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Original Research Article

Determination of Excess Relative Risk of Radon from Residential Buildings in Some Selected Cities in Southwestern, Nigeria

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ABSTRACT

Background and Purpose: One of the major causes of lung cancer has been traceable to the inhalation of radon (^{222}Rn) emanating from indoor residential and workplace buildings. Extensive measurements of radon concentrations in homes have shown that although concentrations vary widely, radon is universally present, raising concerns that radon in homes has a finite possibility of increasing lung-cancer risk for the general population.
Method: A total of 210 residential buildings (30 per city) with commonest combination of covering materials for walls, ceilings and floors in some cities in South-western Nigeria were investigated using RAD7 radon detector. 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 from 54.03Bq m^{-3} to 65.01 Bq m^{-3} for all the combinations investigated from city to city and were found to be higher than the world average of 40 Bq m^{-3} but lower than the recommended action level of 200 Bq m^{-3} set by International Committee on Radiological Protection(ICRP). A test of significance carried out using analysis of variance (ANOVA) revealed that there is significance difference ($p < 0.05$) in the radon concentration from one location to another and among different combinations of covering materials. The estimated lung cancer risk which lie between 13 per million person per year (MPY) to 63 MPY for USEPA, ICRP and UNSCEAR risk models were very low and comparable with data from many countries of the world according to UNSCEAR (1993). The excess relative risks (ERR) increases cumulatively with age up to 54 years and declines discontinuously for ages 55 upward for both the duration and concentration models. At age 75 and above, there is no noticeable difference in the increase in death rate between the duration and concentration models adopted by BEIR VI for all the combinations of covering materials.
Conclusion: This result showed vividly that the risk of developing lung cancer from radon exposure in residential buildings investigated increases with radon concentration and exposure duration with no known threshold concentration below which radon exposure presents no risk.

Key Words: lung cancer risk, indoor radon, covering materials, buildings, excess relative risk, radon concentration.

INTRODUCTION

Radon (Rn-222) is a radioactive gas, with a half-life of 3.8 days formed from radium-226 which is a decay product of Uranium-238. It emanates from rocks and soil and tend to concentrate in enclosed spaces such as underground mines, caves, basements and in buildings. The major source of residential radon is the ground beneath, building materials, and groundwater. The concentration of radon gas in dwellings has been discovered to depend on meteorological condition, geological condition, construction materials and ventilation. (1) It has been estimated that about 55% of the total effective dose received by human beings from all sources of ionizing radiation is attributed to radon and its short-lived progenies. (2) The inhalation of radon in residential buildings have been found to be carcinogenic to the lung and discovered to be the leading cause of lung cancer aside tobacco smoking which annual estimation in a country has been reported to cause between 3 – 14% of all lung cancer. (3,4,5) Radon decays into a series of solid short-lived radioisotopes which deposit within the respiratory tract where they irradiate sensitive cells in the airways. Two of these short-lived progeny, polonium-218 and polonium-214, emit alpha particles and the energy from these alpha particles delivers dose to the lungs thereby leading to the associated lung cancer risk. (6) It has been observed that people spend most of their time in residential buildings and are likely to receive most exposure at home. (7)

Studies of underground miners exposed occupationally to radon, usually at high concentrations, have consistently demonstrated an increased risk of lung cancer for both smokers and non-smokers. Based primarily on this evidence, radon was classified as a human carcinogen by the International Agency for Research on Cancer. (3) Since the 1980s, a large number of studies have directly examined the relationship between indoor radon and lung cancer in the general population. The investigators of the major studies in Europe, North America, and China have pooled their data together, and re-analyzed it centrally. (9,10,11,12,13) These three pooled-analyses present very similar pictures of the risks of lung cancer from residential exposure to radon. Together, they provide overwhelming evidence that radon is causing a substantial number of lung cancers in the general population and they provide a direct estimate of the magnitude of the risk. They also suggest that an increased risk of lung cancer cannot be excluded even below 200 Bq/m^3, which is the radon concentration at which action is currently advocated in many countries. In Africa, particularly Nigeria, attention has not been drawn to the health risk associated with radon exposure. Some measurements of radon concentration in offices and residential buildings are been carried out and reported. (14,15,16,17,18) Of late, research work and studies are however being extended in Nigeria to include measurement of indoor radon concentration and estimation of the radiological risk to organs and tissues due to radon exposure in different compartments of the environment. (19,20,21)

