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# Indoor radon measurement in residential/commercial buildings in Isfahan city

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**ABSTRACT:**

**Introduction**: People are constantly exposed to radiation from natural and artificial sources of radiation. Radon is one of the natural radiation sources that its concentration in very high in some part of the world. The presence of radon gas in the air can increase the risk of lung cancer. In this study, the level of indoor radon in dwellings of Isfahan city was surveyed. It should be mentioned that an active alpha GUARD instrument was used to measure radon concentration. All of the measurments took place during the winter and spring of 2018.

**Materials and methods:** In the present survey, 51 residential/commercial buildings were considered to radon gas monitoring based on the population distribution on 15 urban areas and the population of each area and technical possibilities. In each residential/commercial buildings, sampling was carried out at different floors of the building. A professional radon monitoring device (Alpha GUARD PQ2000 PRO) was used to measure indoor radon gas concentration.

**Results:** The Results of measuring were shown that the radon concentration in the residential/commercial buildings varied from 3 to 251 Bq / m$^3$, with a mean value of 28.57 ± 39.38 Bq / m$^3$. The average annual effective dose received by the residents of the studied area was estimated to be 0.49 mSv. The results showed a significant difference between the average radon concentration in different floors and the different ventilation of the building, higher values in the lower floors and weaker ventilation.

**Conclusion:** Indoor radon concentration in 4 % of the building was determined to be higher than the limit (100 Bq / m$^3$) recommended by the World Health Organization.

## Introduction

Everybody is exposed to a range of natural and man-made radiation sources. The most important radiation contribution is from natural radiation sources, and radon usually accounts for up to 50 % of background radiation. The average annual effective dose from all natural radiation sources was estimated to be about 2.4 mSv, that approximately 1 mSv is due to the inhalation of radon in indoor environments [1]. Radon ($^{222}$Rn) with a half-life of 3.8 days is formed by the decay of Radium ($^{226}$Ra), in the radioactive series of uranium ($^{238}$U) and $^{238}$U is existent naturally in soil and rock in various contents [2]. Radon, depend-

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ing on the geological and geophysical conditions and the type of building materials, can be transferred to the air and gathered there [3]. The main sources of indoor radon that penetrate into the houses are soil through building materials, water, and basement air. Cracks in floor slabs, floor drains, joints and other pores within the foundations of dwellings can elevate the indoor radon concentration [2]. Epidemiological studies in the world have shown obvious evidence of the relationships between indoor radon exposure and lung cancer, even at low radon levels, typically found in dwellings [2].

Based on the World Health Organization (WHO) and the US Environmental Protection Agency (EPA), Radiation dose due to inhalation of radon and its progeny is the second leading cause of lung cancer after smoking [1, 4]. Radon and its progeny, dispersed in the aerosols from the indoor and outdoor air, pose significant radioactive hazards to human lungs. During respiration, radon progeny is deposited in the lungs and irradiates the tissue, thereby damaging cells and causing lung cancer. Radon was classified as one of the human carcinogens by the International Agency for Research on Cancer [5]. Based on a case-control study in the US and North America, exposure to radon is associated with 15,400 to 21,800 cases or approximately 10 % of lung cancer cases annually [1]. WHO was proposed a reference level of 100 Bq / $m^3$ to reduce the health hazards due to indoor radon exposure [6].

many efforts have been made to find possible relationships of indoor radon levels with building construction materials and ventilation condition of dwellings [7, 8]long term measurements are needed. Radiation doses from the building materials vary depending upon the natural radionuclides $^{226}$Ra, $^{232}$Th and their daughter products and $^{40}$K present in them. Cement is the main and important component used in the construction of buildings in many countries. These radio nuclides pose exposure risk due to their gamma ray emission and internally due to radon and its progeny that emit alpha particles. In the present study radon exhalation rate and the activity concentration of $^{226}$Ra, $^{232}$Th and $^{40}$K radionuclides in cement samples used in Aligarh region (U.P.. The results showed that ventilation rate has an inverse relation with indoor radon level. Hence high levels of indoor radon from the building material and from the household water may be reduced by increasing ventilation rate. The highest level of indoor radon concentration was found in the mud type dwellings compared with dwellings made of concrete, cement, and marble. The seasonal variations of indoor radon levels reveal the maximum values in winter and minimum in summer [5]. Some studies have shown relationships between earthquakes [9-11], the age of the houses that were similar in geology and climate [12] and the indoor radon concentrations.

