Chapter Four

MEASUREMENT OF RADIOACTIVITY – A CASE STUDY

4.1 Introduction

Over the last few decades there has been increased concern about public exposures associated with the enhanced natural radiation environment. The sources of environmental activity include cosmic rays, cosmogenic radionuclides, primordial radionuclides, nuclear facilities, nuclear fallouts, etc. The most commonly encountered primordial radionuclides are ^{238}U, ^{232}Th, their decay products and ^{40}K. The presence of these three naturally occurring radionuclides in soils, rocks and building materials result in external and internal exposure to human being. External exposure is caused by the gamma activity of radionuclides in the ground and construction materials, whereas internal exposure results from the inhalation and ingestion of naturally occurring radionuclides in air and diet.

The main source of inventory of radionuclides into the food cycle is ^{137}Cs. Its presence in soil would clearly indicate that the area under study might have received some fallout radioactivity in the past. It is very difficult rather impossible to exactly pin point the sources of contamination. The presence of ^{137}Cs in the soil of Bahawalpur division is considered to be due to nuclear tests conducted by neighboring countries in the past; however, some residual amount may have been due to Chernobyl accident fallout.

Another important source of internal exposure is the α–radioactive noble gas ^{222}Rn, which is the sixth daughter in the decay chain originating from ^{238}U. Being a noble gas and having relatively long half life (3.82 days), radon can easily manage to enter the environment in which we breathe. It is estimated that the average worldwide annual effective dose equivalent from natural sources of radiation, in areas of normal background, is 2.4 mSv, of which 1.275 mSv is contributed by radon (UNSCEAR, 1993).

This chapter is based on our published work (Matiullah et al., 2003; 2004) which deals with the measurement of indoor radon levels and natural radioactivity in the Bahawalpure Division. It may please be noted here that soil is the major part of the building materials used in 60–70% houses of the built-up area in the rural areas and 20–30% in the urban areas in Pakistan.

4.2 Area under study

Bahawalpure is one of the southeastern divisions of Punjab province, Pakistan. It is also the largest division of the province. It comprises three districts namely Bahawalnagar, Bahawalpur and Rahimyar Khan. The division is situated between 27°40'–30°22' North latitudes and 60°45'–73°58' East longitudes. The location of Bahawalpur Division has been shown on the map of Pakistan in Fig. 4.1. It shares its borders with India to the east. The area of the Bahawalpur division is 45588 km^2.

The land of Bahawalpur division may be divided into three main categories according to their physical characteristics. (a) The riverside area (b) Canal irrigated area (c) Desert area including Cholistan and Thar Deserts. The riverside area is situated close to the southern side of the Indus River. The canal-irrigated area is on the south and the Cholistan desert is in the south of irrigated tract up to the indo-Pak border. The surface of the border consists of a succession of sand dunes rising at places to a height of 150 meters and covered with vegetation peculiar to sandy tracts. The land of desert is dark yellowish brown loamy sands/loamy very fine sand with massive to very weak structure, excessively drained. This land is non-saline, non-alkali without mottles. Overlying the sand in many areas is found a deposit of amorphous gypsum from three to six feet thick. The land of irrigated areas is dark yellowish brown to dark brown loams/clay loams homogenized to more than 150 cm with weak to moderate structure (Din, 1970).

For convenience, we selected those towns, which were situated on the road running from north to south throughout the division. These were Minchinabad, Fort Abbas, Hasilpur, Bahawalpur, Liaqatpur, Rahimyar Khan and Sadiqabad. This strip of population is bounded between river on one side and desert area on the other side. All this area is irrigated by canals. The land of this area consists of stiff clay mixed with sand. The remaining station Derawar Fort is in the Cholistan Desert. The sand content in most of the samples is greater due to the neighboring desert. The longitude, latitude, altitude and population of the sampling towns are given in Table 4.1.

The overall climate of the Bahawalpur Division remains hot and dry from March to October. Amongst these cities, the climate of Rahimyar Khan and Sadiq

Abad is relatively humid especially in July and August. The average temperature in summer ranges from 30 °C to 35 °C and in winter, it is 10 °C to 15 °C. In June and July the temperature increases to 48 °C, which results in dust storm. The average rainfall in a year is 10 to 25 cm because Bahawalpur Division is at the tail of the monsoon.

