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*Original Research Article*

# Assessment of Annual Tracheobronchial Effective Dose from Indoor Radon Inhalation in Selected Residential Buildings in Southwestern Nigeria

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## ABSTRACT

**Background and Purpose:** Radon-222 is a major human health challenge among all sources of ionizing radiation. For most people, the greatest exposure to radon comes from homes and affects mainly the respiratory tract, especially the tracheobronchial region. This work assesses the annual tracheobronchial effective dose from indoor radon inhalation in residential buildings with different covering materials for walls, ceilings and floor using different dosimetric lung models.

**Method:** A total of 180 residential buildings with commonest combination of covering materials in some cities in South-western Nigeria were investigated using an active electronic radon gas detector, RAD 7. The commonest combination of covering materials were (A): paint, paint, carpet; (B): paint fiber board, plastic tiles; (C): paint, fiber board, ceramic tiles for walls, ceilings and floors respectively.

**Result:** The mean indoor radon concentration measured ranged between 23.08 Bq $m^{-3}$ and 72.14 Bq $m^{-3}$ for all the residential buildings investigated. Buildings with covering materials C, presented the highest radon concentration. Generally, the mean indoor radon concentration for all combinations of covering materials in all the cities investigated were found to be lower than the recommended action level of 200 $Bqm^{-3}$ and the reference level of 100 $Bqm^{-3}$ set by International Commission on for Radiation Protection and World Health Organization respectively. The annual tracheobronchial effective dose estimated for the different lung dose models ranged from 0.91 mSv – 3.27 mSv for combination (A), 1.00 mSv - 3.60 mSv for combination (B) and 1.09 mSv – 3.94 mSv for combination (C). It revealed that the more recent model gives greater value of the annual tracheobronchial effective dose. It was observed that only the annual tracheobronchial effective doses obtained by the James model presented values that are within the recommended ICRP intervention level of (3-10) $mSvy^{-1}$. Other models gave values of annual tracheobronchial effective doses below the ICRP recommended intervention levels.

**Conclusion:** These imply that all the residential buildings and the different combination of covering materials surveyed in this work will not pose any radiological hazard to the inhabitants.

***Keywords:*** Indoor Radon Inhalation, Radon-222, annual tracheobronchial effective dose, residential buildings

## INTRODUCTION

Radon-222 is a noble gas produced by the radioactive decay of radium-226, which is widely distributed in uranium-containing soils and rocks. The radon readily escapes from the soil or rock where it is generated and enters surrounding water or air. Radon-2 22 decays with a half-life of 3.82 days into a series of short-lived radioisotopes collectively referred to as *radon daughters* or *progeny*. Since it is chemically inert, most inhaled radon-222 is rapidly exhaled, whereas inhaled progeny readily deposit in the air ways of the lung. The nongaseous $^{222}$Rn decay products are partially suspended in air as a mixture of attached and unattached fractions and partially deposited on walls and furniture. (1) In recent years, exposure to radon gas has become a global concern due to its health hazards inside dwellings. (2,3) Radon as a cause of leukemia has also been discussed. (4,5) Subsequent to radon decay into a series of solid short-lived radioisotopes, there are depositions within the respiratory tract where the airways' sensitive cells are irradiated mainly by two of these short-lived progenies(polonium-218 and polonium-214) which are alpha emitters. Inhalation of these radon progeny $^{218}$Po,$^{214}$Pb, and $^{214}$Bi(Pb) in homes and working places constitutes the highest exposure to natural radiation for the general public. (6,7,8,9,10) The energy of the alpha particles dominates dose to the lungs and the associated risk of lung cancer.

