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MEASUREMENT OF INDOOR RADON CONCENTRATION IN DISTRICT MARDAN, KHYBER PAKHTUNKHWA, PAKISTAN

The study of the indoor radon concentration in district Mardan Khyber Pakhtunkhwa (KPK), Pakistan is presented. To know the impact of the dose for Mardan city, 40 CR-39 detectors were installed in different houses for a period of three months. The radon concentration for this phase of the year (early summer) is from 18.45 ± 0.53 to 41.51 ± 3.4 Bq/m^3. The level of indoor radon concentration is the highest in the basements i.e. 41.51 ± 3.4 Bq/m^3 which is within acceptable limit (148 Bq/m^3), recommended by the Environmental Protection Agency. The annual effective dose calculated from this study is E_{Rn} = 0.704 mSv. It was concluded that indoor radon concentration may not suppose any severe threat to the health of residents.

Keywords: radiation measurements, indoor radon, SSNTD's.

1. Introduction

Radon, a radioactive noble gas naturally exists in the environment. It is colourless, odourless and tasteless. These properties of radon gas make it impossible for human sense to be detected. The main producers and generators of radon are Uranium and Thorium. These two exist in earth crust with variation in their quantity. There are three naturally occurring isotopes of radon. Those are ^{219}Rn, ^{220}Rn, ^{222}Rn. Referring to stability ^{222}Rn is more stable among the above three isotopes. This is the off shoot of the decomposed yield of ^{226}Ra. The half life span of ^{222}Rn is 3.82 days. Whereas the ^{219}Rn and ^{220}Rn have shorter half-lives of 55.6 and 3.96 s respectively. They are mostly unnoticed while measuring radon. Radon is acceptably the second biggest threat causing lungs cancer, bronchial tissue damage etc. following smoking [1]. Since the life time of the most abundant isotope of radon, ^{222}Rn, is large compared to the breath in and breath out time, a large quantity of it is breathed in and breathed out before to its decay. Radon has four daughters ^{218}Po, ^{214}Pb, ^{214}Bi, and ^{214}Po. They are in solid form and may be attached with dust particles. During breathing the dust particles bearing radon daughters are inhaled which may happen to stick to epithelial surface in the lungs. As a result, the alpha radiation strives to affect the tissues. Apart from this when radon decays inside the lungs, solid daughters are produced, which stick to the air passage and emit α-particles.

The principal cause for high humidity levels in the basement is soil vapour infiltration on the other hand sub-slab depressurization system besides reducing radon entry into the home, slows down the entry of other chemicals as well. Radon gas always enters into building through ground, cracks or along the pipes. Therefore, when build a house the gapes in walls and cracks in floor should be eliminated. Inside the buildings the indoor radon concentration is subject to change with season. It increases in winter and decreases in summer. During the summers there is a minimum radon concentration inside the buildings. Whereas in winter radon concentration is higher inside the buildings due to poor ventilation and air pressure differentials caused by induced soil suction, also known stack effect or chimney effect [2]. Therefore, radon concentration can be reduced by using exhaust fans, open the windows for fresh air or by using the air conditioners.

2. Location and climate of the study area

The study was carried out in the rural and urban area of Mardan city (Fig. 1). District Mardan is the second largest city of Khyber Pakhtunkhwa (KPK) province in Pakistan. The main city of Mardan district is headquarter of District Mardan within the latitude 34°05′ to 34°32′ N and 71°48′ to 72°25′ E longitudinally. Its adjacent Districts are Sawabi to the East, Charsadda to the West, Malakand to the North and Nowshera to the South. The summer season in District Mardan is very hot. Summer season starts from May to the ends of September. The temperature rises in the mid of June (i.e. 41 °C). The winter season starts in November and ends at the end of February. The severe winter recorded in the months of December and January. The total area of District Mardan is about 1,632 km^2 and its population is 2,373,061 [3].

Fig. 1. Map of the surveyed area taken from Google website.