Table 4.1: Details of the cities included in this study

Name of the city	Population (approx.)	Latitude	Longitude	Altitude (approx.) (ft)
Minchin Abad	42,000	30.00 N	73.40 E	535
Fort Abbas	40,000	29.19 N	72.85 E	475
Hasilpur	88,000	29.71 N	72.55 E	462
Bahawalpur	450,000	29.39 N	71.67 E	380
Derawer Fort	-	28.56 N	71.36 E	400
Liaqatpur	35,000	30.36 N	68.60 E	317
Rahimyar khan	260,000	28.42 N	70.30 E	273
Sadiqabad	156,800	28.30 N	70.13 E	250

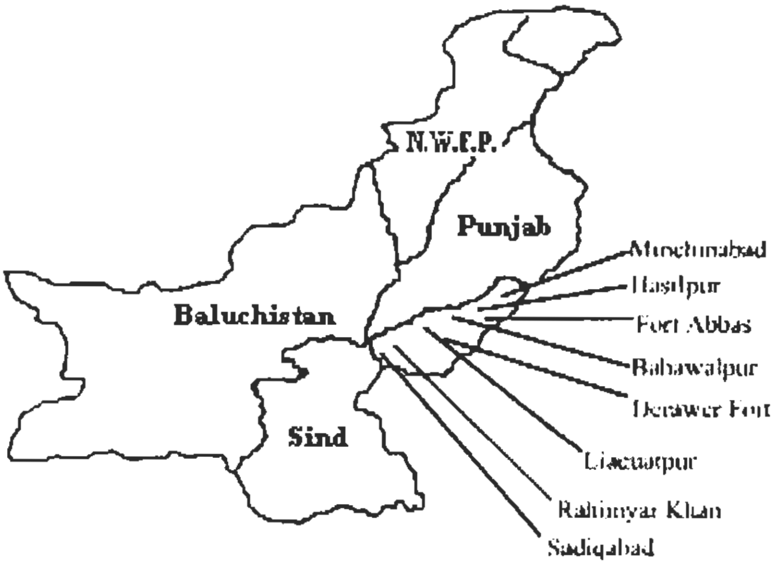

Figure 4.1: *Map of Pakistan showing the cities in Bahawalpur Division selected for soil activity measurements and indoor radon survey.*

4.3 Experimental Procedures

4.3.1 Set-up for determination of activity in soil samples

It is a well known fact that the ^{137}Cs activity decreases linearly with increasing soil depth (Clouvas et al., 2001). Therefore, after removing the organic matter, soil samples were taken from the superficial layer of the earth from the selected five sites of each town. The samples were dried in oven at 110 °C for 24 hours. After drying the samples were ground, homogenized, and screened with a sieve of about 1mm mesh. All the samples, weighing 200 gm each, were then packed in radon impermeable plastic containers. The geometrical dimensions of these samples were kept the same as that of the reference material (soil-375 from IAEA). In order to establish equilibrium between ^{222}Rn and ^{226}Ra, ^{228}Ra and its daughters, the samples were stored for ~ 60 days. Each sample was then counted for 65000 seconds using coaxial HPGe detector having active volume of 180 cm^3. This system consists of an HPGe coaxial detector of 30% efficiency relative to NaI (Tl) scintillator. The measured resolution of the HPGe detector was 2.0 keV at 1.33 MeV full-energy peak of ^{60}Co and peak to Compton ratio was 54:1. The lower limit of detection (LLD) for ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs were determined from the background radiation level for the above counting time using the following relation:

$$LLD = \frac{\sqrt{background + continuum}}{t \times \% yield \times efficiency} \tag{4.1}$$

These values were found to be 2.6 Bq kg^{-1}, 4.15 Bq kg^{-1}, 7.0 Bq kg^{-1} and 1.25 Bq kg^{-1} for ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs respectively with 95% confidence level. The activity levels of ^{232}Th and ^{226}Ra present in the samples were computed using gamma peak 338.4 keV (12%) of ^{228}Ac and 609.3 keV (46.1%) of ^{214}Bi respectively (assuming secular equilibrium). For ^{40}K and ^{137}Cs the peaks of 1460.75 keV (10.7%) and 661.62 keV (84.62%) were used respectively. The software Canberra Genie-2000 was used for the evaluation of the spectra. The expression for the calculation of the activity is given below:

