and analyzing TLD glow curves
Calibration Radiation Source	Cs-137 Standard Source	Standardized irradiation for TLD calibration

Radiopharmaceuticals	Technetium-99m, Iodine-131	Diagnostic and therapeutic procedures
Radiopharmaceutical Generator	99Mo/99mTc Generator from PINSTECH	Elution of Tc-99m for radiopharmaceutical preparation
Ring Dosimeter Calibration Service	N/A	Calibration of TLDs using Cs-137 source in KANUPP
Radiation Protection Regulations	PAK-904 Rev. 1	Regulatory compliance and dose limits of PNRA
Software Used	Microsoft Excel	Dose tabulation, graphs, and statistical analysis

Discussion:

The Hot Lab personnel (RW1 and RW2), who routinely handle unsealed high-activity radiopharmaceuticals such as Iodine-131 (^{131}I), received significantly higher finger radiation doses than NM technologists working in the Gamma Camera and Stress Lab (RW3–RW5), consistent with global reports[7, 8]. Figure 1 shows that the average extremity dose for Hot Lab workers was 58.79 ± 30.48 mrem, while that for other technologists was 18.19 ± 7.30 mrem, a statistically significant difference ($p = 0.000238$). These findings confirm that direct manual handling of therapeutic isotopes results in elevated finger exposure. To mitigate such extremity exposure and making safety culture, the following Radiation safety practices are recommended;

i. All workers used ring dosimeters placed at the base of the index or ring finger on the dominant hand for monthly dose accumulation.:
ii. Use of syringe shields[8,9] during injection procedures can reduce finger doses by 75%–85%, particularly during ^{131}I handling.
iii. Short-tubing butterfly cannulas [10, 11] inserted before radiopharmaceutical administration reduce hand proximity to the source.
iv. Rotation-based work scheduling limits[10] cumulative exposure by distributing high-risk tasks among multiple workers.
v. Hands-on practice with dummy[12] sources enhances technique, safety awareness, and confidence in real procedures.

Following these strategies, along with regular extremity dose monitoring, can effectively minimize the risk of exceeding the annual dose limit of 500 mSv (50,000 mrem) for the fingers while ensuring safe and compliant operation in nuclear medicine facilities such as AEMCK.

Conclusions:

It can be inferred that the measured extremity doses for all five nuclear medicine workers remained well below the recommended annual limit of 500 mSv (50,000 mrem), with rotation-based duties further minimizing cumulative exposure. Periodic monitoring of finger doses is recommended to support safe work practices and maintain proper documentation of radiopharmaceutical handling protocols at AEMCK.

Conflict of interest: Regarding the publishing of this article, the authors affirm that they have no conflicts of interest.

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Declarations

During this study period, no syringe shields were used by staff. Workers wore gloves over the ring dosimeters to prevent radioactive contamination.

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