

# Mapping of Radon ( $^{220}\text{Rn}$ and $^{222}\text{Rn}$ ) Concentration Distribution in a Microclimate Condition Cellar Using Nuclear Track Methodology

Guillermo Espinosa<sup>1\*</sup>, José-Ignacio Golzarri<sup>1</sup>, Alfonso M. Román-Sedano<sup>2</sup>, Fermín Castillo<sup>2</sup>

<sup>1</sup>Instituto de Física, Universidad Nacional Autónoma de México, Circuito de la Investigación Científica, Ciudad Universitaria, Coyoacán, Ciudad de México, México

<sup>2</sup>Laboratorio de Espectroscopia, Instituto de Ciencias Físicas, Universidad Nacional Autónoma de México, Cuernavaca, México  
Email: \*espinosa@fisica.unam.mx

**How to cite this paper:** Espinosa, G., Golzarri, J.-I., Román-Sedano, A.M. and Castillo, F. (2019) Mapping of Radon ( $^{220}\text{Rn}$  and  $^{222}\text{Rn}$ ) Concentration Distribution in a Microclimate Condition Cellar Using Nuclear Track Methodology. *Journal of Environmental Protection*, 10, 919-928.  
<https://doi.org/10.4236/jep.2019.107054>

**Received:** May 8, 2019

**Accepted:** July 20, 2019

**Published:** July 23, 2019

Copyright © 2019 by author(s) and Scientific Research Publishing Inc.  
This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).  
<http://creativecommons.org/licenses/by/4.0/>



Open Access

## Abstract

This work presents the results of the Radon ( $^{220}\text{Rn}$  and  $^{222}\text{Rn}$ ) measurements made with 486 chips of CR-39 (Allyl Dylglicol Poly Carbonate) MASL™ bared detectors, in a reticular mode distribution, inside of a cellar with average indoor radon concentration  $862 \pm 49 \text{ Bq/m}^3$ . The exposure time was 3 months, in microclimate condition of constant temperature, humidity, barometric pressure and no airflow. After these 3 months, all the detectors were chemically etched in KOH 6.25 M solution at  $60^\circ\text{C} \pm 1^\circ\text{C}$  for 18 hours, following a very well established protocol for indoor radon survey by the Dosimetry Applications Laboratory of the Physics Institute of the National Autonomous University of Mexico, and later read automatically by CADIS (Counting Automatically Digital Image System). The results show that each one of the nine measured planes is not homogeneous presenting important differences of indoor radon concentration values. Specifically, the Radon ( $^{220}\text{Rn}$  and  $^{222}\text{Rn}$ ) concentration levels vary for each measured point within the cellar. It is a very important observation to consider for the calculation of dose and radiological risk.

## Keywords

Indoor Radon, Mapping Radon Distribution, Nuclear Track Methodology, NTM

## 1. Introduction

It is very well known that radiation exposure originating from radon inhalation

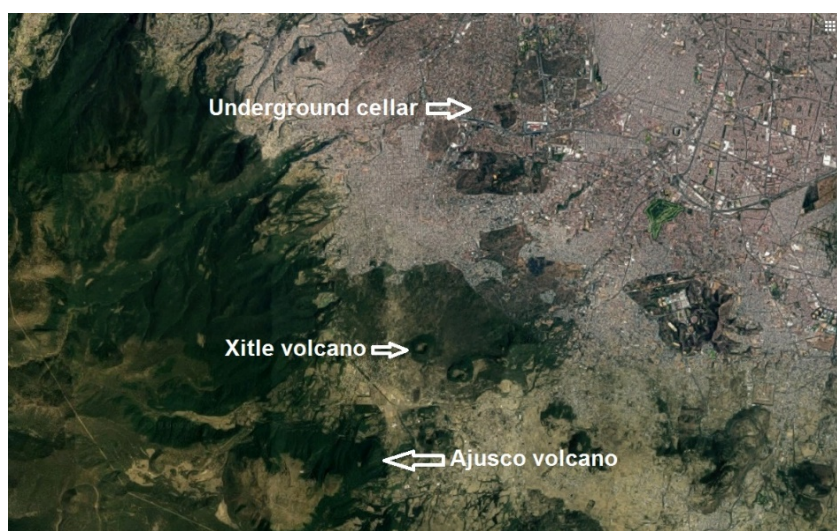
( $^{220}\text{Rn}$ ,  $^{222}\text{Rn}$ , and short-lived decay products or progeny) is almost half of the natural radiation, and significant indoor radon concentrations can cause lung cancer occurrence; therefore its evaluation deserves particular attention in order to minimize the radiological risk to the population [1] [2] [3] [4] [5].

