Chapter Five

RADON EXHALATION RATE FROM SAND & SOIL – A CASE STUDY

5.1 Introduction

Exhalation of ^{222}Rn, α–radioactive inert gas, is associated with the presence of ^{226}Ra and its ultimate precursor uranium in the earth's crust. Although these elements occur in virtually all types of rocks and soils, their concentration varies with specific sites and geological materials. The half life ($\tau_{1/2}$) of ^{222}Rn is 3.82 days. Being a noble gas ^{222}Rn can move large distances through rocks and soils. Radon is both a hazard and a help (Matiullah, 2000). The possibilities of transport of ^{222}Rn within the earth, its waters, and the atmosphere make it a useful tracer for a remarkable variety of geophysical, geochemical, hydrological, and atmospheric purposes (Matiullah et al., 1991). These applications include exploration of resources such as uranium and hydrocarbon deposits (IAEA Tec. Doc. Series No. 186, 1979), studying gas flow and mixing in the atmosphere, recognizing fluid transport within the earth, attempting to predict seismic and volcanic events through premonitory changes in radon concentrations in the earth. These desirable functions of radon are countered by destructive health effects. Sustained exposure of humans to substantial concentrations of radon decay products may produce lung cancer. Radon measurements play a critical role in monitoring human health and safety, both in homes and mines. It is estimated that 50–55% of the average annual dose from natural background radiation is contributed by ^{222}Rn alone (Matiullah et al., 1991)

Health effects of ^{222}Rn and its decay products have been a cause of concern since these isotopes may reach quite high levels in buildings either due to lack of adequate ventilation or by containing strong sources of radon. This has led to numerous studies on the sources and the methods of transport of ^{222}Rn (Kerry, 1982; Keller and Folkerts, 1984; Nazaroff and Nero, 1988). Recently, we have carried out indoor radon survey in seven major cities of the Bahawalpur Division. According to this study, annual average radon concentration was found to be 31 Bq.m^{-3}. This value is slightly higher then the reported global average indoor radon concentration level of 27.2 Bq.m^{-3} for an occupancy factor of 0.8 (Ahmed et al., 1998).

The main sources of indoor radon are the underlying soil, building material and tap water if it is supplied from groundwater in radium–bearing aquifers. However several studies on the exhalation rate of ^{222}Rn from building materials and tap water show that these two sources normally contribute only a small fraction of the total amount of measured ^{222}Rn. Hence the primary source of radon is usually the underlying soil (Kerry, 1982). The presence of ^{226}Ra in building materials is the foremost of the secondary sources and, in some cases, may even dominate. To gain a better insight into the relative contribution of these two sources in Bahawalpur Division and some major cities of NWFP, radon exhalation rate from soil and sand has been studied using CR-39 based NRPB radon dosimeters and presented in this Chapter.

5.2 Theme of the study

Ever since man started living in houses, soil has been the main part of the building materials. It is used as the base material in the form of mud for fixing and holding the bricks in walls and in making the roofs of dwellings. The bricks are also made of soil and are baked in kilns. Mud houses contribute about 60–70% of the built-up area in the rural areas and 20–30% in the urban areas in Pakistan. For the construction of mud houses, usually soil is taken from the vicinity of the construction sites. After the soil, sand is the next important construction material. It is normally mixed with cement and is used for the construction of cemented houses. The volume of sand is usually three to eight times of cement in a sand-cement mixture. Therefore, determination of radon exhalation rate from these materials will be of great help to construction companies in reducing the risk from exposure to radon and its progeny. The main objective of this work is to modify the existing model used for determination of the radon exhalation rate from the samples placed in a closed system. Using the modified model, we then determine exhalation rate from the most commonly used building materials namely soil and sand.

5.3 Theory

In mineral grains, ^{226}Ra decays to ^{222}Rn by emitting an α–particle. Before entering the pore spaces and being available for transport to the indoor environment, ^{222}Rn has to escape from the grain (Semkow, 1990). Most of the radon produced remains within the grain and only a small fraction of it escapes to the pore spaces. This escaped fraction of radon to the pore spaces is called emanation coefficient. Radon emanation depends on ^{226}Ra distribution and its concentration in the grain, grain size, water contents in pore spaces, porosity, etc. (Sasaki et al., 2004; Duenas et al., 1997). The reported emanation coefficient ranges from 0.05 to 0.7 for different materials (e.g. for sand its value ranges from 0.15 to 0.3 (Durrani and Ilic, 1997)). Only a fraction of the atoms produced by emanation will reach the surface of the soil: this is known as exhalation. Diffusion and convection are responsible for the transport of radon in any medium. Radon transport in porous materials can be described by the following multiphase time dependent radon diffusion equation.

