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Radon Concentration in Urban Areas in the North and West of Morocco

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ABSTRACT

Radon is a colorless, odorless radioactive gas produced by the decay of uranium and radium. It is the second cause of cancer of the lungs after smoking. It has been present in Earth's crust since the creation of Earth. Uranium-rich rocks in the deep crust are the main source of radon. Its emanation from the ground surface varies from one point to another depending on the physical characteristics of the terrain crossed as observed in this study between North and West Morocco. A dosimetric study of those emanations was performed by using the LR-115 solid-state nuclear track detector (SSNTD) which was subsequently processed by techniques developed and calibrated in the laboratory. The study revealed high concentrations of this gas in confined spaces at ground level and, in particular, in basements and less-ventilated ground floor rooms. In order to reduce these concentrations of radon and the probability of carcinogenic attacks by these accumulations of this gas, it is recommended to ventilate these premises well. Good air circulation allows the removal of this harmful gas.

INTRODUCTION

Radon is a natural gas produced by the radioactive decay of uranium from subsurface rocks. It is released into the atmosphere and becomes the most critical factor for exposure to natural radiation [1,2]. More than 80 % of the radon emitted into the atmosphere comes from soil and rocks on the surface of the earth [3]. However, in most cases, the dominant transport mechanism is the diffusion caused by the radon concentration gradient between these media and atmospheric air [4], as shown in Fig. 1.

Once on the ground's surface, radon is spreading in the urban environment and everywhere in our homes. Several studies have been done to this day on radon concentrations in homes in different countries such as Ireland [5], Portugal [6], and the USA [7].

Radon is a carcinogen responsible for lung cancer. The US Environmental Protection Agency (EPA) states clearly: "Any exposure to radon poses a risk of lung cancer. The lower the level of radon in your home, the lower the risk of lung cancer in your family." On average, a person receives a higher dose of radiation because of the concentration of this gas in one's home, than one's combined exposure of all other sources of radiation, natural or human-made.

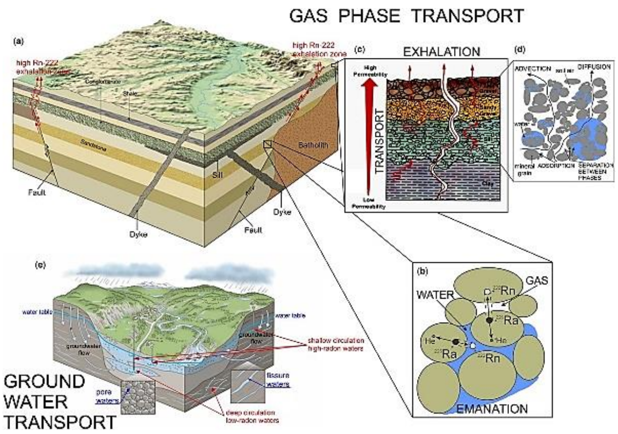

Fig. 1. Ilustration of the process of ^{222}Rn release from the lithosphere into the atmosphere [8].

Radon is the leading cause of lung cancer in people who have never smoked. However, the absolute number of lung cancers caused by radon is

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much higher among people who smoke or have smoked in the past, due to the strong combined effect of smoking and radon [9]. It has also been surmised that radon exposure is a cause of central nervous system tumors. However, a review of published literature did not find enough evidence to so conclude [10].

In this study, we will carry out a radon dosimetry by using the LR-115 Type 2 solid-state nuclear track detector (SSNTD) in two different regions of Morocco, namely Imzouren and Kenitra, as shown in the map in Fig. 2, and in different habitats depending on the altitude of the floor by relation to the ground and the age of the construction, to highlight the different parameters involved. The choice of these two cities is based on the difference of the geophysical nature, in that Kenitra is located in a sandy area while Imzouren is located on a seismic rocky region.

Fig. 2. Location of the two cities studied (Kenitra and Imzouren).

MATERIALS AND METHODS

Measuring device

The device for measuring radon in the urban environment which detected tracks in the area at an altitude of 160 cm from the ground followed the same principle as that which was developed for the measurement of radon in the ground [11] with several modifications. The detectors were suspended in the habitats, which means that the sensitive layer of the LR-115 SSNTD (Fig. 3) was oriented downwards and that the insensitive part was in contact with the PVC tube support in order to keep the film parallel to the ground surface of habitats. The tube support was suspended by a wire to a height of 1.6 m from the ground.

Fig. 3. LR-115 Type 2 solid-state nuclear track detector from Dosirad Laboratory (10 cm × 15 cm).

The distance between the film and the soil surface was chosen to approximately equal the average of the nose level of an adult person to measure the concentration of radon inhaled by a man in his home. The configuration is shown in Fig. 4.