The ICRP 66 lung dosimetric models (11) employed in this work makes it possible to calculate the absorbed doses expected to be received by different parts of the respiratory tract. The various lung dosimetric models used in this work consider the respiratory tract as four anatomical regions; Extrathoracic region (ET); Bronchial region (BB); Bronchiolar region (bb) and Alveolar-intestinal region (AI). Since majority of lung cancer originate from the Bronchial (BB) region, the estimation of the annual tracheobronchial effective doses (mSvy$^{-1}$) from radon for buildings with different combination of covering materials in this work was based on the Bronchial region, (BB) consisting of the trachea and bronchi which is known as the tracheobronchial (T-B) tree. Traditionally, for over five decades, dosimetric approaches are being employed to derive the effective dose per potential alpha energy exposure known as the Dose Conversion Factors (DCF) in mSv/WLM. (12-18) Improvement of the dosimetric lung model has resulted in a better understanding of the model parameters, and the availability of more reliable values thus leading to increasing certainty in the values of the DCFs. Knowledge of DCFs from various lung dosimetric models has assisted in the calculation of dose from radon and its daughter products to different parts of the lungs. Among these are Weibel lung model, (19) ICRP lung model (20) and Yeh-Schum lung model. (21) These models differ from each other by the division of lungs into different parts (generations), the air ways dimension of the generations and the transfer mechanism of daughter product of radon from lungs to other parts of the human body. (22)

It is believed to cause 10% of lung cancer causes in the United States each year. (23) The concentration of radon gas in dwellings has been discovered to depend on meteorological and geological conditions, construction materials and ventilation. (24) The major contributor to the indoor radon concentration is the soil beneath the building. (25) This work seeks to assess the annual tracheobronchial effective dose due to indoor radon inhalation in residential buildings with different covering materials in some cities in south-western Nigeria using the different lung models.

## MATERIALS AND METHOD

### Sampling

For the purpose of this work, six cities (Ogbomoso, Ibadan, Oshogbo, Abeokuta, Ewekoro and Idanre) in south-western Nigerian were selected based on reported geological formations and level of background radiation. (26-29) A total of 180 buildings, (30 per city) with different covering materials were surveyed on a random basis to investigate the radon concentration. The major combinations of covering materials for the walls, ceilings and floors in the cities surveyed in south-western Nigeria are shown in Table 1.

**Table 1: The major combinations of internal covering materials in major cities in south-western Nigeria**

| **Combination** | **Wall** | **Ceiling** | **Floor** |
|---|---|---|---|
| **A** | Paint | Paint | Carpet |
| **B** | Paint | Fiber board | Plastic tiles |
| **C** | Paint | Fiber board | Ceramic tiles |

## Experimental Measurement

In this work, a well calibrated active electronic radon detector (RAD7), with an accuracy below 5% (Durridge, 2020 RAD7 Electronic radon Detector User Manual was employed. (30) The detector is designed to be plugged into a standard household main outlet. It is a portable, easy to use and very sensitive device. RAD7 is an electronic radon detector with spectral analysis. RAD7 is based on a solid-state detector and principle of operation is the electrostatic collection of alpha-emitters with spectral analysis. It is a real-time continuous radon monitor. This means that a varied radon concentration level can be observed during a measurement period. The detailed setup of the radon equipment used for the measurement is as shown in Figure 1. This device has a pump to send the air over the detection system in order to be able to operate with a constant flow rate of 1 l/min. The nominal sensitivity of this system in continuous mode is 0.5 counts/min/pCi/L. The spot measurements were carried out in residential buildings in southwestern, Nigeria. The measurement points were set at 1.5 m above ground level. Sniff mode and circle time was set to be 30 min in accordance with running time of each path of the valve. In order to investigate radon released into the building, the sample was enclosed into a column and airborne radon was measured. Figure 1 shows the schematic representation of the RAD7 equipment used in this study.

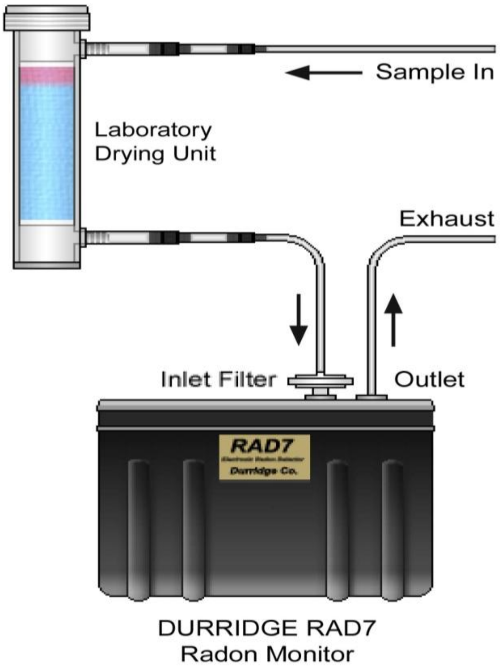

**Figure 1: Schematic Representation of the RAD 7 Equipment (www.durridge.com)**

## Dose Conversion Factors

The ICRP 66 lung dosimetric models employed in this work makes it possible to calculate the absorbed doses expected to be received by different parts of the respiratory tract. The various lung dosimetric models used in this work consider the respiratory tract as four anatomical regions;

