Nationwide survey of radon levels in indoor workplaces in Mexico using Nuclear Track Methodology

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ABSTRACT

This report presents the preliminary results of an indoor workplace radon survey conducted during 2006–2007. Monitoring was carried out in 24 of the 32 federal entities of Mexico, incorporating 26 cities and 288 locations. The area monitored was divided into 8 regions for the purposes of the study: Chihuahua (a state with uranium mines), North-Central, South-Central, Southeast, South, Northeast, Northwest, and West. These regions differ in terms of geographic and geological characteristics, climate, altitude, and building materials and architectonic styles. Nuclear Track Methodology (NTM) was employed for the survey, using a passive closed-end cup device with Poly Allyl Diglycol Carbonate (PADC), known by its trade name CR-39 (Lantrack®), as detector material. Well-established protocols for making continuous indoor radon measurements were followed, including one-step chemical etching in a 6.25 M KOH solution at 60 ± 1 °C with an etching time of 18 h. The track densities were determined with an automatic digital system at the *Instituto de Física de la Universidad Nacional Autónoma de México* (IFUNAM) (Physics Institute of the National Autonomous University of Mexico), and calibrated in facilities at the Oak Ridge National Laboratory (ORNL).

The importance of this survey lies in the fact that it represents the first time a nationwide survey of radon levels in indoor workplaces has been carried out in Mexico. Mean indoor radon levels from continuous measurements taken during and after working hours ranged from 13 Bq m^{-3} (the lower limit of detection) to 196 Bq m^{-3}. Analogous official controls or regulations for radon levels in indoor workplaces do not exist in Mexico. The survey described here contributes to knowledge of the natural radiological environment in workplaces, and will aid the relevant authorities in establishing appropriate regulations. The survey was made possible by the efforts of both a private institutions and the Dosimeter Application Project of the IFUNAM.

1. Introduction

The evaluation of indoor radon activity concentrations is of major interest for public health. It is well-known that radon and its daughters provide the greatest contribution to human exposure from natural background radiation (Kendall et al., 2005). The US Department of Energy, the US Environmental Protection Agency (USEPA) and the European Community have devoted significant effort and financial resources to the measurement of indoor radon levels in houses and other buildings in which people live and work. Indoor radon levels in workplaces in the US and most European countries have been studied extensively (Colgan et al., 2004; Denman, 2008; Rimington, 1992; Sainz et al., 2007; Sciocchetti et al., 2003; Synnott et al., 2006; Wakeford, 2009; Whicker and McNaughton, 2009).

There is no doubt that occupational radiation exposure is a concern to those working in the uranium mining industry. However other workplaces such as offices, banks, hospitals, research institutions and laboratories, university buildings and classrooms, should also be considered as subjecting workers to occupational radiation exposure. The International Commission on Radiological Protection and the European Union have addressed this issue in their publications (ICRP, 1994; European Union, 1996). The relevant sections encourage institutions engaged in monitoring radon levels in dwellings to expand their activities to include the measurements of radon levels in workplaces. Based on this recommendation, the Dosimetry Applications Project of the IFUNAM, with the financial support of private institutions, carried

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out Mexico's first nationwide survey of radon levels in indoor workplaces over a period of one year (2006–2007).

In this report we present the preliminary results of the survey and discuss the relevant characteristics of the workplaces monitored and the difficulties involved in interpreting the results. Twenty four of Mexico's 32 federal entities (comprising 31 states and the Federal District) were included in the survey. A total of 288 sites were monitored, including 26 cities with populations greater than 500,000 inhabitants. Nuclear Track Methodology (NTM), with Poly Allyl Diglycol Carbonate (PADC) as detector material, was employed for the survey. The passive closed-end cup device also employed was originally developed for measurement of radon levels in dwellings.

One important feature of this survey is that workplaces of similar architectural style, construction materials and age were monitored, leading to the result that differences in radon levels are due more to differences in regional geography and geology than to differences between the workplaces within a particular region.

1.1. *Differences between dwellings and workplaces*

It is well-known that there are many differences between workplaces and dwellings which may contribute to differences in indoor radon levels (Orlando et al., 2002; Tommasino, 2001). These differences may be considered as belonging to the category of either *a*) building characteristics, or *b*) occupancy characteristics.

Building characteristics may be further divided into those intrinsic to the building, and those relating to the site of the building. Among the former we note the construction materials; the number, size and purpose of rooms (e.g. kitchen, bedrooms and living rooms in dwellings; and meeting, service and storage rooms and other public and private areas in workplaces); the ventilation systems, maintenance services and size of any water tanks. Site related characteristics include the geological and geographic features of the site such as the climate, humidity, temperature and the presence of aerosols or other chemical contaminants.

Occupancy characteristics to consider include room population density (number of desks per square meter in an office compared with the number of beds per square meter in a bedroom), the spatial distribution of people within a room, the use and time of operation of air conditioning systems, mobility during the time spent inside the building and, most importantly, the length of time spent inside a particular space. The last item will vary greatly for different people depending on whether they work full or part time, are clients or employees, work at home, etc.