$$Activity = \frac{Counts}{t \times \% yield \times efficiency} \tag{4.2}$$

4.3.2 Set-up for radon survey in dwellings

In this work, CR-39 detectors were used. In this context, large sheets of CR-39 having 500 μm thicknesses, supplied by Page Mouldings, Ltd., UK, were cut into small pieces of size 2 cm × 2 cm. Three CR-39 detectors were put into perforated polyethylene bags of size 3cm x 3cm. The bags were then thermally sealed. Thickness of the polyethylene bags used was ~ 55 μm which is greater than the α-particle range in polyethylene. Therefore, the detectors inside the bags were not sensitive to α-particles from the outside of the polyethylene bags. These dosimeters were similar to those reported in the literature (Matiullah et al., 1993; Ahmed et al., 1997). Two dosimeters were installed at each measurement point. The survey was carried out over a year. Four measurements, each corresponding to three months exposure, were collected from each measurement point and were then averaged out.

In order to select houses for this survey, we approached the dwellers through their school-registered children. Many dwellers thought that perhaps CR-39 detectors were spying equipment like camera and that their privacy would be at stake. Therefore, they refused to participate in the survey. Nevertheless, about 70% parents of the school children responded positively. Even after having the consent of the dwellers for allowing us to install the detector, it was not possible for us to install the detectors in all these houses due to several constraints. Therefore we had to short-list the number of houses. Great care was taken in this short listing process. Only those 100 houses were chosen in each city that were relatively the best representatives of the built-up area. The houses selected in each city were then divided into five categories according to the house locations and building characteristics.

In each house, dosimeters were installed in living rooms, bedrooms and kitchens. A total of 600 dosimeters were installed in each city for one measurement. Out of 200 installed dosimeters per city in kitchens, 60 were recovered from Bahawalpur, and 80, 70, 110, 90, 115, 127 were recovered from Rahimyar Khan, Sadiq Abad, Hasilpur, Liaqatpur, Fort Abbas and Minchin Abad respectively. That is, more than 50% of dosimeters installed in kitchens were not recovered because of the mishandling and carelessness of the inhabitants. Therefore, the data concerning radon levels in kitchen is not presented here.

Initially, it was planned to install dosimeters in bedrooms, living rooms, kitchens and stores (a room anywhere in a house, which is used for storage of excess/rarely used household things and is usually kept closed) of the houses. However, the house construction trend in Bahawalpur division is such that stores are usually not constructed as a separate entity in the houses and therefore, a majority of the houses do not have stores. So to keep uniformity, the data concerning radon concentration levels in stores have also not been presented here. It may please be noted here that houses that had stores yielded higher radon levels in stores due to the poor ventilation.

Two thousand eight hundred (2800) dosimeters were installed in the living rooms and bedrooms in the selected houses per season. Out of these installed detectors, 2478, 2368, 2163 and 2625 were successfully recovered in spring, summer, autumn and winter seasons respectively. Excluding the dosimeters installed in the kitchen, 1600 dosimeters per year in each city were installed in bedrooms and living rooms of the houses. Out of which 1334 were collected back from Bahawalpur. Similarly 1267, 1470, 1307, 1473, 1409, 1374 dosimeters were collected back from the cities of Rahimyar Khan, Sadiq Abad, Fort Abbas, Minchin Abad, Hasilpur and Liaqatpur respectively.

After collecting the dosimeters, all the detectors were etched for 4 h in 6 N NaOH at 70 °C and were then counted under an optical microscope. The measured track densities were related to activity (Bq.m^{-3}) using the calibration factor 0.344 tracks per cm^{2} per day = 1 Bq.m^{-3} (Khan et al., 1990).

4.4 Results and Discussion

4.4.1 Activity in soil samples

Table 4.2 shows mean activity levels of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs measured in the soil samples collected from the towns under the present study. It can be seen in this table that the activity of ^{226}Ra ranges from 28.8±0.9 Bq.kg^{-1} in Derawar Fort to 36.5±1.0 Bq.kg^{-1} in Minchinabad. The activity of ^{232}Th ranges from 49.4±1.3 Bq.kg^{-1} in Rahimyar Khan to 58.4±1.4 Bq.kg^{-1} in Minchinabad and Liaqatpur. The activity of ^{40}K ranges from 584.8±13.7 Bq.kg^{-1}in Liaqatpur to 696.1±14.3 Bq.kg^{-1}in Minchinabad. The activity of ^{40}K is seen to be higher than ^{232}Th and ^{226}Ra in all the selected towns. The activity of artificial radionuclide ^{137}Cs is found to be minimum in Rahimyar Khan (0.6±0.2 Bq.kg^{-1}) and is maximum in Fort Abbas (3.0±0.3 Bq.kg^{-1}).