(i) Extrathoracic region (ET)
(ii) Bronchial region (BB)
(iii) Bronchiolar region (bb)
(iv) Alveolar-intestinal region (AI)

Since majority of lung cancer originate from the Bronchial (BB) region, the estimation of the annual tracheobronchial effective doses ($mSvy^{-1}$) from radon for buildings with different combination of covering materials in this work was based on the Bronchial region, (BB) consisting of the trachea and bronchi which is known as the tracheobronchial (T-B) tree. Figure 2 shows the anatomical region as given by ICRP. (31)

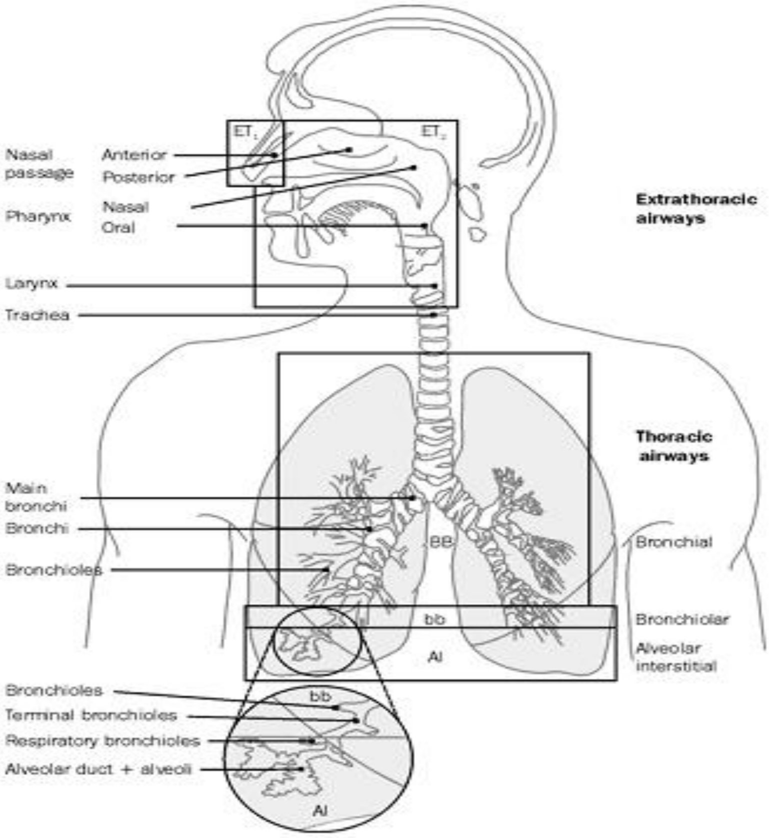

**Figure 2: The anatomical regions of the human lung (ICRP, 1994)**

The ICRP66 lung model was employed in this work because it reviews the old models thereby proposing modifications and improvement of the existing respiratory tract models. The model makes it possible to calculate the absorbed doses expected to be received by different parts of the respiratory tract. The most commonly used lung dose dosimetric model employed in the ICRP 66 lung model are:

1. Jacobi-Eisfeld (J-E) dose model which uses Weibel lung model (16)
2. James-Birchall (J-B) dose model which considers Weibel and Yeh-Schum lung models. (32)
3. The James model which uses the Yeh-Schum model. (33)
4. National Research Council dose model which takes into account the ICRP model. (18)

These models arrived at different dose conversion factors to be used for the calculation of the effective dose to the tracheobronchial (T-B) region of the lung.

