Journal of Environmental Protection, **2011, 2, 1143-1148**
doi:10.4236/jep.2011.29133 Published Online November 2011 (http://www.scirp.org/journal/jep)

An Indoor Radon Survey in Three Different Climate Regions in Mexico, and the Influence of Climate in the Obtained Values

Guillermo Espinosa[1], Richard Gammage[2]

[1]Instituto de Física, Universidad Nacional Autónoma de México, Coyoacán, México; [2]Oak Ridge National Laboratory, Oak Ridge, USA.
Email: espinosa@fisica.unam.mx

Received May 17th, 2011; revised August 19th, 2011; accepted October 2nd, 2011.

ABSTRACT

In this paper we present the results of a survey of indoor radon concentration levels in Mexico. In order to investigate whether differences in climate translate into significant differences in indoor radon concentrations, the country was divided into three climate regions: the northern semi-desert region, the central semitropical region and the southern tropical region. The survey was carried out using nuclear track methodology. The dosimeters employed for the survey were based on the passive closed-end cup device, developed at the Physics Institute of the National Autonomous University of Mexico, and used PADC as detector material. A well-established protocol for chemically etching and reading the detectors was followed. Average annual temperatures differ between regions (from 15˚C to 28˚C) but vary relatively little within each region. Atmospheric temperature is one of the most important factors which need to be considered when carrying out a survey of indoor radon concentrations because temperature largely determines building ventilation habits, and ventilation habits are known to have significant effects on indoor radon concentrations. Other factors, including building construction materials, architectural styles, geological and hydrological characteristics, and seismicity, vary from region to region and within each region. In each of the three regions low levels of indoor radon (from 37 to 179 $Bq \cdot m^{-3}$) were found.

Keywords: *Radon, Indoor Radon, Climate Influence, Nuclear Tracks Methodology*

1. Introduction

The radioactive gas radon is a decay product of naturally occurring uranium. Radon builds up in confined areas, and accounts for approximately 50% of the effective dose to which the general public is exposed [1]. The inhalation of radon progeny such as polonium, lead and bismuth is a significant cause of lung cancer throughout the world. Determining indoor radon concentrations in dwellings and workplaces is thus an important public health problem.

Several national and international organizations and institutions have conducted national surveys of indoor radon concentrations [2-5]. The measurement of indoor radon concentration levels forms a mandatory part of radiation safety procedures in the United Kingdom, the United States of America, the Nordic countries and, in general, countries which experience cold climates for a significant part of year.

The concentrations of radon and its progeny inside a given dwelling depend on numerous factors, the most important of which are the uranium concentrations both in the soil surrounding the dwelling and in the building materials themselves, atmospheric conditions, architectural style (for example, whether there is a slab basement, a crawl space, etc.), porosity of the surrounding soil, building layout, and the ventilation habits of the inhabitants of the building. The large variability in the factors listed above contribute to potentially large variability in indoor radon concentrations and motivate detailed, nation-wide indoor radon surveys such as that described here.

Indoor radon concentration measurements are also important from the public health point of view in countries with more benign climates. In these countries, the ventilation habits of the inhabitants, themselves largely determined by climate, are more important than other factors in determining the differences in the indoor radon levels over large spatial scales.

1.1. Regulations and Action Levels in Selected Countries

A radon action level is a concentration of radon gas above which remedial or protective actions should be carried out. Both the International Commission on Radiological Protection (ICRP) and the International Atomic Energy Agency (IAEA) suggest allowable radon concentrations of 200 to 600 Bq·m^{-3} in dwellings and 500 to 1500 Bq·m^{-3} in workplaces [6,7]. However both agencies allow national authorities a significant degree of autonomy in establishing action levels.

The European Union accepts the reference values recommended by the ICRP in its Publication 65 [7]. The United States Environmental Protection Agency (USEPA) uses a reference level of 148 Bq·m^{-3} for dwellings and 400 Bq·m^{-3} for workplaces [3]. In the UK, the Health and Safety Executive (HSE) [8] has adopted radon action levels of 200 Bq·m^{-3} for dwellings and 400 Bq·m^{-3} for workplaces. In Israel there is a mandatory reference level of 200 Bq·m^{-3} for already existing schools and day care centers and an advisory reference level of 400 Bq·m^{-3} for all other already existing workplaces. For new schools and day care centers the advisory level is 40 Bq·m^{-3} while that for other new workplaces [9]. In contrast, in Mexico there are no specific regulations relating to indoor radon levels in either homes or workplaces. It is hoped that the survey described here will aid the relevant government institutions to establish appropriate regulations in the near future.

