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Lung Cancer Risk Assessment due to Radon and Thoron Exposure in Dwellings in Ortum, Kenya

F. Omonya Wanjala[1,*], N. O. Hashim[1], D. Otwoma[2], J. Kebwaro[3], M. Chege[1], C. Nyambura[1], Atieno Carmen[4]

[1]Kenyatta University, Physics Department, P. O. Box 43844-00100, Nairobi, Kenya
[2]National Commission for Science Technology and Innovation, P. O. Box 30623-00100, Nairobi
[3]Karatina University, School of Pure and Applied Sciences, P.O. Box 1957-10101, Karatina, Kenya
[4]Kenya Methodist University, Nairobi Campus, KEMU Building P.O BOX 45240-00100
*Corresponding author: feliwanjala@yahoo.com

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Abstract Radon and thoron gases are produced by radioactive decay of soil and rocks containing uranium and thorium. Radon and thoron in dwellings constructed using soil and rocks rich in uranium and thorium are considered as a major causes of lung cancer especially for nonsmokers. Despite the dangers that these gases can cause to human health, extensive mapping of concentration of radon and thoron gases in Kenyan dwellings has not been done. This phenomenon leaves a large population at risk of exposure to these gases especially in rural areas where good ventilation is not considered in most of the housing design. In this study, indoor radon and thoron exposure were measured in 7 dwellings chosen using purposive sampling method in Ortum, West Pokot county, Kenya. The radon and thoron concentration in mud houses was determined using a passive radon and thoron discriminative detector (RADUET). The detectors were placed in mud houses at a height of about 2 meters above the ground for 3 months (103 days). The concentrations of radon and thoron were calculated and found to range from 16 ± 6 to 72 ±13 and 18 ±11 to 110 ±30 respectively. The average radon and thoron concentration were found to be 40 ± 19 Bq/m^3 and 54 ± 30 Bq/m^3 respectively, which is below the International Commission on Radiological Protection (ICRP) recommended lower and upper limit of 100 Bq/m^3 and 300 Bq/m^3 respectively. The annual effective dose was found to be 1.03 mSv/y for radon and 0.30 mSv/y for thoron which is within the 1.3 mSv average global annual effective dose due to radon, thoron and its progeny.

Keywords: *radon, thoron, lung cancer, radioactive gas, indoor gases, mud houses, Ortum*

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1. Introduction

Radon and thoron are radioactive colourless and odourless gases found naturally in the environment. Radon and thoron are formed due to the decay of uranium (^{238}U) and thorium (^{232}Th) and accounts for about 55% of the total radiation exposure in the environment [1]. Radon and thoron gas are inert and electrically uncharged but they decay to their progenies which are electrically charged and can attach themselves to dust particles which can be inhaled into the lungs causing potential damage to the cells in the lungs leading to lung cancer [2]. The deposited radon or thoron in the lungs decay by emitting alpha radiation which can damage the DNA leading to lung cancer. People working in mines and those living in places with high background radiation are more likely to suffer from lung cancer. Outdoor radon and thoron are not a major risk because they disperse easily in the environments but indoor radon and thoron which is a result of the use of uranium and thorium rich soil and rocks as building materials is a major public health concern in high background radiation areas (HBRA). This is because radon and thoron emanating from soil and rocks used as building materials is trapped in houses and accumulates to high concentrations especially in houses that are not well ventilated. Hence, monitoring of radon and thoron in houses is important in obtaining data to inform the public on the levels of radon and thoron in their dwellings and in establishing public health protocols geared towards minimizing health risks associated to exposure to ionizing radiation.

Indoor radon concentration studies from different parts of the world have reported with varying results which are dependent on geological outline of parent rocks, nature of housing and ventilation. Studies on radon and thoron concentration in mud dwellings in Mrima Hills located in the Kenyan south Coast have reported average radon and thoron concentration of 34Bq/m^3 and 652Bq/m^3 respectively, indicating that thoron concentration is above the WHO, [3] recommended limit of 300 Bq/m^3 [4]. A

Study conducted in Canada reported that the average concentrations of radon and thoron was 96 Bq/m^3 and 9 Bq/m^3 respectively which is below the recommended lower limit [5].