3. Materials and methods

The focus of the study is to measure the indoor radon concentration in the residential area of district Mardan, to look for changes in radon concentration through a time span of three months and to provide approximate value of quantity of periodical dose taken by the dwellers. The experiment was executed during the summer (from 10 April to 10 July). CR-39 detectors of dimension 1×1.5 cm^2 were prepared. These detectors were distributed and installed in 40 h (mostly in bedrooms) which were chosen randomly. In each house a single dosimeter was fitted. The detectors were fitted in such a way that they were 0.5m below the ceiling, 2m above the ground level and 1m away from the wall. The detectors were fitted inside a plastic chamber which was drilled from both sides. The purpose of these drilled holes (narrow slits) was that the radon could enter in to the plastic chamber easily and could hit the detectors inside this plastic chamber cup as shown in the Fig. 2.

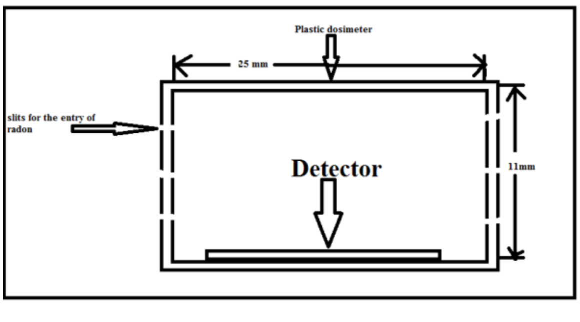

Fig. 2. Cartoon of CR-39 detector installed in a plastic cover with slits in it for entering air.

The detectors were kept away from other objects, that it must not be disturbed. The detectors were fitted for a period of three months. After a period of three months 29 detectors were collected and 11 were lost because of poor care of the dwellers. The detectors were etched with 6M normal solution of NAOH for 3 h at constant temperature of 70 ºC. Finally, the tracks were counted by using optical microscope at 100X. The counted tracks were then converted in radon concentration by using the following equation [4]

$$C_R\left(\frac{Bq}{m^3}\right) = \frac{\rho_m}{K_m} d, \qquad (1)$$

where C_R – radon concentration in Bq/m^3; ρ_m – tracks density (tracks/cm^2); K_m – calibration factor; d – time of exposure in hour. The estimation of radon concentration, in the environment using the passive methods required a parameter which transfers track/cm^2 to Bq/m^3. This parameter can be determined using a standard radon source (^{226}Ra) and electronic instrument to measure the activity concentration in the space by the well-sealed radon chamber. These chambers have been used to determine the calibration factors of CR-39. This calibration factor converts Track density to radon concentration. In our study, the calibration factor is found 0.07587 tracks cm^{-2}h^{-1}/Bqm^{-3}.

4. Results and discussion

The calculated values of indoor radon concentration in different dwellings are tabulated below. The study was carried out in summer for a period of three months (from 10 April to 10 July). Standard deviation of radon concentration values have been calculated using the following formula

$$\sigma_n = \sqrt{\frac{\sum (x - \bar{x})^2}{n}}, \qquad (2)$$

where σ_n – the standard deviation; x – the value of detectors having values of radon concentration in Bq/m^3; $\bar{x}$ – the mean values; n – the total number of values i.e. for ground floor detectors the total number of values are 22. In all Tables the same formula has been used. The values of indoor radon concentration were found varying from 18.45 ± 0.53 Bq/m^3 to 41.51 ± 3.4 Bq/m^3 with an average value of 22.33 Bq/m^3. The average value 22.33 Bq/m^3 is much less than the average value of 40 Bq/m^3 reported for dwellings worldwide [5]. All the measured values are well below the action level of 148 Bq/m^3 recommended by ICRP [6]. Table 1 and Fig. 3 both show that the detectors installed in the basement have the highest value of radon concentration from 41.51 ± ± 3.4 Bq/m^3 to 31.89 ± 2.0 Bq/m^3. Table 2 and Fig. 4 show the radon concentrations on ground floor varying from 21.87 ± 0.44 Bq/m^3 to 24.38 ± ± 0.30 Bq/m^3 while Table 3 and Fig. 5 show the radon concentration of those detectors which were installed on the 1st floor of the buildings. The radon concentration varies from 18.4 5 ± 0.53 Bq/m^3 to 20.16 ± 0.70 Bq/m^3 on the first floors. In Table 4 we compare our present study with different studies carried out in different parts of Pakistan. It is clear from the comparison that the indoor radon concentration level in the present study is much less than that of other studies carried out in Pakistan. The study conducted by Rahman (2007), in KPK (Khyber Pukhtunkhwa), in which a sample of soil from four districts were taken and the level of radon concentration was thoroughly measured [7]. Khan et al. studied indoor radon concentration in the five districts of Hazara division i.e. Abbottabad, Batagram, Haripur, Kohistan and Mansehra [8].