$$\beta\frac{\partial C_a}{\partial t} = D_b\nabla^2 C_a + \frac{K\ \nabla P(x,y,z)\nabla C_a}{\mu} - \beta\lambda C_a + R\rho_b\lambda E \qquad (5.1)$$

With $\beta = (1 - m + Lm)\varepsilon + \rho_b k_a$

$D_b = \beta D_e$

$L = C_w/C_a$

$k_a = C_s/C_a$

$P(x,y,z) = \mathrm{P(x,y,z)} - P_A(z)$

$P_A(z) = P_{atm} - \rho_a gZ$

Where

β = Partition corrected porosity

ε = Total porosity (Volume fraction of the medium occupied by pores)

m = Volume fraction of pores occupied by water. ($\varepsilon_w / \varepsilon$)

L = Ostwald coefficient or solubility coefficient.

k_a = Surface adsorption coefficient.

C_s = ^{222}Rn concentration in solid phase. (Bq.kg^{-1})

C_w = ^{222}Rn concentration in water phase (Bq.m^{-3})

C_a = ^{222}Rn concentration in air phase (Bq.m^{-3})

D_b =Bulk diffusion coefficient. It relates the interstitial concentration of ^{222}Rn to the flux density across a geometric area (m^2.s^{-1}).

D_e =Effective diffusion coefficient. It relates the interstitial concentration of ^{222}Rn to the flux density across the pore area.

K = Intrinsic permeability (m^2)

μ = Dynamic viscosity of air (Pa.s)

$P(x,y,z)$ = Pressure disturbance field at a given location in the soil. (Pa)

$P(x,y,z)$ = Absolute pressure at the point.

$P_A(z)$ = Aerostatic pressure at the depth 'Z'.

P_{atm} = Absolute pressure at the atmospheric surface ($Z = 0$)

g = gravitational acceleration (m.s^{-2})

ρ_a = The soil gas density (kg.m^{-3})

λ = ^{222}Rn decay constant (s^{-1})

ρ_b = Bulk density of the ore sample (kg.m^{-3})

E =Sum of fractional emanation coefficients of ^{222}Rn in air, water and adsorbed phase. ($E_{air} + E_{water} + E_{solid}$)

R = Concentration of ^{226}Ra (Bq.kg^{-1})

In the present study, we have used a hermetically sealed chamber. Therefore, pressure disturbance field remains constant. Consequently, the convective transport term in Eq. (5.1) may be neglected. Moreover, $m = 0$ for dried samples, considering ^{222}Rn diffusion only in Z-direction under the present close chamber case and assuming negligible adsorption of ^{222}Rn on solid surfaces (i.e. $k_a = 0$), $\beta = \varepsilon$, the above equation reduces to the following form.

$$D_e \frac{\partial^2 C_a}{\partial z^2} - \lambda C_a + \frac{R\rho_b \lambda E}{\varepsilon} = 0 \tag{5.2}$$

Eq. (5.2) is a 2nd order inhomogeneous partial differential equation. The general solution of this equation is

$$C_a(Z) = A\sinh\left(\frac{Z}{l_0}\right) + B\cosh\left(\frac{Z}{l_0}\right) + \frac{S}{\lambda} \tag{5.3}$$

Where

$$S = \frac{R\rho_b \lambda E}{\varepsilon} \quad \text{and} \quad l_0 = \sqrt{\frac{D_e}{\lambda}} \text{ is the diffusion length.}$$

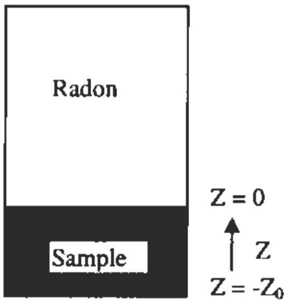
For boundary conditions $C_a(0) = C$ and $\frac{\partial}{\partial z}C_a(z)|_{z=-z_0} = 0$, constants A and B in Eq. (5.3) comes out to be as follows:

$$A = \left(C - \frac{S}{\lambda}\right)\tanh\phi \tag{5.4}$$

$$B = C - \frac{S}{\lambda} \tag{5.5}$$

Where

$$\phi = \frac{Z_0}{l_0}$$



Z_0 = Thickness of the sample in sealed chamber.

C = ^{222}Rn concentration just on the surface of the sample which has to be exhaled from the surface of the sample to void space of the chamber.