For the J-E and J-B models, the dose conversion factors in mSvWLM$^{-1}$are respectively expressed in equations 1 and 2. (34)

$5.3 + 15f_p$ (1)

$5.0 + 62f_p$ (2)

James and NRC models commonly presented a mathematical expression of their models (33) as shown in eqn (3)

$T_{T\text{-}B} = f_pD_u + (1- f_p)D_a$ (3)

Where $D_u$ is dose conversion factor for unattached progeny, $D_a$ = dose conversion factor for attached progeny and $f_p$ is the unattached fraction

Despite the common expressions of James and NRC models (equation 3), the values of $D_u$ and $D_a$ were estimated in James model to be 150 and 7.0 mSvWLM$^{-1}$ respectively, whereas for NRC model, $D_u$ and $D_a$ were estimated to be 80.9 and 7.86 mSvWLM$^{-1}$ respectively. The average unattached fraction of 0.13 (24) (Yu *et al.*, 1998) was employed in all the calculations. With an indoor occupancy factor of 0.4 and the tissue weighting factor of 0.06 for the T-B region, the dose conversion factor for the models of J-E, J-B, James and NRC were respectively computed as 0.010, 0.0185, 0.036 and 0.0245 $mSvWLM^{-1}$

## Annual Tracheobronchial Effective Dose

In order to estimate the annual tracheobronchial effective dose received by the inhabitants of these buildings, one has to take into account the dose conversion factor for the models employed in this work and the indoor occupancy factor. Based on ICRP, (34) at a certain radon concentration C in $Bq/m^3$, the annual absorbed dose, $D_{Rn}$ is usually expressed (in equation 4) in the unit of $mSv\ y^{-1}$ as

$D_{Rn}(mSvy^{-1}) = C_{Rn}.\ D.\ H.\ F.T$ (4)

Where

$C_{Rn}$ = concentration of radon; F = radon equilibrium factor (0.4) ; H = indoor occupancy factor. T is the indoor occupancy time 24h x 365 = 8760h/y and D = dose conversion factor using different dosimetric lung model.

The occupancy factor, 0.8 (34) (ICRP, 1993), valid for inhabitants of the cold climate zone had been reported to over estimates the excess cancer risk in tropical region. (35) Therefore an occupancy factor of 0.4 (40%) as reported by (35) was used for this study.

To calculate the annual effective dose to the tracheobronchial region of the lung, a tissue and radiation weighting factor has to be applied according to ICRP. (36) The annual tracheobronchial effective dose is then calculated according to the equation below:

$H_E\ (mSvy^{-1}) = D_{Rn}\ .W_R.W_T$ (5)

where, $D_{Rn}$ is annual absorbed dose rate ; $W_R$ is Radiation weighting factor for alpha particles, 20 and $W_T$ = Tissue weighting factor for the tracheobronchial region of the lung is 0.06.

## RESULT

### The Indoor Radon Concentration

The indoor radon concentration measured for all the 180 residential buildings surveyed in the six cities for the different covering materials are presented in Table 2 to Table 7.

**Table 2: Indoor Radon concentration for Different Covering Materials (Ogbomoso)**

| S/N | COMBINATION A | | COMBINATION B | | COMBINATION C | |
|---|---|---|---|---|---|---|
| | Age (Yr) | Concentration ($Bq\ m^{-3}$) | Age (Yr) | Concentration ($Bq\ m^{-3}$) | Age (Yr) | Concentration ($Bq\ m^{-3}$) |
| **1.** | 12 | 37.24 ± 1.24 | 5 | 33.38 ± 1.24 | 8 | 51.80 ± 3.01 |
| **2.** | 6 | 33.36 ± 1.52 | 9 | 33.81 ± 1.59 | 11 | 55.58 ± 1.47 |
| **3.** | 8 | 29.60 ± 1.69 | 7 | 37.62 ± 1.64 | 12 | 59.20 ± 1.63 |
| **4.** | 8 | 33.30 ± 1.04 | 8 | 40.72 ± 1.73 | 14 | 62.94 ± 1.05 |
| **5.** | 6 | 29.64 ± 1.08 | 10 | 37.14 ± 2.03 | 12 | 59.24 ± 1.41 |
| **6.** | 4 | 25.96 ± 1.72 | 8 | 40.12 ± 2.14 | 13 | 55.51 ± 2.14 |
| **7.** | 7 | 29.63 ± 2.14 | 11 | 44.61 ± 1.13 | 7 | 55.08 ± 1.52 |
| **8.** | 6 | 29.68 ± 1.94 | 13 | 48.16 ± 1.41 | 9 | 55.64 ± 2.32 |
| **9.** | 10 | 33.34 ± 1.63 | 8 | 44.42 ± 1.52 | 10 | 48.18 ± 1.25 |
| **10** | 12 | 33.31 ± 2.31 | 11 | 48.18 ± 1.23 | 9 | 51.82 ± 1.31 |
| **Mean** | | **31.51 ± 3.18** | | **40.82 ± 5.42** | | **55.50 ± 4.27** |

