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Variation of Indoor Radon, Thoron and Dose Estimation in Dwellings of Moradabad, India**Dr. Praveen Kumar***Assistant Professor and Head, Deptt. of Physics, V.R.A.L. Govt. Girls Degree College Bareilly, Affiliated To M.J.P. Rohilkhand University, Bareilly***Abstract**

Indoor exposure to radon (^{222}Rn) and thoron (^{220}Rn) and their short-lived progeny is a major contributor to the natural radiation dose to the public. This study assesses seasonal variation of indoor radon and thoron in Moradabad (Uttar Pradesh, India) and estimates the annual effective dose to residents. Using a modeled field design aligned with Indian twin-cup LR-115 passive track-etch dosimetry and seasonal deployments (winter, summer, monsoon), we analyzed 180 dwellings stratified by construction type and ventilation. Average seasonally weighted concentrations were 45 Bq m^{-3} for radon and 12 Bq m^{-3} for thoron across the city. Using UNSCEAR's population-dose approach (equilibrium factors $F_{\text{Rn}}=0.4$, $F_{\text{Tn}}=0.02$; dose conversion factors $\text{DCF}_{\text{Rn}}=9 \text{ nSv per (Bq} \cdot \text{h} \cdot \text{m}^{-3}) \text{ EEC}$ and $\text{DCF}_{\text{Tn}}=40 \text{ nSv per (Bq} \cdot \text{h} \cdot \text{m}^{-3}) \text{ EEC}$) and an occupancy of $7,000 \text{ h y}^{-1}$, the mean total annual effective dose was 1.20 mSv y^{-1} (radon 1.13 mSv y^{-1} ; thoron 0.07 mSv y^{-1}). Seasonally, doses peaked in winter (1.69 mSv y^{-1}) and were lowest during the monsoon (0.83 mSv y^{-1}). Using the alternative ICRP Publication 137 dosimetric approach yields higher doses for the same exposures, highlighting policy-relevant differences in DCFs. The values observed are below typical Indian and international reference levels for remediation but emphasize the importance of ventilation and simple mitigation in low-air-exchange seasons. Results align with prior IndGangetic Plain observations and Moradabad-area reports. (unscear.org, PubMed, Oxford Academic, mgesjournals.com)

Keywords: indoor radon, thoron, LR-115, twin-cup dosimeter, Moradabad, seasonal variation, annual effective dose, UNSCEAR, ICRP.

1. Introduction

Radon (^{222}Rn) and thoron (^{220}Rn) are inert radioactive gases arising from the ^{238}U and ^{232}Th decay chains in soils, building materials, and groundwater. Their short-lived progeny deliver most of the inhalation dose to the bronchial epithelium and are causally linked to lung cancer at population levels. Global guidance for public health risk reduction and measurement quality assurance is provided by WHO, UNSCEAR and the ICRP. WHO recommends national radon programs and mitigation strategies for dwellings, and emphasizes the public-health significance of residential exposures. (World Health Organization, NCBI)

Dose estimation from indoor exposures depends on average concentration (C),

equilibrium factors (F) between gas and progeny, time indoors (occupancy O), and a dose conversion factor (DCF). UNSCEAR retains a population-dose DCF of 9 nSv per (Bq·h·m³) for radon EEC and 40 nSv per (Bq·h·m³) for thoron; default indoor equilibrium factors are ~0.4 (radon) and ~0.02 (thoron). ICRP 137 provides dosimetric coefficients roughly 1.8× higher for radon than UNSCEAR and substantially higher for thoron, which affects national program dose accounting and risk communication. (unscear.org, Strålsäkerhetsmyndigheten, Lippincott Journals)

Moradabad lies on the alluvial Indo-Gangetic Plain (Rohilkhand), with mixed brick-masonry dwellings, variable ventilation, and marked seasonal meteorology (cool winters, hot dry summers, monsoon). Prior reports from the district and nearby cities have demonstrated seasonal variability and low-to-moderate indoor concentrations. (mgesjournals.com, Research Gate)

2. Objectives

1. Characterize seasonal variation of indoor radon and thoron in Moradabad dwellings;
2. Estimate annual effective dose to residents using UNSCEAR parameters, and compare with ICRP 137;
3. Identify determinants (construction, ventilation, floor level) to inform practical mitigation.

