Chapter 5

Natural Radioactivity Levels of Ra, Th and K in Soil Samples and Dose Assessment

5.1 General

Radiation exposures from extra-terrestrial sources (cosmic rays and cosmogenic radionuclides) and from terrestrial sources (radioactive nuclides present in the crust of the earth, in building material and in air) form the basic natural radiation background. Among terrestrial ones, decay series of primordials Uranium and Thorium and the long-lived ^{40}K account for much of the radiation to which humans are exposed (UNSCEAR, 2000). The human population is exposed to radiation from these primordials directly, as a result of external exposure, or through incorporation of these radionuclides and their daughters into the body through inhalation or ingestion. In the terrestrial sources category, radon isotopes in uranium and thorium chains play important role via inhalation because of the magnitude of dose they deliver and variability of these doses. The inhalation of natural radionuclides other than radon and its decay products makes only a minor contribution to internal exposure (UNSCEAR, 2008). Surface soil is unanimous source of terrestrial radiation and acts as medium for transfer of radionuclides to biological systems. Although natural radioactivity is found in rocks and soils throughout the earth, the accession specific areas vary relatively within narrow limits. The contamination of soil from radionuclides poses one of the worst environmental problems in terrestrial ecosystems because it acts as a sink as well as source for contaminants (Kumar *et al*., 2011). The knowledge of soil radioactivity thus, is important for radiation impact assessment, radiation protection and exploration.

Radioactivity levels vary greatly depending on the soil type and mineral make-up. Although the average concentrations of natural radionuclides in soils are low, a large variation of the order 1,000 $Bqkg^{-1}$ for ^{238}U, 360 $Bqkg^{-1}$ for ^{232}Th and 3,200 $Bqkg^{-1}$ for ^{40}K have been observed (UNSCAER, 2008). Higher concentrations of ^{238}U, ^{232}Th and ^{40}K for example, are associated with soil developed from acid magmatic rocks and clay and phosphatic sands and clays of these formations are associated with majority of

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uranium (Eisenbud and Gesell, 1997). Lower concentrations of uranium are found in basic rocks (like basalt), while acidic rocks contain higher uranium concentrations (like sedimentary) (NCRP, 1984a). There are exceptions, however, as some shales and phosphate rocks have relatively high content of radionuclides (UNSCEAR, 1993).

Radium-226 is generally found in equilibrium with ^{238}U in rocks and undisturbed soils. Radium-226 and its decay products are responsible for a major fraction of the dose received by humans from the naturally occurring internal emitters. Radium, being an α-emitter, does not add directly to the γ-activity of the environment but does so indirectly through its γ-emitting decay products. It is present in all rocks and soils in variable amounts. Igneous rocks tend to contain somewhat higher concentrations than sandstones and lime stones. Table 5.1 summarizes typical ranges and averages of the concentrations of ^{238}U (and hence 226-Ra), ^{232}Th and ^{40}K in some rocks and soils.

Table 5.1 Ranges and averages of the concentrations of ^{40}K, ^{232}Th, and ^{238}U in typical rocks and soils (NCRP, 1987a)

	Potassium-40		**Thorium-232**		**Uranium-238**	
	% total K	$Bqkg^{-1}$	ppm	$Bqkg^{-1}$	ppm	$Bqkg^{-1}$
Igneous rocks						
Basalt (crustal average)	0.8	300	3-4	10-15	0.5-1	7-10
Mafic	0.3-1.1	70-400	1.6, 2.7 [a]	7, 10 [a]	0.5, 0.9 [a]	7, 10 [a]
Salic	4.5	1100-1500	16, 20 [a]	60, 80 [a]	3.9, 4.7 [a]	50, 60 [a]
Granite (crustal ave)	>4	> 1000	17	70	3	40
Sedimentary rocks						
Shale sandstones	2.7	800	12	50	3.7	40
Clean quartz	<1	<302	<8	<1	<10	<10
Dirty quartz	2	400	3-6	10-25	2-3	40
Arkose	2-3	600-900	2	8	1-2	10-25
Beach sands	<1	<300	6	25	3	40
Carbonate rocks	0.3	70	2	8	2	25
All rock (range)	0.3-4.5	70-1500	1.6-20	7-80	0.5-4.7	7-60
Continental crust (ave.)	2.8	850	10.7	44	2.8	36
Soil (ave.)	1.5	400	9	37	1.8	22

[a] Mean and median, respectively.

