Indoor Radon Concentrations and Assessment of Doses in Four Districts of the Punjab Province - Pakistan

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Indoor radon survey/Seasonal variation/CR-39 based radon detector/Annual effective dose/Punjab Province.

Seasonal indoor radon measurement studies have been carried out in four districts, namely, Jhelum, Chakwal, Rawalpindi and Attock of the Punjab Province. In this regard, CR-39 based detectors were installed in bedrooms, drawing rooms and kitchens of 40 randomly selected houses in each district. After exposing to radon in each season, CR-39 detectors were etched in 6M NaOH at 80°C and counted under an optical microscope. Indoor radon activity concentrations in the houses surveyed ranged from 15 ± 4 to 176 ± 7 Bq m⁻³ with an overall average value of 55 ± 31 Bq m⁻³. The observed annual average values are greater than the world average of 40 Bq m⁻³. Maximum indoor radon concentration levels were observed in winter season whereas minimum levels were observed in summer season. None of the measured radon concentration value exceeded the action level of 200–400 Bq m⁻³. The season/annual ratios for different type of dwellings varied from 0.87 ± 0.93 to 1.14 ± 1.10. The mean annual estimated effective dose received by the residents of the studied area was found to be 1.39 ± 0.78 mSv. The annual estimated effective dose is less than the recommended action level (3–10 mSv).

INTRODUCTION

Radon is a naturally occurring radioactive gas. It is a part of the decay series of ²³⁸U and is formed by the decay of its immediate parent ²²⁸Ra. The amount of radon in the soil depends on complex soil chemistry that varies from place to place. It enters into the water we drink and the air we breathe. From the naturally occurring radio-isotopes of radon, ²²²Rn, is the most significant due to its relatively longer half life. High mobility enable radon to come out from the bedrock, particularly if this is well faulted, into the soil overburden, where it ultimately forms part of the soil gas.¹⁻⁴) The concentration of radon and its decay products show large temporal and local fluctuations in the indoor atmosphere due to the variations of temperature, pressure, nature of building materials, ventilation conditions and wind speed, etc.⁵)

Inhalation of radon and its daughter products may cause significant health hazard when concentrated into the indoor air. During respiration, radon progenies may deposit into the lungs thereby irradiating the cells and may cause lung cancer.⁶⁻¹²) Therefore, measurements of indoor radon levels are extremely important because the radiation dose to the human population due to inhalation of radon (²²²Rn) and its progenies (²¹⁸Po and ²¹⁴Po) contribute more than 50% of the total dose from natural sources.¹³) This makes the role of radon measurement in dwellings highly critical in monitoring human health and safety.

We intend to carry out nationwide indoor radon studies in Pakistan. In this regard, a number of studies have been carried out and reported in the open literature.¹⁴⁻¹⁹) In continuation of the aforesaid studies, the present work deals with the seasonal variation in the indoor radon measurement in four districts of the Punjab Province.

Climate

Pakistan has a subtropical climate characterized by four seasons. Weather in Pakistan is marked with great variations because of its diverse topography. There are following four seasons in Pakistan: A cool and dry winter (December–February), spring (March–May), a hot dry summer season (June–August) and autumn (September–November). The onset and duration of these seasons vary somewhat according to the locations. The area under study, comprising of four districts is shown in Fig. 1. This area falls in the Salt range and Potohar plateau. It has a complex geological history of mountain formation, alluvial-loessic depositions, and erosion cycles. The climate of the area is subhumid to sub-
tropical continental type, receiving maximum rainfall from July to September. The latitude and longitude of the studied region ranged from 33°10′ 0″ N to 33°54′ 30″ N and 73°2′ 37″ E to 73°26′ 30″ E, respectively. Temperatures in the studied areas usually drop to below zero in January and raise more than 40°C in June.

Building characteristics
All the houses surveyed in the Jhelum, Chakwal, Rawalpindi and Attock districts were built from baked bricks, sand and cement. Each room contained one or two windows. These included both single and double story houses. Each house contained at least two rooms and one kitchen. CR-39 based radon detectors were installed in a bedroom, drawing room and kitchen of each selected house. In the case of double storey houses, dosimeters were installed in bedrooms, drawing rooms and kitchens located at the ground floor. All the houses surveyed were detached and semi-detached houses. The roofs and floors were made of concrete.

MATERIALS AND METHODS
Indoor radon concentration levels have been measured in bedrooms, drawing rooms and kitchens of randomly selected 40 houses in each district, namely, Jhelum, Chakwal, Rawalpindi and Attock of the Punjab Province, Pakistan in four seasons (i.e., summer, autumn, winter and spring seasons). As mentioned earlier, summer season span over June, July and August, autumn season is from September to November, winter season begins in December and ends in February and spring season begins in March and ends in May.