1.2. Indoor Radon Survey Strategy

Mexico is a large country in terms of both area and population. It covers an area of 1,967,183 km^2 and extends from the southern border of the United States, in North America, to the northern border of Guatemala, considered to be part of Central America. For the purposes of this study, the country was divided into three climate-based regions: the northern semi-desert region (region I), the central semi-tropical region (region II) and the southern tropical region (region III).

The northern semi-desert region I comprises the following ten states: Baja California, Chihuahua, Coahuila, Sonora, Nuevo Leon, Tamaulipas, Sinaloa, Durango, Zacatecas and San Luis Potosi. The Tropic of Cancer passes through the last seven of these states. Mean annual temperatures in these states vary between 13.5˚C and 25.2˚C and yearly rainfalls vary between 244 and 1305 mm. The semi-tropical central region II comprises the Federal District and the states Aguascalientes, Nayarit, Jalisco, Colima, Guanajuato, Michoacan, Queretaro, Hidalgo, Tlaxcala, Puebla and the State of Mexico. Average yearly temperatures in this region vary from 14.7˚C to 24.8˚C while mean annual rainfalls vary from 387 to 1349 mm. Finally, the southern region, which comprises the states of Morelos, Guerrero, Veracruz, Oaxaca, Tabasco, Chiapas, Campeche, Yucatan and Quintana Roo, presents a tropical climate with average temperatures from 20.6˚C to 26.8˚C and rainfalls from 645 to 2050 mm. The three regions are shown in **Figure 1**.

The indoor radon survey described here was carried out over a one-year period. The measurement period was divided into four three-month periods, corresponding to the (northern hemisphere) fall and winter of 2008 and the spring and summer of 2009. These periods were chosen to coincide as closely as possible with those of the previous national indoor radon survey carried out ten years earlier [10].

1.3. Number and Location of Dwellings and Detectors

Dwellings in the three most populated cities of each state in the country were chosen for the indoor radon level survey. This ensured the inclusion of each state capital in the survey. An exception to the three-city rule was the Federal District (*Distrito Federal*) in region II, which is almost entirely occupied by Mexico City.

Houses of approximately the same age, regardless of architectural style, and where permission had been given by the owner and/or occupants, were chosen randomly for the survey. The measurements were taken in the liv-

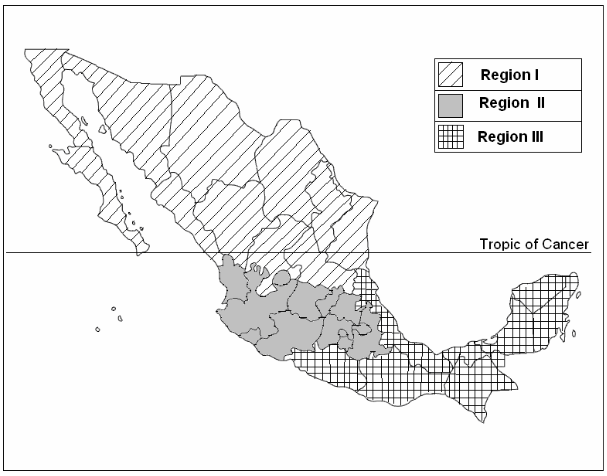

Figure 1. Mexico was divided into three climate-based regions for the purposes of the indoor radon survey: the northern semi-desert region (region I), the central semi-tropical region (region II) and the southern tropical region (region III).

ing rooms, and two detectors were placed at each location. A total number of 3167 dwellings (approximately 100 in each state) were used in the survey.

2. Method

The indoor radon survey was carried out using nuclear track methodology. The dosimeters used for the survey were based on the passive closed-end cup device, developed at the Physics Institute of the National Autonomous University of Mexico (UNAM), with poly allyl diglycol carbonate (PADC) as detector material [11].