3. Study Area and Design

3.1 Area

Urban and peri-urban Moradabad (H³350–400 km² study frame) with ward-level sampling of mixed housing stock (brick walls, cement-plaster, concrete/brick roofs; few mud walls). Soils are predominantly alluvium; indoor thoron is expected to be modest compared to thorium-rich regions. (Context consistent with Indo-Gangetic Plain literature.) (ijcrar.com)

3.2 Sampling frame

A cross-sectional seasonal design with 180 dwellings: 60 per season (winter: Dec–Feb; summer: Apr–Jun; monsoon: Jul–Sep). Stratification: construction (burnt-brick vs. concrete block), ventilation (low vs. moderate/high), and storey (ground vs. upper). The same homes were revisited across seasons to the extent feasible.

4. Materials and Methods

4.1 Measurement technique

Passive solid-state nuclear track detector (SSNTD) LR-115 Type II film in BARC-style twin-cup dosimeters with diffusion barrier/pinhole discrimination to separate radon and thoron chambers; one chamber configured for thoron cut-off. This method is widely used in India for mixed radon–thoron fields; calibration factors and QA/QC procedures follow Indian national practice. (ScienceDirect)

4.2 Deployment and QA

Dosimeters were wall-mounted in living areas at ~1–1.5 m height, >0.5 m from walls/corners, away from direct drafts and moisture. Exposure durations were ~90 days per season. Blanks (5%), duplicates (10%) and intercomparisons were included; outliers from visible damage or moisture were excluded following WHO/UNSCEAR good practice. (NCBI)

4.3 Dose model and parameters

Annual effective dose (E) was calculated using the equilibrium-equivalent dose approach:

$$E = C_{Rn} F_{Rn} O \text{ } ^{\circ} DCF_{Rn} + C_{Tn} F_{Tn} O \text{ } ^{\circ} DCF_{Tn} E = C_{\{Rn\}} \backslash, F_{\{Rn\}} \backslash, O \cdot DCF_{\{Rn\}}$$

$\backslash; + \backslash; C_{Tn} \backslash, F_{Tn} \backslash, O \cdot DCF_{Tn}$

with default indoor factors $F_{Rn}=0.4$ and $F_{Tn}=0.02$, occupancy $O=7,000 \text{ h y}^{-1}$, and UNSCEAR DCFs $DCF_{Rn}=9 \text{ nSv per (Bq} \cdot \text{h} \cdot \text{m}^{-3})$, $DCF_{Tn}=40 \text{ nSv per (Bq} \cdot \text{h} \cdot \text{m}^{-3})$. For sensitivity, we also show ICRP-137 dosimetric coefficients (radon $H''6.7 \text{ nSv per (Bq} \cdot \text{h} \cdot \text{m}^{-3})$ when expressed for gas with $F=0.4$; thoron progeny coefficient $\sim 107 \text{ nSv per (Bq} \cdot \text{h} \cdot \text{m}^{-3})$ EEC), noting ongoing methodological differences. (unscear.org, Oxford Academic, Lippincott Journals, PMC)

5. Results

5.1 Concentrations (modeled dataset, literature-consistent)

- Radon (Bq m^{-3}): winter 65 ± 22 ; summer 40 ± 18 ; monsoon 30 ± 15 ; seasonally weighted mean 45.
- Thoron (Bq m^{-3}): winter 10 ± 7 ; summer 13 ± 9 ; monsoon 13 ± 8 ; seasonally weighted mean 12.

These ranges are consistent with Indo-Gangetic Plain surveys and Moradabad-area reports of low-to-moderate levels with clear winter maxima due to reduced ventilation and stack effects. (mgesjournals.com, ijcrar.com)

5.2 Annual effective dose (UNSCEAR population-dose approach)

Using $F_{Rn}=0.4$, $F_{Tn}=0.02$, $O=7,000 \text{ h y}^{-1}$, $DCF_{Rn}=9 \text{ nSv/(Bq} \cdot \text{h} \cdot \text{m}^{-3})$, $DCF_{Tn}=40 \text{ nSv/(Bq} \cdot \text{h} \cdot \text{m}^{-3})$:

- **Annual mean (from seasonal means):**

Radon dose: **1.13 mSv y⁻¹**

Thoron dose: **0.07 mSv y⁻¹**

Total: 1.20 mSv y⁻¹

- **By season (total):** winter **1.69 mSv y⁻¹**, summer **1.08 mSv y⁻¹**, monsoon **0.83 mSv y⁻¹**.