**Table 3: Indoor Radon Concentration for Different Covering Materials (Ibadan)**

| S/N | COMBINATION A | | COMBINATION B | | COMBINATION C | |
|---|---|---|---|---|---|---|
| | Age (Yr) | Concentration ($Bq\ m^{-3}$) | Age (Yr) | Concentration ($Bq\ m^{-3}$) | Age (Yr) | Concentration ($Bq\ m^{-3}$) |
| **1.** | 5 | 29.63 ± 1.89 | 6 | 33.32 ± 1.85 | 12 | 55.53 ± 2.21 |
| **2.** | 4 | 33.30 ± 1.48 | 4 | 37.20 ± 1.78 | 9 | 48.12 ± 1.38 |
| **3.** | 15 | 40.74 ± 1.73 | 3 | 29.64 ± 2.28 | 11 | 51.50 ± 1.48 |
| **4.** | 6 | 33.38 ± 1.93 | 10 | 44.42 ± 1.35 | 8 | 59.24 ± 3.05 |
| **5.** | 7 | 33.32 ± 2.32 | 8 | 40.70 ± 1.28 | 15 | 62.96 ± 1.83 |
| **6.** | 5 | 29.60 ± 1.83 | 14 | 48.10 ± 1.48 | 16 | 59.20 ± 1.24 |
| **7.** | 9 | 37.02 ± 2.08 | 16 | 51.02 ± 1.93 | 10 | 44.49 ± 1.49 |
| **8.** | 8 | 37.58 ± 1.53 | 7 | 33.04 ± 2.27 | 11 | 55.54 ± 1.89 |
| **9.** | 6 | 40.72 ± 1.62 | 11 | 44.40 ± 1.28 | 14 | 51.81 ± 2.25 |
| **10** | 11 | 38.94 ± 1.94 | 9 | 37.08 ± 1.48 | 21 | 62.93 ± 1.26 |
| **Mean** | | **35.42 ± 4.17** | | **39.90 ± 7.02** | | **55.13 ± 6.17** |

**Table 4: Indoor Radon Concentration for Different Covering Materials (Osogbo)**

| S/N | COMBINATION A | | COMBINATION B | | COMBINATION C | |
|---|---|---|---|---|---|---|
| | **Age (Yr)** | **Concentration ($Bq\ m^{-3}$)** | **Age (Yr)** | **Concentration ($Bq\ m^{-3}$)** | **Age (Yr)** | **Concentration ($Bq\ m^{-3}$)** |
| **1.** | 6 | 33.34 ± 1.38 | 8 | 37.03 ± 1.47 | 10 | 59.28 ± 1.96 |
| **2.** | 8 | 37.03 ± 1.92 | 10 | 44.49 ± 1.20 | 8 | 55.85 ± 3.07 |
| **3.** | 6 | 29.62 ± 2.39 | 7 | 40.77 ± 2.35 | 12 | 59.28 ± 1.73 |
| **4.** | 8 | 40.71 ± 1.46 | 10 | 48.18 ± 1.48 | 16 | 62.91 ± 2.36 |
| **5.** | 11 | 37.32 ± 1.32 | 12 | 44.24 ± 1.19 | 9 | 55.73 ± 1.71 |
| **6.** | 13 | 40.73 ± 2.27 | 11 | 48.53 ± 1.20 | 8 | 48.24 ± 2.13 |
| **7.** | 10 | 33.39 ± 1.58 | 7 | 37.08 ± 2.13 | 6 | 51.56 ± 1.29 |
| **8.** | 8 | 37.41 ± 1.38 | 15 | 48.51 ± 1.59 | 10 | 55.27 ± 1.29 |
| **9.** | 9 | 36.03 ± 1.47 | 12 | 44.84 ± 1.39 | 13 | 62.93 ± 3.39 |
| **10** | 5 | 37.44 ± 2.31 | 13 | 51.58 ± 3.21 | 11 | 51.86 ± 1.72 |
| **Mean** | | **36.30 ± 3.42** | | **44.53 ± 4.95** | | **56.30 ± 4.88** |