Thus building constructions and occupational characteristics make a great difference in the indoor radon measurements, between the homes or dwellings where the people lives in, and private or public offices. The control and measurements of these differences, makes the indoor radon concentration level evaluation a difficult issue. To obtain the "real value" inside of a dwelling becomes an art.

1.2. *A comparison of the regulations and action levels of various countries*

Due to the differences between workplaces and dwellings, they must be considered separately when it comes to evaluating the radiological risks associated with indoor radon exposure and implementing relevant regulations. Below we list some examples of the regulations and indoor radon action levels established in various countries. The regulations vary greatly between countries, in terms of both the coverage of the regulations and the actual radon levels included.

- The European Union (EU) accepts the recommended action levels included in the ICRP-65 of between 500 and 1500 Bq m^{-3} (ICRP, 1994). The USA uses a reference level of 148 Bq m^{-3} for dwellings and a level of 400 Bq m^{-3} for workplaces (USEPA, 2004). In the UK the Health and Safety Executive (HSE) (Kavasi et al., 2006), has adopted a radon action level of 400 Bq m^{-3} for workplaces (Kendall et al., 2005).
- The action level for workplaces in Hungary is 1000 Bq m^{-3}. (Kavasi et al., 2006). Israel uses a mandatory reference level of 200 Bq m^{-3} for existing schools and day care centers (Akerblom, 1999). There are no specific regulations in Mexico relating to indoor radon levels in either homes or workplaces.

1.3. *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 presents widely varying geology and geography. Most cities are located at altitudes greater than 2000 m. Both extended regions of desert and tropical jungle can be found. The west coast suffers from high levels of seismic activity while the east coast endures a hurricane season lasting 9 months of the year. The population of Mexico is 105 million, of which about 22% is concentrated in the centrally located Valley of Mexico, home to the Metropolitan Area of Mexico City. For the purposes of the survey the total area to be monitored was divided into 8 regions: I) the state of Chihuahua (14.6%); II) North-Central (35%); III) South-Central (24.3%); IV) Southeast (5%); V) South (3.1%); VI) Northeast (6%); VII) Northwest (2.4%); and VIII) West (10%). From the 32 states of the Mexican Republic, 24 were survey, with 288 locations distributed in 26 cities. The eight regions and the 24 cities are shown in Fig. 1. The Central North (II) and the Central South (III) regions, include the two more populated places in the country. The Federal District (DF) and the State of Mexico, called Metropolitan area (with population of 22 millions of inhabitants), where the 59.3% of the total measurements were done, it is because the commercial importance, in Fig. 2 is shown the distribution of monitored sites in this Metropolitan area.

The survey was carried out during a period of one year (2006–2007), divided into four periods of three months, coinciding with the four seasons. Two detectors were placed at each place in order to obtain two independent measurements of the same site. The offices in which the measurements were done, are open from 8am to 7pm, six days a week. The air conditioning systems were functioning during the eleven working hours. Offices with similar

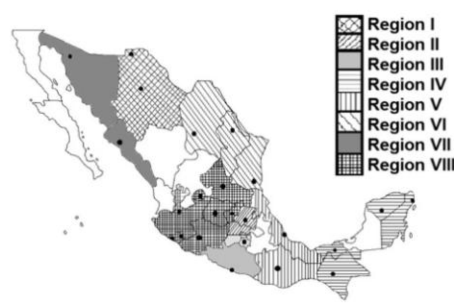

Fig. 1. The 8 regions into which the country was divided for the indoor workplace radon survey.

Fig. 2. Distribution of detector sites in the Metropolitan area of Mexico City.

architecture, construction materials and of similar ages were used for the survey in order to minimize the radon levels due to differences in building characteristics.

2. Experimental

2.1. Radon measurement methodology

Nuclear Track Methodology (NTM) is the most useful measurement technique for large-scale indoor radon measurements (Khan et al., 1989). A passive close-end cup system was used, with the CR-39 (Lantrack®) as detector material (Espinosa and Gammage, 1993). One-step chemical etching in a 6.25 M KOH solution at 60 ± 1 °C, with an etching time of 18 h, was carried out. This process is well-established and highly reliable. The detection system is calibrated annually at the ORNL (USA) radon facilities. The calibration factor is checking systematically and verified every six months and/or when we use a new sheet of detectors in the IFUNAM radon chamber. The detectors were read automatically by a Digital Image Analysis System (DIAS) (Gammage and Espinosa, 1997) and the data automatically analyzed using a PC with Microsoft Excel® software. The methods and procedures used for making large-scale measurements of radon levels in houses and other dwellings were applied here for the measurements of radon levels in indoor workplaces.

Table 1
Mean, minimum and maximum indoor radon levels by region.

	Region	Mean (Bq m^{-3})	Minimum (Bq m^{-3})	Maximum (Bq m^{-3})
I	Chihuahua	44 ± 27	LLD	145
II	North-Central	34 ± 21	LLD	113
III	South-Central	23 ± 18	LLD	153
IV	Southeast	61 ± 35	18	128
V	South	24 ± 12	24	55
VI	Northeast	42 ± 12	23	76
VII	Northwest	66 ± 23	37	112
VIII	West	57 ± 39	16	197

The Lower Limit of Detection (LLD) was 13 Bq m^{-3}.