Table 4.2: Measured mean activity level in the soil of the listed cities of Bahawalpur Division

Name of the city	**Mean Activity Concentration (Bq.kg^{-1})**			
	^{226}Ra	**^{232}Th**	**^{40}K**	**^{137}Cs**
Fort Abbas	29.9±0.9	52.3±1.4	669.1±14.3	3.0±0.3
Minchinabad	36.5±1.0	58.4±1.4	696.1±14.3	2.3±0.3
Hasilpur	30.9±0.9	49.9±1.3	651.2±14.4	1.3±0.3
Bahawalpur	35.1±0.9	57.0±1.4	633.9±14.4	0.8±0.2
Liaqatpur	36.0±0.9	58.4±1.4	584.8±13.7	0.8±0.1
Derawar Fort	28.8±0.9	51.2±1.3	677.9±13.7	2.0±0.2
Rahimyar Khan	31.6±0.9	49.4±1.3	657.6±14.2	0.6±0.2
Sadiqabad	34.2±1.0	52.4±1.3	608.2±13.8	0.8±0.2
Overall Mean value	**32.9±0.9**	**53.6±1.4**	**647.4±14.1**	**1.5±0.2**

To determine the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K by a single quantity, which takes into account the radiation hazards associated with them, a common index so called the radium equivalent activity (Ra_{eq}) is used. It is defined as (OECD, 1979):

$$Ra_{eq} = A_{Ra} + 1.43 A_{Th} + 0.07 A_K \tag{4.3}$$

Where A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K respectively. ^{238}U has been replaced by its decay product ^{226}Ra in the above consideration because there may be disequilibrium between ^{238}U and ^{226}Ra.

Using Eq. (4.3), radium equivalent activity was calculated. The results obtained are shown in Table 4.3. It is clear from Table 4.3 that the level of radium equivalent activity is minimum in Hasilpur (148.4±3.9 Bq.kg^{-1}) whereas it is maximum in Minchinabad (173.6±4.1 Bq.kg^{-1}). Based on the annual external dose limit of 1.5 mGy, the activity limiting terms of radium equivalent is 370 Bq.kg^{-1} (Hamid et al., 2002). It may be seen that radium equivalent activity in soil of Bahawalpur Division is below the recommended limit of 370 Bq.kg^{-1}.

Table 4.3: Measured values of Radium equivalent activity, absorbed dose rate, external hazard index and internal hazard Index in the listed cities of the Bahawalpur Division

Name of the city	Radium Equivalent Activity (Bq.kg^{-1})	Absorbed Dose Rate (nGy.h^{-1})	External Hazard Index	Internal Hazard Index
Fort Abbas	150.5±3.1	76.2	0.4	0.5
Minchinabad	173.6±4.1	84.2	0.5	0.6
Hasilpur	148.4±3.9	74.2	0.4	0.5
Bahawalpur	165.4±4.2	79.2	0.5	0.5
Liaqatpur	164.4±4.0	79.1	0.4	0.5
Derawar Fort	156.5±3.9	75.3	0.4	0.5
Rahimyar Khan	152.8±4.3	74.4	0.4	0.5
Sadiqabad	156.0±4.1	75.5	0.4	0.5

Besides the radium equivalent activity, we have also calculated gamma dose rate (D) in the outdoor air at a distance of 1m above the ground level using the conversion factor published in UNSCEAR, 1988. To do so, the following equation (Selvasekarapandian et al., 2000) was used.

$$D=(6.62C_{Th}+4.27C_U+0.43C_K)\times10^{-10}Gy.h^{-1} \qquad (4.4)$$

Where C_{Th}, C_U, C_K are the average activity concentrations of thorium, uranium and potassium respectively. The calculated values of "D" for the towns of Bahawalpur division are also summarized in Table 4.3. The Absorbed Dose Rate ranges from 74.2 nGy.h^{-1} in Hasilpur to 84.2 nGy.h^{-1} in Minchinabad.

