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Indoor radon survey in Shiraz-Iran using developed passive measurement method

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Background: While in the open air the amount of radon gas is very small and does not pose a health risk, in confined spaces, radon can accumulate to relatively high levels and become a health hazard. Exposure to high levels of radon has been associated with an increased risk of lung cancer, depending on the time length of exposure. Radon level in dwelling of Shiraz with 1,200,000 populations has been sampled and analyzed in this study. Our study could be considered the largest radon study in Iran both time and area wise. *Materials and Methods:* In this study, radon (^{222}Rn) concentration in residential dwellings in Shiraz-Iran was sampled and measured during two consecutive six month periods in 2009-2010. We used Solid State Nuclear Track Detectors (SSNTD), CR-39 polycarbonate films. The survey parameters of radon concentrations were floor types, construction materials and dwelling's age. *Results:* Annual average indoor radon concentration for the survey period was 94±52 Bq/m^3. The calculated mean annual effective doses in basements and different floors were less than the lowest limit recommended action level of 3 mSv by ICRP. *Conclusion:* High radon concentrations are measured in basements and old dwellings; however, due to rapidly changing housing structures and ventilation practices with no intervention, lower levels of radon concentration has been expected in Shiraz. **Iran. J. Radiat. Res., 2011; 9(3): 175-182**

Keywords: *Indoor radon, CR-39, effective dose, electrochemical etching, radon atlas.*

INTRODUCTION

According to the world health organization (WHO), in many countries, radon is the second most important cause of lung cancer after smoking. The proportion of lung cancers attributable to radon is estimated to range from 3% to 14%.

Significant health effects have been seen in uranium miners who are exposed to high levels of radon. However, studies in Europe, North America and China have confirmed that lower concentrations of radon – such as those found in homes, also confer health risks and contribute substantially to the occurrence of lung cancers worldwide (1-3).

For most people, the greatest exposure to radon comes from the home. The concentration of radon in a house depends on:

- the geological formations; i.e., the amount of uranium in the underlying rocks and soils,
- the routes available for the penetration of radon into the home,
- the rate of exchange between indoor and outdoor air, which depends on the construction of the house, the ventilation habits of the inhabitants, and the sealing of windows.

Thus, radon enters homes through: 1) cracks at concrete floor-wall junctions, 2) gaps in the floor, 3) small pores in hollow-block walls 4) sumps and drains.

While in developed countries, radon level monitoring data is essential as a house record, in many developing countries, basic radon data are scarce. A radon distribution map called "Radon Atlas" describes radon levels in a vast geographic region, and it is usually funded by governments due to its important public health benefits. Such maps are readily available for US, UK, Finland and several European Union countries. In Iran, locally funded and sporadic studies in cities such as Tehran, Mashhad, Ramsar, Ardabil, Lahijan, Yazd and Hamadan have been carried out. There is little prospective

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that the government sponsors a systematic study leading to Iran Radon atlas map. The results of present study could be used for providing data for such map in relatively vast and important geographic regions of Iran.

Most methods for the measurement of the ^{222}Rn concentration in air are based on the principle that ^{222}Rn is entering a closed chamber, or it is adsorbed in carbon material, while the radon/thoron decay products in air which would strongly influence the measurement are absorbed before entering the system by a filter [4].

Both radon and its progeny concentrations have been the focus of studies in many countries.

Nsibande *et al.*, surveyed for ^{222}Rn levels inside residence in Swaziland-Africa by solid state nuclear track detectors (SSNTDs) type CR-39 during winter and summer. The ^{222}Rn levels were found to be higher during the winter months than during the summer [5].

Rehman *et al.*, studied the ^{222}Rn exhalation rate from soil and sand samples and ^{226}Ra contents in samples using CR-39 detectors. In addition, they developed a mathematical model to determine the ^{222}Rn exhalation rate from the soil/sand samples [6]. In recent work, an indoor ^{222}Rn measurement survey carried out in 105 workplaces of four districts of the Punjab Province and the Islamabad Capital Territory. All the estimated effective doses delivered to the workers/owners due to the indoor ^{222}Rn were found to be less than the lower limit of ICRP recommended action levels of 3-10 mSv yr^{-1} [3].

