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Indoor Radon (^{222}Rn) Concentration Level Study in Child Care Centers and Kindergartens, Using Nuclear Track Methodology (NTM)

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Abstract: As it is known, staying for long periods of time in a place with high concentration of radon is a health hazard. This health risk can be increased into adulthood, if at infant ages the young people grow inside places with important indoor radon levels. Causal associations between exposure level and lung cancer have been demonstrated in epidemiological studies around the world, suggesting that for younger age children groups, the risk coefficient of lung cancer for inhaled radon and their daughters is about a factor of 4 on children from recent born to 10 years old, and 2 for ages between 10 to 20 years old. The aim of this work is to determine the indoor radon levels where infants, from 3 months to 6 years old, remain long times in child care centers and kindergartens. Indoor radon (^{222}Rn) concentration levels were measured in the child care centers and kindergartens of the 16 political administrative regions, covering 5% of the total in Mexico City. This study was conducted over a one-year period, divided into four three-month periods coinciding with the seasons. Nuclear Track Methodology was selected for the measurements, and a passive close-end-cup-device was designed specifically to be used in children places. In this study, the results of measurements of indoor radon concentration in child care centers and kindergartens in Mexico City are encouraging, finding indoor radon levels between 26 Bq/m^3 and 75 Bq/m^3 with an average value of 51 Bq/m^3. It can be considered that the indoor radon concentration levels are low in this type of buildings, due to the benign climate in the city, the architecture design of the constructions, and the ventilation habits of the population.

Key words: Indoor radon, radon, nuclear tracks, kindergartens.

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], including infants in the process of biological development.

The inhalation of radon is a cause of lung cancer and other public health problems, due mainly to the radon progeny: polonium (^{218}Po), lead (^{214}Pb), bismuth (^{214}Bi) and polonium (^{214}Po). Three factors need to be considered for the health risk calculation: indoor radon concentration in the place, indoors time permanence in the living house and work place that for the kids is the time inside of the child care centers and kindergartens, and infants' ages. The determination of these three factors is very important to understand the health problem of the future middle-age and older population.

The aim of this work is to make the study and evaluation of the indoor radon concentration levels, where infants from 3 months to 3 years old, and kids from 3 to 6 years old, are living during the time inside the child care centers and kindergartens, and including their nurses and teachers.

Unfortunately, up to now there is no indoor radon level concentration official regulation for infants, which is very important to evaluate and consider. The aim of the PAD (Dosimetric Applications Project) of the Physics Institute of the University of Mexico is to contribute to the understanding of the radon health

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effects in the very young ages of the population, in order to prevent future diseases or premature lung cancer in the middle-age people.

For this study, the child care centers and kindergartens of the 16 political administrative regions, covering the 5% of the total of facilities in Mexico City, were measured over one year period time, and divided into four three-month periods coinciding with the seasons.

In the Mexico City map, Fig. 1 shows the 16 political administrative regions and the locations of the child care centers and kindergartens. Table 1 shows the name of the political administrative regions, the child population from 3 months to 6 years old, number of child care centers and kindergartens facilities, and average density population of children in each location [2].

2. Methodology

2.1 Indoor Radon Survey Strategy

Mexico City (Metropolis) is the most populated area in the whole country, 8.9 million of inhabitants, in an area of 1,495 Km^2. The 3.3% of this population are infants between 3 months to 6 years old; it is 296,415 children, with a total of 3,608 child care centers and kindergarten facilities [2]. In this study, the 5% (180) of the total of child care centers and kindergartens facilities in Mexico City were measured.

In Mexico City, the construction materials of the child care centers and kindergartens, public and private in general are: the walls built of red or white clay bricks, the floor and roof made of concrete. Each room has at least, one window and one door, and the buildings usually have one or two levels. Most of the dwellings have had 20 to 50 years since constructed.

The annual average temperature in the city is 17 °C, in summer the temperatures are 19 to 27 °C, and 14 to 25 °C in winter, with a rainfall of 586 mm from May to September. Mexico City is in a high valley at 2,240 meters above the sea level, in a semitropical region of North America, at the Tropical Cancer region [3].