In Table 5 we compare the present study with other studies carried out in different parts of the globe. Again the comparison shows that the present radon concentration value is much less than that of other studies carried out in other parts of the globe. Al-Mosa (2007) made efforts for his study in the local educational institutions of Zulfi city Saudi Arabia (KSA) with the results obtained of high level indoor radon concentration [9]. Another study in this regard was conducted by Algin et al. (2013) which also displayed results greater in indoor radon concentration as compared to the recent study [10].

Table 1. **Radon concentration values by detectors installed in the basements**

Exposure time, h	Average track density		Net track density	Radon concentration	
	Tracks/Fov	Tracks/cm^2·10^4	Tracks/(cm^2·h)	Bq/m^3	Pci/L
2160	0.21 ± 0.14	0.06 ± 0.04	0.26 ± 0.18	41.51 ± 3.4	0.09 ± 0.1
2160	0.20 ± 0.14	0.05 ± 0.04	0.25 ± 0.18	31.89 ± 2.0	0.09 ± 0.1

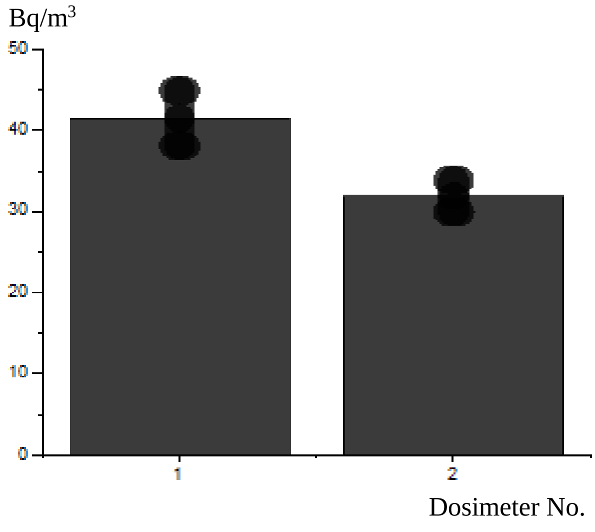

Fig. 3. Radon concentration in different detectors installed in the basement for a period of 2160 h.

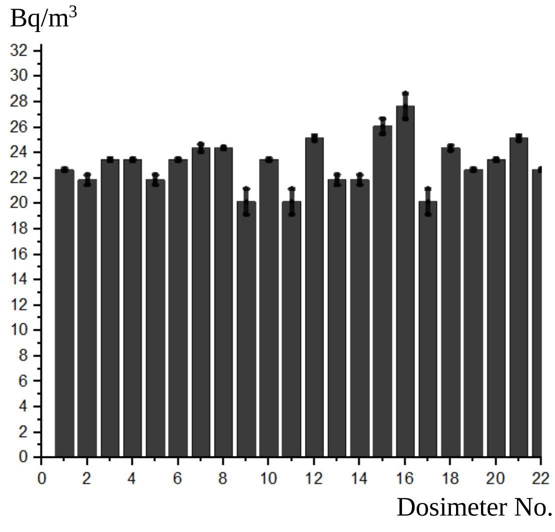

Fig. 4. Radon concentration in detectors installed on the ground floor for a period of 2160 h.

We can see that as we go above in the buildings, radon concentration values decreases. This is because, the radon gas is the denser gas and that's why it is always in maximum concentration in lower portion of the buildings. Another reason is that at the lower part of the buildings, the soil is in maximum ratio and radon always transfer in to the buildings directly from soil beneath and near to the walls. The decrease in the level of radon at upper flour is also due to the good ventilation system as compared to the basements.