Studies of natural activity are important for their radiological impact in addition to their significance as excellent biochemical and geo-chemical tracers in the environment. The geo-chemical behavior of a radionuclide in a given decay-series may vary with the atomic number of the parent and daughter products. For example, the chemical properties in the U decay series range from an inert gas (Rn) to a particle-reactive tetravalent cation (Th). These are the properties which determine the fate of the radionuclides in fuel and mineral-processing flow sheets, their subsequent transport in surficial disposal environments and, ultimately, their biological availability and uptake. Hence, knowledge of these properties and their impact on radionuclide partitioning in industrial and environmental processes is essential to define source terms and dose calculation.

\ Information on external exposure due to terrestrial radiation comes from direct measurements of dose rate or from evaluation based on measurements of radionuclide concentrations in soil. About 98.5% of the radiological effects of the uranium series are produced by radium and its daughter products (Zastawny *et al*., 1979). The exposure due to natural radioactivity of soil samples is thus usually determined from the ^{226}Ra, ^{232}Th and ^{40}K contents. Evaluation of dose rate includes using dose conversion coefficients DCFs ($nGyh^{-1}$ per $Bqkg^{-1}$) for individual radionuclides/decay series' discussed in section 5.2.3. Additional Information on both external dose rates and radionuclide concentrations in soil is available in the literature due to expanded interest in mapping countrywide exposures. Examples of some areas of high natural radiation background across the globe are listed in UNSCEAR's 2008 report. These high background levels may for example, be due to high cosmic radiations (Ganzu, Qinghai areas in China and Denver, Colorado in USA), uranium mines (Brazil and New Jersey in USA), Monazite sand coastal areas (Guarapari and Meaipe in Brazil, Roseta coastal area in Egypt and Kerala and Madras in India) or Thermal waters (Bad Gastein in Austria, Mount Gellert in Hungary and Ramsar in Iran) and others. There are several reasons why the soil radioactivity is extensively studied across the globe.

1. Measurement of natural radioactivity due to gamma rays from the terrestrial materials, and consequently the determination of the dose rate, helps firstly to implement precautionary measures, whenever the dose is found to be above the recommended limits.

2. Agriculture soil contamination is probably the most relevant event because radionuclides could reach humans via the food chain.
3. As level of the natural activity of the soil is related to the type of parent rock and to the soil genesis, analysis of soil radioactivity has importance in mineral prospection.

The present work investigated the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in soil samples from Faridkot, Ferozepur and Muktsar districts of Punjab using Gamma Ray Spectrometry. The activities of ^{226}Ra, ^{232}Th and ^{40}K radionuclides obtained using gamma spectroscopy have been converted in radium equivalent (Ra_{eq}) values (Singh *et al*., 2005). Air absorbed dose rates and corresponding effective doses due to these radionuclides have been calculated for the study region. The results are discussed and compared in light of literature and values reported in United Nations Scientific Committee on Effects of Ionizing Radiations Reports (UNSCEAR, 2000, UNSCEAR, 2008).

5.2 Experimental Techniques

Surface soil samples from 36 locations from three districts collected were dried at 110 °C for 24 h, were pulverized, homogenized and sieved through 110 mesh sizes. About 250 g of meshed soil samples were transferred to a cylindrical acrylic container sealed and were kept for 30 days to attain secular equilibrium between ^{238}U, ^{232}Th and their daughter products to be analysed for gamma emitting radionuclides using gamma spectrometry. Activity concentration of radionuclides ^{238}U (^{226}Ra), ^{232}Th and 40K was determined in soil samples using high purity Germanium (HPGe) coaxial n-type detector (ORTEC, Oak Ridge, USA) at Inter University Accelerator Centre (IUAC), New Delhi. The principle and working of a gamma spectrometer is given in section 2.6. The detector has a resolution of 2.0 KeV at 1332 KeV and relative efficiency of 20%. The output of the detector is analyzed using a 4K ADC system connected to PC and the spectrum was analyzed using the locally developed software ***C****ollection and* ***A****nalysis of* ***N****uclear* ***D****ata using* ***L****inux n****E****twork* or CANDLE. The detector is shielded using 4" Lead on all sides to reduce the background level of the system. The gamma-ray spectrometer energy calibration was performed using ^{60}Co, ^{137}Cs and ^{133}Ba disc sources. The efficiency calibration for the system was carried out using secondary standard of uranium ore in geometry available for sample counting. Efficiency values were plotted