The measurement of indoor radon is an art, because the radon distribution in a room depends on many factors, as has been determined in several studies [6]-[11]. Some of these factors are: location, size and shape of the dwelling, construction materials, ventilation system, and ventilation habits, architecture style, environmental temperature and measurement place temperature, humidity, type and distribution of objects or furniture inside a room, among others. All these factors make the radon measurements in each place unique.

Because of the radon concentration, data obtained are the basis for calculation of the dose and risk of cancer and the public health. Therefore, the efforts of the analysis and measurements of radon should be exhaustive and very accurate [12]. The aim of this study is to measure the radon concentration distribution inside of a microclimate-controlled condition cellar, using 486 chips of bared CR-39 Nuclear Track Detectors (NTD) distributed in a reticular mode.

### Location

The zone where is located the house and the underground cellar, under study, is shown in **Figure 1**. It is a residential area in the south part of Mexico City, with medium population density (3960 habitants per  $\text{km}^2$ ) with in general, single-family houses. This zone is close to the volcanic chain called “*Ajusco-Chichinautzin Sierra*”, has a semi-tropical climate, and it is surrounded by forest and national parks. As complementary information, the National Autonomous University of Mexico campus, with more than 349,515 students and 40,578 academics [13], is located in this area, too.



**Figure 1.** Location of the underground cellar, In the Xitle volcano area. (<https://www.google.com/maps/>)

The cellar with microclimate conditions studied is underground, inside of the lava of the extinct, 1600 years ago, “Xitle” volcano (from Nahuatl “Xictli” that means “belly button”) with the coordinates  $19^{\circ}12'N$   $99^{\circ}15'W$ , and to 2300 meters above sea level. This area has and high seismicity activity all the year round. The house and the underground cellar are shown in the plane of **Figure 2**.

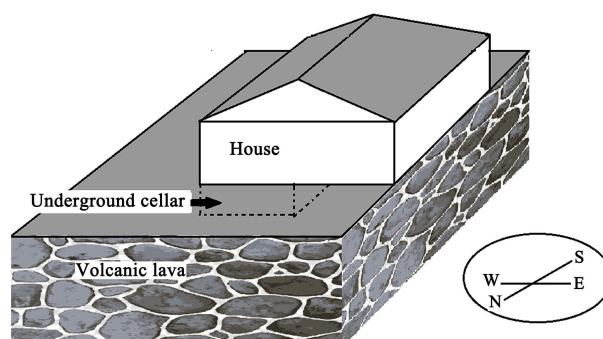
## 2. Methodology

The measurements of radon concentration inside a cellar, were made with a reticular grid, with  $9 \times 6$  detectors in each of the 9 planes, from the top to the bottom of the cellar, as can be observed in **Figure 3**.

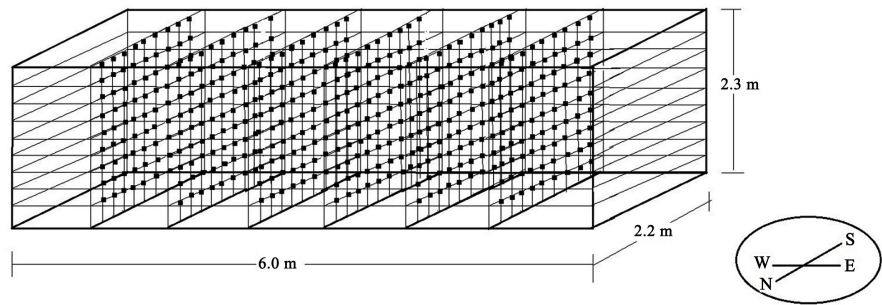
The cellar dimensions are  $6.0 \times 2.2 \times 2.3$  meters (length, width and height) with a total volume of  $30.36 \text{ m}^3$ . The total exposure time to indoor radon and thoron was 3 months, with a main concentration of  $862 \text{ Bq/m}^3$  value measured along a year with two active certified monitors: the AlphaGUARD model D-2000 and the Durrige Rad-7 [14], as is shown in **Figure 4**. The two times of opening the door can be observed in the discontinuities in **Figure 4**. The room is underground, below the house construction, surrounded by volcano rocks (lava) from an extinct volcano in Mexico. The material has high porosity and can keep in radon gas, plus constant radon emanation from the volcanic ground. This room location characteristics made the microclimate conditions of the cellar, as radon ( $^{220}\text{Rn}$  and  $^{222}\text{Rn}$ ) concentration, indoor temperature, relative humidity, and barometric pressure constants. **Figure 5** and **Figure 6** show the measured data during 3 months of exposure to radon inside the room. The ventilation is very poor because the room remains closed during this time. The small door at the top was opened only two times in order to review the data and monitor operation.