The detectors were prepared and the tracks read following a well-established protocol. Before exposure the detectors were chemically pre-etched in order to eliminate surface impurities, scratches and irregularities, washed in distilled water and dried. After exposure the tracks were developed using a one-step chemical etch in a 6.25M KOH solution at 60 ± 1˚C for 18 hours. The detectors were then washed in running dis- tilled water and dried in desiccant paper. This process is well established and highly reliable [12].

The tracks were counted automatically by a Digital Image Analysis System (DIAS) [13] and the data automatically analyzed using a PC with Microsoft Excel software. The detection device was calibrated using the Oak Ridge National Laboratory radon chamber [10]. The process was verified using the chamber at the Physics Institute of the UNAM every three months, or whenever new CR-39 material arrived from the producer.

2.1. Detect to Protect

Differences in recommended indoor radon action levels are due both to spatial differences in uranium concentrations and to the cost of mitigation procedures. There is only way to manage the problem of indoor radon: to "Detect to Protect" [14]. This philosophy underlines the importance of measuring indoor radon levels, particularly in dwellings and workplaces, by reminding us that appropriate mitigation or protection measures are only able to be determined and taken if indoor radon levels have first been measured.

2.2. Dose Calculation Method

The effective dose and the derived risks are associated mainly with the inhalation of short-lived polonium (^{218}Po and ^{214}Po), a radon progeny alpha emitter. A comprehensive analysis of the radiation dose should consider detailed information on this aerosol as well as the degree of disequilibrium between radon and its progeny for each site and for each season. The literature reports values of the equilibrium factor ranging between 0.36 and 0.52, which suggests that an average value of 0.4 could be acceptable in order to estimate exposure to radon progeny from radon concentration measurements [1].

3. Results

Table 1 shows the geological characteristics, basic environmental factors, architecture style and seismicity, and ventilation methods most commonly found in each of the three regions of the survey.

Table 2 lists the states in each region, the number of dwellings monitored in each state, the minimum, maximum and mean radon concentration in each state, the standard deviation of the radon concentration in each state, the total number of dwellings monitored in each region, and the mean radon concentration in each region. The most important observation is that no state average

Table 1. The geological characteristics, basic environmental factors, architecture style and seismicity, and ventilation methods most commonly found in each of the three regions.

	Region I	**Region II**	**Region III**
Climate classification	Semi-desert	Semi-tropical	Tropical
Soil characteristics	Lithosols, regosols, aridisols, sierozem, desertic soils	Lithosols, regosols, volcanic ashes, vertisols, lateritic oxisols	Lithosols, regosols, alluvial soils, rendzinas, gleysols, savanna soils
Hydrological characteristics	Groundwater, no river or lakes	Rivers and some small lakes	Important river systems and lakes
Building materials	Clay brick, stone and concrete	Clay brick, stone, gypsum and concrete	Adobe, wood and palm leaf roofs
Architecture	Rustic, without basements	Colonial and semi-rustic, without basements	Traditional and rustic without basements
Ventilation	Non air-conditioned, open windows	Non air-conditioned, open windows	Non air-conditioned, open windows and doors
Mean annual rainfall	492 mm	762 mm	1080 mm
Mean annual temperature	20.7˚C	17.6˚C	24.7˚C
Seismicity	High at the pacific coast and low in central and Mexican Gulf coast	High in all the region	High at the pacific coast and low in the Mexican Gulf coast

Table 2. The states in each region, the number of dwellings in each state, the minimum, maximum and mean radon concentration, and the standard deviation of the radon concentration, in each state, the number of dwellings in each region, and the mean radon concentration in each region.