CR-39 based radon detectors were used in this study. CR-39 plastic detectors were purchased from the Page Mouldings limited, England having 500 μm thicknesses. Large sheets of CR-39 were cut into small detectors of size 1.5 cm × 1.5 cm which were then placed into the NRPB dosimeters (now called the Radiation Protection Division of the Health Protection Agency). The detectors were installed in bedrooms, drawing rooms and kitchens on quarterly basis at a head height above the ground level. The distance of the installed detectors from the ceiling was about 1 m whereas from walls it was about 20 cm. After an exposure period of three months, these detectors were replaced by fresh detectors in each season.

After exposure, detectors were then etched in 6M NaOH at 80°C and were counted under an optical microscope. The observed track densities were related to radon concentration levels using calibration factor of 2.7 Tracks.cm⁻².h⁻¹/kBq m⁻³. The seasonal correction factor was calculated by dividing the arithmetic mean of each season (i.e. summer, autumn, winter, spring) by the annual arithmetic mean.

RESULTS
As mentioned above, indoor radon concentration levels have been measured in 160 houses (40 houses per district) in four districts of the Punjab province namely, Jhelum, Chakwal, Rawalpindi and Attock in each season of the year. The results obtained are summarized in Tables 1–3. All data are listed as a file in “Supplementary Material” of the electronic version in J-STAGE.

Table 1 shows minimum and maximum indoor radon concentration levels observed in each district in each season of the year. As may be seen in this table, radon concentration levels in Jhelum district vary from 18 ± 6 to 176 ± 7 Bq m⁻³ whereas in Chakwal district variation is from 19 ± 6 to 164 ± 13 Bq m⁻³. Indoor radon variation is seen to range from 16 ± 9 to 165 ± 17 Bq m⁻³ and 15 ± 4 to 137 ± 14 Bq m⁻³ in Rawalpindi and Attock districts, respectively. Maximum values of radon concentration (i.e. 176 ± 7 Bq m⁻³) has been observed in winter season in the district of Jhelum and minimum value of 15 ± 4 Bq m⁻³ is found in the district Attock in summer season.

Both district and seasonal wise average of indoor radon concentration for the four districts of the Punjab province are shown in Table 2. Yearly average radon concentration levels in the studied four districts are 59 ± 34, 56 ± 32, 52 ± 28, 51 ± 31 Bq m⁻³, respectively whereas seasonal average radon levels were found to be 62 ± 34, 56 ± 28, 53 ± 33 and 48 ± 29 Bq m⁻³ in districts Jhelum, Chakwal, Rawalpindi and Attock, respectively. Overall arithmetic mean of the area surveyed was found to be 55 ± 31 Bq m⁻³.

The annual average indoor radon value in the studied area varied from 51 ± 31 Bq m⁻³ (Attock) to 59 ± 33 Bq m⁻³ (Jhelum). These values are higher than that of the world average value of 40 Bq m⁻³ (UNSCEAR, 2000). This may be due to the higher concentration of the radioactive elements

Fig. 1. Shaded portion of the map showing the studied area of four districts of the Punjab Province, Pakistan.
From the observed indoor radon levels, seasonal correction factor for drawing rooms, bedrooms and kitchens were calculated by dividing the mean for each cycle (i.e. winter, spring, autumn and summer), by the annual arithmetic mean. The results obtained are shown in Table 3. The mean seasonal correction factors were found to be 1.14 ± 1.10, 1.02 ± 0.89, 0.97 ± 0.70 and 0.87 ± 0.93 for winter, spring, autumn and summer seasons, respectively.

As may be seen in Table 3, the yearly average values in drawing rooms, bed rooms and kitchens of the districts Jhelum and Chakwal are 66 ± 37, 65 ± 34, 46 ± 29 and 64 ± 40, 61 ± 22, 44 ± 32, respectively. Whereas in the districts of Rawalpindi and Attock, yearly average values are 53 ± 26.
Bq m\(^{-3}\), 56 ± 31 Bq m\(^{-3}\), 47 ± 28 Bq m\(^{-3}\) and 54 ± 32 Bq m\(^{-3}\), 54 ± 30 Bq m\(^{-3}\), 44 ± 30 Bq m\(^{-3}\), in drawing rooms, bedrooms and kitchen, respectively. From the measured radon levels, mean radon concentrations have also been calculated and were found to be 59 ± 34 Bq m\(^{-3}\), 59 ± 29 Bq m\(^{-3}\) and 45 ± 30 Bq m\(^{-3}\) in drawing rooms, bedrooms and kitchen, respectively.