## 3. Chemical Etching and Its Readout Process

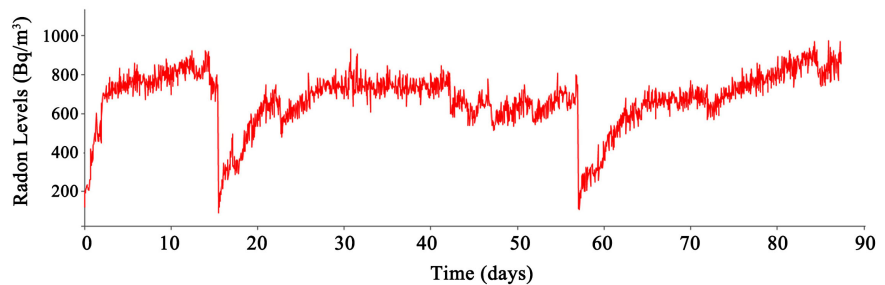
After the 3 months of exposure time, the detectors were removed and chemically etched, all together, under the same conditions, for 18 hours in a 6.25 M KOH solution at  $60^{\circ}\text{C} \pm 1^{\circ}\text{C}$ , in a thermo-controlled regulated bath. After the chemical etching, the CR-39 detectors were washed in distilled water and dried, following a very well-established protocol in the laboratory [15] [16] [17] [18].



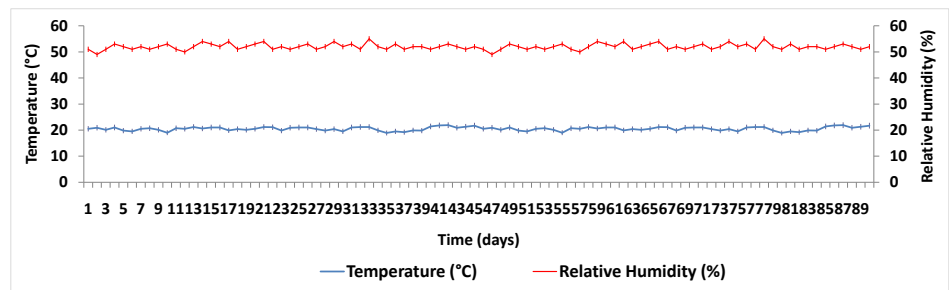
**Figure 2.** Plane of the house and underground cellar, in a lava zone from extinct Xitle volcano.



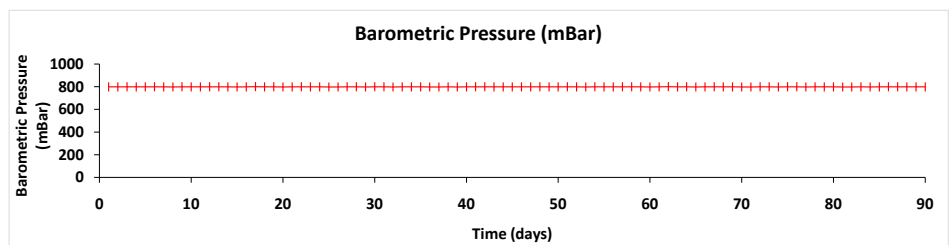
**Figure 3.** Reticular distribution of the 486 passive nuclear track detectors, showing the position of each one.



**Figure 4.** Indoor radon in the cellar during the experiment, measured with the Alpha-GUARD certificated monitor.



**Figure 5.** Measured values of temperature and relative humidity (automatic system), With the AlphaGUARD certificated monitor.