Diffusion length (l_0) of radon through dry porous soil is very large (1.55 m) as compared to the thickness ($Z_0 = 2cm$) of the sample, $\phi \to 0$, therefore, $\lim_{\phi \to 0} \tanh\phi = \phi$

Eq. (5.4) then reduces to:

$$A = \frac{Z_0}{l_0}\left(C - \frac{S}{\lambda}\right) \tag{5.6}$$

Substituting Eqs. (5.5) and (5.6) in Eq. (5.3) we get

$$C_a(Z) = \frac{Z_0}{l_0}\left(C - \frac{S}{\lambda}\right)\sinh\left(\frac{Z}{l_0}\right) + \left(C - \frac{S}{\lambda}\right)\cosh\left(\frac{Z}{l_0}\right) + \frac{S}{\lambda} \tag{5.7}$$

Eq. (5.7) gives pore air ^{222}Rn concentration at any depth (Z) in the sample. The exhalation of ^{222}Rn from the surface of the sample start at $Z = 0$. The exhalation rate of ^{222}Rn per geometric surface area, for one-dimensional case is given by

$$F = -D_b \frac{\partial C_a}{\partial z} \tag{5.8}$$

Differentiating Eq. (5.7) with respect to Z and substituting it in Eq. (5.8) we get

$$F = \frac{D_b}{l_0}\left[\frac{Z_0}{l_0}\left(\frac{S}{\lambda} - C\right)\cosh\left(\frac{Z}{l_0}\right) + \left(\frac{S}{\lambda} - C\right)\sinh\left(\frac{Z}{l_0}\right)\right] \tag{5.9}$$

As mentioned above, ^{222}Rn starts exhaling from the surface of the sample i.e. at $Z = 0$, Eq. (5.9) reduces to

$$F = \frac{D_b Z_0}{l_0^2}\left(\frac{S}{\lambda} - C\right) = \frac{Z_0 D_b S}{l_0^2 \lambda} - \frac{Z_0 D_b C}{l_0^2} \tag{5.10}$$

Since $D_b = D_e \varepsilon = l_0^2 \lambda \varepsilon$ and $S = \dfrac{R\rho_b \lambda E}{\varepsilon}$

$$F = R\rho_b \lambda E Z_0 - \varepsilon \lambda Z_0 C$$

$$F = F_0 - \omega C \tag{5.11}$$

Where

$$F_0 = R\rho_b \lambda E Z_0 \tag{5.12}$$

$\omega = \varepsilon \lambda Z_0$, Known as back diffusion constant for given material

In a closed chamber, which contains a sample, ^{222}Rn concentration increases with the passage of time from zero to its maximum value. However, after reaching its maximum value, back diffusion of radon also take place, which reduces the ^{222}Rn concentration by a factor ω in the chamber.

Concentration of ^{222}Rn at any time t in void space of the chamber depends on its source and sink. The natural decay of ^{222}Rn and its back diffusion are the only processes responsible for the removal of ^{222}Rn from the chamber volume. The ^{222}Rn concentration at any time t in void space of the chamber may therefore be estimated by the following differential equation.

$$\frac{dC(t)}{dt}=\frac{F_0A}{V}-\left(\frac{\omega A}{V}+\lambda\right)C(t) \qquad \textbf{\textit{(5.13)}}$$

Applying the initial condition $C = 0$, at $t = 0$, solution of the Eq. (5.13) is as follow

$$C(t)=\frac{F_0A}{\omega A+\lambda V}\left[1-e^{-\left(\frac{\omega A}{V}+\lambda\right)t}\right] \qquad \textbf{\textit{(5.14)}}$$

After rearrangement, Eq. (5.14) may be written as

$$F_0=\frac{C(t)[\omega A+\lambda V]}{A\left[1-e^{-\left(\frac{\omega A}{V}+\lambda\right)t}\right]} \qquad \textbf{\textit{(5.15)}}$$

Where

A = Surface area of the sample (m^2)

V = volume of the void space in a closed chamber (m^3).

T = ^{222}Rn accumulation time in a closed chamber.

All the quantities on the right hand side of Eq. (5.15) are known except $C(t)$. We have experimentally determined the value of $C(t)$ using CR-39 based NRPB radon dosimeter. Putting the value of $C(t)$ in Eq. (5.15), exhalation rate, F_o was determined. The exhalation rate F, corrected for back diffusion, was determined using Eq (5.11). From exhalation rate, ^{222}Ra concentration was determined using Eq. (5.12).