Several studies have been carried out to assess indoor radon variations in Iran. Seasonal indoor radon variations study in four cities in Northern Iran showed very high radon levels during fall and winter [7]. The study concluded that housing structures heating practices contribute to indoor radon accumulation. In addition, the correlation coefficients related to warm and cold season ^{222}Rn variation data were obtained. In another study, radon levels of dwelling's basements in Yazd city were assessed using portable radon gas surveyor active measurements [8]. Despite vicinity of Yazd Uranium mines of Saghand (180 Km from Yazd), high levels of radon concentration did not observe in the Yazd study. Tehran has been the subject of another radon study where radon concentration in public tap water was measured [9]. The mean radon concentration in Tehran tap water was 3.70±0.94 BqL^{-1} which accounts for annual total effective dose to adults to be about 10 µSv. Tehran study concluded that the radon levels in tap water actually used by people are low enough, and below the proposed limits in other countries.

Indoor radon and radon progeny were surveyed at Campinas-Brazil during two successive periods of six months. The CR-39 detector was used as an alpha-spectrometer taking into account the size and the gray level of round tracks measured under an automatic optical microscopy system [10].

In these studies, the most common method for long-term indoor radon exposure estimates were based on passive dosimeters which selectively could assess radon gas.

In the present work, we measured indoor ^{222}Rn levels during two successive periods of six months in rooms of 131 dwellings at Shiraz city by using passive integrated radon detectors.

MATERIALS AND METHODS

The ^{222}Rn survey was carried out in limited samples of dwelling of Shiraz city during two consecutive six months. We obtained a non-biased sample by distributing the dosimeters randomly, especially when the sample of the houses being monitored was large [11]. The general statistical approach was based on observational statistical method in which the data was collected from one dependent variable (radon concentration), and four independent variables (age, structure type and number of floors of dwellings and seasonal change).

Spatial grid and mesh generation to locate the sampler location based on geographical extension is currently practiced [12]. The Google Earth online software is a very useful tool to do so. The dwellings were selected on the Shiraz map in Google earth by the place-mark tool. Figure 1 illustrates Shiraz geographicalcharacteristic with sampling position place-marks. CR-39 based detectors were installed during two successive six month periods in 131 dwellings. There were 35 samples in basements, 46 samples in ground floor (1.5 m above ground), 26 samples in the first floor and 24 samples in the second floor. The samplers were installed at least 10 cm away from the walls in the breathing height for the entire exposure period.

The CR-39 polycarbonate solid state nuclear track detectors (SSNTDs) were used as the passive sampler. The sampler consisted of a 2.9×2.9 cm (250 µm thicknesses) CR-39 polycarbonate film which was placed inside a plastic diffusion chamber by a holder. This integrated passive sampler was developed by Atomic Energy Organization of Iran (AEOI), and the detection chemical etching and track density measurements as well as calibration have been fully explained by Sohrabi [13].

Since variation in etching temperature could lead to inconsistency in etched-track characteristics and add to measurements uncertainty [14], we have designed and built an electrochemical etching chamber with temperature control and stabilization system.

Another improvement was the use of an automated counting system which was based on a high resolution scanner and related image processing software. Once the electrochemical etching was performed, the etched CR-39 films were scanned and counted by developed software (called NTC) with high accuracy. The system was calibrated using the conventional counting system.

