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Assessment of Radon Concentration in Tobacco of Some Brands Cigarette Sold in Côte d'Ivoire

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Abstract This work deals with the detection and measurement of radon, a radioactive gas, in the tobacco of nine brands of cigarettes sold in Côte d'Ivoire. The measurements were carried out using Solid State Nuclear Tracks Detectors (SSNTD), LR 115 type 2. The activity concentration varies from 31 ± 2 Bq/m^3 to 44 ± 2 Bq/m^3 with an average of 37 ± 2 Bq/m^3. The corresponding annual effective dose ranges from 0.78 ± 0.05 mSv/y to 1.10 ± 0.06 mSv/y with an average of 0.94 ± 0.05 mSv/year. Results showed that only three out of nine cigarette brands studied had annual effective doses greater than 1 mSv/year. On the other hand, the average of all these different brands is below this public dose limit recommended by the International Commission on Radiological Protection. About the Potential Alpha Activity, it varies from 3.35 mWL to 4.72 mWL with an average of 4.02 mWL. The risk of lung cancer per million inhabitants ranges from 14 to 20 people per million.

Keywords: *Tobacco, SSNTD, annual effective dose, potential alpha activity, Côte d'Ivoire*

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1. Introduction

Radon is considered today as the main source of exposure of the population to ionizing radiation [1]. Radon does not present any risk once inhaled as it is almost entirely re-exhaled. In another way, its short-lived progeny are deposited along the respiratory tract, causing tissue damage to the most sensitive cells of the bronchi. Exposure to radon progeny as a carcinogen of the tracheobronchial tree was first established in the 1950.

In 1987, radon was classified as a lung carcinogen in humans by the International Agency for Research on Cancer (IARC) following epidemiological studies [2] which were tested by laboratory studies in rats. Indeed, as radon decays, it emits particles.

2. Materials and Method

2.1. Sample Collection

The tobacco samples used for the radon activity measurements are part of the total of sixteen (16) brands sold in Côte d'Ivoire. Nine (9) brands of cigarette were sampled for analysis.

Table 1. Tobacco cigarette brands sold in Côte d'Ivoire sampled for the assessment

Samples	Origin (Country)
Dunhill	England
Marlboro Gold	Switzerland
Craven A	England
Fine Rouge	Côte d'Ivoire
Davidoff	Ukraine
Fine Duo	Côte d'Ivoire
Marlboro Rouge	Switzerland
Craven click	England
Excellence	Côte d'Ivoire

2.2. Sample Preparation

The tobacco samples were dried in an oven at a constant temperature of 60°C for 4.5 hours and then crushed using a mechanical grinder. Finally, the powder obtained was sieved using a small-mesh sieve to obtain a fine powder, free of impurities and coarse lumps.

2.3. Measurements

The detection device consists of a SSNTD film LR-115 type 2, one cylindrical plastic can with a diameter of 8 cm and a height of 15 cm. The height of the cup allows the radon gas to reach the detector fixed on the top of the can. The LR-115 films were taped with paper tape to the inside of the cover of each cup. The concave sensing face of the detector was oriented towards the tobacco powder (10g) deposited in the bottom of the cup. Once prepared, the device was carefully sealed to avoid any gas dissipation and to guarantee the secular equilibrium between radon and its progeny. Eleven (10) LR-115 type 2 films were installed in eleven (10) cups, nine (9) of which contained tobacco powder and one was left empty to determine the background. Ninety one (91) days after their installation, the detectors were removed, rinsed thoroughly with tap water, dried and then stored in envelopes.

2.4. Chemical Etching of the Detectors

The detectors were washed with tap water and put into NaOH solution with a concentration of 2.5 mol.L^{-1} at a constant temperature of 60°C during 120 min [4,5]. After that, each detector was washed again with tap water, then, rinsed using distilled water during two (2) minutes. Finally, the detectors were dried before the counting phase.