5.4 Experimental Procedures

5.4.1 Setup for CR-39 Detectors

The main objective of this study was to develop a model by solving the multi-phase radon transport equation for a sample placed in a closed system. After applying boundary conditions, an expression/Mathematical Model for exhalation rate along with back diffusion term was obtained. Applying this model, radon exhalation rate from the soil and sand samples collected from towns of the Bahawalpur Division (Punjab) and some major cities of the North West Frontier Province (NWFP) was determined.

For sample collections, Bahawalpur Division was divided into eight regions. One town was chosen from each region. For convenience, we selected towns that are situated on the road running from north to south throughout the division. These included Minchinabad, Fort Abbas, Hasilpur, Bahawalpur, Liaqatpur, Rahimyar Khan and Sadiqabad. This strip of population is bounded between river on one side and desert on the other side. The remaining station, Derawar Fort, is in the Cholistan desert. Similarly, for the sake of convenience, samples were collected from major cities of NWFP, namely, Peshawar, Mardan, Nowshera and D.I. Khan. Both soil and sand samples (15 each) were collected from each town/city under study. The soil samples were taken in such a way that, first; top 5 cm surface layer was removed and then samples were taken. The sand samples were collected from construction sites and local suppliers in the cities concerned. It must be borne in mind that main sources of sand in almost all the areas understudy are various rivers and streams including river Kabul, river Sawat, Kalpani stream and river Indus. Therefore some samples were also taken directly from streams and rivers around the cities understudy.

All the samples were crushed, dried in oven at 110 °C and their bulk densities were determined. All the samples had nearly same densities (i.e. 1.75 $g.cm^{-3}$). These samples (each weighing 0.5 kg) were then put into plastic containers of volume 5.4×10^3 cm^3. Each sample made 2 cm thick layer having surface area 143 cm^2 in the container. After installing the CR-39 based NRPB radon dosimeters at a distance of 25 cm from the surface of the samples, the containers were hermetically sealed. The dosimeters were exposed to radon for three weeks. During this time period, about 98% of equilibrium level is reached between ^{226}Ra and ^{222}Rn. This resulted in exposure of the dosimeters to variable levels of radon concentration (i.e. starting from zero concentration level to equilibrium concentration level). Therefore effective exposure time of the NRPB dosimeters to radon was calculated using the following relation.

$$T_{effective} = t - \tau\left(1 - e^{-\lambda t}\right) \qquad (5.16)$$

Where
τ = Mean life of radon (5.5 days)
t = total exposure length (days)
λ = ^{222}Rn decay constant

It may please be noted here that this type of correction is needed only for closed system (Durrani and Ilic, 1997). The effective time calculated from Eq. (5.16) was ~ 365 h. After the exposure, CR-39 detectors were etched in 25% NaOH at 80 °C for 16 h and counted under an optical microscope. The track densities were related to the radon concentration level using calibration factor of 2.7 Tracks.cm^{-2}.h^{-1}/kBq.m^{-3} (Miles, 2005).

5.4.2 Set-up for HPGe based Gamma spectrometry

Oven dried samples, weighing 200 g each, were packed in plastic bottles and then hermetically sealed. In order to establish equilibrium between ^{222}Rn and ^{226}Ra, the samples were stored for ~30 days (~8 $\tau_{1/2}$ of ^{222}Rn). Each sample was then counted for 10,000 seconds using coaxial HPGe detector having active volume of 180 cm^3. The detector's relative efficiency and energy resolution at 1.33 MeV (^{60}Co) was 30% and 2.0 keV respectively. The software Canberra Genie-2000 was used for the evaluation of the spectra. The detector was calibrated with reference material, namely, soil-375, which was provided by the International Atomic Energy Agency (IAEA). The specific activity of ^{226}Ra was determined using the gamma energy 609.3 keV (yield 46.1%) of ^{214}Bi (assuming equilibrium). The Lower Level of Detection (LLD) at 609.3 keV was 5 Bq.kg^{-1}.

5.5 Results and discussion

5.5.1 ^{222}Rn exhalation rate and ^{226}Ra contents using CR-39 detector

As mentioned earlier, radon exposed CR-39 detectors were etched in 25% NaOH at 80 °C for 16 h and counted under an optical microscope. From the measured track densities, ^{222}Rn concentrations (C) in the plastic containers were determined using the calibration factor 2.7 Tracks.cm^{-2}.h^{-1}/kBq.m^{-3} (Miles, 2005). Having determined the ^{222}Rn concentrations, its exhalation rate from sample surface was calculated using Eqs. (5.15) and (5.11). ^{226}Ra contents in each sample were calculated using Eq. (5.12). The results obtained are shown in Table 5.1 to Table 5.4.