Region REGION I	State	Number of dwellings monitored	Min (Bq·m^{-3})	Max (Bq·m^{-3})	Mean (Bq·m^{-3})	Std. Deviation (σ)
1	Baja California	90	77	120	88	7.52
2	Baja California Sur	90	50	90	70	5.10
3	Sonora	90	70	92	74	5.93
4	Chihuahua	95	85	179	130	7.83
5	Coahuila	90	72	110	98	5.86
6	Nuevo León	100	77	118	97	7.64
7	Tamaulipas	90	66	93	81	7.52
8	Sinaloa	95	48	87	77	6.31
9	Durango	95	51	92	82	5.91
10	Zacatecas	100	82	122	110	7.73
11	San Luis Potosí	100	67	100	88	7.21
	Total	1035		Average	90.5	6.78
REGION II	State	Number of dwellings monitored	Min (Bq·m^{-3})	Max (Bq·m^{-3})	Mean (Bq·m^{-3})	Std. Deviation (σ)
12	Aguascalientes	90	77	115	101	7.33
13	Nayarit	90	48	80	75	6.25
14	Jalisco	90	57	110	97	7.56
15	Colima	80	47	74	69	7.12
16	Guanajuato	100	63	112	99	7.81
17	Michoacan	100	76	124	80	7.60
18	Queretaro	100	77	120	110	7.42
19	Hidalgo	80	67	109	97	6.93
20	Tlaxcala	80	72	97	87	6.91
21	Puebla	100	99	135	115	7.45
22	Estado de México	200 **	57	103	87	5.91
23	Distrito Federal	200 **	59	130	85	6.12
	Total	1310		Average	91.8	7.03
REGION III	State	Number of dwellings monitored	Min (Bq·m^{-3})	Max (Bq·m^{-3})	Mean (Bq·m^{-3})	Std. Deviation (σ)
24	Morelos	93	48	103	74	6.23
25	Guerrero	89	45	97	70	7.12
26	Veracruz	95	42	78	65	6.05
27	Oaxaca	90	55	101	87	7.16
28	Tabasco	90	41	87	62	5.82
29	Chiapas	90	43	86	58	5.40
30	Campeche	90	41	79	55	5.50
31	Yucatan	95	37	81	51	5.37
32	Quintana Roo	90	48	77	69	5.51
	Total	822		Average	65.7	6.02

** Densely-populated locations.

indoor radon concentration, and hence no regional average concentration, is above the USEPA recommended action level of 148 Bq·m^{-3}. These measured values are surprising, being lower than the average in door radon concentrations measured in other countries by other surveys [2,15,16].

The frequency distribution of state average radon concentrations is shown in **Figure 2**. It can be seen that most states have mean indoor radon concentrations of between 60 and 100 Bq·m^{-3}.

Dose Calculation Results

Given the average indoor radon concentration and building occupancy rates, the WISE Uranium Project calculator allows the calculation of dose rates for individuals exposed. The values used in these calculations are from the ICRP-65 [7]. **Table 3** shows values for the radiation dose per hour and per year, and the health risk for an individual exposed to radon and its decay products assuming the minimum and maximum radon concentrations found in this survey, 37 Bq·m^{-3} and 179 Bq·m^{-3} respectively, and an 80% occupancy rate.

4. Conclusions

In general, the low average indoor radon concentrations found mean that indoor radon poses a low health risk in these areas.

An important purpose of this paper is to show that climate and the associated ventilation habits are important parameters to consider in the context of indoor radon concentration surveys which include a large number of measurements and cover large geographical areas.

We hope that this experience can be of use to other researchers who seek to carry out surveys of indoor radon concentrations in other countries with climatologically and economic conditions similar to those of Mexico, and contribute to an extension of the coverage of indoor radon surveys at a worldwide level.

Finally, we conclude that indoor radon concentration levels do not change drastically over a period of ten years in the absence of dramatic changes in climatic or geographical conditions.

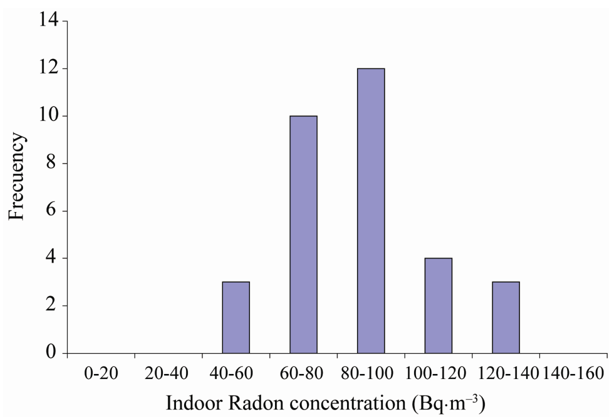

Figure 2. Frequency distribution of state mean indoor radon levels.