2.2 Working Day and Exposure Times

The 3 months to 6 years child care centers and kindergartens open between 7:00 to 9:00 in the morning, and close from 13:00 to 16:00 in the afternoon; it is a

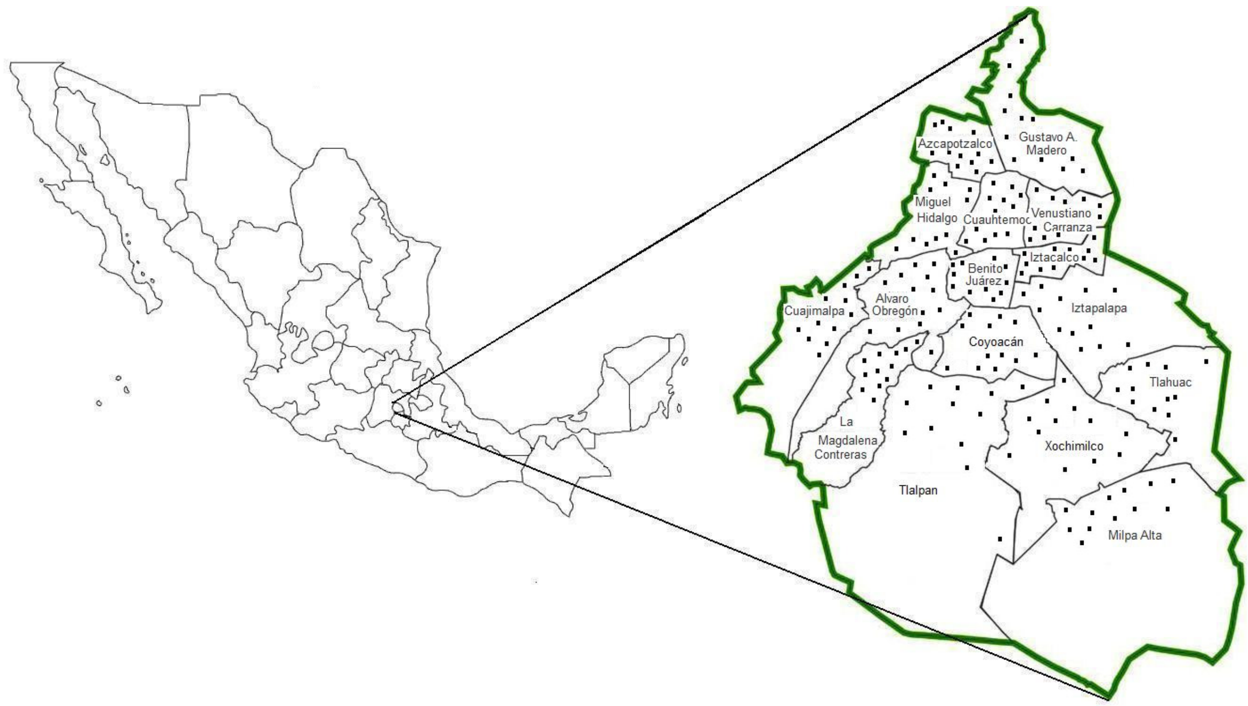

Fig. 1 Mexico City administrative regions with the measured locations.

Table 1 Name of the political administrative regions, the child population from 3 months to 6 years old, number of Child Care Centers and Kindergartens facilities, and average density population of children in each facility.

	Code	Political administrative region names	Number of children from 3 months to 6 years	Child Care Centers and Kindergartens facilities	Average number of children in each facility
1	AO	Alvaro Obregón	23,503	274	86
2	AZ	Azcapotzalco	14,988	166	90
3	BJ	Benito Juárez	13,431	229	59
4	CY	Coyoacán	19,383	259	75
5	CJ	Cuajimalpa	9,285	110	84
6	CH	Cuauhtémoc	18,000	224	80
7	GM	Gustavo A Madero	38,974	433	90
8	IC	Iztacalco	13,412	149	90
9	IZ	Iztapalapa	54,867	726	76
10	MC	Magdalena Contreras	7,985	94	85
11	MH	Miguel Hidalgo	14,315	191	75
12	MA	Milpa Alta	4,898	41	119
13	TL	Tláhuac	13,384	131	102
14	TP	Tlalpan	21,270	274	78
15	VC	Venustiano Carranza	14,164	167	85
16	XC	Xochimilco	14,556	140	104

minimum of 6 hours or a maximum of 9 hours exposure time inside a room, a day. Considering 5 working days a week, and 44 working weeks a year, give totals of 1,320 hours a year in the first case, and 1,980 in the second, that the infants remain indoors in the child care centers and kindergartens.

To this accumulative indoor time, when the infants are breathing radon, it should not be added the indoor radon permanence at home, which is at least 2,920 hours a year (8 hours × 365 days), in order to calculate the total risk of exposure to indoor radon for the young kids.

3. Experimental

The NTM (Nuclear Track Methodology) is one of the most commonly used one for indoor radon long-period and massive measurements, because of its characteristics: low cost, simplicity, large number of measuring devices available, and easy manipulation and control, allowing to find out the average indoor radon concentration values over one year or more [4].