Extensive measurements of radon concentrations in homes show that although concentrations vary widely, radon is universally present, raising concerns that the observed increment of lung cancer cases among the general public could be due to radon exposure, especially those who spend a majority of their time indoors. There is therefore, a need to characterize the possible risks across the range of exposures received by the population. In this work, the lung cancer risk due to indoor ^{222}Rn emanating from residential buildings with different covering materials in some cities in South-western Nigeria is estimated.

MATERIALS AND METHOD

Sampling

For the purpose of this work, six cities (Ogbomoso, Ibadan, Oshogbo, Abeokuta, Ewekoro and Idanre) in southwestern Nigerian were selected and a total of 210 buildings, 30 in each city with different covering materials were surveyed on a random basis to investigate the radon concentration. A repeated measurement was carried out in one of the study sites at a different season, so as to investigate the seasonal variation. The choice of buildings surveyed in this work includes:

(i) those on the ground floor (since the sites on the ground level have higher indoor concentration due to additional radon source in the soil under the building).

(ii) those that were constructed from cement bricks.

(iii) those that fit into the three commonest combinations of covering materials surveyed.

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

A radon detector (RAD7), manufactured by Durridge Company, USA, was employed to measure indoor radon concentration. It is a portable, easy to use and very sensitive device. RAD7 is an active electronic radon detector with spectral analysis. Its operation is based on a solid-state detector and the electrostatic collection of alpha-emitters with spectral analysis. 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 litre/min. The nominal sensitivity of this system in continuous mode is 0.5 counts/min/37 Bqm^{-3}. The spot measurements were carried out in residential buildings in south-western Nigeria. The measurement points were set at 1.5 m above ground level. Sniff mode and cycle 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.

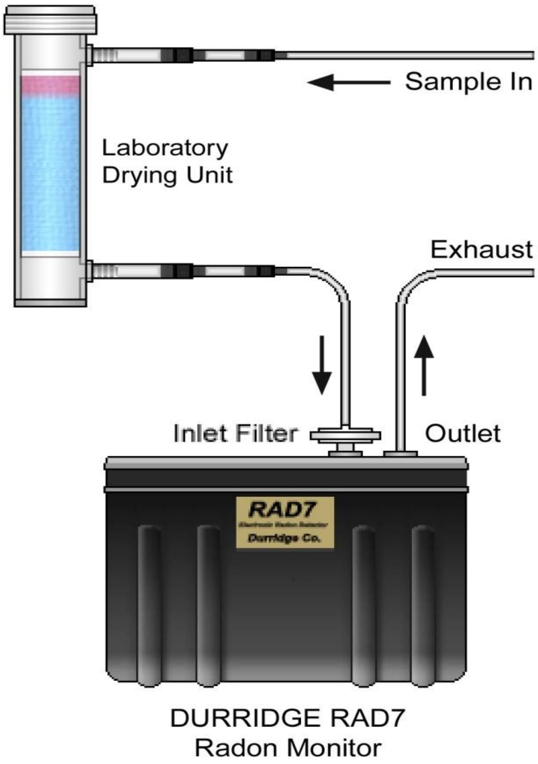


Figure 1: Schematic Representation of the RAD 7 for Indoor Radon Measurement [22]

Lung Cancer Risk Models

A number of models for the calculation of lung cancer risk due to indoor radon exposure have been reported in the literature. (23,2,25) The excess cancer risk per million person per year (MPY) was determined for buildings with different combination of covering materials as follows:

Excess Cancer Risk = F x OF x RF x WLM (1)

Where

F = equilibrium factor (0.4)

OF = indoor occupancy factor (0.4), corresponding to about 10 hours daily.

RF = Risk factor (EPA, ICRP and UNSCEAR).

WLM = A conversion factor of which 73.9 Bqm^{-3} = 1 $WLM.y^{-1}$ has been used to convert the radon concentration to work level month. (26)

Using the data for the mean indoor radon concentration for the three different covering materials given in Table 1, the excess lung cancer risks have been calculated using the risks coefficient recommended by EPA, ICRP and UNSCEAR presented in Table 2.