Comparing the radon exhalation rates in soil and sand samples, it may be seen in Tables 5.1–5.4 that the primary source of the indoor radon in Bahawalpur division is sand. In NWFP, the primary source of indoor radon is the soil. Maximum and minimum values of ^{222}Rn exhalation rates for soil samples of the Bahawalpur Division were found to be 3.33 Bq.m^{-2}.h^{-1} in Liaqatpur and 1.56 Bq.m^{-2}.h^{-1} in Derawer Fort. In NWFP, maximum and minimum values of ^{222}Rn exhalation rates for soil samples were found to be 4.66 Bq.m^{-2}.h^{-1} in D.I. Khan and 2.49 Bq.m^{-2}.h^{-1} in Peshawar & Nowshera. The ^{222}Rn exhalation rate from the sand samples ranged from 2.78 Bq.m^{-2}.h^{-1}, in Sadiqabad, to 20.81 Bq.m^{-2}.h^{-1}, in Derawer Fort. In NWFP its value ranged from 0.997 Bq.m^{-2}.h^{-1}, in D.I. Khan, to 4.2 Bq.m^{-2}.h^{-1}, in Peshawar.

Specific activity of ^{226}Ra was calculated in the soil samples, which ranged from 28 to 36.5 Bq.kg^{-1} in Derawar Fort and Minchinabad of the Bahawalpur Division, respectively. In NWFP, minimum/maximum values ranged from 40.9 to 51.9 Bq.kg^{-1}, in Peshawar and D.I. Khan, respectively. In sand samples radium activity ranged from 49.2–215 Bq.kg^{-1}, in Sadiqabad and Derawer Fort, respectively. In NWFP, radium activity ranged from 22.6 to 27.0 Bq.kg^{-1}, in D.I. Khan and Peshawar respectively.

Table 5.1: Minimum and maximum values of ^{222}Rn exhalation rate and radium activity in the soil samples collected from the Bahawalpur Division

Town	Exhalation rate F (Bq.m^{-2}.h^{-1})			Average activity of ^{226}Ra (Bq.kg^{-1})
	Minimum	Maximum	Arithmetic mean	
Minchin Abad	2.15	3.28	2.84±0.15	36.5±1.8
Fort Abbas	1.95	2.75	2.33±0.13	29.9±1.4
Hasilpur	1.83	3.05	2.41±0.14	30.9±1.5
Bahawalpur	2.47	2.93	2.73±0.16	35.1±1.6
Derawer Fort	1.56	2.82	2.18±0.15	28±1.2
Liaqatpur	2.28	3.33	2.80±0.18	36±1.4
Rahimyarkhan	1.89	2.98	2.46±0.15	31.6±1.4
Sadiqabad	2.38	2.96	2.66±0.15	34.2±1.6

Table 5.2: Minimum and maximum values of ^{222}Rn exhalation rate and radium activity in the soil samples collected from the listed cities of NWFP

City	Exhalation rate F (Bq.m^{-2}.h^{-1})			Average activity of ^{226}Ra (Bq.kg^{-1})
	Minimum	Maximum	Arithmetic mean	
Peshawar	2.49	4.00	3.19±0.17	40.9±2
Mardan	2.62	4.37	3.37±0.22	43.3±2
Nowshehra	2.49	4.30	3.55±0.20	45.6±2.4
D.I.Khan	3.55	4.66	4.04±0.28	51.9±2.5

Table 5.3: Minimum and maximum values of ^{222}Rn exhalation rate and radium activity in the sand samples of the Bahawalpur Division

Town	Exhalation rate F (Bq.m^{-2}.h^{-1})			Average activity of ^{226}Ra (Bq.kg^{-1})
	Minimum	Maximum	Arithmetic mean	
Minchin Abad	5.18	7.43	6.29±0.35	80.7±3.6
Fort Abbas	6.67	8.85	7.74±0.48	99.3±4
Hasilpur	6.89	9.97	8.41±0.47	108±5.4
Bahawalpur	6.36	8.52	7.88±0.40	101±4.2
Derawer Fort	12.67	20.81	16.7±1.10	215±11.6
Liaqatpur	13.96	17.46	15.7±0.92	202±9.5
Rahimyarkhan	5.45	9.28	7.35±0.51	94.3±4.4
Sadiqabad	2.78	4.96	3.85±0.21	49.4±2.6