Houses in Ortum are built using about 90% of the soil and rocks from the region. Studies by Wanjala et al., [6] showed that the activity concentration of radionuclides ^{238}U, ^{232}Th and ^{40}K in soil used for construction of dwellings in Ortum region were found to be withing the world average values. The average activity concentration of ^{238}U, ^{232}Th and ^{40}K in the rock samples were found to be lower than the world average and also lower than the activity concentration in soil samples.

2. Materials and Methods

2.1. Study Area

Ortum is a semi-arid area which is located in Rift Valley, West Pokot County, Kenya. It is about 470 km North West of Nairobi City and lies between longitude 35^0 00' 0'' E and 35^0 30' 0''E and latitude 1^0 40' 0''N and 1^0 10' 0''N with an altitude of about 1420m above the sea level as shown in figure 1. Ortum region is surrounded by Cheranganyi and Ortum hills with high presence of granitic and silicon rocks which are associated with high levels of background radiation. The main economic activities of the people include agriculture, keeping livestock and mining of stones. The study was carried out in 7 mud houses in Ortum as shown in Figure 2 with the geographical position of the houses shown in Figure 3.

2.2. Radon and Thoron Measurement in Mud Houses

The radiation exposure due to inhalation of radon and thoron gas in mud houses in Ortum was determined using a passive integrating radon-thoron discriminative monitor called the RADUET as shown in Figure 4 and Figure 5. The RADUET monitor is small, portable, compact and easy to use for measurement of radon and thoron concentration in dwellings. RADUET is cylindrical and made of electroconductive plastic which consists of two different diffusion chambers with an inner volume of approximately 30cm^3. The CR-39 (Figure 6 and Figure 7) was used as a detecting material which is placed at the bottom of the chamber using a sticky clay. Radon in air defuses into the chamber through a small invisible air gap between the lid and bottom of the detector while thoron can scarcely enter the chamber due to its small pathway because of its very short half-life of 55.4 seconds compared to radon with a half-life of 3.82 days.