Table 2: Lifetime Probability of Fatal Lung Cancer due to Lifetime Exposure to Radon Progeny

Study	Cancer deaths per million persons per WLM	Reference
ICRP, 1987	250	2
EPA, I986	115-400	27
UNSCEAR, 1988	200-450	24

The BEIR VI Excess Relative Risk Model

There are a number of models for estimating the excess relative risk of developing lung cancer from inhaling radon in homes. In this study, the excess relative risk of lung cancer associated with indoor radon exposure was estimated using the BEIR VI risk model. The BEIR VI risk model was preferred because it considered multiple time exposure window and it allows for several age categories unlike other models. The other risk models focused on one exposure time window prior to the date of diagnosis for cases. They also assumed that the radon exposure that occurred outside of a specified exposure time window does not contribute to lung cancer risk. This assumption may be over simplified for risk modelling. This BEIR VI model is a relative-risk model in which radon exposure has a multiplicative effect on the background rate of lung cancer. It allows the effect of exposure to vary flexibly with the length of time that has passed since the exposure, with the exposure rate, and with the attained age.

The BEIR VI model employed the duration model and the concentration model. The concentration model assumes that the risk increases as the exposure rate (*i.e.* radon concentration) decreases down to some limiting value, whereas the duration model assumes that the risk increases as the exposure duration is increased to some limiting value. The model relating radon exposure to risk of death from lung cancer by BEIR VI in the two models can be represented as:

$$ERR = \beta(\omega_{5-14} + \theta_{15-24}\ \omega_{15-24} + \theta_{25+}\ \omega_{25+})\varphi_{age}\gamma_z \qquad (2)$$

Where

β = risk coefficient (exposure-response parameter)

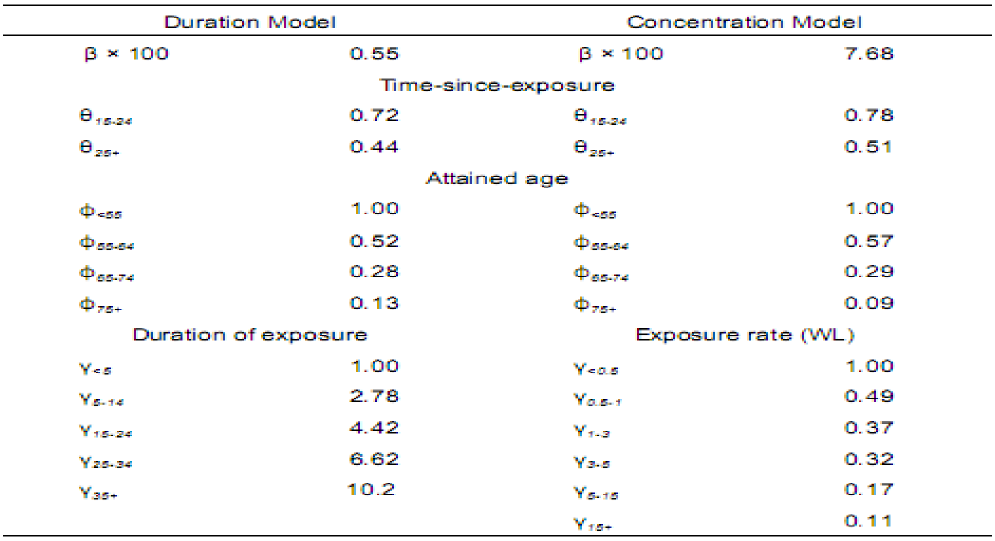
ω = radon exposure window in WLM for categories of ages before the attained age. (2)

φ_{age}= modifying effect of age

γ_z = modifying effect of radon concentration

The values for this parameters for both duration model and concentration models are summarized in Table 3.

