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Radon Dose Determination and Radiological Risk in Some Mexican Caves with CR-39 Detectors

A. Chavarria[1]* iD, J.I. Golzarri[2] and G. Espinosa[2]

[1]Sciences Faculty, National Autonomous University of Mexico

[2]Instituto de Física, Universidad Nacional Autónoma de México, Cd. de México 04520 México; Condensed Matter Department, Physics Institute, National Autonomous University of Mexico

*acchs2002@yahoo.com.mx (Corresponding Author)

ARTICLE INFORMATION

ABSTRACT

Radon (^{222}Rn) is a radioactive gas, from the ^{238}U decay chain, that contributes in large part of the natural radiation dose to which humans are exposed. Radon is the second cause of lung cancer after tobacco. The US-EPA considers a concentration of 148 Bq/m³ for homes and 400 Bq/m³ for workplaces as the reference level. Caves are closed spaces where ^{222}Rn, which emanates from the surrounding minerals and rocks, can accumulate and reaches large concentrations that can represent a health risk for the guides, speleologists and visitors who spend time in these spaces. This work uses the previously recorded radon concentrations in 8 caves in Mexico and calculates the average dose range and the average annual dose for each of them with the "Wise" public domain program (http://www.wise-uranium.org/rdcrn.html) to determine the level of radiological risk with 2,000 1,000 and 500 working hours per year. Karmidas cave had the highest average ^{222}Rn concentration with 27,633.3 Bq/m3 and for 2,000 working hours per year an average annual dose rate of 347.1 mSv/y. Los Riscos cave had the lowest average concentration with 384.7 Bq/m³ and for 2,000 working hours per year an average annual dose rate of 4.832 mSv/y. These results show that all the caves studied present values, with 2,000 working hours per year, that exceed 3 mSv/y for workplaces and must be considered by the people who work in these places. A casual tourist visiting the caves does not present any radiological risk, while guides and speleologists should consider it.

Introduction

Radon (^{222}Rn) is a naturally occurring gas product of the decay of radium (^{226}Ra), it has a half-life of 3.8 days, is part of the uranium (^{238}U) decay chain and it is the main source of natural radiation to which the human being is exposed. According to the United States Environmental Protection Agency (US-EPA) and the World Health Organization (OMS) ^{222}Rn is the second cause of lung cancer after the Tabaco. In nature, ^{222}Rn emanates constantly from the soil and reaches concentrations of less than 50 Bq/m³ [12] because it's constantly being diluted on atmosphere; however in closed spaces like caves or mines it can accumulate to reach concentrations of KBq/m³ [1-6]. Caves are cavities that are formed in the interior of the earth due to different geological, chemical, volcanic, wave and wind processes and can extend up to several kilometers and reach great depths. These geological formations have been exploited by man throughout his history in many different ways, for example, they were used as housing by our ancestors approximately 5,00,000 years ago [8]. Inside these places the ^{222}Rn

concentrations may vary due to internal factors such as ventilation, types of surrounding minerals, length of the cave; also to external factors such as atmospheric conditions and geographical location [7].

Mexico is a country with around 7,000 caves in its territory [10] and many of them are a natural attraction for national and foreign visitors like Cacahuamilpa Caves, while others are frequented by speleologists and researchers, many of whom spend a lot of time inside them. Several studies have measured the concentration of ^{222}Rn inside caves in different countries such as Ireland [4], Slovenia [11], Hungary[13], Jamaica [9], Brazil [1], Ecuador [14] among others. In México Borau et al. (1993) measured ^{222}Rn concentration inside three caves located in the state of Guerrero. In another work Espinosa et al. (2008) determined the concentration of ^{222}Rn in a cave in the state of Oaxaca. Finally in 2013 Espinosa et al. measured the ^{222}Rn concentration in two caves in the state of Querétaro and two in the state of Puebla, where they also observed an interesting coincidence between ^{222}Rn concentrations and

bat distribution; these animals are distributed in areas with medium and low gas concentrations.

Due to its effect on health, it is important to monitor the ^{222}Rn present in caves in order to know the radiological risk to which people who frequent these places may be exposed [1]. The main of this work is to calculate the dose of ^{222}Rn, based on data previously collected and published in eight caves in the Mexican Republic to determine the radiological risk to which guides, speleologists who frequent these spaces may be exposed.