The sources of radon gas production in closed environments are divided into three main groups: 1. Soil and underground rocks; 2. Construction materials used (stone and sand); 3. Water used in the home (kitchen and bathroom). The main source of radon gas is the type of soil in the building area. Therefore, radon concentration varies depending on the type of soil, porosity, cracks, and pores present in the building, as well as different ventilation patterns in different buildings, from one region to another and from a structure to another structure. After leaving the soil, radon gas penetrates into the building through any space that can flow through the air. The amount of radon released into the buildings depends on the type of rock and the soil on which the house is built. It is well-known that most natural materials such as sand, soil, cement, and rock, as building materials for the construction of houses and buildings, etc., are composed of different stones

and crust. Such substances are often rich in radioactive elements. The ways of radon entering the building can be summarized as follows [13, 14]:
- Cracks in the walls and floor of the building
- Building fittings
- Pores around water supply and sewage networks
- Empty spaces inside the walls
- Water in the bathroom and kitchen

Radon gas is soluble in water, and especially in the wells, it is more likely to exist. Generally, a very low percentage of radon in water (0.01 %) is released and released into the air. Many studies have shown that radioactive substances in bottled water, especially mineral water, are more distributed than water [15].

Many studies around the world have been conducted to measure radon concentration in closed environments. The monitoring of radon gas concentrations has been carried out in many cities of Iran such as Yazd, Lahijan, Ardabil, Sar-Ein, Naein, Hamadan, Taft, Ashkezar, Mehriz, Harat, Bafgh, Tabas, Meybod, Ardakan, Abarkooh, Qom, Mashhad, Tabriz, Shiraz, Sari, Ramsar, Gorgan, and Khorramabad [1, 2, 16-18]by using passive alpha-track detector (CR-39. In some cases, the average concentration of radon in several dwellings was above 100 $Bq / m^3$ [2].

Each person usually spends more than 80 % of his/her time at home or in closed places. Therefore, indoor radiation monitoring is very important for estimating indoor radiation exposure [2,19]. Before this survey, there were no data available about radon concentrations in Isfahan region.

## Materials and methods

### *Study area*

Isfahan province is located in the central part of Iran, and it is neighboring Markazi, Qom and Semnan provinces from the north, Yazd, and Khorasan-e-Jonubi from the east, Fars, and Kohgiloyeh-v-Boyerahmad from the south, and from the west it neighbors with Lorestan and Chahармahal-o-Bakhtiari provinces and has 25 counties (Fig. 1).

Isfahan city, the capital of Isfahan province, is located 435 km from Tehran, the capital of Iran. Its longitude and latitude are 51°39′ and 32°38′, respectively, with the elevation of 1571 me above sea level. The average daily temperature in the city of Isfahan is 15.6°C. The population census in 2015 revealed this area to have a population of 1,961,260 people in 400 $km^2$. According to the latest divisions, the city of Isfahan is divided into 15 area (Fig. 2) with different dimensions and populations [20].


Fig. 1. Location of Isfahan Province and Isfahan City in Iran


Fig. 2. Urban areas of Isfahan city

Table 1. Area of Isfahan city and number of sampling point

| Area number | Population (person) | Number of sampling points |
|---|---|---|
| 1 | 79,091 | 2 |
| 2 | 69,120 | 2 |
| 3 | 110,368 | 3 |
| 4 | 133,731 | 3 |
| 5 | 150,865 | 4 |
| 6 | 112,129 | 3 |
| 7 | 168,732 | 4 |
| 8 | 239,756 | 6 |
| 9 | 75,168 | 2 |
| 10 | 207,803 | 5 |
| 11 | 58,841 | 2 |
| 12 | 136,376 | 4 |
| 13 | 132,469 | 3 |
| 14 | 164,850 | 4 |
| 15 | 121,961 | 3 |
| Sum | 1,961,260 | 51 |

***Data collection***

This study was carried out during winter to spring of 2018. generally, there are two major approaches to prepare the maps of radon: 1) area-based, and 2) population-based [1]. In this study, we used the estimation of indoor radon measurement points based on area. To achieve this goal, for each area, depending on its population and available facilities, and consulting with relevant experts, 2 to 6 Points were selected (Table 1). Accordingly, 51 residential and commercial buildings were selected randomly on the city map of Isfahan. The sampling distribution was almost homogenous.