The main objective of measuring radioactivity was to make an estimate of radiation dose likely to be delivered to the general public externally. To limit the radiation dose to permissible dose equivalent limit of 1 mSv.y^{-1}(ICRP-60, 1991), a number of models have been proposed in the literature. One such model (Beretka and Mathew, 1985), proposed to serve as a criterion in the than Federal Republic of Germany in the early 1980's, was:

$$\frac{1}{370}(A_{Ra}+1.43A_{Th}+0.07A_K)\leq 1 \qquad (4.5)$$

Considering this criterion, external hazard index is defined as

$$H_{ex}=\frac{A_{Ra}}{370}+\frac{A_{Th}}{259}+\frac{A_K}{4810} \qquad (4.6)$$

The calculated values of external hazard index for the towns studied are given in Table 4.3. It can be seen in this table that maximum and minimum values of the external hazard index are 0.5 in Hasilpur and 0.4 in Derawar Fort and Rahimyar Khan respectively.

There is also a radiation hazard threat to respiratory organs due to the ^{222}Rn, decay product of ^{226}Ra, and its short-lived decay products. To account for this threat the maximum permissible concentration for radium must be reduced to half of the normal limit, i.e.185 Bq.kg^{-1} (Beretka and Mathew, 1985). Considering this limit, the internal hazard index H_{in} is defined as:

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \qquad (4.7)$$

As can be seen in Table 4.3, the maximum internal hazard index is found to be 0.6 in the soil of Minchinabad and the same is minimum in Derawar Fort, which is 0.5.

The mean activity of ^{226}Ra measured in the soil of Bahawalpur division (32.9±0.9 Bq.kg^{-1}) is higher than many countries like Belgium, China, Cyprus, Egypt, Greece, India and Iran, etc. Whereas it is lower than Algeria, Bangladesh, Bulgaria, Brazil, Hong Kong, Japan, Denmark and U.S.A. Some Pakistani areas like Charsaddah District, D. I. Khan, Eastern salt range of Punjab and Islamabad have higher ^{226}Ra level then Bahawalpur Division. Similarly the level of ^{232}Th in Bahawalpur Division is 53.6 Bq.kg^{-1}. It is higher then world average value of 30 Bq.kg^{-1}.

The mean radium equivalent activity, external hazard index, internal hazard index and terrestrial absorbed dose rate in the towns of Bahawalpur division are 158.5±4.1 Bq.kg^{-1}, 0.4, 0.5 and 77.32 nGy.h^{-1}, respectively.

The mean level of activity of ^{137}Cs in the soil of Bahawalpur Division has been found to be 1.45 Bq.kg^{-1}. Although it is very difficult to pin point the origin of ^{137}Cs due to unavailability of data for Pakistan, it may be attributed to the nuclear tests conducted by the neighboring countries and the fallout due to Chernobyl accident. This level is acceptable and is comparable with the published data of other countries. The countries like Algeria, Egypt, North Taiwan and Nile Delta have ^{137}Cs activity levels of ~ 20, ~ 5 and ~ 2 Bq.kg^{-1} respectively while in Bahawalpur division it was found to be ~ 1.5 Bq.kg^{-1}.

To check and calculate as to how much effective dose equivalent will be received by the public due to the activity in soil, the annual effective dose equivalent was calculated using the formula (Zaidi et al., 1999)

$$E_{air} = TQD_{air} \times 10^{-6} \qquad (4.8)$$

where the value of Q is 0.7 $Sv.Gy^{-1}.y^{-1}$ for environmental exposure to gamma rays of moderate energy and T is time in hours in one year, i.e., 8760 hours. The annual effective dose equivalent in Bahawalpur Division was calculated using Eq. (4.8). It was found that the annual effective dose in the Bahawalpur division was ~0.5 $mSv.y^{-1}$ which is well below the permissible dose equivalent of 1 $mSv.y^{-1}$.

4.4.2 Indoor Radon Levels

In the past, our group has carried out radon measurement studies in some cities of Pakistan like Peshawar, Kohat and Bannu. Those studies were of exploratory nature and were not done in a systematic manner. The present study was initiated from Bahawalpur Division of Pakistan, where no radon measurement survey has been done before, with the plan to continue the survey systematically throughout the country. For this purpose the indoor radon concentration levels were measured in the houses of Fort Abbas, Minchin Abad, Hasilpur, Bahawalpur, Liaqatpur, Rahimyar Khan and Sadiq Abad of the Bahawalpur Division using CR-39 detectors.