The UMAX™ PowerLook 2100XL slide

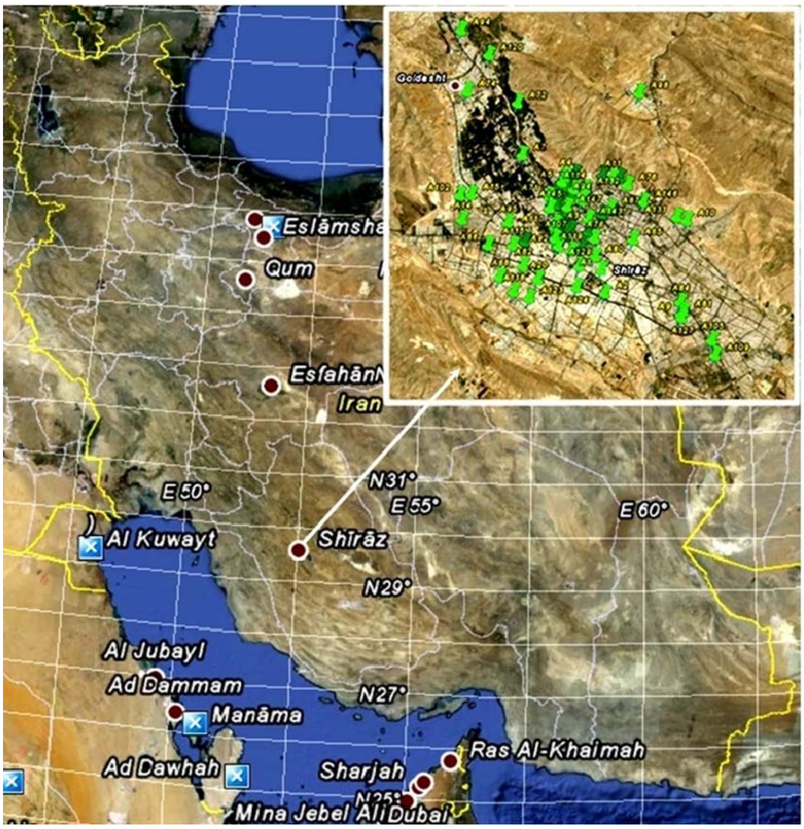

Figure 1. Radon sampling locations in Shiraz dwellings.

scanner with proper frame holder was used to obtain a complete image of 32 radon film detectors by one feed.

Due to aging and fading effects during the sampling and measurement period, some detectors were rejected during the evaluation periods which made a total number of 262 samples from two campaigns (i.e 131 detectors for each six months period).

RESULTS AND DISCUSSION

The indoor radon level in Shiraz was evaluated for different parameters. The effect of floors height was marked as basement, ground floor, first (1st) floor, and second (2nd) floor. The effects of construction material and the dwellings' age on radon concentration level were two main surveyed parameters.

Effect of floor types

Figures 2 and 3 show the frequency distribution of the number of rooms as a function of indoor radon concentration of the surveyed points in the first halves of the year, respectively.

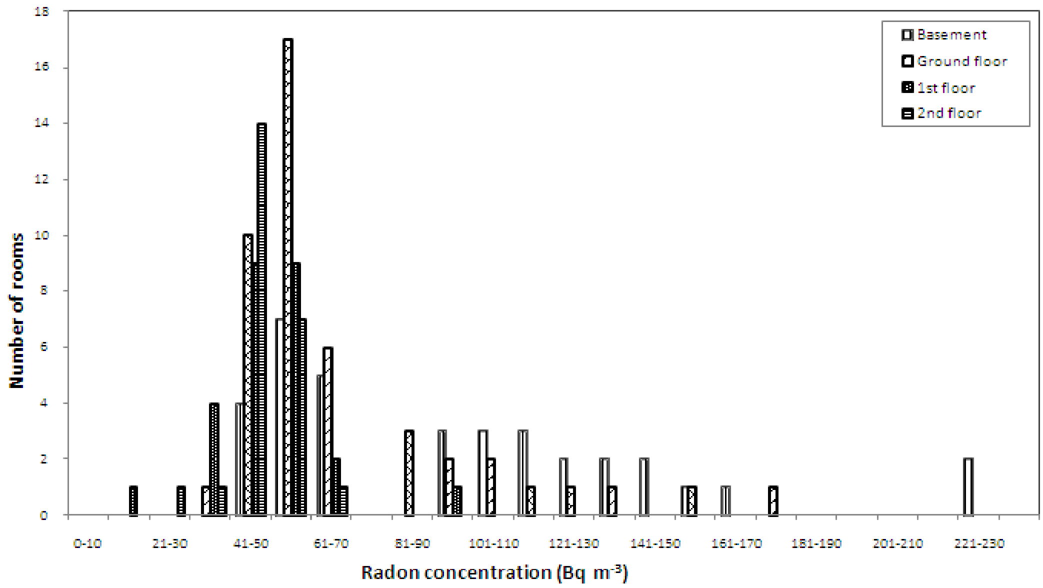

Figure 2. Distribution of radon concentration during spring and summer in Shiraz dwellings.