To determine the parameters affecting the concentration of radon in indoor air, a form was used to collect information, such as the type of building (residential or commercial), the type of building materials, the type and number of floors, type of wall and floor coverings, cracking and splitting on the wall and roof, and the heating and ventilation systems.

For each location, several radon measurements were performed according to the number of possible locations for installation, the number of building floors, the ability to change the condition and type of ventilation of the environment, and so on.

***Measurement details***

A professional radon monitor (AlphaGUARD PQ2000 PRO) was used to measure indoor radon gas concentration that is a portable, battery- or net-operated radon monitor with high storage capacity. In addition to measurement radon concentration in the air, AlphaGUARD also can simultaneously measure and record ambient temperature, relative humidity and atmospheric pressure with its integrated sensors. This radon monitor is suitable for the continuous monitoring of radon concentrations between 2–2000000 Bq / m$^3$. It is both suited for short- or long-term examination inside (e.g. in buildings) as well as outdoor and is capable for operating in two alternative modes: 1) diffusion mode with a 10 or 60 min measuring cycle. 2) flow mode in a 1 or 10 min measuring cycle [21]. In this study, the diffusion mode with 10 min measuring cycle was used for at least one or more hours.

AlphaGUARD monitor placed in the selected location according to the U.S. EPA protocols [22]. Based on this protocol it must be set in the respiratory zone at least 1.5 m above the floor, at a distance more than 0.5 m from window and roof, 0.4 m from the wall and at a minimum of 20 cm from any other object. Also, the measuring device should not be in the air flow due to heating, ventilation, doors, fans, and windows and must not be turned off or moved to another location during the measurement. In places close to radiators, fireplaces, or heaters or exposed to direct sunlight, it should be avoided to install the device, avoid opening and closing doors and windows during measurement [6, 22-23].

In this study, for residential or commercial buildings with more than one floor, several measurements have been made. For example, in a building with three floors, for each floor, measurements are made in both non ventilated and non-ventilated conditions in accordance with this protocol, and then the results for that building are summarized. Considering that each person commonly spends more than 80 % of his/her time at home or in closed places, The average annual effective dose received due to inhalation radon gas and its daughters (mSv / year) is derived from Eq. (1) [24–26] the IAEA is authorized to establish standards of safety for protection against ionizing radiation and to provide for the application of these standards to peaceful nuclear activities. The regulatory related publications by means of which the IAEA establishes safety standards and measures are issued in the IAEA Safety Standards Series. This series covers nuclear safety, radiation safety, transport safety and waste safety, and also general safety (that is, of relevance in two or more of the four areas:

$$D_{year} = 5.56 \times 10^{-6} \times C_F \times E_F \times C_{Rn} \times T \times Q_F \quad (1)$$

Where;

$D_{year}$: Annual effective dose (mSv.year$^{-1}$)

$C_F$: Dose conversion factor; for members of the public is 1.1 mSv / (mJ.h / m$^3$) and 1 Bq / m$^3$= 5.56 × 10$^{-6}$ mJ / m$^3$

$E_F$: Equilibrium factor for radon progeny; 0.4
$C_{Rn}$: Radon Concentration (Bq / $m^3$)
T: Signifies the hours for a year; (365×24=8760 h)
$Q_F$: Coefficient of occupancy; 0.8

After completing the measurements and collecting required information, all the data and information were entered into SPSS 16.0 and Excel 2010 and the results of measurement of radon concentration and the relationship between the factors and parameters affecting it were analyzed.