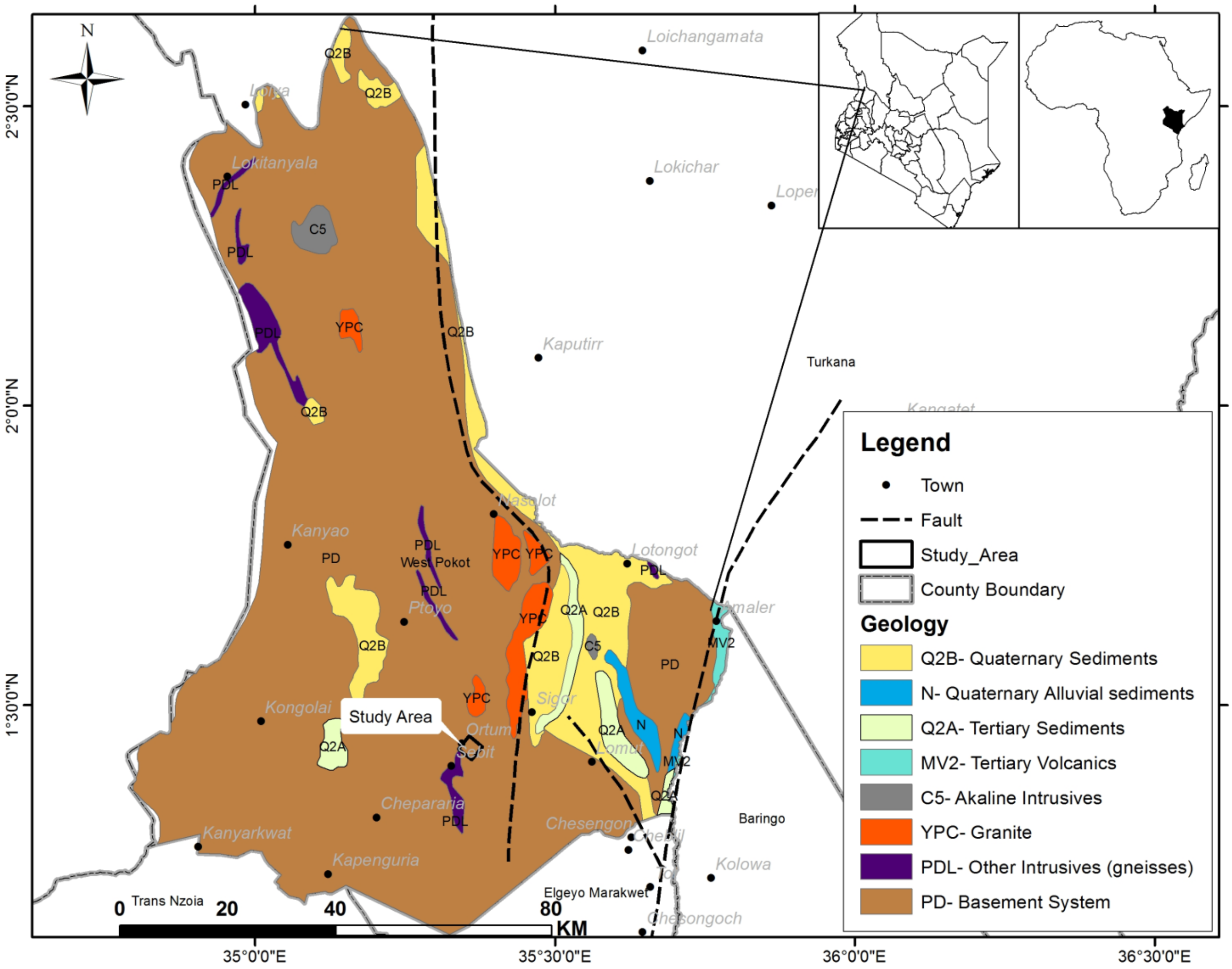

Figure 1. Geological map of Ortum in West Pokot County

Figure 2. Photograph of mad walled houses with grass roofing

Figure 3. Map showing the geographical position of sampled houses for radon and thoron measurement

For thoron to be detected, six holes of 6 mm in diameter are opened at the side of the other chamber and covered with an electroconductive sponge in order to prevent the radon and thoron decay products and aerosols from getting inside. The monitors were then exposed for about 3 months (103 days) and the CR-39 plates were removed from the chamber and chemically etched using a 6 M NaOH solution at 60°C for 24 hours [7]. The alpha tracks on the CR-39 plate formed due to the decay of radon and thoron were determined using a microscope to count the alpha tracks in order to calculate the track density as shown in Figure 8. The thoron progeny concentration was then obtained as equilibrium equivalent thoron concentration (EETC) using the track density and conversion factor.

The relationship between the track density (DT) and thoron progeny concentration, i.e. equilibrium equivalent thoron concentration is expressed as shown in Equation 1 [8]

$$\mathrm{EETC} = \frac{DT}{C \times T} \tag{1}$$

Where DT is the track density (tracks/mm^2), C is the conversion factor experimentally obtained (0.017 tracks/mm^2/ (Bq/m^3 day)), T is the exposure period (103 day) and EETC the equilibrium equivalent thoron concentration (Bq/m^3).

Radon and thoron concentrations were obtained using the total track densities replaced into equations 2 and 3 respectively.

$$C_{Rn} = (d_L - b) \times \frac{f_{Tn2}}{t \times (f_{Rn1} \times f_{Tn2} - f_{Rn2} \times f_{Tn1})} - (d_H - b) \times \frac{f_{Tn1}}{t \times (f_{Rn1} \times f_{Tn2} - f_{Rn2} \times f_{Tn1})} \tag{2}$$

$$C_{Tn} = (d_H - b) \times \frac{f_{Rn1}}{t \times (f_{Rn1} \times f_{Tn2} - f_{Rn2} \times f_{Tn1})} - (d_L - b) \times \frac{f_{Rn2}}{t \times (f_{Rn1} \times f1_{Tn2} - f_{Rn2} \times f_{Tn1})} \tag{3}$$

C_{Rn} and C_{Tn} are the mean radon and thoron concentrations in Bq/m^3, d_L and d_H are the alpha track densities (track/m^2)

taken from the CR-39 detectors of low and high air-exchange rate chambers, f_{Rn1} and f_{Tn1} are the calibration coefficients for radon and thoron for the low air exchange chamber, f_{Rn2} and f_{Tn2} are the calibration coefficients for radon and thoron for the high air-exchange rate chamber, t is the exposure time in hours and b is the background track density of the CR-39 detector in tracks/m^2.