2. Global Regulations and Action Levels

Action levels and regulations for ^{222}Rn vary from country to country, e.g. in the United States indoor action levels are 148 Bq/m³ in homes and 400 Bq/m³ in workplaces [16]; in the United Kingdom workplace action levels are 400 Bq/m³ and dose limits are 5 mSv/year. The European Union has action level ranges from 500 Bq/m³ to 1,500 Bq/m³ for workplaces. Mexico does not have regulations regarding radon levels in enclosed public and private spaces; for this reason, the regulations established by the US-EPA for intramural radon concentrations are taken into account.
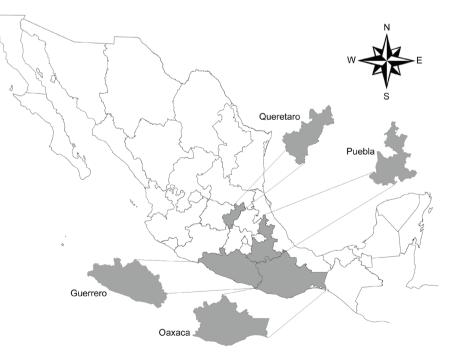
3. Methodology

For this work the results of Borau et al. (1993) and Espinosa et al. (2008, 2013) were used. These authors used the technique of nuclear track in solids in CR-39 plastic (Lantrack®) detectors to measure the concentration of ^{222}Rn in eight caves in the Mexican Republic. This method is the most suitable for this type of environment since it is low cost, can be used for long periods of time, is not affected by environmental factors such as temperature and humidity, is easy to transport and handle, and has a high efficiency in the detection of alpha particles. Total exposure times for detectors inside the caves were between three and six months (Table 1). After being recovered, all plastics chemically etched in a thermo regulated bath. The tracks formed were counted and the ^{222}Rn concentrations were calculated for each cave.For more detailed description of the methodology consult Borau et al. (1993) and Espinosa et al. (2008, 2013).

4. Caves Description

Aguacachil cave is located in the state of Guerrero (Figure 1), at 18°35'30" north and 94°34'2" west, in a region with an altitude of 1,500 m above sea level. It has 1,618 m in its course, 169 m of maximum depth (Figure 2). Four sampling points were established where the CR-39 detectors were placed.

Las Pozas Azules are located in Acuitlapan, also in the state of Guerrero (Figure 1), at 18°37'26" north and 99°32'55.7" west. They have a length of 1,649 m and a depth of 197 m (Figure 2). Four sampling points were established in this cave where the CR-39 detectors were placed.
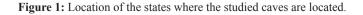

Figure 1: Location of the states where the studied caves are located.

Figure 2: Studied caves. A.- Aguacachil, B.- Pozas Azules, C.- San Jeronimo, D.- Gabriel, E.- Los Riscos, F.- El Judío, G.- Coyozochico, H.- Karmidas.

The San Jerónimo cave is located near Tenancingo, also in the state of Guerrero (Figure 1), at 18°40'11" north and 99°30'36" west. The San Jerónimo River runs through this place. Four sampling points were established where the CR-39 detectors were placed. It is a space visited by tourists and speleologists who can take several hours to visit this cave (Figure 2).

Gabriel cave is located in the southern state of Oaxaca at 18°27'25" north and 96°40'34" west at an altitude of 110 m above sea level. The cave (Figure 2) is 1,500 m long, with a chimney 250 m from the entrance. Fifteen sampling points were established where CR-39 detectors were placed. The temperature average is 25.2° C.

Los Riscos cave is located in the state of Querétaro (Figure 1) at 21°11'38" north and 99°30'50" west at an altitude of 1,122 m above sea level, with a length of 550 m and a depth of 39 m (Figure 2), an average temperature of 18°C and a relative humidity of 85%. Twelve sampling points were established where the CR-39 detectors were placed.

El Judío cave, also located in the state of Querétaro (Figure 1), at 21°11'38" north and 99°30'50" west, is made of limestone, is 48 m long and 25 m deep, has two entrances, an interior temperature of 21° C and a relative humidity of 50% (Figure 2). Six sampling points were established where the CR-39 detectors were placed.

The Coyozochico cave is located in the Sierra Norte of the state of Puebla (Figure 1) at 19°57'00" north and 97°24'36" west. It has a length of 170 m, an average temperature of 19° C, 68% relative humidity (Figure 2). Seven sampling points were established where CR-39 detectors were placed.

Karmidas Cave is located in the state of Puebla (Figure 1) at 19°58'10" north and 97°38'36" west. It is 260 m long (Figure 2), has an average temperature of 18° C and 65% relative humidity. Nine sampling points were established where the CR-39 detectors were placed.

For more detail description of each caves consult Borau et al. (1993) and Espinosa et al. (2008, 2013).