**Table 5: Indoor Radon Concentration for Different Covering Materials (Ewekoro)**

| S/N | COMBINATION A | | COMBINATION B | | COMBINATION C | |
|---|---|---|---|---|---|---|
| | **Age (Yr)** | **Concentration ($Bq\ m^{-3}$)** | **Age (Yr)** | **Concentration ($Bq\ m^{-3}$)** | **Age (Yr)** | **Concentration ($Bq\ m^{-3}$)** |
| **1.** | 12 | 62.04 ± 1.74 | 15 | 64.23± 1.01 | 15 | 68.46 ± 2.03 |
| **2.** | 11 | 56.24± 1.83 | 12 | 58.71 ± 1.92 | 08 | 58.28 ± 1.091 |
| **3.** | 10 | 40.24 ± 1.79 | 15 | 73.14 ± 1.38 | 12 | 64.24 ± 1.84 |
| **4.** | 7 | 38.40 ± 2.14 | 11 | 43.84 ± 2.83 | 18 | 77.22 ± 3.10 |
| **5.** | 12 | 55.28 ± 1.92 | 12 | 61.73 ± 1.29 | 14 | 62.03 ± 1.76 |
| **6.** | 10 | 42.14 ± 2.22 | 19 | 71.47 ± 1.49 | 10 | 56.17 ± 1.29 |
| **7.** | 18 | 64.30 ± 1.94 | 10 | 56.92 ± 1.39 | 12 | 60.42± 3.04 |
| **8.** | 21 | 72.04 ± 1.73 | 13 | 69.51 ± 3.06 | 22 | 78.58 ± 1.08 |
| **9.** | 14 | 53.08 ± 1.74 | 9 | 46.89 ± 1.22 | 14 | 68.34 ± 2.47 |
| **10** | 16 | 70.23 ± 2.65 | 17 | 71.32 ± 2.37 | 16 | 76.62 ± 1.62 |
| **Mean** | | **55.40 ± 12.11** | | **61.78 ± 10.31** | | **67.04 ± 8.19** |

**Table 6: Indoor Radon Concentration for Different Covering Materials (Abeokuta )**

| S/N | COMBINATION A | | COMBINATION B | | COMBINATION C | |
|---|---|---|---|---|---|---|
| | **Age (Yr)** | **Concentration ($Bq\ m^{-3}$)** | **Age (Yr)** | **Concentration ($Bq\ m^{-3}$)** | **Age (Yr)** | **Concentration ($Bq\ m^{-3}$)** |
| **1.** | 13 | 62.34 ± 1.20 | 8 | 52.43 ± 1.98 | 11 | 70.58 ± 2.83 |
| **2.** | 11 | 70.41 ± 1.39 | 14 | 82.04 ± 2.37 | 13 | 83.47 ± 1.17 |
| **3.** | 18 | 80.42 ± 2.73 | 12 | 66.52 ± 1.59 | 10 | 62.43 ± 3.76 |
| **4.** | 19 | 72.08 ± 1.69 | 10 | 78.01 ± 1.64 | 8 | 57.43 ± 2.28 |
| **5.** | 8 | 58.80 ± 1.93 | 12 | 64.46 ± 1.53 | 12 | 80.44 ± 1.48 |
| **6.** | 10 | 79.52 ± 1.82 | 14 | 83.00 ± 1.59 | 15 | 66.20 ± 1.29 |
| **7.** | 12 | 61.14 ± 2.24 | 12 | 72.35 ± 3.31 | 15 | 68.84 ± 3.01 |
| **8.** | 11 | 63.48 ± 1.05 | 16 | 60.32 ± 1.83 | 12 | 73.48 ± 1.13 |
| **9.** | 16 | 78.73 ± 1.77 | 11 | 83.42 ± 2.53 | 11 | 82.51 ± 2.18 |
| **10** | 10 | 60.05 ± 2.55 | 15 | 74.20 ± 1.63 | 14 | 76.04 ± 1.37 |
| **Mean** | | **68.67 ± 8.61** | | **71.68 ± 10.53** | | **72.14 ± 8.70** |