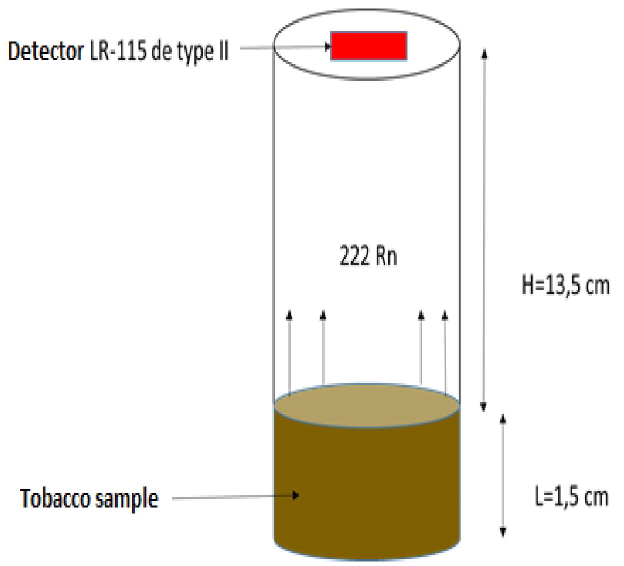

Figure 1. Schematic diagram of the sealed-cup technique

2.5. Counting of the Number of Tracks

The counting device is composed of an optical microscope, a video camera Charge Couple Device (CDD). The Optika Vision Pro PLUS software installed on the laptop allows the image processing. The SSNTD film is placed on a glass slide and the track density ρ has been determined.

2.5.1. Calculation of Tracks Density

The activity concentration of radon in the air above the sample measured in (Bq/m^3) is given by the following equation:

$$C = \frac{\rho - \rho_0}{KT} \text{ [6]} \qquad (1)$$

Where C is radon concentration, ρ : tracks density (Tr/cm^2), K: the calibration factor (Tr/cm^2 J/ (Bq/m^3)), T: Time of exposure in days, ρ_0 : the background noise. The calibration factor K obtained by the Somogyi et al [7] equation.

$$a_1 \le a \le a_0, K = \frac{C}{4} a \cos\theta_c \left(2 - \frac{a_1}{a} - \frac{a}{a_0}\right)$$

Where a is the radius of the plastic bottle (cm), θ_c is critical angle and equal to 40°;

C = 96 Tr/cm^2/30 days for 1pCi/L so $\frac{3,2}{37}$ Tr/cm^2 /day/ (Bq/m^3) is the normalization constant

And $K = 0.033$ *Tr/cm^2 /day/ (Bq/m^3).*

2.5.2. The Activity Concentration Density

Radon activity concentration density in the different samples is calculated from the model proposed by Somogyi [8]. According to this model, the number of radon atoms "exhaled" from the sample surface is equal to the number of radon atoms in the can air above the sample multiplied by the decay probability.

Where C is the radon activity concentration in the air (Bq/m^3), λ: radon decay constant (/day),

$$C_{Rn}\left(\frac{Bq}{m^3}\right) = \frac{C\lambda ht}{L} \qquad (2)$$

T: exposure time (days), h: distance between sample and SSNTD (cm); L: sample height (cm).

2.5.3. Potential Alpha Energy Activity (PAEC)

The potential Alpha Energy Activity (PAEC) in terms of units (WL) corresponds to the concentration of potential alpha energy of short-lived radon progeny in equilibrium with a radon activity concentration of 3700 Bq/m^3.

$$PAEC(WL) = \frac{FC}{3700} \qquad (3)$$

where F is the equilibrium factor between radon and its decay that is 0.4 [9].

2.5.4. Annual Effective Dose (AED)

The Annual Effective Dose (AED) is obtained using the following equation:

$$AED(m\,Sv/year) = C \times F \times H \times T \times D \qquad (4)$$

Where C is the radon activity concentration; F: the equilibrium factor which is equal to 0.4; H: the occupancy factor which is equal to 0.8; T: Time in hours for a year T=8760 h/year; D: Dose conversion factor which is equal to 9.10^{-6} (mSv/(Bq/hm^3).

2.5.5. Lung Cancer Per Year and Per Million Inhabitants (CPPP)

Lung cancer cases per year and per million populations (CPPP) were obtained using the following equation:

$$CPPH = EAD \times \left(18 \times 10^{-6} mSv/year\right) \text{ [11]} \qquad (5)$$

3. Results and Discussion

3.1. Results

Table 2 shows the results of the analysis of the non-strippable detector LR-115 Type 2 exposed to nine (9) brands of cigarettes for 91 days. The radon concentration values found varies from 31 ± 2 Bq/m^3 in Marlboro Gold to 44 ± 2 Bq/m^{-3} in the Ukrainian brand Davidoff. The evolution of this activity concentration in studied cigarette brands, is illustrated by Figure 1. We have also included in Table 2, the radon activity density. This quantity presents the same evolution profile as the activity concentration.