Table 3:Parameter Estimated for BEIR VI models. (28)



Duration Model		Concentration Model	
$\beta \times 100$	0.55	$\beta \times 100$	7.68
Time-since-exposure			
θ_{15-24}	0.72	θ_{15-24}	0.78
θ_{25+}	0.44	θ_{25+}	0.51
Attained age			
$\phi_{<55}$	1.00	$\phi_{<55}$	1.00
ϕ_{55-64}	0.52	ϕ_{55-64}	0.57
ϕ_{65-74}	0.28	ϕ_{65-74}	0.29
ϕ_{75+}	0.13	ϕ_{75+}	0.09
Duration of exposure		Exposure rate (WL)	
$\gamma_{<5}$	1.00	$\gamma_{<0.5}$	1.00
γ_{5-14}	2.78	$\gamma_{0.5-1}$	0.49
γ_{15-24}	4.42	γ_{1-3}	0.37
γ_{25-34}	6.62	γ_{3-5}	0.32
γ_{35+}	10.2	γ_{5-15}	0.17
		γ_{15+}	0.11

RESULTS AND DISCUSSION

Consciously, all the surveyed buildings were on the ground floor. Tables 4 to 9 showed the mean radon concentration for buildings with different covering materials for selected cities.

Table 4: Indoor Radon concentration for Different Covering Materials in Ogbomoso

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

Table 5: Indoor Radon Concentration for Different Covering Materials in Ibadan

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

Table 6: Indoor Radon Concentration for Different Covering Materials in Osogbo

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

Table 7: Indoor Radon Concentration for Different Covering Materials in Ewekoro

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

Table 8: Indoor Radon Concentration for Different Covering Materials in Abeokuta (Dry Season)

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

Table 9: Indoor Radon Concentration for Different Covering Materials in Abeokuta (Raining Season)

S/N	COMBINATION A	COMBINATION B	COMBINATION C
	Concentration (Bq m^{-3})	**Concentration (Bq m^{-3})**	**Concentration (Bq m^{-3})**
1.	84.93 ± 1.34	76.68± 1.92	76.48 ± 1.29
2.	70.34 ± 2.33	92.44 ± 2.14	78.42 ± 1.92
3.	91.44 ± 1.45	87.38 ± 2.63	72.34 ± 4.49
4.	88.07 ± 1.27	79.97 ± 1.27	75.08 ± 2.29
5.	73.49 ± 1.73	90.41 ± 1.35	83.05 ± 1.72
6.	76.03 ± 2.53	89.23 ± 2.29	91.42 ± 3.27
7.	77.40 ± 1.28	82.40 ± 1.13	86.02± 2.64
8.	82.43 ± 1.06	96.62 ± 1.01	74.06 ± 1.29
9.	90.03 ± 1.84	73.40 ± 3.04	80.40 ± 2.46
10	72.59 ± 2.23	88.47 ± 1.48	94.31 ± 1.26
Mean	**80.68 ± 7.71**	**85.70 ± 7.35**	**81.16 ± 7.47**

Table 10: Indoor Radon Concentration for Different Covering Materials in Idanre

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

Table11: Estimated excess lung cancer risk per million person per year (MPY) for building with different combination of covering materials.

Combinations	Radon Concentration (Bq m^{-3})	Excess Lung Cancer Risk per MPY		
		EPA	**ICRP**	**UNSCEAR**
A	54.03	13.62 - 47.36	29.20	23.68 - 53.28
B	59.49	14.91 – 51.84	32.40	25.92 – 58.32
C	65.01	16.19 – 56.32	35.20	28.16 – 63.36

DISCUSSION

Radon Concentration

The mean indoor radon concentration measurement for different covering materials on internal building surfaces for walls, ceilings and floors for all the cities surveyed for combinations (A), (B) and (C) were found to be 54.03, 59.49 and 65.01 Bq m^{-3} respectively. In all cities investigated, combination (C) generally contributed the highest to the indoor radon concentration while combination (A) contributed the least except in Abeokuta where combination B contributed the highest during the raining season (Figure 9). The elevated concentration of indoor radon in combination C in most of the cities investigated may be due the contribution of high compact and less porous clay used in the manufacture of ceramic tiles, in addition to that contributed by the wall and ceiling materials compared to plastic tiles and carpet in combination A and B which do not contain any form of soil or rock in their production.