against energy for particular geometry and were fitted by least squares method to an empirical relation that takes care of the nature of efficiency curve for the HPGe detector. For calibration of the low background counting system, a secondary standard was used. The secondary standard was calibrated with the primary standard (RGU-1) obtained from the International Atomic Energy Agency (IAEA). The soil samples were counted for a period of 72, 000 seconds and the spectra were analyzed of the photo peak of ^{226}Ra, ^{232}Th daughter products and ^{40}K. The net count rate under the most prominent photo peaks of radium and thorium daughter peaks were calculated by subtracting the respective count rate from the background spectrum obtained for the same counting time. Then the activity of the radionuclide was calculated from the background subtracted area prominent gamma ray energies. The concentrations of radionuclides were calculated using the following equation:

$$\text{Activity } (\text{Bqkg}^{-1}) = \frac{\text{CPS}}{\text{w}\times\gamma\times\varepsilon} \pm \frac{(\text{CPS})^{1/2}}{\text{w}\times\gamma\times\varepsilon} \quad (5.1)$$

where,

CPS = Net count rate per second {(sample counts-background counts)/Total counting time}

w= weight of sample in kg

γ = Branching Intensity, and

ε = Efficiency of the detector.

A typical spectrum of a soil sample using HPGe-detector with gamma peaks of various radionuclides is showen in Figure 5.1. Gamma transitions line 1460keV of ^{40}K is used for the analysis of Potassium. ^{226}Ra emits 186 keV, but is not used due to interference by 185.7 keV line of ^{235}U. As an alternative, 1764 line (out of 609.3, 934.1, 1120.3 1729.6, 1764, 2204.2 and 2447.8 keV lines) of ^{214}Bi (a daughter nuclide of radium) has been used for the measurement of activity concentration of ^{226}Ra. Another reason for using this energy for radium estimation is a better photo peak to Compton ratio in the 1700-1820 energy window. Thorium-232 too has several daughter peaks which could be used; like ^{208}T1 has an intense line at 583 keV, but this line cannot be resolved from the 609 keV line of ^{214}Bi. Besides, this energy area has a fairly large attenuation correction (approximately 30%). The only other higher energy line that has

good peak to Compton ratios and minimal interferences is the 2614 keV gamma. The region of interest (ROI) set for ^{232}Th is 2550-2680 keV. The minimum detectable activity (MDA) values for the prominent gamma emitters are shown in Table 5.2. The minimum detectable activity (MDA) for each radionuclide was determined from the background radiation spectrum using formula (Currie, 1968):

$$\text{MDA } (\text{Bqkg}^{-1}) = \frac{4.66\text{B}^{1/2}}{\text{T}\times\gamma\times\varepsilon\times\text{w}} \quad (5.2)$$

where,

B is the background counts, T is the counting time (s), c is the gamma emission probability, e is the absolute efficiency of the detector at particular gamma energy and w is the sample weight (kg).

5.2.1 Radium Equivalent Activity

The distribution of ^{226}Ra, ^{232}Th and ^{40}K in soil is not uniform. Uniformity with respect to exposure to radiation thus, has been defined in terms of radium equivalent activity in Bqkg^{-1} to compare the specific activity of materials containing different amounts of ^{226}Ra, ^{232}Th and ^{40}K. According to the literature, it is considered that 370 Bqkg^{-1} of Ra_{eq} activity produces a rate of effective equivalent dose of 1.5 mSvyear^{-1} (Ahmed and El-Arabi, 2005).

It is calculated through the following relation (Yu *et al*., 1992):

$$Ra_{eq} = C_{Ra} + 1.43C_{Th} + 0.077C_K \quad (5.3)$$

where,

C_{Ra}, C_{Th} and C_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bqkg^{-1}, respectively. While defining Ra_{eq} activity, it has been assumed that 370 Bqkg^{-1} ^{226}Ra or 259 Bqkg^{-1} ^{232}Th or 4810 Bqkg^{-1} ^{40}K produces the same gamma dose rate. Radium Equivalent Activity Ra_{eq}, is a one of the most widely used parameters to express external exposure in radiological protection for radiological risk assessment and has been in practice for over 40 years for the assessment of radiological hazard of radioactivity in environmental materials. Nationwide surveys have been carried out to determine the radium equivalent activity of soil across the world (Ibrahiem *et al*., 1993; Al-Jundi *et al*., 2003; Mireles *et al*., 2003; Singh *et al*., 2003).