## Results and discussion

### *The concentration of radon in Isfahan*

In this study, the measured values were in the range of 3-251 Bq / $m^3$, which for 50 % of these results had a concentration below 16 Bq / $m^3$. The mean of the measurements was 35.287 Bq / $m^3$ and the highest value was equal to 251 Bq / $m^3$. The summary of these results is presented in Table 2 and Fig. 3.

### *Factors affecting radon concentration*

Comparing the conditions of residential/commercial buildings in Isfahan city, it was found that the ventilation, floor, and application of measurement location are the main factors affecting radon concentration. Other factors such as materials used in floor and walls, the presence or absence of cracks, type of wall and floor covering did not show any significant differences. Being located on the active fault path and being close to the earthquake center and also the type of water used are the other factors that affect radon concentration which is not investigated in this study. However, the results of some of the most important factors are mentioned in the following.

### *The effect of the type of building on radon concentration*

Table 3 and Fig. 4 show the results of measuring radon concentration separately for residential and commercial buildings. The average radon concentration in commercial units was approximately 50 % lower than that of residential units. The average radon concentration for commercial units was 16.36 and for residential units 31.93 Bq / $m^3$, which are acceptable values in comparison with the action recommended by the World Health Organization (100 Bq / $m^3$). The nature of commercial units, the openness of the doors of these units, as well as the arrival and departure of customers and favorable air circulation, can lead

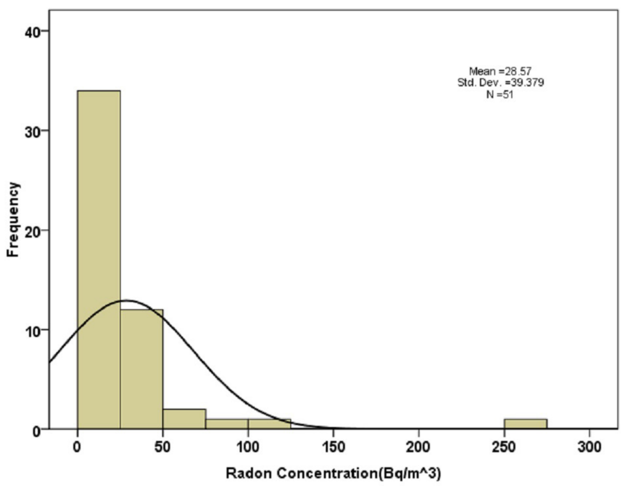


Fig. 3. The histogram of radon concentration in 51 residential,commercial locations of Isfahan

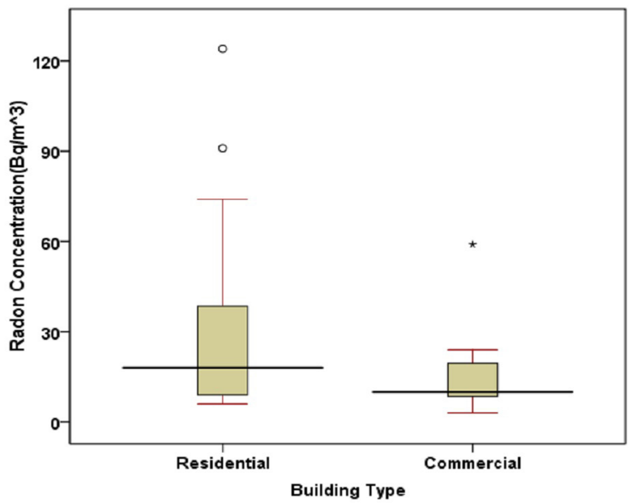


Fig. 4. The concentration of radon in residential and commercial buildings

Table 2. Descriptive statistics of indoor radon concentrations in 51 residential/commercial locations

| Radon concentration (Bq / m$^3$) | | | | | |
|---|---|---|---|---|---|
| No. of Location | Mean ± SD† | Minimum | Maximum | Median | G.M‡ |
| 51 | 28.57±39.38 | 3 | 251 | 16 | 17.89 |

†SD= Standard deviation, ‡G.M= Geometrical mean

Table 3. The concentration of radon in residential and commercial buildings

| Radon concentration (Bq / m$^3$) | | | | | | |
|---|---|---|---|---|---|---|
| Building type | N | Mean± SD† | Min | Max | Median | G.M‡ |
| Residential | 40 | 31.92±43.56 | 6 | 251 | 18 | 20.07 |
| Commercial | 11 | 16.36±15.72 | 3 | 59 | 10 | 11.78 |

†SD= Standard deviation, ‡G.M= Geometrical mean

to a decrease in the accumulation of radon gas and, consequently, a lower average radon concentration in these units.