Figure 4. Photographs of the RADUET Monitors used for Measurements in this study

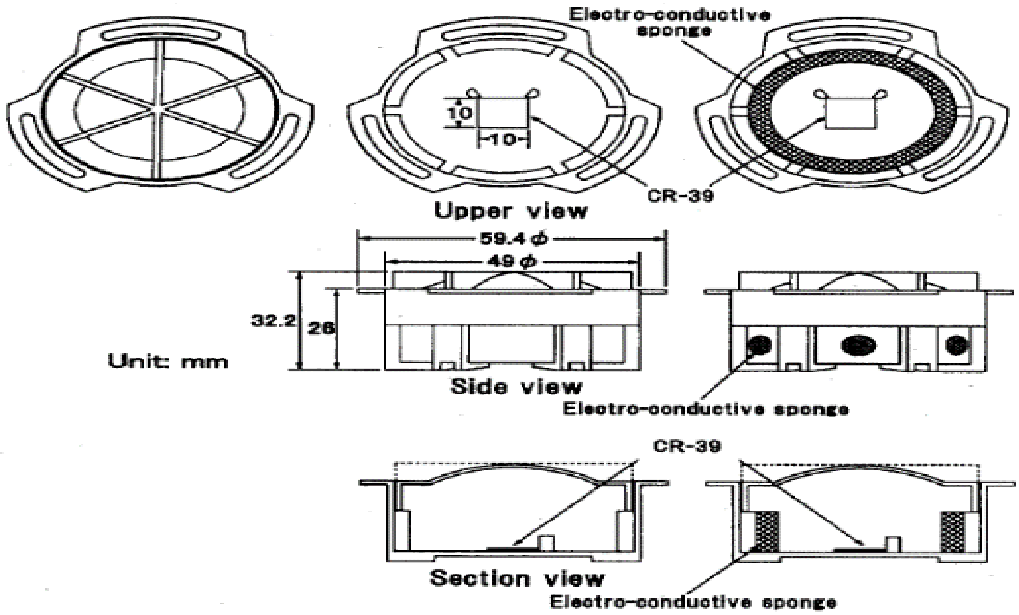

Figure 5. Schematic diagram of the RADUET (Tokonami et al., 2015)

Figure 6. The CR-39 plate

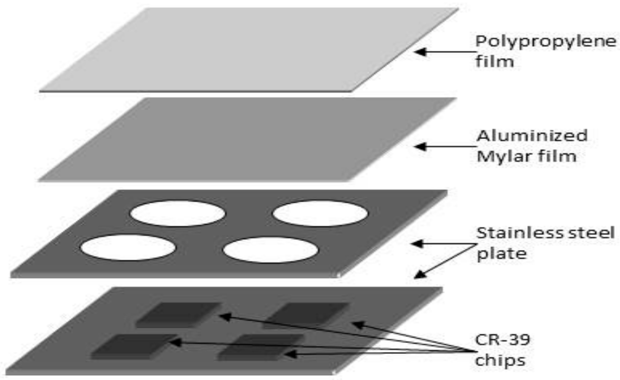

Figure 7. CR-39 Schematic diagram [8]