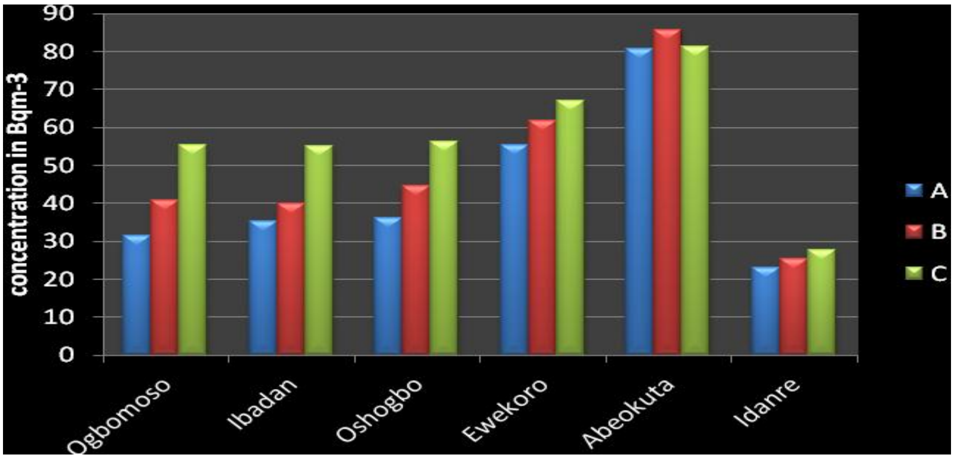


Figure 2: A graph showing variation in indoor radon concentration for different combination of covering materials.

In all the cities investigated, Abeokuta has the highest mean radon concentration of 85.70 Bqm^{-3}. The elevated concentration may be connected to the fact that Abeokuta metropolis has mainly uranium-rich granite, which is a major source of radon- 222, as its underlying substrata. This has been reported as a contributory factor for the high radiation background observed at Abeokuta[29] (Jibiri *et al.,* 2009). The mean value for all the combinations of covering materials used for internal surfaces were found to be lower than the recommended action level of 200 Bqm^{-3} set by ICRP and the reference level of 100 Bqm^{-3} set by WHO. The results of this study with different combination of covering materials for the internal surfaces in most of the buildings were significantly low. The mean indoor radon concentrations obtained in the buildings surveyed in this study were comparable with the range of values obtained in other studies in Southwestern Nigeria. (30,17,16)

A test of significance of the covering type on indoor radon concentration carried out using analysis of variance (ANOVA) revealed that there is significance difference ($p < 0.05$) in the radon concentration from one location to another and among different combinations of covering materials. However, the post-hoc (Duncan) test carried out showed that Abeokuta, Ewekoro and Idanre contributed significantly to the observed variation in indoor radon among locations. There was a significant difference in the variation in the indoor radon concentration obtained for Abeokuta during the raining and the dry seasons.

The mean value of the indoor radon concentration for all the combinations of covering materials investigated were above those reported for Cyprus, Belgium, Poland, Romania Kazakhstan and USA but lies above that reported for Egpyt, Czeck Republic and Finland. (31) However, the mean values of radon concentration for all combinations of covering materials were higher than the world average of 40 Bqm^{-3} for all the cities investigated. (32)

Lung Cancer Risk

The lifetime cancer risk due to lifetime exposure for all combination of covering materials (Table 11) were found to lie between 13 – 56 MPY, 29 – 56 MPY and 23 – 63 MPY for EPA, ICRP and UNSCEAR models respectively. As expected, the cancer risk increases with increased indoor radon concentration. It was observed that for the same value of indoor radon concentration levels, the excess cancer risk calculated using the risk coefficient recommended by EPA, ICRP and UNSCEAR varied significantly from one another using the test of ANOVA (p <

0.05). The lifetime cancer risk obtained using the UNSCEAR model differs from the EPA and ICRP models by an amount as much as 47 MPY. The result of the cancer risk also reveals that the excess deaths per million persons per year (MPY) due to cancer per unit exposure to radon and its short lived daughters were lower than the world average reported by BEIR-IV (33) US EPA(34) and UNSCEAR(35) models respectively.

Excess Relative Risk

Table 12 and Figure 3 showed how the estimated excess relative risks for a constant lifetime exposure depend on attained age. Up to age 55, the relative risks increase because cumulative (weighted) exposures increase with age. The excess relative risks then decline (discontinuously) at ages 55, 65, and 75 for all combinations of covering materials. Combination C recorded the highest percentage increase in death rate from lung cancer.