***The effect of the places of presence or work of people on radon concentration***

Other factors that are effective in the accumulation of radon gas are the spaces and situations of spending time on work or life. These spaces include a bedroom, a reception hall, a warehouse, a parking lot, a corridor and a waiting room, a work office, etc. According to the type of life and activity, the presence of people in these spaces is varying. Figure 5 shows the results associated with these spaces.

The results show that the highest mean radon concentration measured in the warehouse that is close to the recommended action level by the World Health Organization (100 Bq / m$^3$). In other areas, the results were acceptable. Since most of these warehouses are located on the lower floors or underground, and often closed, with no ventilation or windows, radon gas accumulation has taken place in most of them. For other spaces due to better ventilation, good air circulation or close to open spaces, lower results were obtained.

***The effect of the ventilation and floor on radon concentration***

The relationship between the average concentration of radon gas with ventilation status and the floor number or height from the ground are shown in Tables 4, 5 and Figs. 6, 7.

As shown in these charts, radon gas accumulation in the lower floor near the ground was higher, so that in both strong and weak ventilation conditions, the highest mean radon concentration is related to the basement and the lowest average concentration is obtained from the upper floors.

The results showed 4 % (2 cases) had radon levels higher than the action level (100 Bq / m$^3$) recommended by the WHO and Other findings were below the level recommended. Also, 70% of the results were less than the mean value, which is an acceptable level in comparisons such as Ramsar and Mahallat in Iran and other areas with high natural radioactive.

Table 4. Radon concentrations in various ventilations

| Radon concentration (Bq / m$^3$) | | | | | | |
|---|---|---|---|---|---|---|
| Ventilation | N | Mean ± SD† | Min | Max | Median | G.M‡ |
| No | 30 | 36.27 ± 48.58 | 6 | 251 | 21 | 22.01 |
| Yes | 21 | 17.57 ± 14.52 | 3 | 59 | 12 | 13.31 |

