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Indoor radon measurement and effective dose assessment of 150 apartments in Mashhad, Iran

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Abstract Environmental monitoring and indoor radon measurement are important for public health, to estimate the cancer risk of respiratory system and, if necessary, to suggest proper methods that reduce indoor radon level. In this research, indoor radon concentration in the air has been measured in 150 apartments in Mashhad city. The result demonstrates about 94.7% of apartments have radon concentration less than 100 Bq/m^3, taken by WHO as the action level, and 5.3% have the concentration higher than this level. As well as, annual radon dose has been assessed using the equation for annual effective dose calculation introduced by United Nations Scientific Committee on the Effects of Atomic Radiation.

Keywords Indoor Radon measurement · Radon effective dose · Mashhad city

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Introduction

Everybody is exposed in daily life to radon present in the atmosphere everywhere (UNSCEAR 1982, 2000; EPA 1991). In indoor spaces, such as houses and apartments, radon originates by emanation from under base soil and building materials; also, it is released from materials brought into the room, such as radon-rich water or natural gas fuel, and radon in inlet air, which may in turn have a normal concentration of the gas or an increased concentration derived from sources outside the room.

Recently, Chen (2005) published a valuable review of radon doses in epidemiological assessment and physical dosimetry aspects. The greatest fraction of natural radiation exposure in humans results from inhalation, indoor, and in work places like mines, of the decay products of radon, which are α-emitting short lived daughters such as ^{218}Po and ^{214}Po (Mansour et al. 2005; Abbady et al. 2004; Mowlavi et al. 2009; Abu-Jarad 1997; Somlai et al. 2007; Panatto et al. 2006). It has been estimated that radon and its short-lived decay progenies contribute with three quarters of the annual effective dose received by man from natural terrestrial sources and induce about half of the dose from total sources (UNSCEAR 1982, 2000; EPA 1991).

About the action level of radon, WHO has suggested that homeowners take actions when radon levels exceed 100 Bq/m^3. This is a much more conservative figure than the Environmental Protection Agency (EPA) action level of 148 Bq/m^3 (EPA 1991), which has been the USA standard for many years (WHO 2009).

In this study, indoor radon concentration has been measured at 150 apartments in Mashhad. Mashhad, in northeast of Iran, is the second big city after Tehran, the capital of Iran, with about 2.4 million fix population. The city is found on 985 m above the sea level with 36°17′45″ N, 59°36′43″ E geographical coordinates. From a geological point of view, in the south of Mashhad, there are Kalaj mountains with granitic hilly lands cover by silty deposits, in the northwest is Kale Ghaemabad with more sandy soil, and the rest is plateau with mix of loamy-clay and soft sandy soils.

Materials and methods

Portable Radon Gas *S*urveyor SILENA

Model 5S has been applied to measure indoor radon concentration. The system is particularly well suited for this type of measurement, as it is portable, easy to use, and very sensitive. Portable Radon Gas *S*urveyor SILENA (PRASSI) equipment has a pump to send the air over the detection system that can operate with a constant flow rate of 3 l/min, and its alpha detector is a ZnS(Ag) scintillation cell with 1830 cm^3 volume. The sensitivity of this system in continuous mode is 4 Bq/m^3 during the integration time of 1 h.

The PRASSI system was calibrated by the factory with a ^{226}Ra solution source having certified emission of ^{222}Rn. The Company provides the purchaser with a calibration certificate. The calibration parameters corresponding to the PRASSI system in 700 V as the operating high voltage are given as follow:

- Radon gas efficiency in continues mode was 22.6 cpm/Bq;
- Grab sampling efficiency was 97.4 cpm/Bq;
- Background was 1.48 cpm.

We got the samples in various points of the Mashhad City, with emphasize on an approximately uniform distribution to cover all of the zones. Figure 1 shows Mashhad location in Iran and the sampling sites. We have measured radon concentration in 150 apartments during fall of 2009. The apartments have been selected to be in the ground floor, with the age less than 30 years, built form local materials such as concrete, plaster and clay bricks. Measurements have been done three times in half an hour per each apartment, during around 7:00–10:00 A.M. in bedrooms or living rooms.