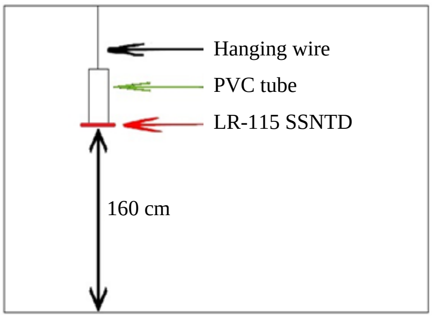

Fig. 4. Radon measurement device with LR-115 SSNTD.

Development of the LR-115 SSNTD

The development of the LR-115 SSNTD went through three main steps to provide a usable quantitative data. The first step was based on etching the LR-115 SSNTD with a basic solution of NaOH at a concentration of 2.5 mol/l and a temperature of 60 °C for a duration of 2 hours in order to make the tracks, caused by the radon, visible under the microscope [12,13], as illustrated in Fig. 5.

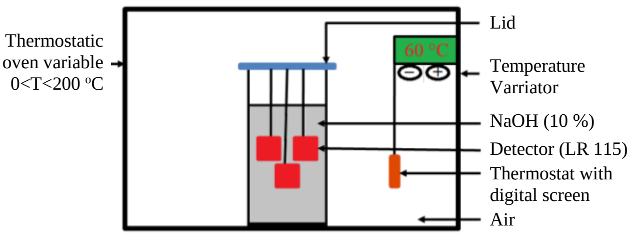

Fig. 5. Conditioning of the chemical etching of the LR-115.

The second step, after rinsing the LR-115 SSNTD with distilled water to stop the chemical reaction, was digitizing the film using a microscope equipped with a digital camera connected to a computer, as shown in Fig. 6.

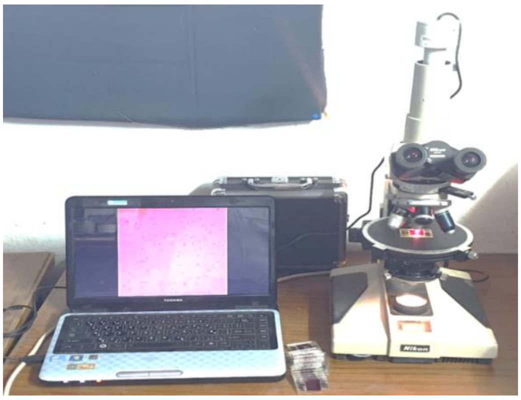

Fig. 6. Scanning the LR-115 SSNTD.

The last step was based on the ImageJ2 open-source software package that allows us to process the image of the LR-115 SSNTD and then proceed to count the tracks, as shown in Fig. 7.

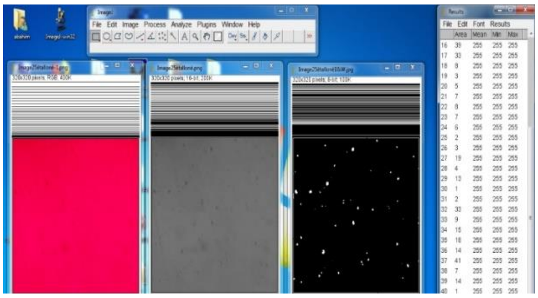

Fig. 7. Image processing and track counting by ImageJ2 software package.

The uncertainty of the measurements of our technique is 14 % of maximum following 30 measures of framing of the uncertainty.

Calculation of radon concentration in Bq/m^3

Once the count is completed, the result found is expressed in numbers of tracks per square centimeter, but to obtain the value of the radon concentration, we must calibrate our LR-115 SSNTD. A characterization study of LR-115 Type 2 detectors for indoor radon-222 monitoring with determination of the calibration factor was recently completed [14]. The activity concentration of radon-222 is calculated using Eq. (1).

$$C_{Rn-222} = \frac{N}{K.t} \quad (1)$$

In Eq. (1), the meaning of the symbols are as follows:

$C_{Rn\text{-}222}$ the concentration of radon in Bq/m^3.
N the density of tracks in track/mm^2.
K calibration factor ≈ 8.402×10^{-5} (tracks/(hours mm^3))/(Bq/m^3)
t exposure time in hours.

In our case, the density of tracks has been measured in track/cm^2, and the duration in hour $t = 24J$ (J = duration in days). Thus, by substituting numerical values to Eq. (1), Eq. (2) is obtained.

$$C_{Rn-222} = \frac{N}{8.402\times10^{-3}\times24J} \quad (2)$$

Geolocation of the sites studied

In the field we have chosen several habitats in two different regions, Kenitra in North-West Morocco (sandy region) and Imzouren in the Northern (Rif) of Morocco (rocky region), as shown in Fig. 8.