The dose calculation for each sampling point of the areas studied was carried out using the public domain software "Wise" [17], to determine the radiological risk to which guides and speleologists who frequent these sites may be exposed. Three different times were considered for doses calculation: 2,000, 1,000 and 500 hours per year and an equilibrium factor of 0.4 was considered for ^{222}Rn and its children, since this is an average value among the values reported in the literature [15].

5. Results and Discussion

Table 1 summarizes the location, methodology and average ^{222}Rn concentration recorded in each of the eight caves studied. It can be seen that Karmidas cave in the state of Puebla has the highest concentration of ^{222}Rn (27633.3 Bq/m^3), while Los Riscos in the state of Querétaro has the lowest (384.7 Bq/m^3). The variations in ^{222}Rn concentrations observed in Table 1 are related to the concentrations of ^{238}U and ^{226}Ra present in the minerals of each cave, rock porosity, the ventilation of the site which may be due to the presence of chimneys or the proximity to the cave entrance; the presence of rivers and water accumulation as well as the internal temperature of each cave and earthquakes are factors that affect the concentration of ^{222}Rn [3-5]. All these characteristics of each cave make them unpredictable and dynamic environments, which can be influenced by external factors such as rain, wind, altitude, atmospheric pressure and season. For this reason it is necessary to carry out constant measurements to better understand the dynamics of these environments.

Table 1: Caves studied and their general radon concentration.

Cave	Location State	Methodology	Time Months	^{222}Rn Average Concentration (Bq/m^3)
Aguacachil	Guerrero	Cr-39	3	1160
Las Pozas Azules	Guerrero	Cr-39	3	1150
San Jerónimo	Guerrero	Cr-39	3	1530
Gabriel	Oaxaca	Cr-39	6	2500
Los Riscos	Queretaro	Cr-39	6	384.7
El Judío	Queretaro	Cr-39	6	471.6
Coyozochico	Puebla	Cr-39	6	511.9
Karmidas	Puebla	Cr-39	6	27633.3

Table 2 lists the average dose rate and average annual dose rate values calculated with the "Wise" public domain software [17] and the average ^{222}Rn concentration in table 1 for the eight caves studied. With 2,000 working hours per year all caves exceeds the reference value of 3 mSv/y for workplaces; Karmidas cave has the highest value of annual dose rate (347.1 mSv/y) and Los Riscos cave has the lowest (4.832 mSv/y). A tourist guide or a speleologist who spends 2,000 hours in any of these caves should consider the radiological risk to which they are exposed.

Table 2: Average dose values and average annual dose for each sampling point in each cave and general average.

Cave	Occupancy time (per year) (h)	Average Dose Rate µSv/h	Average Annual dose rate mSv/y	Occupancy time (per year) (h)	Average Dose Rate µSv/h	Average Annual dose rate mSv/y	Occupancy time (per year) (h)	Average Dose Rate µSv/h	Average Annual dose rate mSv/y
Aguacachil	2,000	7.286	14.57	1,000	7.286	7.286	500	7.286	3.643
Las Pozas Azules		7.192	14.44		7.192	7.192		7.192	3.596
San Jerónimo		9.609	19.22		9.609	9.609		9.609	4.805
Gabriel		15.7	31.41		15.7	15.7		15.7	7.852
Los Riscos		2.416	4.832		2.416	2.416		2.416	1.208
El Judío		2.962	5.924		2.962	2.962		2.962	1.481
Coyozochico		3.215	6.43		3.215	3.215		3.215	1.607
Karmidas		173.5	347.1		173.5	173.5		173.5	86.8

With 1,000 working hours per year, the caves that present an average annual dose below the reference limit are El Judio (2.962 mSv/y) and Los Riscos (2.416 mSv/y); the Coyozochico cave presents a value of 3.215 mSv/y slightly exceeding the reference value.

With 500 working hours per year Karmidas cave still exceeds the reference valuefor workplaces recording an average annual dose value of 86.8 mSv/y, 29 times higher than the 3 mSv/y. Aguacachil and PozasAzules caves present values of slightly higher than the reference value with 3.643 mSv/y and 3.596 mSv/y respectively.

Table 3 shows the number of hours required by an individual in each cave to reach the annual reference level of 3 mSv/y and the percentage of risk of cancer. These calculations were also done with the "Wise" program [17].

Table 3: Number of hours required for each cave to reach the annual reference dose and the percentage of cancer risk calculated with the program "Wise".