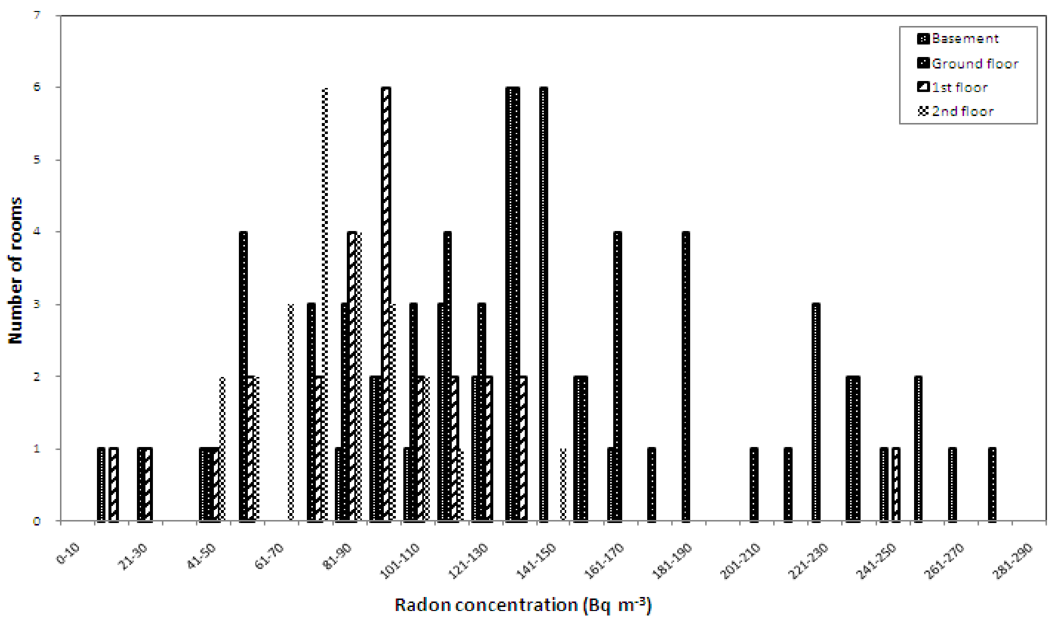

Figure 3. Distribution of radon concentration during Fall and Winter in Shiraz dwellings.

Annual average radon concentration in different floors of multistory dwellings is plotted in figure 4.

Figure 4 indicates that the basements have the highest radon concentration compared with other floors and the second six months (autumn and winter) had higher radon concentrations.

The annual effective doses were estimated because of radon concentration in floors, for some consideration.

Dose estimation

We used the UNSCEAR-2000 model [15], in order to estimate the annual mean effective dose ($mSv\ y^{-1}$) due to indoor radon by the following formula

$$E = C \times F \times H \times T \times D$$

Where C is the ^{222}Rn concentration (in $Bq\ m^{-3}$), F is the equilibrium factor (0.4 for indoor measurement), H is the occupancy factor (0.8 for indoor measurement), T is the hours for a year ($8760\ h\ y^{-1}$), and D is the dose conversion factor ($9.0\ nSv\ Bq\ m^{-3}\ h^{-1}$). Table 1 shows the results of radon concentration measurements and corresponding estimated annual mean effective doses in the basements and the floors.

Table 1. Radon concentration and annual effective doses estimation in the dwellings.

	Radon concentration ($Bq\ m^{-3}$)				Dose ($mSv\ y^{-1}$)
	Min	Max	Median	Overall G.M†	
Basement	42.9	245.1	125.5	108.6 ± 55.0	2.7
Ground floor	32.5	280.7	87.1	87.2 ± 54.6	2.2
1st floor	17.4	116.6	56.8	62.8 ± 38.7	1.5
2nd floor	30.0	146.7	56.0	60.5 ± 23.7	1.5