Table 2. **Radon concentration values in the ground floors where the detectors were installed for a period of 2160 h**

Room type	Average track density		Net track density	Radon concentration	
	Tracks/Fov	Tracks/cm^2·10^4	Tracks/(cm^2·h)	Bq/m^3	Pci/L
Bedroom	0.0106 ± 0.0010	0.0014 ± 0.0003	0.0721 ± 0.0015	22.66 ± 0.10	0.61 ± 0.01
Bedroom	0.0107 ± 0.0030	0.0046 ± 0.0010	0.0509 ± 0.0120	21.87 ± 0.44	0.60 ± 0.09
Bedroom	0.0042 ± 0.0001	0.0012 ± 0.0003	0.0815 ± 0.0108	23.46 ± 0.10	0.63 ± 0.01
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Bedroom	0.0107 ± 0.0030	0.0046 ± 0.0010	0.0509 ± 0. 0120	21.87 ± 0.44	0.60 ± 0.09
Bedroom	0.0042 ± 0.0001	0.0012 ± 0.0003	0.0815 ± 0.0108	23.46 ± 0.10	0.63 ± 0.01
Bedroom	0.0149 ± 0.0030	0.0042 ± 0.0009	0.1002 ± 0.0210	24.38 ± 0.30	0.71 ± 0.08
Bedroom	0.0149 ± 0.0030	0.0042 ± 0.0009	0.1002 ± 0.0210	24.38 ± 0.30	0.71 ± 0.08
Bedroom	0.0318 ± 0.0020	0.0101 ± 0.0020	0.0131 ± 0.0068	20.16 ± 0.70	0.54 ± 0.03
Bedroom	0.0042 ± 0.0001	0.0012 ± 0.0003	0.0815 ± 0.0108	23.46 ± 0.10	0.63 ± 0.01
Drawing room	0.0318 ± 0.0020	0.0101 ± 0.0020	0.0131 ± 0.0068	20.16 ± 0.70	0.54 ± 0.03
Bedroom	0.0210 ± 0.0050	0.0071 ± 0.0020	0.0112 ± 0.0240	25.17 ± 0.20	0.71 ± 0.02
Bedroom	0.0107 ± 0.0030	0.0046 ± 0.0010	0.0509 ± 0.0120	21.87 ± 0.44	0.60 ± 0.10
Bedroom	0.0107 ± 0.0030	0.0046 ± 0.0010	0.0509 ± 0.0120	21.87 ± 0.44	0.60 ± 0.10
Bedroom	0.0316 ± 0.0070	0.010 ± 0.0010	0.1269 ± 0.0270	26.09 ± 0.62	0.70 ± 0.01
Bedroom	0.0517 ± 0.0120	0.015 ± 0.0030	0.1535 ± 0.0302	27.67 ± 1.02	0.74 ± 0.01
Bedroom	0.0318 ± 0.0020	0.0101 ± 0.0020	0.0301 ± 0.0070	20.16 ± 0.70	0.54 ± 0.03
Bedroom	0.0149 ± 0.0030	0.0042 ± 0.0010	0.1002 ± 0.0210	24.38 ± 0.30	0.71 ± 0.08
Bedroom	0.0016 ± 0.0010	0.0014 ± 0.0010	0.0721 ± 0.0015	22.66 ± 0.10	0.61 ± 0.01
Bedroom	0.0042 ± 0.0001	0.0012 ± 0.0003	0.0815 ± 0.0180	23.46 ± 0.10	0.63 ± 0.01
Bedroom	0.0102 ± 0.0050	0.0071 ± 0.0020	0.0112 ± 0.0240	25.17 ± 0.20	0.71 ± 0.02
Bedroom	0.0016 ± 0.0010	0.0014 ± 0.0010	0.0702 ± 0.0105	22.66 ± 0.10	0.61 ±0.01

Table 3. **Radon concentration values on the first floor with exposure time of 2160 h**