Cave	Reference Level mSv/y	Hours in the cave	Annual dose rate mSv/y	Excess lifetime cancer risk
Aguacachil	3	420	3.06	0.015%
Las Pozas Azules		420	3.033	0.015%
San Jerónimo		320	3.075	0.015%
Gabriel		192	3.015	0.015%
Los Riscos		1245	3.008	0.015%
El Judío		1015	3.006	0.015%
Coyozochico		935	3.006	0.015%
Karmidas		17	2.95	0.015%

A person who enters Karmidas cave requires a stay of just over 17 hours in a day to reach the reference level, or to make 8 tours of approximately two hours each. With the data in table 3 it can be seen that a casual tourist is not exposed to radiological risk when visiting each of the 8 caves. In Gabriel cave are necessary around 192 hours per year to reach the annual reference dose of 3 mSv/y; in San Jeronimo cave the time required to reach the annual reference dose is about 320 hours. Because in Aguacachil cave and Las Pozas Azules the concentration of ^{222}Rn is almost the same, the time to reach the annual reference dose is around 420 hours per year. On the contrary, the guides can make numerous

tours in these places, and speleologists can even stay there for several days.

In Mexico speleologists and cave guides have a radiological risk associated with their profession that they should be aware of. The doses of environmental radiation they receive during the tours they take in these environments vary from cave to cave and must be measured constantly. Therefore, the use of portable monitors will be of great help in regulating the times of stay and the length of the tour.

Conclusions

All studied caves have high ^{222}Rn concentration. The doses calculated for each cave with 2,000 working hours per year exceed the recommended doses for workplaces. It is recommended that guides and speleologists routinely use portable radon monitor so they can know the dose of environmental radiation they receive during their tours. Tourists who occasionally visit the eight caves studied and stay a few hours in them will not exceed the recommended annual limit and therefore will not present a radiological risk.

Competing Interests

The corresponding author declares no conflicting of interests.

Acknowledgments

References

[1]   S. Alberigi, B.R.S. Pecequilo, H.A.S. Lobo and M.P. Campos, Radiation Protection Dosimetry **145**, 252 (2011). https://doi.org/10.1093/rpd/ncr054

[2]   J. Borau, A. Gonzales, G. Espinosa and J.I. Golzarri, Nuclear Tracks and Radiation Measurements **22**, 287 (1993). https://doi.org/10.1016/0969-8078(93)90069-G

[3]   A.A Cigna, International Journal of Speleology **34**, 1 (2005). https://doi.org/10.5038/1827-806X.34.1.1

[4]   J.T. Duffy, J.S. Madden, G.M. Mackin, A.T. McGarry and P.A. Colgan, Environment International **22**, 415 (1996). https://doi.org/10.1016/S0160-4120(96)00140-7

[5]   G. Espinosa, Radon gas in caves (Original: Gas Radón en Cuevas). (Physics Institute, National Autonomous University of Mexico, Mexico, 2016).

[6]   G. Espinosa, J.I. Golzarri, R.E. Gammage, L. Sajo-Bohus, J. Viccon-Pale and M. Signoret-Poillon, Radiation Measurements **43**, S364 (2008). https://doi.org/10.1016/j.radmeas.2008.04.033

[7]   G. Espinosa, J.I.Golzarri, E. Vega-Orihuela and J.B. Morales-Malacara, Journal of Radioanalytical and Nuclear Chemistry **296**, 43 (2013). https://doi.org/10.1007/s10967-012-1975-8

[8]   A. Hoffman, J.G. Palacios-Vargas and J.B. Morales-Malacara, Manual of Biospeleology (Original: Manual de Bioespeliología). (National Autonomous University of Mexico, Mexico, 1986).

[9]   C.N. Grant, G.C. Lalor and M. Balcazar, Applied Radiation and Isotopes **71**, 96 (2012). https://doi.org/10.1016/j.apradiso.2012.07.007

[10] C. Lazcano, Gaceta UNAM. No. **41**, 21 (1983).

[11] P. Jovanovič, Environment International **22**, 429 (1996). https://doi.org/10.1016/S0160-4120(96)00142-0

[12] W.W. Nazaroff, Reviews of Geophysics **30**, 137 (1992). https://doi.org/10.1029/92RG00055

[13] P. Szervin, Environment International **22**, 389 (1996). https://doi.org/10.1016/S0160-4120(96)00137-7

[14] F.A.G. Paz, Y.A.G. Romero and R. Zalakeviciute, Journal of Radiation Research **60**, 759 (2019). https://doi.org/10.1093/jrr/rrz064

[15] UNSCEAR, Sources and effects of ionizing radiation. (United Nations, New York, 2000).

[16] US-EPA Environments Division (6609 J). US-EPA, Washington, DC (2004).

[17] WISE. http://www.wise-uranium.org/rdcrnh.html. (2009). Accessed 10 Aug 2020.