3. Results

3.1. Survey statistics

We were not authorized to make measurements at 7 of the 288 sites (2.4% of the total). Thus the number of detectors installed at the beginning of each 3-month period was 562 (97.6%). At the end of each period (1st, 2nd, 3rd and 4th), 82.1%, 83.3%, 80.1% and 79.7% of the detectors, respectively were recovered and analyzed. The detectors were lost inside of the buildings or during the transportation back to the analysis laboratory.

Table 2
Mean, minimum and maximum indoor radon levels, by federal entity.

	Federal entity	Region	Mean value (Bq m^{-3})	Minimum value (Bq m^{-3})	Maximum value (Bq m^{-3})
I	Chihuahua	Chihuahua	62 ± 28	22	145
	Ciudad Juárez		28 ± 14	LLD	69
II	Distrito Federal	North-Central	22 ± 13	LLD	69
	Estado de México		42 ± 20	LLD	113
	Hidalgo		55 ± 25	23	94
III	Distrito Federal	South-Central	20 ± 13	LLD	57
	Estado de México		26 ± 10	LLD	50
	Guerrero		44 ± 54	16	153
	Morelos		34 ± 11	17	54
IV	Quintana Roo	Southeast	107 ± 12	100	128
	Tabasco		27 ± 7	18	34
	Chiapas		33 ± 3	30	36
	Yucatán		77 ± 10	65	93
V	Oaxaca	South	38 ± 14	24	55
	Veracruz		30 ± 6	25	38
VI	Nuevo León	Northeast	42 ± 12	23	76
	Coahuila		43 ± 10	36	55
	Tamaulipas		42 ± 14	24	70
VII	Sinaloa	Northwest	46 ± 8	37	56
	Sonora		74 ± 15	52	88
VIII	Aguascalientes	West	60 ± 25	19	86
	Colima		41 ± 17	25	59
	Guanajuato		34 ± 15	16	64
	Jalisco		80 ± 60	23	197
	Michoacán		51 ± 31	18	84
	San Luís Potosí		60 ± 31	27	104

The Lower Limit of Detection (LLD) was 13 Bq m^{-3}.

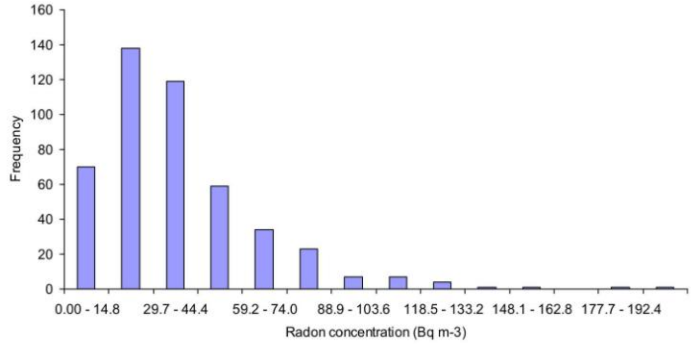

Fig. 3. Frequency distribution of radon levels (average annual values).

In Table 1 are shown: the mean, minimum and maximum radon levels measured for each of the 8 regions.

Table 2 shows: the mean, minimum and maximum radon levels measured for each federal entity. And in Fig. 3 is shown the frequency distribution of radon levels (average annual values) of the total monitored sites.

3.2. Comparison between indoor radon in workplaces and houses

If we compare the results of indoor radon level measurements in workplaces and homes, in some of the locations, we find out that the indoor radon levels in workplaces monitored are lower than in houses. For the Metropolitan area the mean value for workplace was 28 Bq m^{-3}, and for homes 123 Bq m^{-3}; Guadalajara (Jal) 80 Bq m^{-3} vs 160 Bq m^{-3}; and for Monterrey (NL) 42 Bq m^{-3} vs 69 Bq m^{-3} (using the values reported for homes in previous studies in Espinosa and Gammage, 1999).

In the present survey, the average effective doses in the workplace was estimated between 0.13 and 0.37 mSv for 2000 working hours in a year, for the minimum and maximum mean values on the regions.

4. Conclusions

A comparison of the results of prior surveys of indoor radon levels in Mexican dwellings with those of the present survey demonstrates that radon levels are lower in the indoor workplaces monitored in this work, than in dwellings already measured. An important reason is that while the workplaces monitored have air conditioning systems operating during office hours, most Mexican houses (excluding those in the northern regions of the country) do not have air conditioning.

Eighty two percent of the workplaces monitored, have similar architectural style, construction materials and similar construction age, the indoor radon concentration is largely due to variation in the geological and geographical characteristics of the sites. As this is the first survey of indoor radon levels in workplaces, in Mexico, no comparisons regarding workplaces can be made. Many factors complicate the measurement of radon levels in indoor workplaces, but the more important to consider is the general public's fear to hear about radiations.

Acknowledgments

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