**Figure 6.** Measured values of a barometric pressure (automatic system), With the Alpha-GUARD monitor.

All the detectors with the formed tracks were read on both sides, 10 fields each side with CADIS (Counting Automatic Digital Image System), developed at the PAD-IFUNAM laboratory. The average track density data of each detector, with

the spatial position in the cellar, was analyzed and plotted with an Origin Pro 8.5.1 software. The radon concentration distribution is reproduced point by point for the 486 detectors, forming the map of the radon distribution inside the cellar.

#### 4. Results and Discussion

The radon concentration levels obtained are shown in **Figure 7**. Each figure represents one level from top to bottom of the cellar. As we can observe, none of the planes shows a uniform radon concentration.

With these experimental results it is shown that the concentration of radon ( $^{220}\text{Rn}$  and  $^{222}\text{Rn}$ ) cannot be considered homogeneous inside a room with micro-climate and controlled conditions; and of course, there is also no homogeneity in indoor intramural radon concentration when there are variable conditions, as determined by other authors cited in this paper.

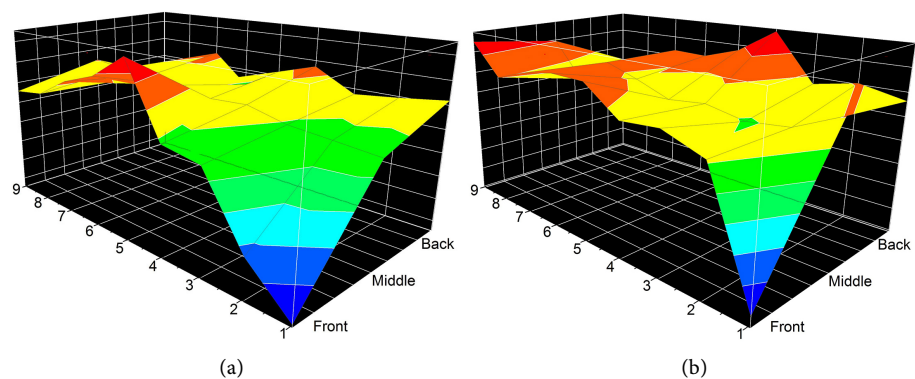
So, to do the calculation of radiological dose or risk by radon or personal dosimetry, it is suggested to make the precise measurements inside the room, in the area of interest. These experimental data confirm the results of the mathematical simulations of the works [6]-[11], where it is determined that radon is not homogeneous nor regular in its concentration in an interior.