Table 12: Estimation of Excess Relative Risk of Lung Cancer from Radon Exposure for different Age Groups

Age Group	Combination	% increase in death rate from lung cancer	
		Duration Model	Concentration Model
< 55 y	A	2.92	4.22
	B	3.14	4.62
	C	3.36	4.92
55 -64 y	A	1.54	2.41
	B	1.64	2.58
	C	1.75	2.80
65 – 74 y	A	0.83	1.22
	B	0.88	1.31
	C	0.94	1.43
75+ y	A	0.38	0.37
	B	0.41	0.41
	C	0.44	0.44

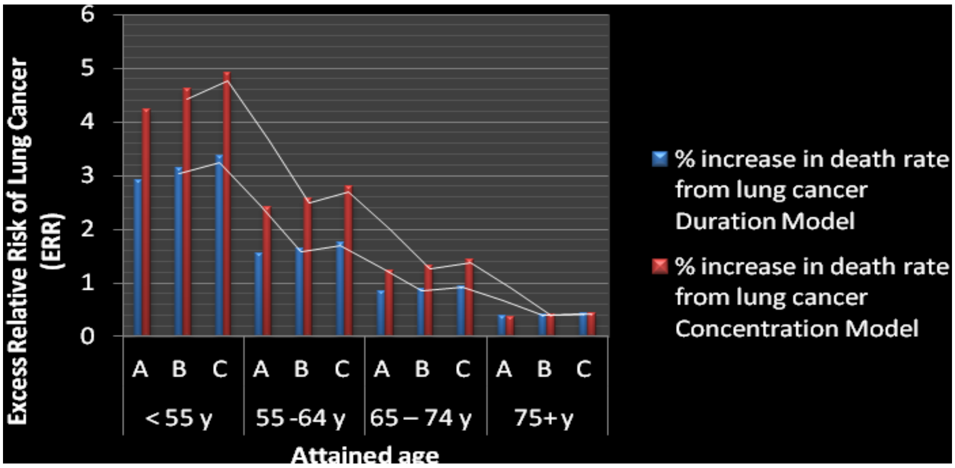


Figure 3: A graph of ERR against attained age using the duration and concentration model for different covering materials.

At age 75 and above, there is no noticeable difference in the increase in death rate between the duration and concentration models adopted by BEIR VI for all combinations of covering materials. These results showed vividly that the risk of developing lung cancer from radon exposure in residential building investigated increases with radon concentration and exposure duration. It also shows that these two approaches are closely related, since, for fixed total exposure, increased duration means decreased exposure rate.

CONCLUSION

The variations of indoor radon concentrations in buildings, in some major cities in the south-western Nigeria having different covering materials for internal surfaces were measured, using an active radon detector. The mean indoor radon concentrations for all combinations of covering materials were generally low.

However, the mean indoor radon concentration for all the combinations of covering materials across all locations were higher than the world average of 40 Bqm^{-3} (32) and lower than the recommended action level of 200 Bqm^{-3} set by ICRP and the reference level of 100 Bqm^{-3} set by WHO. A test of significance (ANOVA) revealed that there is significance difference ($p < 0.05$) in the radon concentration from one location to another and among different combinations of covering materials. The lung cancer risk from exposure to radon and its daughter products for all combinations of covering materials which lie between 13 million persons per year to 63 million person per year for EPA, ICRP and UNSCEAR models were very low the world average and comparable with data from many countries of the world. (2) The excess relative risks for a lifetime exposure was found to increase cumulatively with age up to 54 years and decline discontinuously for ages 55 and above for all combinations of covering materials with combination C recording the highest percentage increase in death rate from lung cancer. At age 75 and above, there is no noticeable difference in the increase in death rate between the duration and concentration models adopted by BEIR VI for all combinations of covering materials. These results showed vividly that the risk of developing lung cancer from radon exposure in residential building investigated increases with radon concentration and exposure duration. The result of the lung cancer risk obtained in this work shows that there is no known threshold concentration below which radon exposure presents no risk.

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