In this study, the houses surveyed ranged from those occupied by very poor people (self ventilated) to those occupied by very rich people (modern air-conditioned houses). The seasonal variation of the indoor radon levels depends on several parameters that include type of house, radon source, living habits of the inhabitants, ventilation system of the house, heating of the house and outside climate. The study showed minimum radon levels in the summer season and maximum levels in the winter season. The radon levels in autumn and spring seasons were comparable within experimental errors. This seasonal variation may be attributed to the fact that in the hot summer season, public of the Bahawalpur Division who live in self ventilated houses always keep the windows open which results in minimum radon levels. On the other hand, they normally keep the windows of the houses closed in winter season that results in poor ventilation and hence increased radon levels. The measured minimum and maximum values, averaged over a year, of the indoor radon concentration levels along with arithmetic and geometric means are given in Tables 4.4 and 4.5.

Table 4.4: Average indoor radon concentration levels (Bq.m^{-3}) in bedrooms of the listed cities of Bahawalpur Division.

Name of the City	Min. Value	Max. Value	A.M.	G.M.
Hasilpur	09	39	22	20
Fort Abbas	05	34	25	20
Rahimyar Khan	08	54	28	26
Minchin Abad	15	45	32	28
Sadiq Abad	07	67	38	34
Bahawalpur	25	77	44	42
Liaqatpur	29	83	50	47

Table 4.5: Average indoor radon concentration levels (Bq-m^{-3}) in sitting rooms of the listed cities of Bahawalpur Division.

Name of the City	Min. Value	Max. Value	A.M.	G.M.
Hasilpur	09	67	26	24
Fort Abbas	09	45	29	26
Rahimyar Khan	11	38	26	26
Minchin Abad	17	47	28	27
Sadiq Abad	11	77	42	37
Bahawalpur	29	96	63	40
Liaqatpur	26	63	45	43

As can be seen from these tables, the average indoor radon concentration levels (i.e. G.M) in bedrooms and sitting rooms of the cities surveyed is lowest in Hasilpur and is highest in Liaqatpur. The trend of radon concentration levels in sitting rooms and bedrooms is, however, slightly different from one another. This may be due to the relatively more usage of the sitting rooms and bedrooms and its ventilation conditions.

The reported average global indoor radon concentration level is 27.2 Bq.m^{-3} for an occupancy factor of 0.8 (Nazaroff & Nero, 1988). Comparing this value with the average indoor radon concentration level in Bahawalpur Division, it is clear from

Tables 4.4 and 4.5 that the average radon concentration levels in Sadiq Abad, Bahawalpur and Liaqatpur are considerably higher than that of the reported global average value. In the bedrooms of Fort Abbas, the average radon concentration value is slightly higher than 27.2 Bq.m^{-3} and is slightly less than 27.2 Bq.m^{-3} in the sitting rooms. In the cities of Minchin Abad, Hasilpur and Rahimyar Khan, the radon concentration levels are lower than the reported global average value of 27.2 Bq.m^{-3}.

Using the data given in Tables 4.4 and 4.5, excess lung cancer risks have been calculated at the estimated life-time (i.e. the age of 70 years) using the risk coefficients recommended by UNSCEAR and EPA. The results obtained in terms of excess lung cancer risk per million per year (MPY) are given in Tables 4.6 and 4.7. The following equation was used for the assessment of the Excess lung Cancer Risk (*ECR*):

$$ECR = 0.5 \times 0.8 \times RF \times WLM \qquad (4.9)$$

Where 0.5 is the equilibrium factor and 0.8 is the occupancy factor (the fraction of time spent indoors by the occupants). A conversion factor of 73.9 Bq.m^{-3} = 1 WLM.Y^{-1} has been used to convert radon concentration level into WL (Nazaroff and Nero, 1988). It may please be noted here that the occupancy factor 0.8, over estimates the excess lung cancer risk in the rural areas but may be valid for the inhabitants of the urban regions of Pakistan. In rural areas, people spend most of the time in open air. Even during night time, they sleep outside in the open air

It can be seen in Tables 4.6 and 4.7 that for the same values of the indoor radon concentration levels, the excess lung cancer risk calculated using the risk coefficients recommended by EPA and UNSCEAR greatly differ from one another. This variation, as mentioned earlier, is due to the use of different assumed parameters in different models.

It is clear from Tables 4.6 and 4.7 that indoor radon concentration levels and correspondingly the excess lung cancer risk due to the radon are not high in the Bahawalpur Division of Pakistan.