Table 2. Tracks density and concentrations of radon in different tobacco samples

Name and code of sample	Time of exposure (days)	Tracks density (Tr/cm^2)	Rn concentration (Bq/m^3)	Rn Activity density (Bq/m^3)
Dunhill (01)	91.700	114 ± 7	38 ± 2	5650 ± 2331
Marlboro gold (02)	91.701	94 ± 6	31 ± 2	4643 ± 1919
Craven A (03)	91.702	126 ± 7	42 ± 2	6223 ± 2565
Fine rouge (04)	91.703	121 ± 7	40 ± 2	5986 ± 2468
Excellence (05)	91.704	107 ± 6	35 ± 2	5275 ± 2177
Davidoff (06)	91.705	132 ± 7	44 ± 2	6539 ± 2694
Fine duo (07)	91.706	108 ± 6	34 ± 2	5136 ± 2121
Marlboro rouge (08)	91.707	116 ± 7	38 ± 2	5729 ± 2363
Craven A click (09)	91.708	101 ± 6	33 ± 2	4998 ± 2065
Mean	-	113 ± 7	37 ± 2	5575 ± 2300
Minimum	-	94 ± 6	31 ± 2	4642 ± 1919
Maximum	-	132 ± 7	44 ± 2	6539 ± 2694

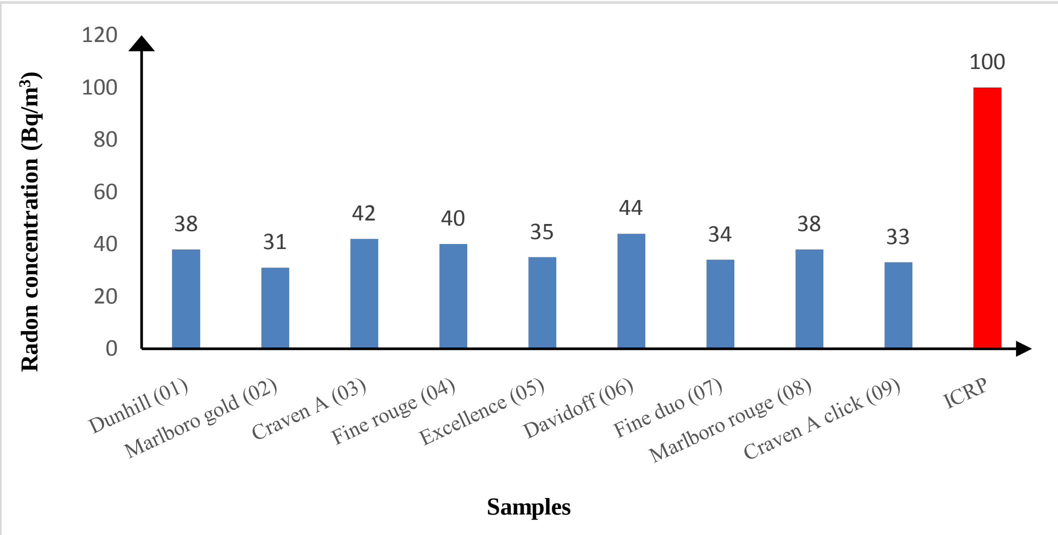

Figure 2. Radon concentration in the tobacco samples

Table 3. Potential alpha energy concentration and annual effective dose in different tobacco samples

Sample	Potential alpha energy concentration (mWL)	Annual effective dose (mSv/an)	Lung cancer case per million inhabitants
Dunhill (01)	4.08	0.95 ± 0.06	17
Marlboro gold (02)	3.35	0.78 ± 0.05	14
Craven A (03)	4.49	1.05 ± 0.06	19
Fine rouge (04)	4.32	1,01 ± 0.06	18
Excellence (05)	3.81	0.89 ± 0.05	16
Davidoff (06)	4.72	1.10 ± 0.06	20
Fine duo (07)	3.71	0.87 ± 0.05	16
Marlboro rouge (08)	4.14	0.97 ± 0.06	17
Craven A click (09)	3.61	0.84 ± 0.05	15
Mean	4.02	0.94 ± 0.05	17
Minimum	3.35	0.78 ± 0.05	14
maximum	4.72	1.10 ± 0.06	20