The frequency distribution of indoor radon concentration (Bq m\(^{-3}\)) for different seasons in the studied districts is shown in Figs. 2–4. As may be seen in these figures, indoor radon concentration range from 21–30 Bq m\(^{-3}\) were observed in 110 rooms (i.e. bedrooms, drawing rooms and kitchens) of the studied area. In 278 rooms, it ranged from 0–50 Bq m\(^{-3}\) whereas in 134 rooms, indoor radon concentration was in the range of 51–100 Bq m\(^{-3}\). In 62 rooms, indoor radon concentration ranged from 101–150 Bq m\(^{-3}\). In
21 rooms in winter season and 3 rooms in spring season, indoor radon concentration was in the range of 151–200 Bq m\(^{-3}\). In this range, no single value of indoor radon observed in autumn and summer seasons.

Correlation of the radon activity concentrations in winter versus spring, autumn and summer seasons for the rooms surveyed is shown in Fig. 5 whereas radon activity concentrations in drawing rooms versus bedrooms and kitchens of the 160 studied houses in summer and winter seasons is shown in Figs. 6 and 7.

From the measured indoor levels, annual effective dose for each district in each season has also been calculated and shown in Fig. 8. In this regard, occupancy factor = 80%, equilibrium factor = 0.4, and dose conversion factor = 9.0 \times 10^{-6} mSv Bq m\(^{-3}\) h\(^{-1}\) were used (UNSCEAR-2000). The calculated mean annual effective dose came out to be 1.39 ± 0.78 mSv.
DISCUSSION

CR-39 detectors were used for the measurement of indoor radon levels. Measurements were performed in four districts of the Punjab Province in different seasons. CR-39 based radon dosimeters were installed in bedrooms, drawing rooms and kitchens of the 160 randomly selected houses and were exposed to indoor radon in each season. Minimum and maximum measured indoor radon levels in dwellings are depicted in Table 1. The difference in the values of indoor radon levels may be due to the different ventilation conditions, the nature and type of building materials used in construction of houses and the variation of the radionuclides in the soil beneath the dwellings. However, these values are less than the lower limit of the action levels (200–600 Bq m$^{-3}$), recommended by the International Commission on radiological Protection (ICRP, 1993).21

As may be seen in Table 2, maximum overall average value of radon concentration ($62 \pm 34$ Bq m$^{-3}$) is observed during the winter season and minimum ($48 \pm 29$ Bq m$^{-3}$) is recorded during the summer season. This may partially be due to the fact that doors and windows of the dwellings remain closed most of the times in winter and remain open during other seasons.

Values of the seasonal/annual ratios of the indoor radon levels and yearly average radon concentration for different types of dwellings in four districts of the Punjab province are given in Table 3. Seasonal correction factor is seen to be higher in winter and lower in summer season. Although there are different average values of the indoor radon and seasonal correction factor for drawing rooms, bedroom and kitchens yet this difference is not statistically significant. The variations in yearly indoor radon levels may be explained as follows: Drawing rooms are used occasionally if and when guests/friends visit the dwellers. On the other hand bedrooms and kitchens are frequently used and are normally kept well ventilated. Therefore, drawing rooms have relatively higher indoor radon concentration levels.

As may be seen in Fig. 5, there is a strong correlation between winter, spring, autumn and summer seasons in region C. Residents of the houses in region C will always be exposed to higher radon concentration. Region A and B imply rich ventilation for one condition and poor ventilation for another condition. Region D implies rich ventilation for both conditions and region C implies poor ventilation for both conditions. Region C in Figs. 6 and 7 implies poor ventilation as compared to the other regions. Dwellers of this region will always be exposed to higher radon levels. Small number of dots in region B and D (see, Figs. 6 and 7) indicate those bedrooms and kitchens wherein ventilation poor and radon concentration is higher than 20 Bq m$^{-3}$. In winter (see, Fig. 7), points show higher indoor radon concentration in region A, B and C. In Fig. 6, points are distributed homogeneously as compared to that in Fig. 7. The difference of correlation pattern between Fig. 6 and Fig. 7 may be due to the seasonal difference and the reason is not clear.

The annual effective dose in different seasons (see, Fig. 8a) is found to be higher in winter and lower in summer season. For clarity, district wise annual effective dose in decreasing order is shown in Fig. 8b.

CONCLUSION

It has been observed that District Jhelum has relatively higher indoor radon levels as compared to the other districts. Overall arithmetic mean of the present survey ($55 \pm 31$ Bq m$^{-3}$) is higher than the world average values of the indoor radon levels ($40$ Bq m$^{-3}$). Nevertheless, present values are lower than the recommended action levels (200–400 Bq m$^{-3}$). Maximum value of the indoor radon concentration is observed during the winter whereas minimum concentration value has been observed in the summer season. The maximum values were found in drawing rooms and minimum values were found in kitchens. The annual effective dose in the study area is less than even the lower limit of the recommended action level (3–10 mSv).

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