**Table 7: Indoor Radon Concentration for Different Covering Materials (Idanre)**

| S/N | COMBINATION A | | COMBINATION B | | COMBINATION C | |
|---|---|---|---|---|---|---|
| | **Age (Yr)** | **Concentration ($Bq\ m^{-3}$)** | **Age (Yr)** | **Concentration ($Bq\ m^{-3}$)** | **Age (Yr)** | **Concentration ($Bq\ m^{-3}$)** |
| **1.** | 8 | 19.24 ± 1.28 | 10 | 22.38 ± 1.28 | 8 | 23.30 ± 1.29 |
| **2.** | 6 | 18.52 ± 1.39 | 8 | 19.86 ± 2.36 | 16 | 31.86 ± 3.65 |
| **3.** | 10 | 20.31 ± 2.29 | 7 | 27.48 ± 1.18 | 8 | 24.31 ± 3.34 |
| **4.** | 18 | 31.43 ± 1.19 | 11 | 23.08 ± 3.03 | 13 | 33.34 ± 1.78 |
| **5.** | 10 | 24.08 ± 1.32 | 11 | 26.81 ± 1.90 | 10 | 26.49 ± 1.864 |
| **6.** | 12 | 21.43 ± 2.16 | 6 | 19.24 ± 1.36 | 11 | 29.68 ± 2.25 |
| **7.** | 8 | 18.05 ± 1.053 | 12 | 24.16 ± 1.72 | 12 | 28.19 ± 2.21 |
| **8.** | 12 | 28.73 ± 1.39 | 13 | 32.18 ± 3.68 | 6 | 22.02 ± 1.73 |
| **9.** | 10 | 18.73 ± 2.45 | 8 | 28.32 ± 1.49 | 12 | 30.48 ± 1.33 |
| **10** | 15 | 30.24 ± 1.35 | 15 | 30.05 ± 2.52 | 10 | 28.43 ± 2.45 |
| **Mean** | | **23.08 ± 5.21** | | **25.36 ± 4.31** | | **27.81 ± 3.74** |

## Annual Tracheobronchial Effective Doses

Table 8 shows the result of the annual tracheobronchial effective dose calculated using different lung dosimetric models.

**Table 8: Annual tracheobronchial effective doses ($mSvy^{-1}$) calculated for buildings with different combinations of covering materials using different lung dose models**

| COMBINATION | J-E | J-B | NRC | JAMES |
|---|---|---|---|---|
| A | 0.91 | 1.68 | 2.23 | 3.27 |
| B | 1.00 | 1.85 | 2.45 | 3.60 |
| C | 1.09 | 2.02 | 2.68 | 3.94 |

## DISCUSSION

### ***Indoor Radon Concentration***

The mean indoor radon concentration measurement for all the cities surveyed ranged between 23. 08 Bqm$^{-3}$ and 68.67 Bqm$^{-3}$ for combination A; 25.36 Bqm$^{-3}$ and 71.68 Bqm$^{-3}$ for combination B and 27.81 Bqm$^{-3}$ and 72.14 Bqm$^{-3}$ for combination C. In all cities investigated, combination (C) contributed the highest to the indoor radon concentration while combination (A) contributed the least. The elevated concentration of indoor radon in combination C in all the cities investigated may be due the contribution of clay in the manufacturing of ceramic tiles in addition to that contributed by the wall and ceiling materials compare to plastic tiles and carpet in combination A and B which do not contain any form of soil or rock in their production. The mean indoor radon concentration were found to be significantly different ($p < 0.05$) among the different combination of covering materials indicating that building materials have significant effect on the indoor radon concentration in the study area.