†G.M = Geometrical mean

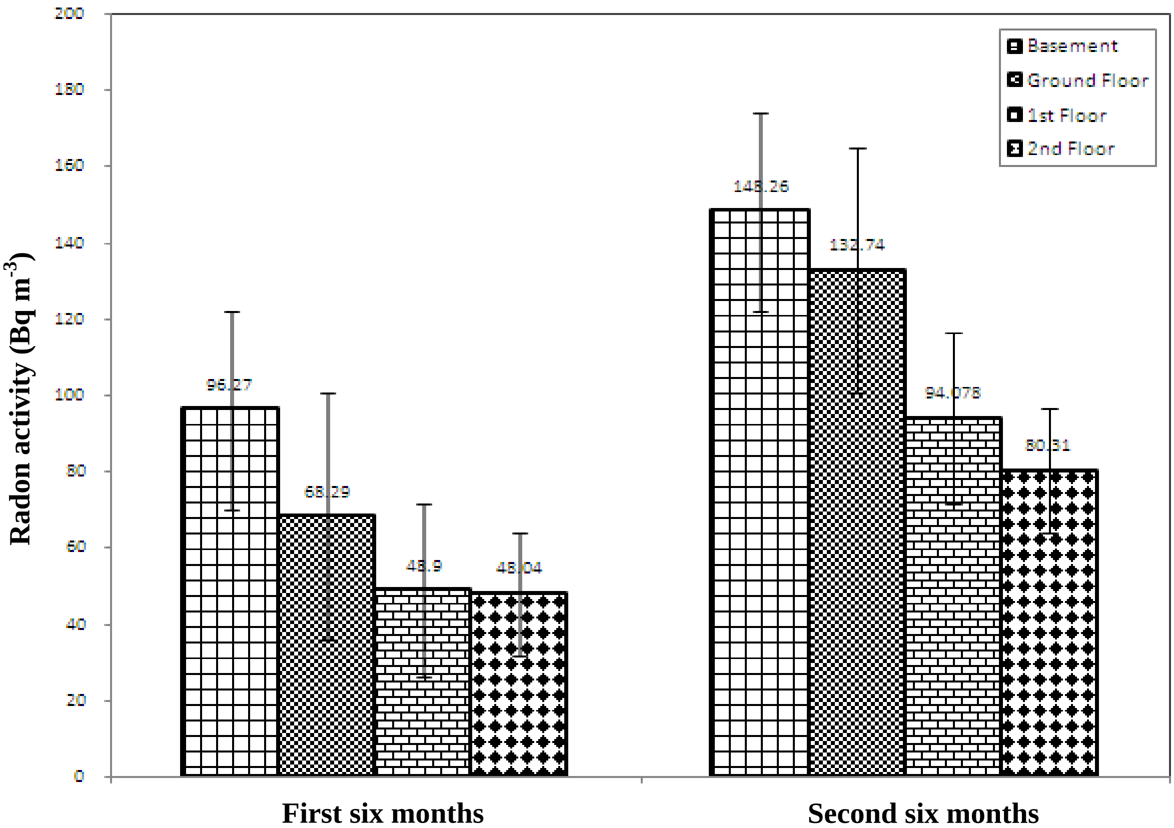

Figure 4. Annual averaged radon concentration variations in different floors of multistory dwellings. The error bars are 1 SD based on replicates.

ICRP-69 recommends an action level of 200 Bq m^{-3} (corresponding to an annual dose of 3 mSv y^{-1}) for the radon in dwellings (16).

On the basis of ICRP-69, 6% of samplers placed in basements and in ground floors were found to have more than 200 Bq m^{-3} radon concentrations. But, the averaged measured radon concentration in the basements and the floors of the dwellings, as shown in figure 4, were lower than action level. It has been obvious that indoor radon mitigation could be achieved by employing a proper internal sheath, emphatically for unpainted dwellings, and better ventilation. Permit regulations, as well as improvements in building practice enforced by law, have caused the newer houses to have lower radon levels. Shiraz is a fast growing city and due to land scarcity, older houses are being disappeared and multistory apartment building complexes are emerging. It can be concluded that in long run, total population dose due to indoor radon would further decrease.

In addition, according to ICRP-65 the values of annual mean effective doses were found to be less than the lower limit of recommended action levels of 3-10 mSv y^{-1} (17).

The effect of construction material

To study the effect of construction materials on the indoor radon levels, dwellings with three types of structure materials, adobe (9 houses), concrete (19 houses), and brick walls (103 houses) were sampled. Figure 5 displays the effect of construction material on the indoor ^{222}Rn concentration.