The three steps of the method are: (I) exposure to indoor radon inside the measured places; (II) chemical etching process; and (III) track density reading. The first 2 steps already were explained, and the results, step III, are obtained multiplying the track density found by the calibration factor, in order to have the indoor radon concentration in Bq/m^3. These values are shown in Table 2.

3.1 Indoor Radon Methodology

The indoor radon survey was carried out using NTM. The devices used for the survey were based on the passive closed-end cup system, developed at the Physics Institute of UNAM (the National Autonomous University of Mexico), with a specific design to be used in the child care centers and kindergartens for these measurements. This device is very attractive to the infants, easy to hang, pleasing to the sight of children. Two models of these detection devices are shown in Fig. 2. Making their replacement every 3 months is expected and desired by the infants.

Two Passive Devices were placed in each measured room, and replaced every three months for a new one, during one year; the first period (I) from December 2014 to March 2015, the second period (II) from March to June 2015; the third period (III) from June to September 2015, and the fourth period (IV) from September to December 2015.

Fig. 2 Close end cup device designed for the measurement of indoor radon levels concentration in Child Care Centers and Kindergartens (PAD-IFUNAM).

The radiation sensitive material chosen was the CR-39 (poly allyl diglycol carbonate) Lantrack® chip, inside of a 330 mL volume hard plastic cup, and closed with a high porosity plastic bag in order to permit the pass of the radon gas, and no solids [5, 6].

3.2 Chemical Etching and Track Density Reading

After the exposure time, the detectors were chemically etched in KOH (Potassium Hydroxide) solution, 6.25 M at 60 ± 1 °C for 18 hours. The detectors were then washed in running distilled water and dried in desiccant paper, following a well-established, and highly reliable protocol [4].

The tracks were counted automatically by a DIAS (Digital Image Analysis System) [7] and the data automatically analyzed using a PC (Personal Computer) with Microsoft Excel software. The detection device was calibrated using the Oak Ridge National Laboratory radon facilities [1]. The process was verified using the radon chamber at the Physics Institute of the UNAM every three months, or whenever new CR-39 material arrived from the producer.

4. Results and Discussion

4.1 Total Average Indoor Radon Concentration Value in the Child Care Centers and Kindergartens, and Data Comparison

Table 2 shows the indoor radon concentration average values of the child care centers and kindergartens facilities in each political administrative region for the four measurement periods, and the last column of

Table 2 Indoor radon data concentration of each measured period (3 months), and the average values in each political administrative region of Mexico City Child Care Centers and Kindergartens.

	Code	Indoor radon Period I (Bq/m^3)	Indoor radon Period II (Bq/m^3)	Indoor radon Period III (Bq/m^3)	Indoor radon Period IV (Bq/m^3)	Indoor radon Average value (Bq/m^3)
1	AO	44 ± 6	51 ± 9	39 ± 7	58 ± 11	48 ± 8
2	AZ	49 ± 8	67 ± 13	54 ± 8	75 ± 12	61 ± 10
3	BJ	53 ± 11	69 ± 11	57 ± 10	74 ± 9	63 ± 10
4	CY	48 ± 9	60 ± 9	47 ± 8	52 ± 10	52 ± 9
5	CJ	30 ± 5	45 ± 9	44 ± 8	38 ± 9	39 ± 8
6	CH	57 ± 7	72 ± 11	68 ± 11	67 ± 11	66 ± 10
7	GM	56 ± 6	65 ± 10	65 ± 9	50 ± 9	59 ± 7
8	IC	26 ± 6	34 ± 6	37 ± 9	36 ± 7	33 ± 7
9	IZ	44 ± 7	53 ± 8	57 ± 10	42 ± 9	48 ± 9
10	MC	29 ± 9	40 ± 7	39 ± 8	36 ± 8	36 ± 4
11	MH	60 ± 11	71 ± 11	69 ± 13	64 ± 11	66 ± 12
12	MA	35 ± 8	49 ± 10	44 ± 8	43 ± 9	43 ± 9
13	TL	28 ± 6	42 ± 9	38 ± 6	37 ± 8	36 ± 5
14	TP	46 ± 13	59 ± 10	57 ± 9	56 ± 10	55 ± 11
15	VC	54 ± 6	72 ± 12	64 ± 14	63 ± 11	63 ± 11
16	XC	39 ± 8	51 ± 9	49 ± 9	46 ± 9	46 ± 9

Table 3 Indoor radon data comparison in Child Care Centers and kindergartens measured in different countries.