G.M= Geometrical mean‡ ,SD= Standard deviation†

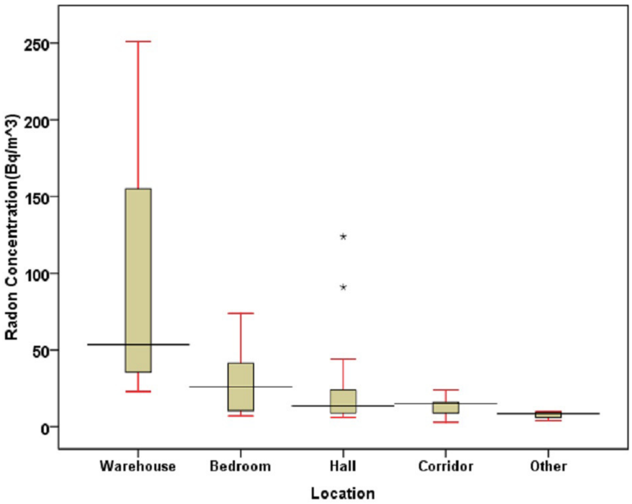


Fig. 5. The average concentration of radon various locations

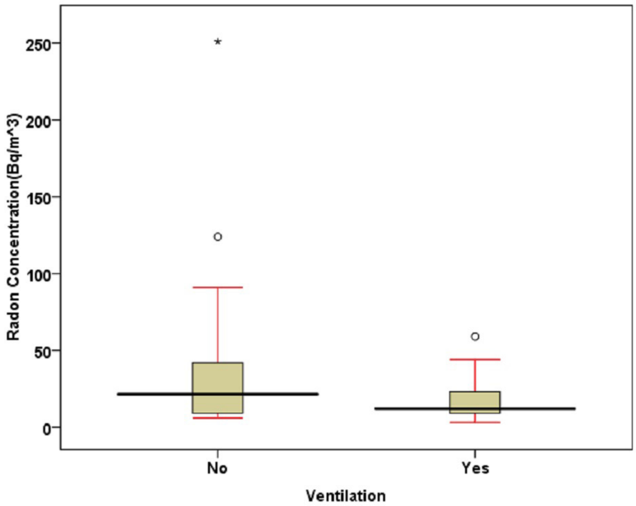


Fig. 6. The relationship between ventilation with average concentration of radon

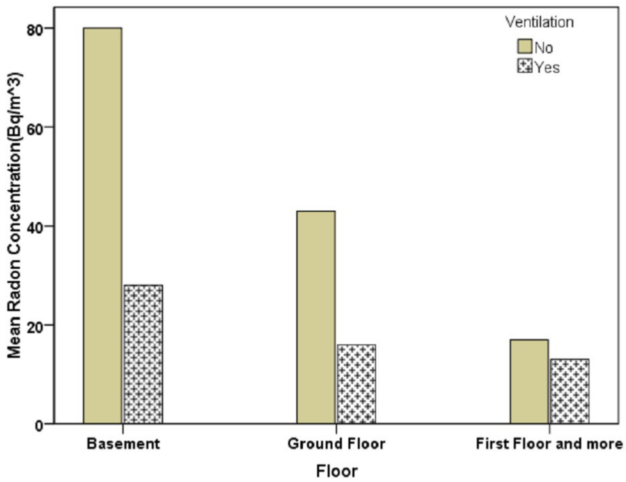


Fig. 7. The relationship between ventilation and floor with average concentration of radon

Since the mean radon concentration in Isfahan is 31.93 Bq / m$^3$, the approximate average annual effective dose from radon inhalation is 0.49 mSv / y (range: 0.05 and 4.30 mSv / y). This amount is lower than the dose received from radon in areas with high levels of radioactivity. In 5 of these measurements (10 % of the results), the doses received above 1 mSv / y were obtained. These values relate to situations where ventilation is not favorable or in the underground and ground floors. However, the average annual effective dose of the residential and commercial buildings was lower than the action level.

The cause of high radon concentration in some locations could be due to weak ventilation or contact buildings with the soil, hence radon in the

Table 5. Radon concentrations in various floors and ventilations

| Radon concentration (Bq / m$^3$) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Floor Number | Ventilation | N | Mean ± SD† | Min | Max | Median | G.M‡ |
| Basement | no | 5 | 80.2 ± 99.97 | 22 | 251 | 44 | 53.04 |
| | yes | 4 | 28.5 ± 21.61 | 8 | 59 | 23 | 22.59 |
| Ground floor | no | 10 | 43.1 ± 40.50 | 6 | 124 | 26 | 27.31 |
| | yes | 10 | 16.54 ± 14.39 | 3 | 44 | 11 | 11.85 |
| First floor and more | no | 15 | 17.37 ± 11.11 | 6 | 42 | 12 | 14.22 |
| | yes | 7 | 13.0 ± 7.21 | 6 | 27 | 10 | 11.60 |

†SD = Standard deviation, ‡G.M = Geometrical mean

soil can easily enter the indoor spaces through the floor cracks. In the majority of apartments, the basements or ground floors a can act as a reservoir for accumulation of radon. The results of this study are consistent with those of several studies [3, 27].

Decreasing radon concentration with increasing distance from the earth has been shown in several studies [2, 28]. Owing to the higher levels of radon in basements, it can be stated that the main source of radon in buildings is the release of radon from the soil and rocks in the earth. Also, due to the higher density of radon gas than the air, it accumulates at lower levels.

In previous studies, it was shown that living rooms have a lower radon concentration than bedrooms [1]. Low concentration of radon in the living room is due to sufficient ventilation.

## Conclusion

Indoor radon concentrations were detected in 51 residential and commercial buildings of Isfahan city, Iran. To conclude, indoor radon concentration in Isfahan city is a health risk for about 4 % of locations. The results of this study could be used for providing radon map of Iran.

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## Competing interests

The authors declare that there is no conflict of interest that would prejudice the impartiality of this scientific work.

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## Ethical considerations

Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc) have been completely observed by the authors.

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