As could be seen from this figure, due to high porosity for ^{222}Rn emission of the adobe walls, they have had the highest ^{222}Rn concentration while the concrete walls had the lowest. The main source of indoor ^{222}Rn comes from dwelling construction materials and dwelling's ventilation during the second six months. Then justification could be due to natural ventilation in the first six months (spring and summer) of the year when residents open the windows. Meanwhile,

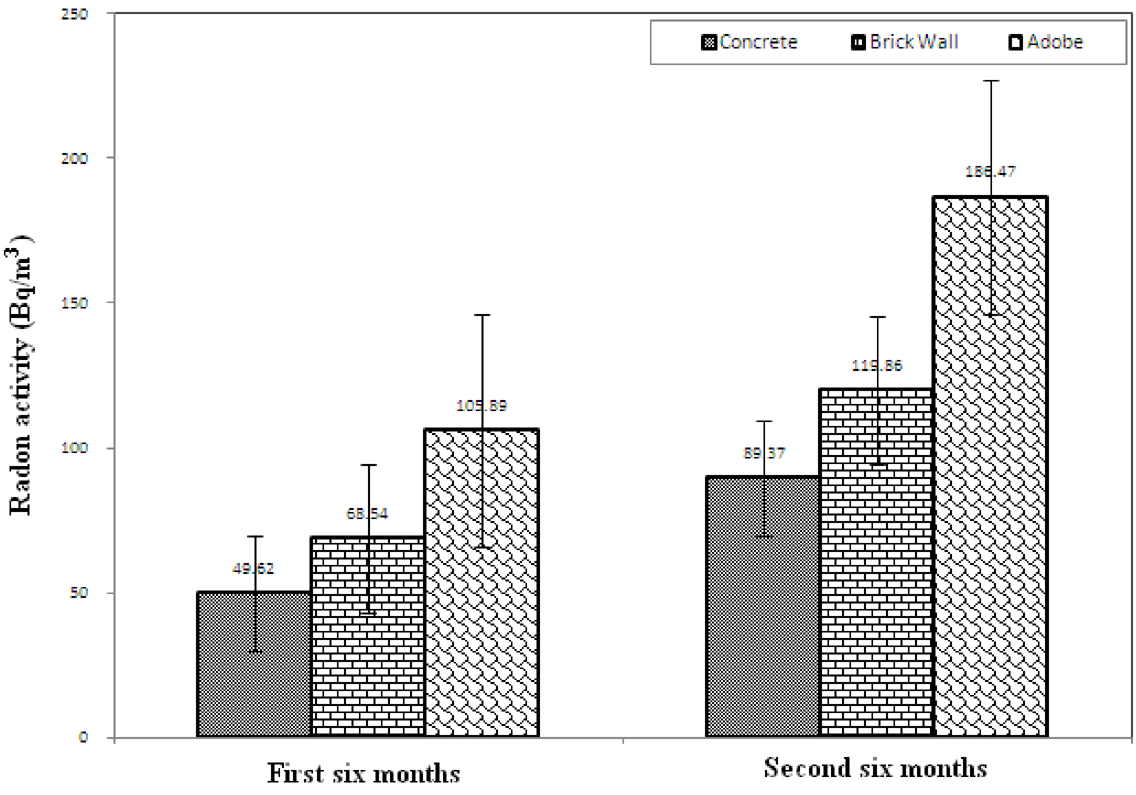

Figure 5. Variation of radon concentration with construction materials during the first and second halves of sampling year. The error bars are 1 SD based on replicates.

during cold winter, residents use natural gas and close all the vents which had caused the accumulation of radon emanated from building cracks.

The effect of dwellings age

The ^{222}Rn level as a function of the dwelling age was estimated by sampling dwellings with age diversity. The surveyed dwellings age ranges were from new dwellings to dwellings with over 45 years old of age.

Figure 6 illustrates the significance of dwellings age on radon concentration.

As expected, the newer buildings with use fresh construction materials had lower ^{222}Rn levels.

Finally, surveying a vast populated area needs a good preparation and public education to minimize the samplers' losses which are irreplaceable to the study. If the dwellings are selected involuntarily, the residents should be well informed of radon survey and its benefits for their well-being. By this study, Shiraz, as a place to live in and/or to visit, is considered as a low radiation area with respect to radon concentration. Shiraz could be considered as having one of the lower radon levels among cities surveyed in Iran [7] as shown in figure 7.