Table 5.2 Characteristics of the gamma-ray spectrometer system

Parameter	Radionuclide		
	^{226}Ra	^{232}Th	^{40}K
Gamma lines used (keV)	1764 (^{214}Bi)	2614 (^{208}Tl)	1460
Percentage efficiency	1.39	1.37	4.16
MDA (Bqkg^{-1}) for 1,20,000s counting time, (7.5 × 6.5cm) cylindrical plastic container geometry	8	7	5

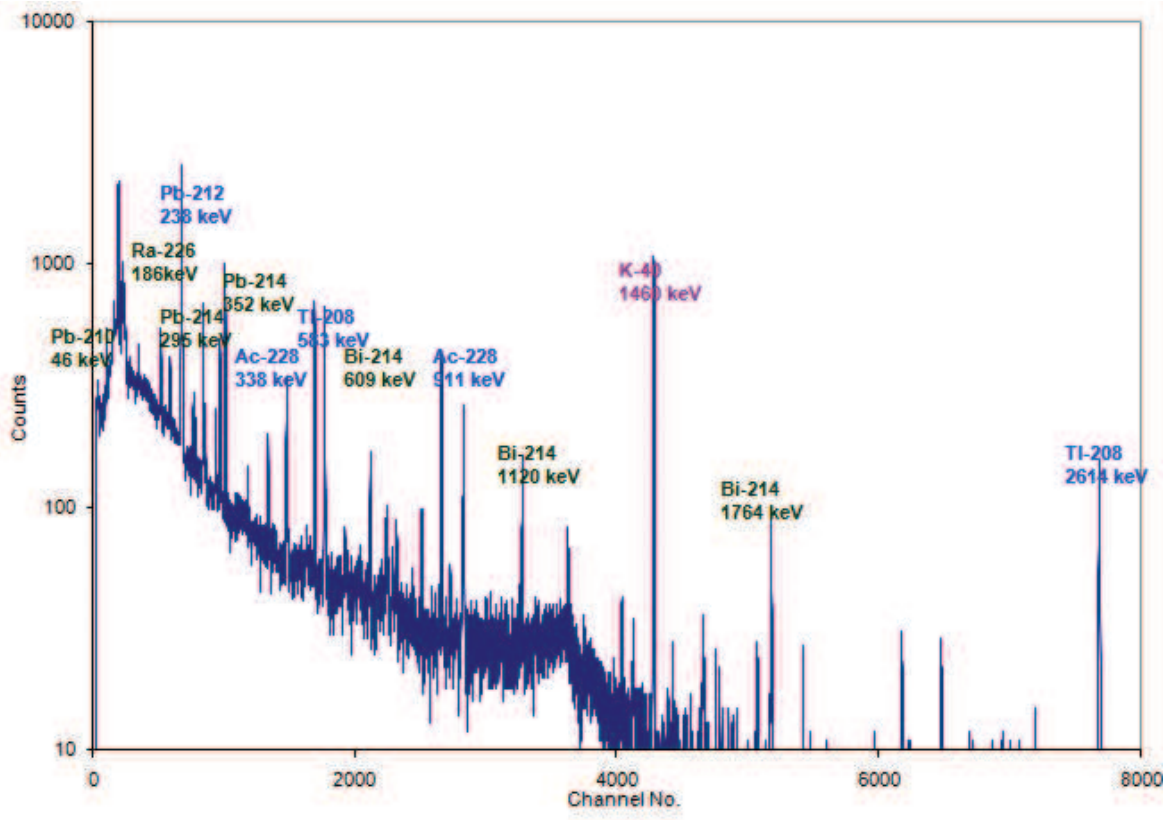

Figure 5.1 Typical gamma spectrum of a soil sample using HPGe-detector showing gamma-ray peaks of various radionuclides