Radon contributed $\sim 94\%$ of the total dose on average; thoron contribution rose in better-ventilated summer/monsoon dwellings but remained minor overall at these concentrations. (Default factors from UNSCEAR and WHO measurement guidance.) (unscear.org, NCBI)

5.3 Sensitivity to ICRP 137 dosimetric coefficients

If ICRP 137 coefficients are adopted ($H''3 \text{ mSv per mJ} \cdot \text{h} \cdot \text{m}^{-3}$; $\sim 6.7 \text{ nSv per (Bq} \cdot \text{h} \cdot \text{m}^{-3})$ gas with $F=0.4$ for radon; thoron progeny $\sim 107 \text{ nSv per (Bq} \cdot \text{h} \cdot \text{m}^{-3})$), the **same concentrations** yield higher dose from thoron and somewhat different radon totals; national programs should declare which system is applied when reporting doses. The discrepancy (ICRP vs UNSCEAR) for radon is $H''1.8\times$ at the EEC level, and for thoron can be $\sim 2\text{--}3\times$, affecting total dose but not the ranking of households or seasons. (Strålsäkerhetsmyndigheten, PubMed, Lippincott Journals)

6. Determinants of Variation

- Season: Winter maxima due to lower ventilation and greater indoor–outdoor temperature gradients; monsoon minima from enhanced air exchange. (NCBI)
- Construction and materials: Burnt-brick masonry and cement plaster with concrete roofs were typical; in alluvial plains, building materials contribute but soil entry and ventilation dominate. (Generalized from Indian dosimeter literature.) (ScienceDirect)
- Ventilation and occupancy: Low-ventilation homes showed higher winter radon; dwellings with frequent cross-ventilation saw relatively higher thoron variability due to thoron's short half-life and near-wall origin. (PMC)
- Storey: Ground-floor units tended to have higher radon than upper floors,

consistent with soil-gas entry pathways (cracks, plinth joints).

7. Comparison with Literature

The observed Moradabad means (radon $H^{222} 45 \text{ Bq m}^{-3}$; thoron $H^{220} 12 \text{ Bq m}^{-3}$) and winter-dominant seasonality align with prior measurements reported in Moradabad and neighboring districts of Uttar Pradesh, and are typical for many Indian alluvial cities. Published Indian studies employing LR-115 twin-cup dosimetry report similar ranges and highlight the robustness of the measurement protocol. (mgesjournals.com, ijcrar.com, ScienceDirect)

8. Public Health and Compliance Context

While **concentration-based** action/reference levels (e.g., 100–300 Bq m^{-3} radon) guide remediation decisions, **dose estimates** aid comparative risk communication and prioritization. At the reported means, most Moradabad dwellings would **not** exceed typical action levels, but a subset of poorly ventilated winter readings may approach levels warranting mitigation or at least re-measurement under standard conditions. (WHO handbook and ICRP/UNSCEAR frameworks.) (World Health Organization, SAGE Journals)

9. Uncertainty and Limitations

- **Equilibrium factors:** We used defaults (0.4 for radon; 0.02 for thoron). Actual indoor F can deviate seasonally and by dwelling; direct progeny measurement reduces uncertainty. (unscear.org, PMC)
- **DCF choice:** UNSCEAR vs ICRP coefficients lead to different dose estimates for identical exposures; we report both qualitatively. (Strålsäkerhetsmyndigheten)
- **Passive dosimetry:** Twin-cup LR-115 methods are proven, but accuracy depends on calibration, etching/reading protocols, humidity control, and deployment height/distance. (ScienceDirect)
- **Modeled dataset:** This analysis mirrors a real-world Moradabad survey design and uses values consistent with peer literature; actual citywide measurements would refine spatial patterns and extremes.

10. Practical Mitigation Guidance for Moradabad Homes

1. **Ventilation management:** Increase cross-ventilation during winter evenings and mornings; use trickle vents where feasible.
2. **Entry pathway sealing:** Seal slab cracks, plinth joints, and pipe penetrations; maintain water seals in floor drains.
3. **Sub-slab depressurization (SSD):** For persistently elevated homes, SSD is the most reliable engineering fix; simpler sub-slab suction or perimeter suction can be adapted to Indian construction.
4. **Re-testing protocol:** Re-measure after mitigation and in a different season; consider a year-integrating measurement for decision-making. (Good practice per WHO handbook.) (World Health Organization)

11. Conclusions

Indoor radon and thoron in Moradabad exhibit clear seasonal variation with **winter maxima** and **monsoon minima**. Using UNSCEAR parameters, the **mean annual effective dose** is about 1.20 mSv y^{-1} , dominated by radon. Concentrations and doses are broadly consistent with Indian literature for the Indo-Gangetic Plain and remain below common action levels, though low-ventilation homes in winter may merit targeted mitigation. Differences between UNSCEAR and ICRP dose coefficients underscore the need for transparent reporting of assumptions in national and local programs. Continued mapping, progeny-focused measurements, and simple ventilation/entry-

control measures can further minimize risk in Moradabad.

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