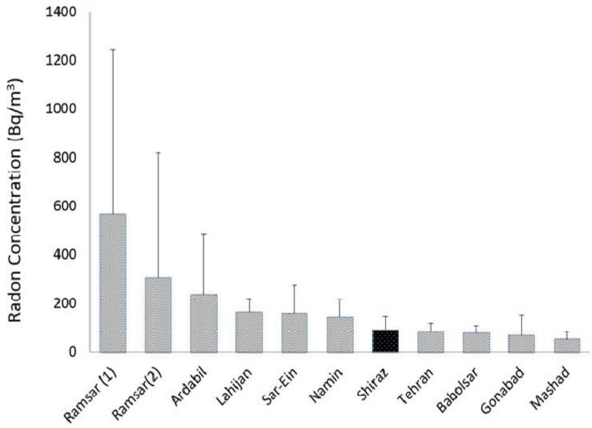

Figure 7. Mean annual radon concentration in different cities in Iran.

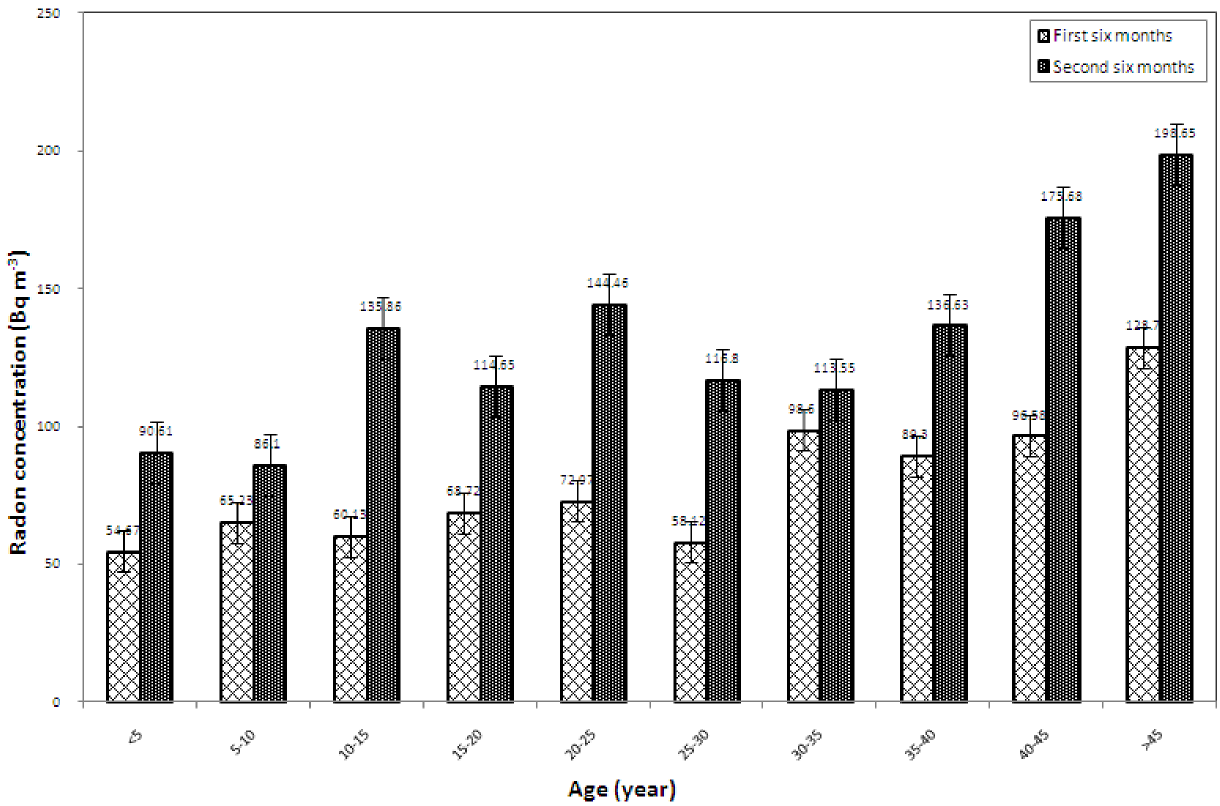

Figure 6. Variation of radon concentration with dwelling age in the first and second halves of sampling year. The error bars are 1 SD based on replicates.