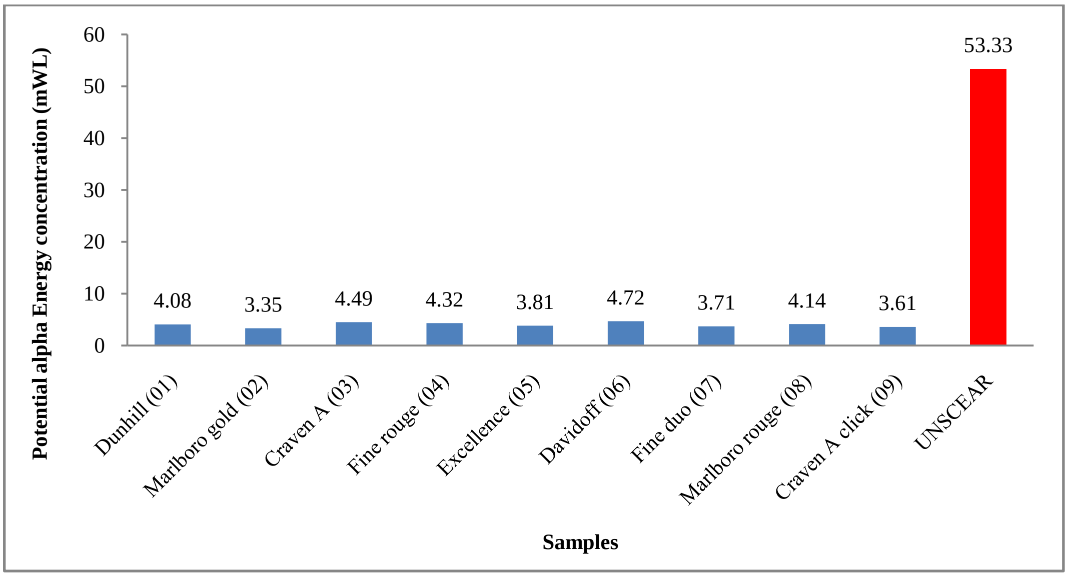

Figure 3. Potential Alpha Energy Concentration (PAEC)

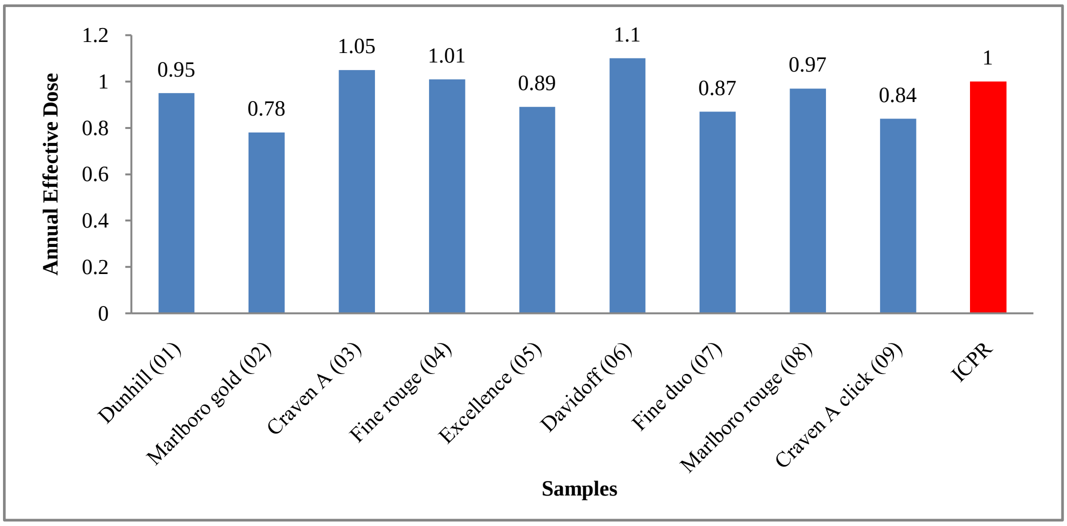

Figure 4. Annual effective Dose

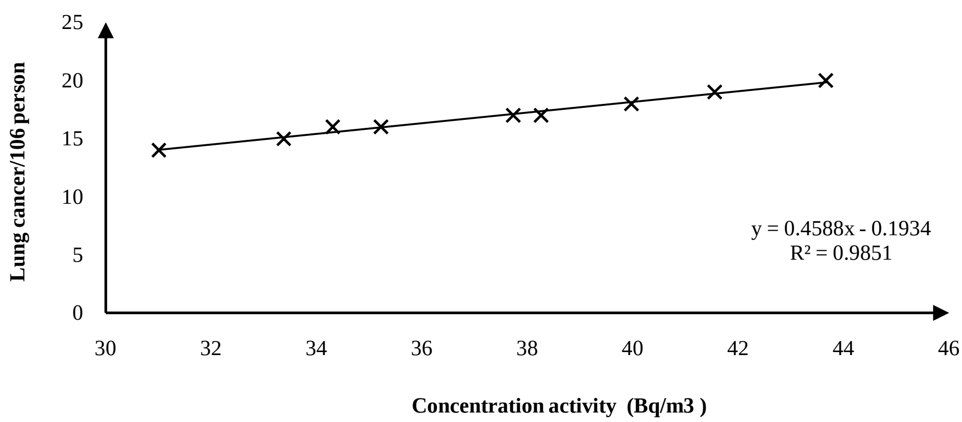

Figure 5. Correlation between radon concentration and lung cancer per year per million person