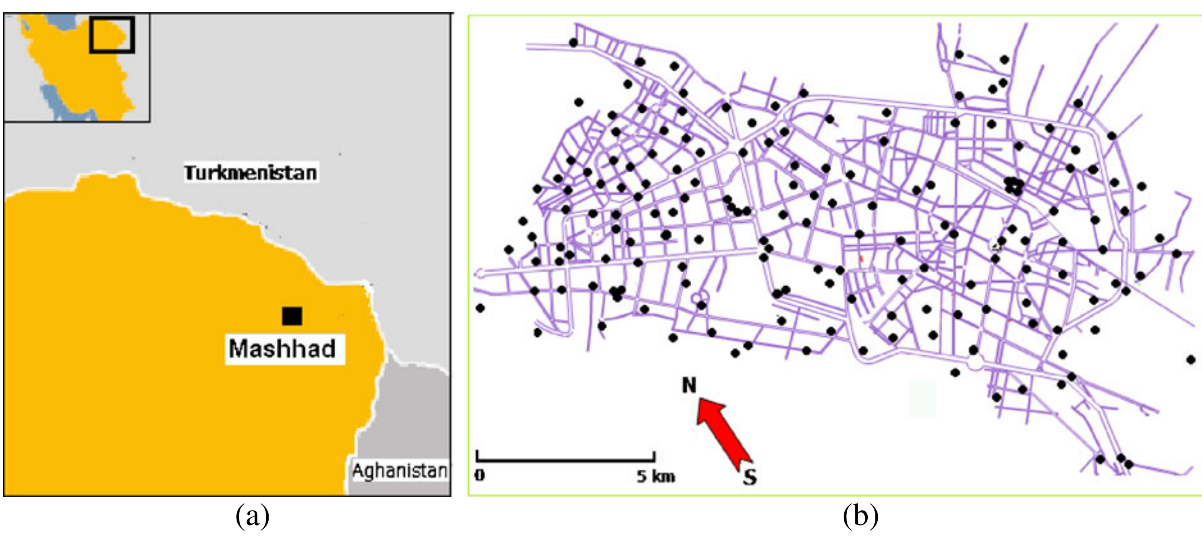

Fig. 1 **a** Mashhad location in Iran, **b** the map of Mashhad where bold points (*dots*) show the sampling sites

Results and discussion

The average of three measurements has been considered as the mean value of radon concentration in each apartment. As shown in Fig. 2, about 94.7% of apartments have radon level lower than 100 Bq/m^3 which is taken as the action level by WHO (2009), and only in 5.3% of samples indoor radon concentration is more than 100 Bq/m^3. Nevertheless, in all of apartments, the radon concentration is less that 148 Bq/m^3, which is the action level of EPA (1991). According to the obtained data, the minimum and maximum radon concentrations in the apartments are 12.3 and 135.2 Bq/m^3, respectively, with an arithmetic mean of 31.9 Bq/m^3. We must mention the mean outdoor radon level was 9.7 Bq/m^3 in that period.

Radon effective dose assessment

Indoor radon has been determined to be the second leading cause of lung cancer after tobacco smoking (Marley et al. 1998). Radon effective dose value describes the harmful effects of radon on the human body; therefore, it is necessity to calculate the radon dose from radon concentration. There are large uncertainties in dosimetric assessments and epidemiological aspects for the conversion of a radon exposure to a radon dose (Chen 2005). We used UNSCEAR's radon dose conversion factor as it lies between dosimetric and epidemiological dose conversions (WHO 2009; IARC 1988). UNSCEAR suggests that in estimating the effective doses, the following factors are applied (IARC 1988):

- An indoor radon decay product equilibrium factor of $E_f = 0.4$
- A radon effective dose coefficient factor of $C_f = 9$ nSv/(Bq h m^{-3})
- An indoor occupancy factor of $O_f = 0.8$, which is the fraction time that people spend indoors, but not essentially in their homes. It means, during one year ($T = 365 \times 24$ h), people spend about 7,008 h at indoor spaces like home and office.

So, the equation for annual effective dose (D_y) due to radon concentration is:

$$D_y = E_f C_f O_f Q_{Rn} T \quad (1)$$

where Q_{Rn} is the radon concentration in Bq/m^3 scale. By using this equation, annual radon effective dose has been calculated. The apartments have been classified in three groups: radon concentration from outdoor measured level to half of WHO action level; from half of action level

Table 1 Annual radon effective dose assessment in some apartments of Mashhad

Indoor radon concentration range (Bq/m^3)	Number of apartments	Annual effective dose range (mSv)
10–50	134	0.25–1.26
50–100	9	1.26–2.52
100–150	7	2.52–3.78

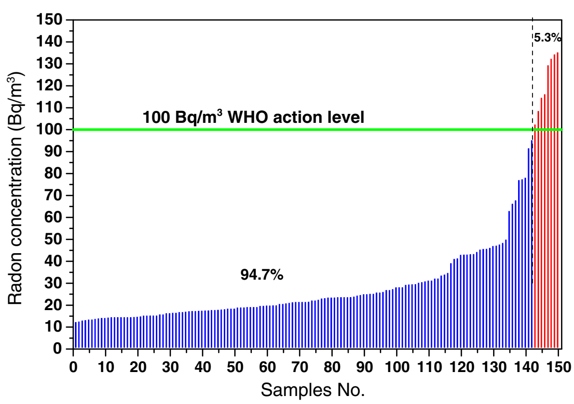

Fig. 2 The histogram of indoor radon concentration in 150 apartments

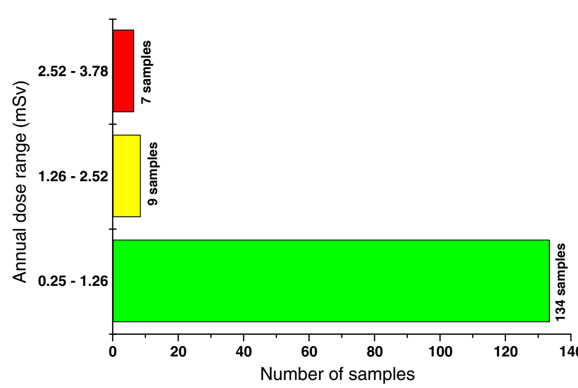

Fig. 3 The histogram of annual effective dose of 150 apartments

to the action level, and more than the action level (Table 1). Also, the histogram presentation of dose range against the frequency has been shown in Fig. 3.

Conclusion

The measurements result demonstrate 94.7% of apartments have radon level less than 100 Bq/m^3, advised as the action level by WHO, and just 5.3% have higher radon concentration. Although this research may assure the public people of Mashhad that indoor radon concentration in the area is not so high, to improve the social health it is advisable to train them how to reduce the indoor radon level by simply ways, such as using fans or air circulate systems.

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