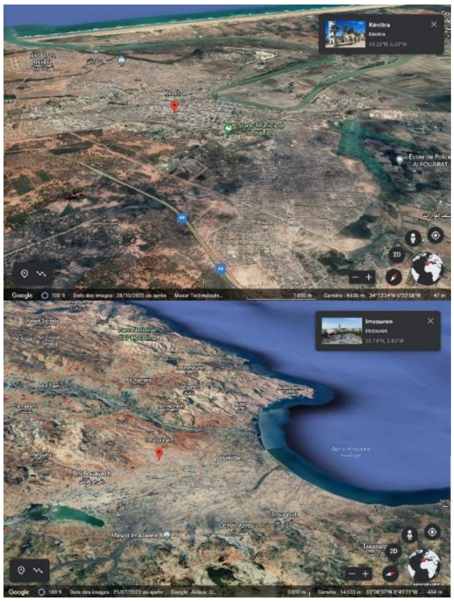

Fig. 8. Satellite image of the two regions captured by Google Earth.

RESULTS AND DISCUSSION

The devices were placed in different habitats, different districts, and different floors in buildings of the two cities, namely Kenitra (54 sensors) and Imzouren (30 sensors), respectively, to measure the radon concentrations. One such device is shown in Fig. 9. To anticipate possible damage or loss of the solid-state nuclear track detector, precautions have been taken by tripling the number of sensors on each floor.

Fig. 9. Field measuring device.

Ninety days later, we recovered the stations for development in the laboratory. Once the track revelation and counting steps were completed, the results were obtained for five habitats in Kenitra and three dwellings in Imzouren. Those results are presented in Table 1 and Table 2, respectively.

Table 1. Radon-222 concentration in different habitats and floors in Kenitra.

Habitats (Kenitra)	Housing Information	Levels	Number of traces/cm^2	Concentration of Radon Bq/cm^3
H1K	New villa under 10 years	Cellar	1320±185	72.73±10.18
		Ground floor	810±113	44.63±6.25
		Floor1	240±34	13.22±1.85
		Floor2	60±8	3.31±0.46
H2K	Old building more than 25 years old	Ground floor	1580±221	87.06±12.19
		Floor1	920±129	50.69±7.10
		Floor2	100±14	5.51±7.10
		Floor3	30±4	1.65±0.23
H3K	Old house more than 15 years	Garage	1380±193	76.04±10.65
		Floor1	840±118	46.29±6.48
		Floor2	90±13	4.96±0.69
H4K	Very old house over 40 years old	Ground floor	1790±251	98.63±13.81
		Floor1	1290±181	71.08±9.95
		Floor2	160±22	8.82±1.23
H5K	New building less than 10 years old	Garage	1350±189	74.39±10.41
		Floor1	180±25	9.92±1.39
		Floor2	30±4	1.65±0.23

As shown in Table 1, there are significant differences in radon concentrations in garages, ground floors and cellars from one habitat to another. The maximum value is reached in the oldest house, H4K (98.6 Bq/m^3), followed by H2K (87 Bq/m^3) and H1K, H3k, and H5k, with values close to 74 Bq/m^3 (Fig. 10).

This variation is associated with two factors. The first factor is the vertical distance between the soil surface and the habitats; the second is the deterioration of buildings and their aging. The deterioration of building materials is evidenced by the appearance of micro-cracks and even the appearance of open macro-cracks allowing the emanation of radon.

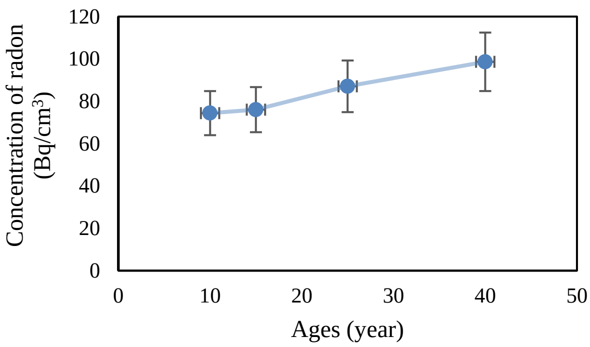

Fig. 10. Radon concentration by age of habitat.

Radon concentrations decrease by 30 % to 50 % between (garages, ground floor, cellars) and the first floor. The short lifetime of radon does not allow it to travel a long distance. A large amount of the gas would transmute along the way.

For upper floors (from the second floor upward); the radon concentration hardly exceeds 10 Bq/m^3. This value remains almost the same in all the upper floors. The aeration and the short half-life of radon, which is 3.82 d, reduce the distance traveled in buildings and release the little gas that is produced there.