Room type	Average track density		Net track density	Radon concentration	
	Tracks/Fov	Tracks/cm^2·10^4	Tracks/(cm^2·h)	Bq/m^3	Pci/L
Store	0.0090 ± 0.0040	0.0007 ± 0.0003	0.0134 ± 0.006	19.24 ± 0.17	0.52 ± 0.04
Bedroom	0.0134 ± 0.0060	0.0054 ± 0.0024	0.0178 ± 0.008	20.16 ± 0.23	0.54 ± 0.01
Bedroom	0.0134 ± 0.0060	0.0054 ± 0.0024	0.0178 ± 0.008	20.16 ± 0.23	0.54 ± 0.01
Bedroom	0.0134 ± 0.0060	0.0054 ± 0.0024	0.0178 ± 0.008	20.16 ± 0.23	0.54 ± 0.01
Bedroom	0.0313 ± 0.0140	0.0073 ± 0.0032	0.0402 ± 0.018	18.45 ± 0.53	0.50 ± 0.01

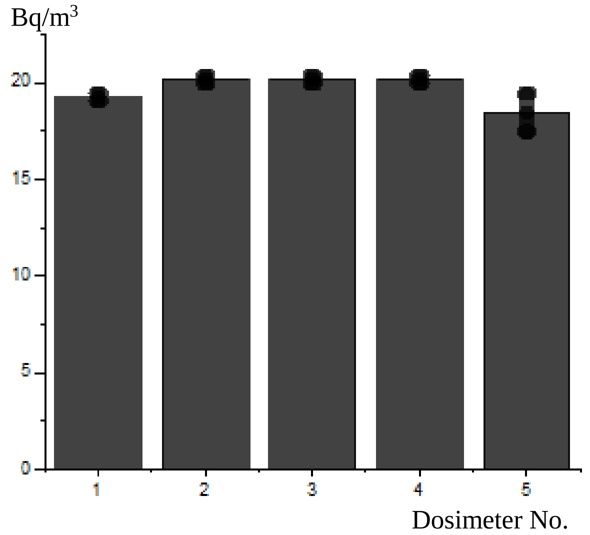

Fig. 5. Radon concentration in detectors installed on the first floor for a period of 2160 h.

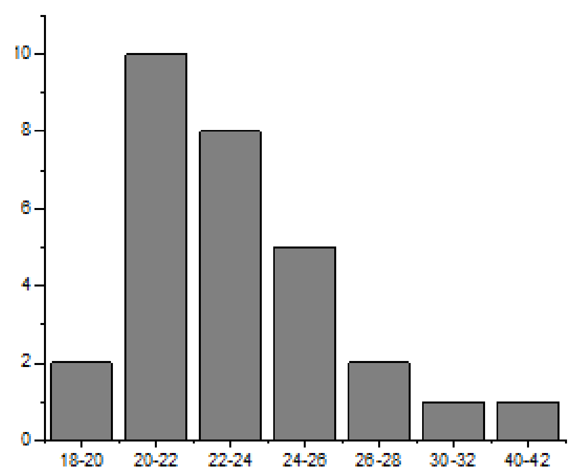

Fig. 6. Frequency of radon concentrations distribution.

Table 4. **Comparison of indoor radon level in the different cities of Pakistan [7]**

Area	Indoor radon level, Bq/m^3
Abbotabad	102 ± 34
Mansehra	106 ± 26
Haripur	140 ± 42
Battagaram	102 ± 22
Kohistan	114 ± 28

Table 5. **Comparison of indoor radon levels in the different parts of the world**

Area	Indoor radon level, Bq/m^3	References
Zulfi city KSA	74.67 ± 3.04	[9]
Eskisehir, Turkey	214 ± 43.1	[10]
Bareilly India	155.12 ± 10.7	[11]
Finland	123 ± 8.9	[12]
Italy	70 ± 5.1	[13]
Romania	115 ± 8.3	[14]
Sweden	108 ± 23	[15]
Turkey	132 ± 19.7	[16]
U.S.A	46 ± 7.8	[17], [18]

The frequency distribution of the measured indoor radon concentration in different dwellings is shown in Fig. 6. The chart shows that 7 % dwellings has the radon concentration between 18 - 20 Bq/m^3. It is also clear from Fig. 6 that, 34 % of dwellings have the radon concentration between 20 - 22 Bq/m^3. The measurements show that 27 % of detectors recorded radon concentration between 22 - 24 Bq/m^3. 17 % detectors show the radon concentration between 24 - 26 Bq/m^3. Similarly, the results show that only 7 % detectors recorded the concentration between 26 - 28 Bq/m^3. 3 % detectors record the radon concentration between 30 - 32 Bq/m^3 and 40 - 42 Bq/m^3. The maximum radon concentration is measured in basements.