Country	Minimum (Bq/m^3)	Maximum (Bq/m^3)	Average indoor radon concentration (Bq/m^3)	Measurement method	Reference
Egypt (Cairo)	29	75	44	NTD	8
Finland	NR	NR	211	NTD	9
Italy (Parma)	10	108	30 ± 19	NTD LR-115	10
Italy (South East)	21	1,047	246 ± 17	NTD-CR-39	11
Kosovo	20 ± 15	194 ± 16	NR	ASC	12
Kuwait	8	26	18 ± 6	NTD	13
Mexico	26 ± 6	75 ± 12	51 ± 9	NTD-CR-39	Present study
Servia	27 ± 5	145 ± 20	59.6 ± 1.6	Rad7	14
Slovenia	252 ± 18	1,700 ± 85	732 ± 34	ASC	15
Slovenia	58	5,600	133	ASC	16
Spain (Galicia)	119 ± 2	2,084 ± 63	174 ± 3	CC & AG	17
Sweden	NR	NR	107	NTD	18

NR = Non Reported; NTD = Nuclear Track Detectors; ASC = Alpha Scintillation Cells;
CC = Charcoal Canister; AG = AlphaGUARD; Rad7 = Durridge Rad7.

the table is shown the average values of these four periods. With these obtained values the average indoor radon concentration of the child care centers and kindergartens was calculated and it is 51 ± 9 Bq/m^3 in the 2015 year. It is significantly low compared with the indoor radon concentration in Mexico City houses [4], and also compared with the values reported of indoor radon in child care centers and kindergartens of other countries.

As can be observe in Table 3, the indoor radon concentration in the child care centers and kindergartens in different countries shows a huge dispersion of concentration, from very low values of 8 Bq/m^3 to highest of 5,600 Bq/m^3, inside of a room with infants below 6 years old. This is clear and very well known, due to the differences in geological, geographic, climate, and environmental conditions.

Some extreme cases reported are: Slovenia from 58 Bq/m^3 to 5,600 Bq/m^3, Galicia (Spain) with 119 Bq/m^3 to 2,084 Bq/m^3, Italy from 21 Bq/m^3 to 1,047 Bq/m^3, and others. With all these indoor radon concentration levels found, the importance to measure and evaluate the indoor radon concentration levels inside of the child care centers and kindergartens over the world is very clear, because the knowledge of the radon concentration in child care centers and kindergartens will change the health of future adults, by acting promptly with the indoor radon mitigation process.

The low indoor radon levels of 51 ± 9 Bq/m^3, inside of the child care centers and kindergartens facilities of the different institutions in Mexico City, can be due to the benign climate, the geologic characteristics, architecture of the buildings, and the habits of ventilation of the population.

5. Dose Calculation

For the dose calculation, the WISE (World Information Service Energy) code was chosen, considering the minimum and maximum remanence time of 6 and 9 hours inside of the rooms, the average value of the radon level concentration of 51 Bq/m^3, and an equilibrium factor of 0.4. With these values, the calculated dose for 6 hours is 0.506 mSv/y and for 9 hours is 0.760 mSv/y, for the kids inside of the child care centers and kindergartens.

In order to determine the real risk to exposure to indoor radon of a child, the value of received dose in the child care centers and kindergartens, should be accumulative to the dose received at home. It is 2,920 hours (8 hours × 365 days) exposed to the indoor radon concentration level at home. By using the average value of indoor radon measured in Mexican houses of 84.1 Bq/m^3 [4], the calculated dose is 1.851 mSv/y. The total dose for a Mexican child from 0.3

months to 6 years old is between 2.357 mSv/y and 2.611 mSv/y.

6. Conclusion

As a conclusion based on the indoor radon concentration levels found in this paper, it is very important to measure indoor radon concentration in the child care centers and kindergarten in order to know the concentration values and radiological risk of the infants, and these measurements should be mandatory worldwide.

In the case of finding out that the rooms or classrooms have high radon concentration levels, the people should not be there, and children activities inside the room should be forbidden, until the radon mitigation process is implemented.

The recommendation is to have indoor radon concentration levels of maximum 50 Bq/m^3 for infants of 3 months and up to 2 years old, and 100 Bq/m^3 for kids from 2 to 6 years old, and achieve these levels of radon concentrations, using the current mitigation methods. The same recommendation is valid for primary and high schools, with the respective changes in radon concentration levels.

Make a thorough study to establish the levels of indoor radon concentration, for infants and children under 18 years old of age, to avoid health problems and early lung cancers in future human generations. And finally, continuing with studies of the effects of radon during the process of growth of infants and adolescents is to prevent health risks in the future.

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