Another measurement of radon was repeated during the same period in the ground floor of the H2K habitat in Kenitra, but using ventilator-assisted ventilation (extractor). In room with mechanical ventilation, the activity concentration was 45.2 Bq/m^3, as presented in Fig. 11.

This value represents a reduction of almost 50 % compared with that measured without aeration. Thus, aeration reduces the concentration of radon in the air.

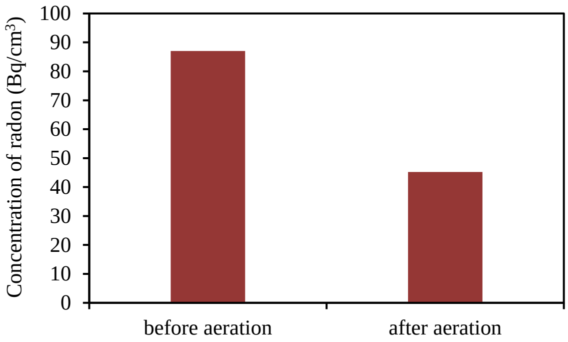

Fig. 11. Radon concentration before aeration and after aeration (H2K).

Table 2. Radon-222 concentration in different habitats and floors in Imzouren.

Habitats (Imzouren)	Housing Information	Levels	Number of traces/cm^2	Concentration of Radon Bq/cm^3
H1I	New house less than 10 years	Ground floor	1980±277	109.10±15.27
		Floor1	1080±151	59.51±8.33
		Floor2	110±15	6.06±0.85
H2I	New house less than 10 years	Ground floor	1820±255	100.28±14.04
		Floor1	1150±161	63.37±8.87
		Floor2	140±20	7.71±1.08
		Floor3	40±6	2.20±0.31
H3I	Old house more than 15 years	Garage	2480±347	136.65±19.13
		Floor1	1670±234	92.02±12.88
		Floor2	200±28	11.02±1.54

Table 2 shows the same relationship between the rediscovered habitats and the floors previously observed, as well as the radon-to-age relationship of the buildings. A difference in radon concentrations at the garages, ground floor from one habitat to another, seems to be greater in Imzouren than in Kenitra. The maximum value is reached at the oldest house H3I (136.7 Bq/m^3), then H1I and H2I with values close to 100 Bq/m^3. This makes it possible to anchor the hypothesis of the deterioration of building materials with its micros and macro cracks favoring the emanation of radon.

By comparing the radon concentrations in cellars, ground floors and garages between Kenitra and Imzouren, we found a significant difference exceeding 30 %, as shown in Fig. 12. This clear variation can be associated with two factors. The first factor is the different geological nature of the two regions: sandy-clay substratum in Kenitra and marl-limestone in Imzouren. The second factor is seismicity: Kenitra is seismically stable whereas Imzouren is a seismically active region. The main factor in this variation in radon concentration remains strongly related to the seismic activity and less to the lithological variation between Kenitra and Imzouren. This opens up the opportunity for radon to emanate even more.

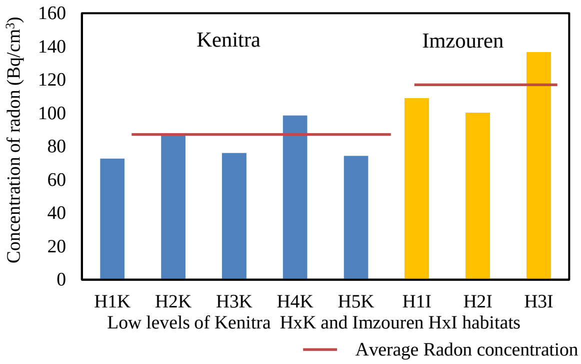

Fig. 12. Radon concentration at Low levels of Kenitra (HxK) and Imzouren (HxI) habitats.

CONCLUSION

This study made it possible to measure the concentration of radon in two Moroccan regions, the North and the West. The results showed that the higher the habitat is from the ground surface, the lower the concentration of radon, such that the concentration decreases by almost half from one floor to another. Ventilation significantly influences the radon concentration. The study also demonstrated that the concentration of radon does not depend only on altitude, but also on the geological nature of the soil. The average radon concentration in the habitats of Imzouren exceeds that of Kenitra. This difference is explained by the seismic activity of the Imzouren region, which by its rugged terrain favors the emanation of radon to the surface and then to the habitats.

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AUTHOR CONTRIBUTION

The first author, A. Tayebi, and the third author, M. Tayebi, equally contributed on the ground as the main contributors of this paper. All authors read and approved the final version of the paper.

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