Table 4.6: Estimated excess lung cancer risk per million per year (MPY) in bedrooms of the listed cities of the Bahawalpur Division

Name of the city	Radon Concentration Level ($Bq.m^{-3}$)	Excess Lung Cancer Risk per MPY		
		EPA	UNSCEAR	ICRP
Hasilpur	20	12–43	16–49	26
Rahimyar Khan	20	12–43	16–49	26
Minchin Abad	26	16–56	21–63	34
Fort Abbas	28	17–61	23–68	37
Sadiq Abad	34	21–74	28–83	45
Bahawalpur	42	26–91	34–102	56
Liaqatpur	47	29–102	38–114	62

Table 4.7: Estimated excess lung cancer risk per million per year (MPY) in sitting rooms of the listed cities of the Bahawalpur Division

Name of City	Radon Concentration Level ($Bq.m^{-3}$)	Excess Lung Cancer Risk per MPY		
		EPA	UNSCEAR	ICRP
Hasilpur	24	15–52	19–58	32
Fort Abbas	26	16–56	21–63	34
Rahimyar Khan	26	16–56	21–63	34
Minchin Abad	27	17–58	22–66	36
Sadiq Abad	37	23–80	30–90	49
Bahawalpur	40	25–87	32–97	53
Liaqatpur	43	27–93	35–105	57

Nevertheless, it would be desirable to educate the people about possible sources of the radon, their harmful effects and remedial actions. Houses should be well ventilated and if possible forced ventilation like exhaust fans should be installed. The people should be properly educated for future construction of the houses and consideration of remedial actions at the design time of different buildings. In this context, on our proposal the government of Pakistan has launched a TV commercial about the remedial actions for protection against radon and its daughters. The TV commercial was aired regularly on national TV but was stopped after some time because of sponsorship problem. It may also be borne in mind that smoking is far more important cause of lung cancer than that of radon exposure (Field and Becker, 2001; Field; 2001). Therefore, it seems logical that more attention should be paid to educate the public on the hazard of smoking. In this context, Ministry of Health (Pakistan) has launched an intensive campaign on radio and TV against smoking for the last two decades or so.

Sufficient indoor radon concentration levels data are available for many countries of the world. For the sake of comparison such data have been gathered (Durrani and Ilic, 1997 & references quoted therein) and are given in Table 4.8. Table 4.8 provides information on measurement made in some of the countries, giving duration of exposure, mean radon concentrations and excess lung cancer risk only due to the radon exposures calculated according to EPA and UNSCEAR standards. It is clear from Table 4.8 that the excess lung cancer risk in Bahawalpur Division of Pakistan is higher than those in Austria, Canada, China, Denmark, Germany (Cuttbus), Japan, Netherlands, New Zealand, United Kingdom and United States and lower than many countries of the world namely Finland, France, Ireland, Italy, Portugal, Spain and Sweden.

Table 4.8: Excess lung cancer risk for general population of the listed countries

Countries	Duration of Exposure	Radon concentration level (Bq.m^{-3})	Excess lung cancer risk per MPY	
			EPA	UNSCEAR
Canada	Grab sample	14	9–30	11–34
Austria	Grab sample	15	9–32	12–37
United States	1 year	17	11–37	14–41
New Zealand	1 year	18	11–39	15–44
China(7 Provinces)		20	12–43	16–49
Germany(Cottbus)	3 months	23	14–50	19–56
Japan	1 year	23	14–50	19–56
Netherlands	1 year	24	15–52	19–58
United Kingdom	6 months	25	16–54	20–61
Denmark	6 months	29	18–63	24–71
Norway	6 months	30	19–65	24–73
*Pakistan (B.P.Division)	3 months	30	19–65	24–73
Ireland	6 months	37	23–80	30–90
Portugal	4 months	37	23–80	30–90
Germany(F.R.)	3 months	40	25–87	32–97
France	60 days	41	26–89	33–100
Spain	-	43	27–93	35–105
Sweden	-	56	35–121	45–136
Italy	1 year	62	39–134	50–151
Finland	1 month	64	40–139	52–156

*** This study**

4.5 CONCLUSION

To conclude, indoor radon levels and natural radioactivity levels have been measured in the selected cities of Bahawalpure Division (Pakistan). The mean activities of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs were found to be 32.9±0.9, 53.6±1.4, 647.4±14.1 and1.5±.2 Bq.kg^{-1} respectively. The mean radium equivalent activity Ra$_{eq}$, external hazard index, internal hazard index and terrestrial absorbed dose rate of area under study are 158.5±4.1 Bq.kg^{-1}, 0.4, 0.5 and 77.32 nGy.h^{-1} respectively. The levels of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs in the soil of the Bahawalpur Division were comparatively higher than the world average whereas radium equivalent activity, external hazard index, internal hazard index and terrestrial absorbed dose rate were below the recommended limits. The annual effective dose equivalent to the public was found to be 0.5 mSv.y $^{-1}$.