In Table 3 are grouped the values of the potential alpha energy activity, the annual effective dose and the lung cancer case per million inhabitants. The potential alpha energy activity (PAEC) varies from 3.35 mWL in sample (02) to 4.72 mWL in the sample (06) for an average of 4.02 mWL. The Annual Effective Dose (AED) observed in Table 3 is from 0.78 mSv/year minimum for sample (02) to 1.10 mSv/year for sample (06) maximum. The evolution of these different quantities (Potential Alpha Energy Activity (PAEC) of EPA, annual effective dose (AED) and lung cancer case per million inhabitants (CPPP) is shown in Figure 3, Figure 4 and Figure 5.

3.2. Discussion

The results obtained show that radon concentration varies from one brand to another. It is between 31 ± 2 Bq/m^3 and 44 ± 2 Bq/m^3 with an average of 37 ± 2 Bq/m^3. It is noted that all the values measured in the different brands of cigarettes studied are below the limit of 100-300 Bq/m^3 recommended by the ICRP [12]. About the potential alpha energy activity, the values range from 3.35 mWL to 4.72 mWL with an average of 4.02 mWL. These values are also well below the 53.33 mWL recommended by UNSCEAR [13]. The annual effective dose (AED) as shown in Table 4 ranges from 0.78 ± 0.05 mSv/year to 1.10 ± 0.06 mSv/year with an average of 0.94 ± 0.05 mSv/year. Out of the 9 samples studied, only three (3) are values slightly above 1 mSv/year, the lower limit recommended by the ICRP. These are samples (3), (4) and (6) among which the Fine rouge brand manufactured in Ivory Coast. The same thing is observed for the brand Fine: Fine Rouge and Fine Duo. This phenomenon is probably due to the origin or the quality of the tobacco used. The risk of radon-induced lung cancer varies from 14 to 20 per million inhabitants. Overall, the results recorded in this work remained lower than those measured in cigarettes sold in Iraq [14] and Saudi Arabia [15].

The correlation between radon concentration in tobacco and lung cancer has also been studied (Figure 5). The coefficient of determination, R^2 = 0.9851, shows that 98.51% of the variations of the number of lung cancer per million inhabitants are explained by the radon concentration in the studied brands of tobacco and 1.49% depends on other factors. The strong positive correlation found in this work, is similar to what has been observed in studies conducted in Iraq.

Table 4. Comparison of this study with values reported from other countries

Country	Mean	References
Iraq	432.30 Bq/m^3	Abdalsattar et al. 2015
Saudi Arabia	97 to 204 Bq/m^3	Syed et al. 2012
Côte d'Ivoire	37± 2 Bq/m^3	Present work

4. Conclusion

The results showed that the radon activity concentration in the nine (9) tobacco brands studied ranged from 31 ± 2 Bq/m^3 to 43 ± 2 Bq/m^3 and the highest concentration was found in the "Davidoff (06)" cigarette while the lowest concentration was found in the Marlboro gold (02) brand. The annual effective dose (AED) ranged from 0.78 ± 0.05 mSv/year to 1.10 ± 0.06 mSv/year with an average of 0.94 ± 0.05 mSv/year. Out of the 9 samples analyzed, only three (3) showed values slightly above 1 mSv/year, the lower limit recommended by the ICRP. These are Davidoff, Craven A and Fine Rouge 3 brand sold in Côte d'Ivoire. Overall, the values we found remain lower than those measured in cigarettes sold in Iraq and Saudi Arabia.

We need to continue this work in heavy metals to understand scientifically why for the same brand, Craven, we have: AED (Craven A) higher than 1mSv and AED (Craven click) lower than 1mSv. The same thing for the brand Fine, concerning Fine Rouge and Fine Duo. A positive correlation was observed between radon concentrations and lung cancer per year per million people for these same samples. The risk of radon-induced lung cancer varies from 14 to 20 per million inhabitants is truly present. This study should be extended to other cigarette brands sold in the country.

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