Table 5.4: Minimum and maximum values of ^{222}Rn exhalation rate and radium activity in the sand samples collected from the listed cities of NWFP

City	Exhalation rate F (Bq.m^{-2}.h^{-1})			Average activity of ^{226}Ra (Bq.kg^{-1})
	Minimum	Maximum	Arithmetic mean	
Peshawar	1.08	4.2	2.10±0.12	27.0±1.3
Mardan	1.01	2.98	1.89±0.11	24.3±1.4
Nowshehra	1.49	2.52	1.80±0.09	23.1±1.2
D.I. Khan	0.997	2.52	1.76±0.10	22.6±1.1

5.5.2 Determination of ^{226}Ra contents Using HPGe detector

Here specific activity of ^{226}Ra (C_{Ra}) in each soil and sand sample was determined using the gamma ray peak of ^{214}Bi (609.3 keV, yield 46.1%). From the measured specific activity of ^{214}Bi, ^{226}Ra contents were calculated assuming secular equilibrium between ^{214}Bi and ^{226}Ra. The results obtained are shown in Table 5.5–5.8 these results are close to those shown in Table 5.1–5.4 within experimental errors.

By comparing the values of ^{226}Ra activity, determined with CR-39 based NRPB dosimeters and HPGe in Tables 5.1–5.8 it is clear that results obtained are in good agreement within experimental errors. This study has revealed that radon exhalation rate from the sand of the Bahawalpur Division, is relatively much higher than from its soil. Unlike the Bahawalpur Division, radon exhalation rate from the sand of the major cities of NWFP is relatively much lower than from its soil. Comparing the radon exhalation rate from the samples under study, it is found that sand of the Bahawalpur Division shows higher exhalation rate than that of NWFP sand. On the other hand soil of NWFP shows relatively higher exhalation rate than that of Bahawalpur Division. This factor should be taken into account while constructing new houses in these areas. For example, to reduce indoor radon levels, besides taking other remedial actions the people of the Bahawalpur Division may like to bring sand from NWFP or some other place for construction purposes.

Table 5.5: Measured average ^{226}Ra activity in the soil samples collected from the listed towns of the Bahawalpur Division

Town	Average activity of ^{226}Ra (Bq.kg^{-1})	Town	Average activity of ^{226}Ra (Bq.kg^{-1})
Minchin Abad	39.23±1.6	Derawer Fort	30.12±1.1
Fort Abbas	30.54±0.9	Liaqatpur	37.08±1.7
Hasilpur	31.76±1.6	Rahimyar Khan	35.08±1.5
Bahawalpur	33.45±1	Sadiqabad	32.18±1.2

Table 5.6: Measured average ^{226}Ra activity in the sand samples collected from the listed towns of the Bahawalpur Division

Town	Average activity of ^{226}Ra (Bq.kg^{-1})	Town	Average activity of ^{226}Ra (Bq.kg^{-1})
Minchin Abad	87.58±3	Derawer Fort	195.05±9.6
Fort Abbas	94.73±3.5	Liaqatpur	208.68±9.7
Hasilpur	115.3±4.9	Rahimyar khan	96.85±4.6
Bahawalpur	113.12±5.1	Sadiqabad	53.55±2

Table 5.7: Measured average ^{226}Ra activity in the soil samples collected from the listed cities of NWFP

City	Average activity of ^{226}Ra (Bq.kg^{-1})
Peshawar	38.36±1.5
Mardan	44.08±2.3
Nowshehra	49.75±1.8
D.I.Khan	58.13±2.6

Table 5.8: Measured average ^{226}Ra activity in the sand samples collected from the listed cities of NWFP.

City	Average activity of ^{226}Ra (Bq.kg^{-1})
Peshawar	27.65±1.1
Mardan	25.88±1.2
Nowshehra	24.19±1.2
D.I. Khan	22.91±0.8

5.6 Conclusion.

To conclude, a mathematical model has been developed and successfully applied to determine the radon exhalation rate from the soil/sand samples collected from the Bahawalpur Division and NWFP. Relatively higher radon exhalation rate is found from the soil of NWFP and sand of the Bahawalpur Division. This factor should be taken into account while constructing new houses in theses areas. To reduce indoor radon levels in new houses to be constructed, besides taking other remedial actions the people of the Bahawalpur Division may like to bring sand from NWFP or some other place for construction purposes whereas NWFP people should take precautionary measures to avoid the inflow of radon into the houses.

5.7 References

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