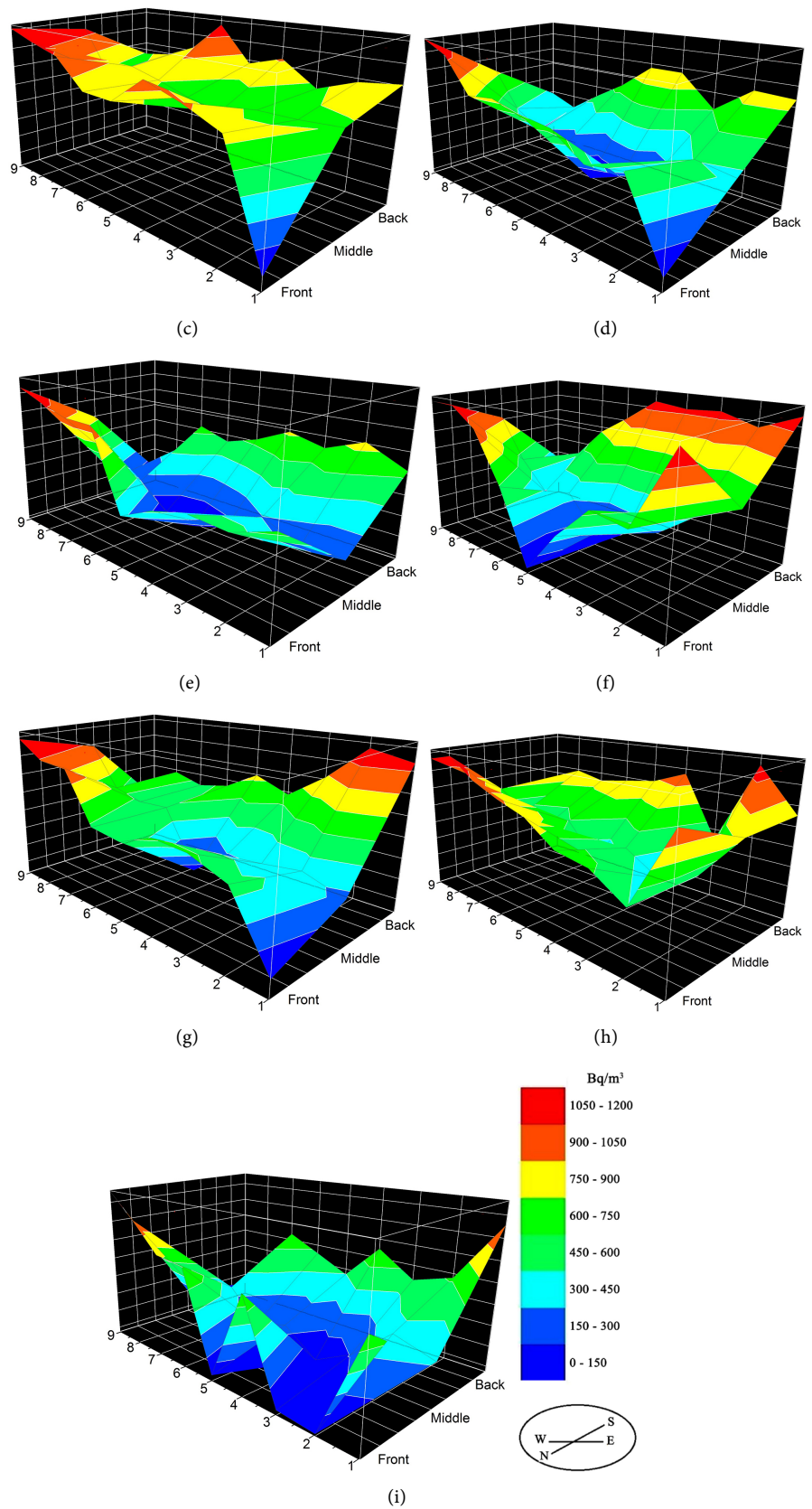
The experimental radon concentration value exhibits variations, ranging from 10% to more than 60% of the average value measured with dynamic, certified and calibrated monitors.

As can be observed in **Figure 8**, the radon concentration is not uniform in the total volume of the room, but in each layer, there are variations ranging from 10% to 35%, already having taken in consideration the statistical variation of the measurement method. In addition to that there are also variations in each of the 9 measured layers, giving this a very characteristic and peculiar distribution of radon concentration inside the cellar.

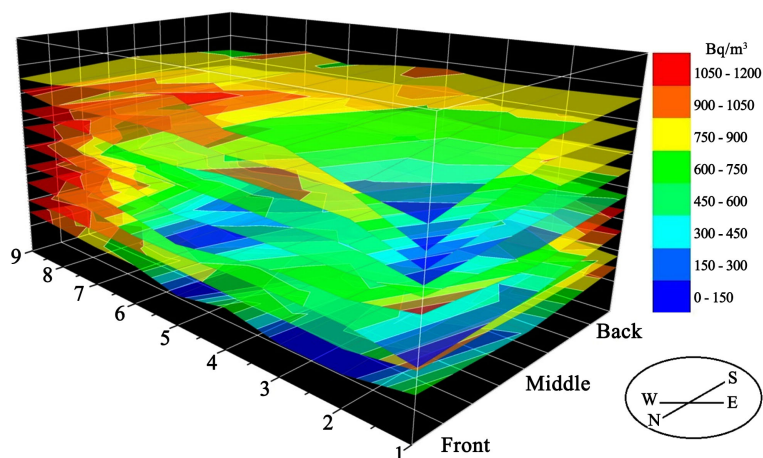
It is also possible to observe the decrease of this one, which is smaller, in the area where the small door is located, and which was opened twice in this period of 3 months of continuous exposition.

These results give us a clear indication that the distribution of radon in a room is not uniform.





**Figure 7.** Radon concentration levels obtained, plane by plane, from the top (a) to the bottom (i).



**Figure 8.** Radon ( $^{220}\text{Rn}$  and  $^{222}\text{Rn}$ ) concentration distribution, in each of the 9 measured planes inside the cellar. (the dynamic of this data can be observed in this link: <http://www.fisica.unam.mx/personales/espinosa/investigacion7.php>).