From the measured indoor radon concentration levels, excess lung cancer risk has been calculated using the risk coefficients recommended by EPA and UNSCEAR. Due to the unavailability of smoking data for the public in the Bahawalpur Division, lung cancer risk has been calculated using only radon exposure. According to the EPA model, the lifetime excess lung cancer risk due to the life time exposure is found to vary from 12 per million per year to 102 per million per year in the cities surveyed. These values vary from 16 per million per year to 114 per million per year if UNSCEAR limits are applied. According to the EPA and UNSCEAR models, the over all average value of the lifetime excess lung cancer risks due to the life time exposure in the Bahawalpur Division vary from 19–65, 24–73 respectively.

4.6 References

- Ahmed, N., Matiullah and Khatibeh, A.J.A.H., 1997 .Indoor radon levels and natural radioactivity in Jordanian Soil. Radiat. Prot. Dosim., 71, 231–233.
- Beretka, J. and Matthew, P.J., 1985. Natural radioactivity of Australian building materials, industrial wastes and by-products. Health Phys., 48, 87–95.
- Clouvas, A., Xanthos, S., Antonopoulos-Domis, M., 2001. Extended survey of indoor and outdoor terrestrial gamma radiation in Greek urban area by in situ gamma spectrometry with portable Ge detector. Radiat. Prot. Dosim., 94, 233–46.
- Din, M.M., 1970. Bahawalpur State. Sang-e-Meel Publications, Lahore, Pakistan.
- Field, R.W. and Becker, K., 2001. Topics Under Debate. Does Exposure to Residential Radon Increase the Risk of Lung Cancer? Radiation Protection Dosimetry, 95, 75–81.
- Field, R.W., 2001. A Review of Residential Radon Case-Control Epidemiologic Studies Performed in the United States. Reviews on Environmental Health Preprint, 16, 151–167.
- Hamid, B.N., Chowdhury, M.I., Alam, M.N. and Islam, M.N., 2002. Study of Natural Radionuclide Concentrations In An Area Of Elevated Radiation Background In The Northern Districts Of Bangladesh. Radiat. Prot. Dosim., 8, 227–230.
- ICRP 60, 1991. Recommendations of the International Commission on Radiological Protection. ICRP Publication 60, Annals of the ICRP, Pergamon Press, Oxford. UK.
- Khan, A.J., Varshney, A.K., Prasad, R., Tyagi, R.K. and Ramachandran, T.V., 1990. Calibration of a CR-39 plastic track detector for the measurement of Radon and its daughters in Dwellings. Nuclear Tracks Radiat. Meas., 17, 497–502.
- Matiullah, Bashir, A., Yang, X. and Ahmed, A., 1993. Recent studies on radon- a measure of living standard. Nucl. Tracks and Radiat. Meas., 22, 399–402.

- Matiullah, Ahad, A., Rehman, S. and Mirza, M.L., 2003. Indoor radon levels and lung cancer risk estimates in seven cities of the Bahawalpure Division, Pakistan. Radiat. Prot. Dosim., 107, 269–276.
- Matiullah, Ahad, A., Shakeel ur Rehman, Shafi ur Rehman and Faheem, M., 2004. Measurement of natural radioactivity in the soil of Bahawalpure Division. Radiat. Prot. Dosim., 112, 443–447.
- Nazaroff, W.W. and Nero, A., 1988. Radon and its Decay Products in Indoor Air. John Wiley and Sons.
- OECD, 1979. Exposure to radiation from natural radioactivity in building materials. Report by a group of experts of the OECD Nuclear Energy Agency, Paris, France.
- Selvasekarapandian, S., Sivakumar, R., Manikandan, N.M., Meenakshisundaram, V., Raghunath, V.M., Gajendran, V., 2000. Natural radionuclide distribution in soils of Gudalore, India. Applied Radiat. Isotopes, 52, 299–306.
- UNSCEAR, 1988. Sources and Effects of Ionizing Radiation. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), Report to the General Assembly.
- Zaidi, J.H., Arif, M., Ahmad, S., Fatima, I., Qureshi, I.H., 1999. Determination of natural radioactivity in building materials used in Rawalpindi-Islamabad area by γ-ray spectrometry and instrumental neutron activation analysis, Applied. Radiat. Isotopes, 51, 559–564.