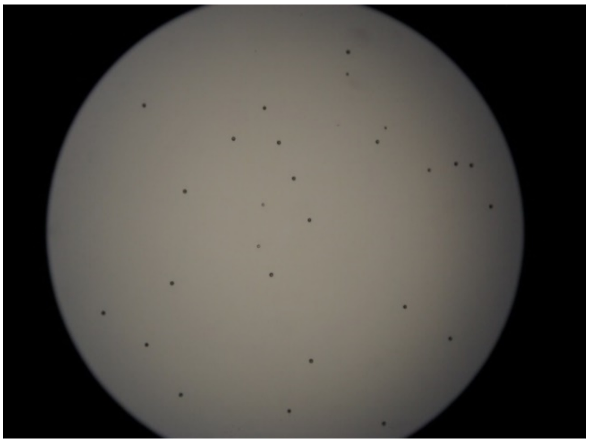

Figure 8. Typical image of formed tracks in the CR-39 [8]

The Annual effective dose exposure (E) due to radon and thoron was evaluated using Equations 4 and 5 [5].

$$E_{Rnp} = C_{Rn} \times 0.4 \times 7000 \times \left(9x10^{-9}\right) \quad (4)$$

$$E_{Tnp} = C_{Th} \times 0.02 \times 7000 \times \left(40x10^{-9}\right) \quad (5)$$

Where C_{Rn} and C_{Th} are radon and thoron concentration respectively, 0.4 and 0.02 are the typical equilibrium factors for radon and thoron respectively, 7000 is the time in hours spent in a dwelling in a year and the (9 nSv (Bq h m^{-3}))$^{-1}$ and (40 nSv (Bq h m^{-3}))$^{-1}$ are dose conversion factors for radon and thoron progeny, respectively (Chen *et al.*, 2015). The World Health Organization (WHO, 2009) recommends that the upper levels of radon should not exceed 300 Bq/m^3 or 8 pCi/L (1 pCi/L = 37 Bq/m^3) which is equivalent to an effective dose of 5 mSv.

2.3. Cancer Risk Calculations due to Radon Exposure

2.3.1. The Excess Relative Risk (ERR)

The excess relative risk (ERR), is the cumulative increase in lung cancer risk with time due to exposure to indoor radon. Cancer risk due to exposure to radon in dwellings depend on many factors including ventilation, deposition pattern, clearance rate, age, sex and if one smokes or not. Using the exposure-age-concentration (EAC) model by Hunter et al., 2015, the cumulative radon exposure w with a three exposure time windows, w=w5-14 + w15-24 + w25+, which is the exposures received by residents at 5-14, 15-24 and 25 years or more prior to attained age respectively was calculated using the equation 6 provided by Hunter et al., [9]

$$ERR = \beta\left(w_{5-14} + 0.78w_{15-24} + 0.51w_{25+}\right)\theta_{age} \quad (6)$$

Where β is the slope of the exposure-risk relationship (β = 0.0768); w is the radon exposure, w5-14, w15-24 and w25+ represent cumulative radon exposures expressed in working level months (WLM) received during time windows of 5-14 years, 15-24 years and 25+ years or more prior to the attained age, respectively, θ_{age} is the attained age-related modification factor. Under this model, exposures received during the previous 5 years are assumed not to increase the risk of lung cancer and ERR was assumed to be the same for males and females.

Radon exposure w is given by the equation 7

$$W = C_{Rn}(T \times EF \times CF) \quad (7)$$

Where w is the exposure due to radon (WML), T is the time resident spend in the house, EF is the radon equilibrium factor and CF is the conversion factor

2.3.2. Lifetime Cancer Risk

The estimated excess lifetime cancer risk (ELCR) due to indoor exposure to radon for residents in Ortum was computed using the equation 8 given by Obed et al., [10].

$$ELCR = D \times LT \times RC \quad (8)$$

Where, ELCR is the excess lifetime cancer risk, D is the effective dose (Sv/y) x LT is the lifetime expectancy for residents in Ortum which is 70 Years for Kenyan citizens and RC is the risk conversion factor (SV^{-1}).

3. Results and Discussions

3.1. Exposure due to Radon and Thoron

The radon and thoron levels varied from one house to another mainly due to variations in ventilation, size of the house and the geological differences in the building materials used to construct the houses. The results of the track densities from CR-39 plates installed in mud houses was recorded as shown in Table 1. The equilibrium equivalent thoron concentration (EETC), radon thoron concentration (C) and the annual effective dose (E) due to radon and thoron exposure was calculated using equation 1, 2, 3, 5 and 6 respectively and the results shown in Table 1 and Table 2.