## 5. Previous Results from Other Research Groups and Relationship with This Work

Zhuo *et al.* (2001) proposed in the paper entitled “Simulation of the concentrations and distributions of indoor radon and thoron”; a simulation model, showing probable patterns of radon gas circulation as a function of airflow, and three-dimensional radon distribution patterns, based on the radon emanation source and the airflow. The results are very valuable, and the radon pattern presented helps to understand the experimental results of this work [11].

Later on, Urusevik *et al.* (2008) published a theoretical study of the indoor radon distribution and its simulation using a mathematical model. The authors suggest a room with rectangular geometry and “infiltration outlets” of  $20 \times 20$  cm. The results are spectacular and very valuable, showing the spatial distributions of thoron and radon in a series of figures, identifying very well the influencing parameters [9].

Gyorfi and Csige (2011), in the paper “Effect of atmospheric pressure variations on the  $^{222}\text{Rn}$  activity concentration in the air of a wine cellar”, perform the calculations and mathematical simulation using measurements of radon concentration variation in an underground cellar room, similar to the “motive” of this work, as function of the barometric variations of atmospheric pressure. The authors found a very peculiar rectangular pattern of distribution of radon inside of the cellar room, showing a greater concentration in the walls and ceiling [8].

In the same year De With and De Jong (2011) in their proposed “Simulation of thoron and thoron progeny concentrations in the indoor environment”, where the results showed some thoron accumulation on the center, and a distribution on “layers” [10].

Akbari and Mahmoudi (2012) presented a numerical simulation of the indoor radon transportation effects, as function of the temperature and relative humidity. The results show a decreasing in radon concentration based on the increase

of these variations [6].

These published works and many others show the scientific interest and relevance of the knowledge about the distribution of radon and thoron gases, product of the radioactive disintegration chains of the natural uranium and thorium contained in our planet Earth.

## 6. Conclusions

The distribution of indoor radon concentration inside of an enclosure is not uniform or homogeny; on the contrary, each place specifically presents radon concentrations and peculiar distributions. Because of that, the evaluation of the radon concentration as well as its distribution is a requirement to determine health risks to the population.

The evidence of radon non-homogeneous distribution inside a room is available, both via simulation and experimental measurements specifically, which confirm that the indoor radon concentration distribution is very peculiar and local.

It is very important, both from a scientific and health point of view, to understand and know the dynamics of radon gas ( $^{220}\text{Rn}$  and  $^{222}\text{Rn}$ ) in different media, depending on the possible parameters that affect it.

About the dynamics in this case, a small flux of outdoor radon through the concrete and brick walls cellar, and the different density between radon gas and the air in the room, can make this distribution, from the floor to the ceiling inside the complex.

These variations of indoor radon concentration should be considered in most cases to have real data on indoor radon concentration, areas of greater exposure and areas of lower radiological risk, both for its mitigation and for its control.

All these models and simulations, plus experimental work and measurement, will serve to know and better understand the behavior of the radon gas dynamics, depending on the different environmental factors, and thus be able to make a more accurate calculation of doses and the radiological risk in public health by radon.

## Acknowledgements

The authors wish to thank to A. Chavarría, P. Carrasco, A. Cortes, M. Cuautle, A. García, N. González, J. Martínez, L. Martínez, L. Novoa and M. Veytia, for their technical help. This work was partially supported by UNAM-DGAPA-PAPIIT project IN-102819.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

## References

- [1] Espinosa, G., Golzarri, J.I., Rickards, J. and Gammage, R.B. (1999) Distribution of