5. Conclusion

In the above study we have measured indoor radon concentration in the residential area of district Mardan, through a time span of three months to provide approximate value of quantity of periodical dose taken by the dwellers. Early summer was targeted to carry out the experiment (10 April to 10 July) where the detectors were installed for a period of three months. Solid State Nuclear Track Detectors type CR-39 were used to measure the radon concentration by counting the tacks created by the alpha decay of radon. The conclusions of this study are as follow:

1. The average value found in the present study (22.31 Bq/m^3) is much less than that of the world wide average indoor radon level (40 Bq/m^3). Nevertheless, the measured value is much less than the action level (148 Bq/m^3) recommended by ICRP. Table 1 and table 2 show that the radon concentration values vary between 18.45 ± 0.53 Bq/m^3 to 41.51 ± ± 3.4 Bq/m^3.
2. The value of the effective dose (0.704 mSv/y) is much less than the action level (3 mSv/y) recommended by ICRP. This shows that no remedial action is required to overcome indoor radon level in dwellings.
3. It has also been observed that the maximum radon concentrations were measured in basements and ground floor of the buildings.
4. The building construction, geological condition and value of humidity play an important role in order to decide the indoor radon level.
5. No remedial actions are required to fix the homes.

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ВИМІРЮВАННЯ КОНЦЕНТРАЦІЇ РАДОНУ У ВНУТРІШНІХ ПРИМІЩЕННЯХ У М. МАРДАН ПРОВІНЦІЇ ХАЙБЕР-ПАХТУНХВА, ПАКИСТАН

Представлено дослідження концентрації радону у внутрішніх приміщеннях у м. Мардан провінції Хайбер-Пахтунхва, Пакистан. У різних будинках терміном на три місяці було встановлено 40 детекторів CR-39. Концентрація радону для цієї пори року (початок літа) становить від 18,45 ± 0,53 до 41,51 ± 3,4 Бк/м^3. Найвища концентрація радону спостерігається в підвалах, тобто 41,51 ± 3,4 Бк/м^3, яка відповідає допустимій межі (148 Бк/м^3), рекомендованій Агентством з охорони навколишнього середовища. Річна ефективна доза, розрахована відповідно до цього дослідження, дорівнює E_{Rn} = 0,704 мЗв. Було зроблено висновок про те, що концентрація радону у приміщенні не може представляти серйозної загрози здоров’ю населення.

Ключові слова: вимірювання радіації, радон у приміщеннях, твердотільні трекові детектори.

ИЗМЕРЕНИЕ КОНЦЕНТРАЦИИ РАДОНА ВО ВНУТРЕННИХ ПОМЕЩЕНИЯХ В Г. МАРДАН ПРОВИНЦИИ ХАЙБЕР-ПАХТУНХВА, ПАКИСТАН

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Представлено исследование концентрации радона во внутренних помещениях в г. Мардан провинции Хайбер-Пахтунхва, Пакистан. В различных домах сроком на три месяца были установлены 40 детекторов CR-39. Концентрация радона для этого времени года (начало лета) составляет от 18,45 ± 0,53 до 41,51 ± 3,4 Бк/м^3. Самая высокая концентрация радона наблюдается в подвалах, т.е. 41,51 ± 3,4 Бк/м^3, которая соответствует допустимому пределу (148 Бк/м^3), рекомендованному Агентством по охране окружающей среды. Годовая эффективная доза, рассчитанная согласно этому исследованию, равна E_{Rn} = 0,704 мЗв. Был сделан вывод о том, что концентрация радона в помещении не может представлять серьезной угрозы здоровью населения.

Ключевые слова: измерение радиации, радон в помещениях, твердотельные трековые детекторы.

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