Table 3. Radiological risk assuming an 80% occupancy time per year.

Radon concentration	**37 Bq/m^3**	**179 Bq/m^3**
Dose (per hour)	92.96 nSv/h	449.7 nSv/h
Dose (per year)	651.9 µSv/y (0.163 WLM/y)	3.153 mSv/y (0.788 WLM/y)

5. Acknowledgements

The authors wish to thank to J.I. Golzarri for his technical help. This work was partially supported by Oak Ridge National Laboratory (managed by UT-Battelle Corp.) and by PAPIIT-DGAPA-UNAM project 1N101910.

REFERENCES

[1] United States Scientific Committee on the Effects on Atomic Radiation (UNSCEAR), "Sources and Effects of Ionizing Radiation," United Nations, New York, 2000.

[2] J. C. Miles, "Mapping Radon Prone Areas by Log-Normal Modeling of House Data," *Health Physics*, Vol. 74, No. 3, 1998, pp. 370-378. doi:10.1097/00004032-199803000-00010

[3] United States Environmental Protection Agency (USEPA), Environments Division (6609J), "A Citizen's Guide to Radon: The Guide to Protecting Yourself and Your Family from Radon," Washington DC 20460 US EPA 402-K-02-006, 2004.

[4] J. J. Whicker and M. W. McNaughton, "Work to Save Dose: Contrasting Effective Dose Rates from Radon Exposure in Workplaces and Residences against the Backdrop of Public and Occupational Regulatory Limits," *Health Physics*, Vol. 97, No. 3, 2009, pp. 248-256.

[5] World Health Organization (WHO), "Handbook on Indoor Radon, A Public Health Perspective," 2009.

[6] International Atomic Energy Agency (IAEA), "Radiation Protection against Radon in Workplaces Other than Mines," *Safety Report Series*, Vol. 33, 2003, pp. 11-12.

[7] International Commission on Radiological Protection (ICRP), "Protection against Radon-222 at Home and Work," ICRP Publication 65, Pergamon Press, Oxford, 1994.

[8] N. Kavasi, T. Kovacs, C. Nemeth, T. Szabo, Z. Gorjanacs, A. Varhegyi, J. Hakl and J. Somlai, "Difficulties in Radon Measurements in Workplaces," *Radiation Measurements*, Vol. 41, No. 2, 2006, pp. 229-234. doi:10.1016/j.radmeas.2005.02.001

[9] G. Akerblom, “Radon Legislation and National Guidelines Swedish Radiation Protection Institute,” SSI Report, 99-18, ISSN 0282-4434, 1999.

[10] G. Espinosa and R. B. Gammage, “Indoor Radon Concentration Survey in Mexico,” *Journal of Radioanalytical and Nuclear Chemistry*, Vol. 236, 1998, pp. 227-229. doi:10.1007/BF02386347

[11] G. Espinosa and R. B. Gammage, “Measurement Methodology for Indoor Radon Using Passive Track Detector,” *Applied Radiation and Isotopes*, Vol. 44, No. 4, 1993, pp. 719-723. doi:10.1016/0969-8043(93)90138-Z

[12] G. Espinosa, J. I. Golzarri, J. Bogard, I. Gaso, G. Ponciano, M. Mena and N. Segovia, “Indoor Radon Measurements in Mexico City,” *Radiation Measurements*, Vol. 43, Suppl. 1, 2008, pp. 431-434. doi:10.1016/j.radmeas.2008.03.039

[13] R. B. Gammage and G. Espinosa, “Digital Image System for Track Measurements,” *Radiation Measurements*, Vol. 28, No. 1-6, 1997, pp. 835-838. doi:10.1016/S1350-4487(97)00193-5

[14] M. Walchuk, “Speaking up about Radon,” Health Physics News, Vol. XXXVIII, No. 4, 2010, pp. 1, 4-7.

[15] H. Arvela, H. Reisbacka and P. Keraenen, “Radon Prevention and Mitigation in Finland: Guidance and Practice,” *Proceedings of the American Association of Radon Scientists and Technologists* 2008, Las Vegas NV, 14-17 September 2008.

[16] H. Friedmann, “Final Results of the Austrian Radon Project,” *Health Physics*, Vol. 89, 2005, pp. 339-348.