Table 1. Results of average track density and EETC

	House geographic Position		CR-39 ID Plate	Track density	EETC (Bq/m^3)
House 1	1° 26’ 17.4” N	35°21’ 26.8” E	G151 -154	8.1 ± 0.5	4.7 ±1.1
House 2	1° 25’ 53.4” N	35°21’ 22.5” E	G223-226	14.5 ± 2.6	8.8 ± 1.5
House 3	1° 26’ 4.50” N	35°21’ 57.1” E	G055-058	1.5 ± 0.2	0.9 ± 0.6
House 4	1° 25’ 46.2” N	35°21’ 48.5” E	G051-054	10.2 ± 0.5	6.0 ± 1.2
House 5	1° 25’ 28.6” N	35°21’ 38.8” E	G043-046	18.4 ± 0.7	10.7 ± 1.0
House 6	1° 25’ 47.2” N	35°22’ 17.4” E	G063-066	12.3 ± 0.6	7.2 ± 1.1
House 7	1° 25’ 30.1” N	35°22’ 06.8” E	G087-090	2.5 ± 0.2	1.4 ± 0.3
			Average	9.64 ± 0.76	5.67 ± 0.97

Table 2. Results of radon and thoron concentration (Bq/m^3)

	Radon	C_{Rn} (Bq/m^3)	E_{Rn} mSv/y	Thoron	C_{Tn} (Bq/m^3)	E_{Th} mSv/y	Ration C_{Rn}/ C_{Tn}
House 1	G025	16± 6	0.4032	G026	47 ±14	0.2632	0.34
House 2	G013	46± 7	1.1592	G014	110 ±30	0.6160	0.42
House 3	G029	72 ±13	1.8144	G030	35 ±16	0.1960	2.06
House 4	G021	49 ±7	1.2348	G022	73 ±26	0.4088	0.67
House 5	G019	38 ±5	0.9576	G020	55 ±20	0.3080	0.69
House 6	G023	46 ±7	1.1592	G024	42 ±20	0.2352	1.10
House7	G015	18 ±7	0.4536	G016	18 ±11	0.1008	1.00
	Average	40 ±19	1.03		54 ±30	0.304	

The results show that radon concentration ranged from 16 ± 6 to 72 ± 13 Bq/m^3 with an average of 40 ± 19 Bq/m^3 and thoron ranged from 18 ± 11 to 110 ± 30 Bq/m^3 with an average of 54 ± 30 Bq/m^3. The average radon concentration falls within the world average level of 40 Bq/m^3 as reported by Chen *et al.*, [5] while thoron concentration is 5 times higher than the world average concentration of 10 Bq/m^3 given by UNSCEAR, [11]. The radon and thoron concentration in mud house in Ortum were lower than the lower limit of 100 Bq/m^3 and the higher limit of 300 Bq/m^3 propose by WHO [3] except for G013. The levels of radon and thoron were lower than the action level of 1% of the buildings having radon concentration above 200 Bq/m^3 as stated by Wanjala, [12] for minimum health hazard. The average annual effective dose due to exposure to radon and thoron was found to be 1.03 and 0.30 mSv respectively which is below the recommended range of 3–10 mSv/y given by the International Commission of Radiological Protection (ICRP) and level of 10 mSv/y by World Health Organization (WHO). The total annual effective dose due to radon and thoron is 1.33 mSv which is within the average (1.3 mSv) global annual effective dose due to radon and its progeny given by Kumar et al., [13] and below the upper limit of 10 mSv/y recommended by ICRP, [14].

The results show that residents of Ortum are exposed to low levels of radon and thoron and hence the risk of residents getting lung cancer due to exposure to radon, thoron and their progeny is low. Houses in Ortum have poor ventilation and therefore, it is recommended that houses in the region should be designed and constructed to ensure that there is good ventilation to allow radon and thoron to escape from the houses to reduce exposure.