- Indoor Radon Levels in Mexico. *Radiation Measurements*, **31**, 355-358.
- [2] Espinosa, G., Golzarri, J.I. Bogard, J., Gaso, I., Ponciano, G., Mena, M. and Segovia, N. (2008) Indoor Radon Measurements in Mexico City. *Radiation Measurements*, **43**, S431-S434. <https://doi.org/10.1016/j.radmeas.2008.03.039>
- [3] Somlai, J., Gorjánác, Z., Várhegyi, A. and Kovács, T. (2006) Radon Concentration in Houses over a Closed Hungarian Uranium Mine. *Science of the Total Environment*, **367**, 353-365.
- [4] Tell, I., Bensryd, I., Rylander, L., Jönsson, G. and Daniel, E. (1994) Geochemistry and Ground Permeability as Determinants of Indoor Radon Concentrations in Southernmost Sweden. *Applied Geochemistry*, **9**, 647-655. [https://doi.org/10.1016/0883-2927\(94\)90025-6](https://doi.org/10.1016/0883-2927(94)90025-6)
- [5] Varley, N.R. and Flowers, A.G. (1998) The Influence of Geology on Radon Levels in S.W. England. *Radiation Protection Dosimetry*, **77**, 171-176. <https://doi.org/10.1093/oxfordjournals.rpd.a032307>
- [6] Akbari, K. and Mahmoudi, J. (2012) Numerical Simulation of Radon Transport and Indoor Air Conditions Effects. *International Journal of Scientific & Engineering Research*, **3**, 1-9.
- [7] Akbari, K. and Mahmoudi, J. (2018) Simulation of Radon Mitigation in Residential Building with Ventilation. <https://pdfs.semanticscholar.org/9b44/fb43cb1719de58a4c01d2565eb58140a86c1.pdf>
- [8] Gyorfı, T. and Csige, I. (2011) Effect of Atmospheric Pressure Variations on the <sup>222</sup>Rn Activity Concentration in the Air of a Wine Cellar. *Journal of Radioanalytical and Nuclear Chemistry*, **288**, 229-232. <https://doi.org/10.1007/s10967-010-0947-0>
- [9] Urosevic, V., Nikezic, D. and Vulovic, S. (2008) A Theoretical Approach to Indoor Radon and Thoron Distribution. *Journal of Environmental Radioactivity*, **99**, 1829-1833. <https://doi.org/10.1016/j.jenvrad.2008.07.010>
- [10] De With, G. and De Jong, P. (2011) Simulation of Thoron and Thoron Progeny Concentrations in the Indoor Environment. *Journal of Building Physics*, **35**, 101-127. <https://doi.org/10.1177/1744259111398634>
- [11] Zhuo, W., Iida, T., Moriizumi, J., Aoyagi, T. and Takahashi, I. (2001) Simulation of the Concentrations and Distributions of Indoor Radon and Thoron. *Radiation Protection Dosimetry*, **93**, 357-368. <https://doi.org/10.1093/oxfordjournals.rpd.a006448>
- [12] Denman, A.R., Groves-Kirkby, N.P., Groves-Kirkby, C.J., Crockett, R.G.M., Phillips, P.S. and Woolridge, A.C. (2007) Health Implications of Radon Distribution in Living Rooms and Bedrooms in U.K. Dwellings—A Case Study in Northamptonshire. *Environment International*, **33**, 999-1011. <https://doi.org/10.1016/j.envint.2007.01.011>
- [13] Universidad Nacional Autónoma de México (UNAM) (2018) Portal de estadística universitaria. <http://www.estadistica.unam.mx/numeralia/>
- [14] Espinosa, G., Golzarri, J.I., Jaso, I., Mena, M. and Segovia, N. (2013) An Intercomparison of Indoor Radon Data Using NTD and Different Dynamic Recording Systems. *Radiation Measurements*, **50**, 112-115. <https://doi.org/10.1016/j.radmeas.2012.11.005>
- [15] Espinosa, G. (1994) Trazas Nucleares en Sólidos. Instituto de Física, Universidad Nacional Autónoma de México.
- [16] Espinosa, G. and Gammage, R.B. (2003) A Representative Survey of Indoor Radon in the Sixteen Regions in Mexico City. *Radiation Protection Dosimetry*, **103**, 73-76. <https://doi.org/10.1093/oxfordjournals.rpd.a006119>

- [17] Mazur, D., Janik, M., Loskiewicz, J., Olko, P. and Swakon, J. (1999) Measurements of Radon Concentration in Soil Gas by CR-39 Detectors. *Radiation Measurements*, **31**, 295-300. [https://doi.org/10.1016/S1350-4487\(99\)00135-3](https://doi.org/10.1016/S1350-4487(99)00135-3)
- [18] Orlando, C., Orlando, P., Patrizii, L., Tommasino, L., Tonnarini, S., Trevisi R. and Viola, P. (2002) A Passive Radon Dosemeter Suitable for Workplaces. *Radiation Protection Dosimetry*, **102**, 163-168. <https://doi.org/10.1093/oxfordjournals.rpd.a006085>