The lowest indoor radon concentration was recorded in Idanre while the highest was recorded in Abeokuta. This observed variation could be as a result of the geological formations which earlier studies had identified Abeokuta to have the highest background radiation in the southwestern Nigeria. (37, 27, 38) The mean indoor radon concentration for all the combinations of covering materials in all the cities investigated were found to be higher than the world average of 40 Bq m$^{-3}$ with the exception of combination A for both Ogbomoso and Ibadan. However, the mean indoor radon concentration for all combinations of covering materials in all the cities investigated were found to be lower than the recommended action level of 200 Bqm$^{-3}$ set by ICRP (34) and the reference level of 100 Bqm$^{-3}$ WHO. (39) The result of this study with different combination of covering materials for the internal surfaces in most of the buildings were significantly low.

### ***Annual Tracheobronchial Effective Dose***

The annual tracheobronchial effective dose calculated for different lung dose models ranged from 0.91 – 3.27 mSv for combination (A), 1.00 - 3.60 mSv for combination (B) and 1.09 – 3.94 mSv for combination (C).

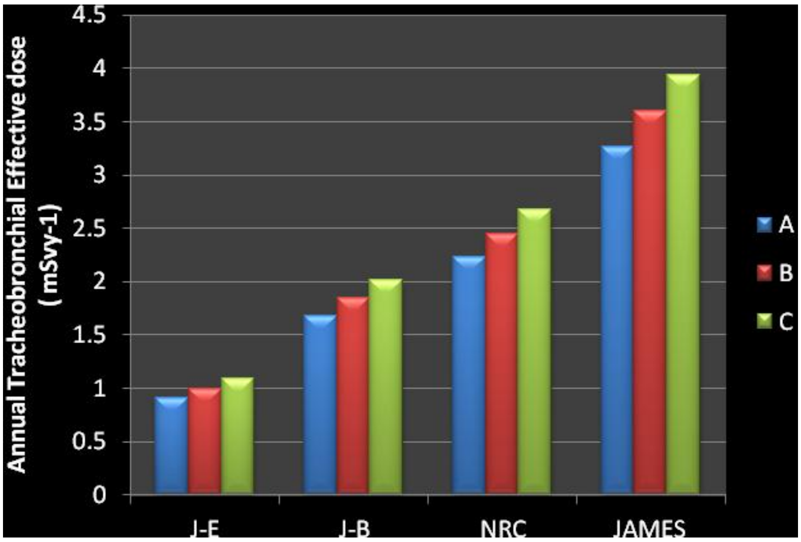

**Figure 3: Annual tracheobronchial effective doses (mSvy$^{-1}$) calculated for buildings with different combinations of covering materials using different lung dose models**

It was observed that only the annual tracheobronchial effective dose obtained by the James model presented the highest values and they were within the recommended ICRP intervention level of (3-10) $mSvy^{-1}$ (34) for all combination of covering materials. This study revealed that the more recent model indicates a greater value of radon (and progenies) inhaled dose to the lung, thereby in tandem with the WHO recent observation and reasons for lowering the indoor radon maximum contaminant level. (39)

## CONCLUSION

Assessment of annual tracheobronchial effective dose from indoor radon inhalation in residential buildings has been carried out using different dosimetric lung models with the aid of an active electronic radon detector. The mean indoor radon concentration for all combinations of covering materials in all the cities investigated were found to be lower than the recommended action level of 200 $Bqm^{-3}$ set by ICRP (34)) and the reference level of 100 $Bqm^{-3}$ set by WHO. (39) The result of the mean indoor radon concentration obtained in this study with different combination of covering materials for the internal surfaces in most of the buildings investigated were significantly low. It was observed that the annual tracheobronchial effective dose obtained by the James model falls within the recommended ICRP intervention level of (3-10) $mSvy^{-1}$ (34) while the Jacobi-Eisfeld, James-Birchall and the NRC models fall below the recommended ICRP intervention level for all combination of covering materials. (34) It also reveals that the more recent model gives greater value and that a person living in a building with combination (A) receive an annual dose smaller than someone living in combinations (B) and (C). These imply that all the residential buildings and the different combination of covering materials surveyed in this work will not pose any radiological hazard to the inhabitants.

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