3.2. Cancer Risk Calculations

3.2.1. Excess Relative Risk

Using the average radon concentration (C_{Rn}) of 40 Bq/m^3 in dwellings in Ortum which is equivalent to 1.081 pCi/L (1 Bq/m^3 = 0.027 pCi/L), the exposure due to radon (w) for a resident who spend 70% of their time (T) in the house, with radon equilibrium factor (F) of 0.4. the exposure (w) is determined using equation 6.

$$w = (1.081\, pCi/L\ 0.7x0.4WL\ x0.516WLM\left(WLy^{-1}\right)$$
$$= 0.1561\ WLM\ /\ y$$

for a resident in Ortum who has lived for 70 year, the cumulative radon exposure (w) with a three exposure time windows, that $w = w_{5\text{-}14} + w_{15\text{-}24} + w_{25+}$, where exposures received 5-14, 15-24 and 25 years or more prior to attained age respectively [2] as expressed in equation 6 provided by Hunter et al., [9].

Where β is the slope of the exposure-risk relationship (β = 0.0768); $w_{5\text{-}14}$, $w_{15\text{-}24}$ and w_{25+} represent cumulative radon exposures expressed in working level months (WLM) received during time windows 5-14 years, 15-24 years and 25+ years or more prior to the attained age, respectively, θ_{age} is the attained age-related modification factor (categorised as: $\theta_{age\,<\,55}$ =1; $\theta_{age\ 55\text{-}64}$ = 0.57; $\theta_{age\ 65\text{-}74}$ = 0.29; $\theta_{age\ 75+}$ = 0.09. Under this model, exposures received during the previous 5 years are assumed not to increase the risk of lung cancer and ERR was assumed to be the same for males and females.

For a resident in Ortum who has lived for 70 years, the ERR given by equation 6 is;

$$ERR = 0.00768\begin{pmatrix}0.1561x10 + 0.78x0.1561\ x10 \\ +0.51x0.1561x50\end{pmatrix} = 0.051$$

This implies that the excess relative risk for a person who has lived in Ortum for 70 years is 0.051 or 5.1%. which means that about 5 out of 100 persons living in Ortum are likely to get lung cancer due to exposure to radon and thoron gas.

3.2.2. Excess Lifetime Lung Cancer Risk

The estimated excess lifetime lung cancer risk (ELCR) due to indoor exposure to radon was computed using the equation given by Obed et al., [10].

$$ELCR = Effective\ dose\ (D)\,(Sv/y)$$
$$x\ Lifetime\ expectancy\ \ (LT)\ \ (Years)$$
$$xRisk\ conversion\ Factor\ \ (RC)\ \ \left(SV^{-1}\right)$$

Using the effective dose of 1.03 mSv/y, life expectancy of 70 years for residents in Ortum and RC= 0.055 Sv^{-1}

$$ELCR = 1.03\ mSv/y\ x\ 70\ years\ x\ 5.5\ x\ 10^{-5} mSv^{-1}$$
$$= 0.00396.$$

Hence the excess lifetime risk of someone getting cancer in Ortum is 0.4%.

4. Conclusion

The results of the average radon (^{222}Rn) and thoron (^{220}Rn) concentration and the annual effective dose received by residents of Ortum in mud houses is lower than the ICRP, 2014 and WHO, 2009 recommended values for workplace [3,14]. This implies that the risk due to radon and thoron exposure in dwellings in Ortum is below the action level and lower than the threshold lower and upper limits of 100 Bq/m^3 and 300 Bq/m^3 recommended by WHO, 2009. The excess relative risk and lifetime cancer risk show that there is low risk of residents of Ortum getting lung cancer due to exposure to radon and thoron in their dwellings. Based on the linear no threshold model assumption, it is important to note that chronic exposure to even small amounts of radon and thoron can still lead to respiratory health hazards including lung cancer. We therefore recommend that residents of Ortum should ensure that their dwellings are well ventilated to reduce the concentration of radon and thoron gas in their houses so as to limit exposure to radon and thoron gas thereby reducing the risk of getting lung cancer.

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