REFERENCES

1. Lubin JH, Wang ZY, Wang LD, Boice JD Jr, Cui HX, Zhang SR, Conrath S, Xia Y, Shang B, Cao JS, Kleinerman RA (2005) Adjusting Lung Cancer Risks for Temporal and Spatial Variations in Radon Concentration in Dwellings in Gansu Province. *China Radiat Res, **163:** 571-579.*
2. Krewski D, Lubin JH, Zielinski JM, Alavanja M, Catalan VS, Field RW, Klotz JB, Létourneau EG, Lynch CF, Lyon JI, Sandler DP, Schoenberg JB, Steck DJ, Stolwijk JA, Weinberg C, Wilcox HB (2005) Residential Radon and Risk of Lung Cancer: A Combined Analysis of 7 North American Case-Control Studies. *Epidemiology, **16:**137-145.*
3. Darby S, Hill D,Auvinen A, Barros-Dios JM, Baysson H, Bochicchio F, Deo H, Falk R, Forastiere F, Hakama M, Heid I, Kreienbrock L, Kreuzer M, Lagarde F, Mäkeläinen I, Muirhead C, Oberaigner W, Pershagen G, Ruano-Ravina A, Ruosteenoja E, Rosario A, Schaffrath, Tirmarche M, Tomasek L, Whitley E, Wichmann HE, Doll R, Watts G (2005) Radon in homes and risk of lung cancer: collaborative analysis of individual data from 13 European case-control studies. *BMJ, **330:** 223-227.*
4. Becker D and Kaul A (2005) Radiological protection. Springer-Verlag Berlin Heidelberg., Germany, p. 10-41 – 10-49.
5. Nsibande MC, Mahlobo M, Farid SM (1994) Radon levels inside residences in Swaziland. The science of the total environment: 181-185.
6. Shafi-ur-Rehman, Matiullah, Shakeel-ur-Rehman, Rahman S (2006) Studying ^{222}Rn exhalation rate from soil and sand samples using CR-39 detector. *Radiation Measurements, **41:** 708-713.*
7. Hadad K, Doulatdar R, Mehdizadeh S (2007) Indoor radon monitoring in northern Iran using passive and active measurements. *Journal of Environmental Radioactivity, **95:** 39-52.*
8. Bouzarjomehri F and Ehrampoosh MH (2008) Radon level in dwellings basement of Yazd-Iran. *Iran J Radiat Res, **6:** 141-144.*
9. Alirezazadeh N (2005) Radon concentrations in public water supplies in Tehran and evaluation of radiation dose. *Iran J Radiat Res, **3:** 79-83.*
10. Hadler JC, Neman RS, Iunes PJ, Pereira OLS, Paulo SR (2008) Indoor radon and radon progeny survey at Campinas-Brazil using CR-39: Final results. *Radiation Measurements, **43:** S440–S444.*
11. Font L (2009) On radon surveys: Design and data interpretation. *Radiation Measurements, **44:** 964-968.*
12. Van Groenigen JW, Stein A, Zuurbier R (1997) Optimization of environmental sampling using interactive GIS. *Soil Technology, **10:** 83-97.*
13. Sohrabi M (1999) New developments on electrochemical etching processes at the atomic energy organization of Iran. *Radiation Measurements, **31:** 115-120.*
14. Ibrahimi ZF, Howarth CB, Miles JCH (2009) Sources of error in etched-track radon measurements and a review of passive detectors using results from a series of radon inter-comparisons. *Radiation Measurements, **44:** 750-754.*
15. UNSCEAR (2000) United Nations Scientific Committee on the effects of atomic radiation.
Source and effects of ionizing radiation. New York: United Nations.
16. ICRP Publication 69 (1995) Age-dependent doses to members of the public from intake of radionuclides: Part 3. Ingestion dose coefficients.Pergamon Press, New York.
17. ICRP Publication 65 (1993) Protection against radon-222 at home and at work. Oxford: Pergamon Press.