5.2.2 Air-Absorbed and Effective Dose Rate

An estimation of dose assessment from the activity concentration of γ emitters can be obtained in soils. The results of the measurements of the absorbed dose rate in air are reported in units of $nGyh^{-1}$. All the values given are for dose rates from terrestrial γ rays 1 m above the ground and exclude any contribution from either cosmic rays or instrument background. The decay of naturally occurring radionuclides in soil produces a gamma-beta radiation fields in soil that also crosses the soil-air interface to produce exposures in humans. External exposures outdoors arise from terrestrial radionuclides present at trace levels in all soils. The external gamma dose rate in air was calculated from the measurement of concentration of the relevant radionuclides in soil. The external terrestrial γ-radiation absorbed dose rate in air at a height of about 1 meter above the ground was calculated by using the conversion factor of 0.0417 $nGyh^{-1}$ per $Bqkg^{-1}$ for ^{40}K, 0.462 $nGyh^{-1}$ per $Bqkg^{-1}$ for ^{226}Ra, and 0.604$nGyh^{-1}$ per $Bqkg^{-1}$ for ^{232}Th (UNSCEAR, 2000).

$$D\ (nGyh^{-1}) = 0.462C_{Ra} + 0.604C_{Th} + 0.0417C_K \qquad (5.4)$$

where,

C_{Ra}, C_{Th} and C_K are the activity concentrations ($Bqkg^{-1}$) of radium, thorium and potassium in the soil samples.

Annual estimated average effective dose equivalent received by the population is calculated taking account of a conversion factor of 0.7 $SvGy^{-1}$ and outdoor and indoor occupancy factors of 20% and 80% respectively (UNSCEAR, 2008). The annual effective doses are then determined as follows:

$$\text{Indoor (nSv)} = \text{Absorbed dose rate } (nGyh^{-1}) \times 8760\ h \times 0.8 \times 0.7SvGy^{-1} \qquad (5.5a)$$

$$\text{Outdoor (nSv)} = \text{Absorbed dose rate } (nGyh^{-1}) \times 8760\ h \times 0.2 \times 0.7SvGy^{-1} \qquad (5.5b)$$

5.2.3 External Hazard Index (H_{ex})

The external hazard index is an evaluation of the hazard of the natural gamma radiation. The concept of the hazard index (HI) has been around for a number of years and has been used for evaluation of potential hazards associated with both radiological

and non-radiological hazards. For example; in the case of radiological contaminants in soil and/or building materials, the value of this index (usually expressed as the concentration in the medium of interest- soil or building material divided by the reference concentration for the contaminant in that medium) must be less than unity in order to keep the radiation hazard to be insignificant. Maximum value of H_{ex} equal to unity corresponds to the upper limit of Ra_{eq} (370 $Bqkg^{-1}$). It is defined as (Beretka and Mathew, 1983):

$$H_{ex} = \frac{C_{Ra}}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} < 1 \qquad (5.6)$$

where,

C_{Ra}, C_{Th} and C_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K $Bqkg^{-1}$, respectively.

5.4 Results and Discussion

Results obtained for the soil samples of 36 locations of the region using gamma ray spectrometry analysis for the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K and corresponding calculated radium equivalent activity (Ra_{eq}), absorbed dose rates, Annual effective doses, Hazard indices (Hex) are given in Tables 5.3 and 5.4 respectively.

The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in soil were found to vary as 10.0-55.2 $Bqkg^{-1}$ (mean 32.7 $Bqkg^{-1}$), 30.3-140.3 $Bqkg^{-1}$ (mean 58.8 $Bqkg^{-1}$) and 188.2-531.0 $Bqkg^{-1}$ (mean 330.0 $Bqkg^{-1}$) respectively. Obtained results immediately fetch comparison with global data, which is given in Table 5.5. Table is modified version of Table 5 from UNSCEAR 2000. Table shows the nationwide (India) average radioactivity levels of ^{226}Ra, ^{232}Th and ^{40}K in soil are 29 $Bqkg^{-1}$ (range 7-81 $Bqkg^{-1}$), 64 $Bqkg^{-1}$ (range 14-160 $Bqkg^{-1}$) and 400 $Bqkg^{-1}$ (range 38-760 $Bqkg^{-1}$), respectively. This infers that whereas ^{226}Ra content is up by 12.8% than national average for the study region, ^{232}Th and ^{40}K are lower in content by 8.13% and 7.5% respectively.

Table 5.3 ^{226}Ra, ^{232}Th, ^{40}K activity in the soil samples from different locations in Faridkot, Muktsar and Ferozepur districts, Punjab, India

S. No.	Location	Radium concentration C_{Radium} (Bqkg^{-1})	Thorium concentration $C_{Thorium}$ (Bqkg^{-1})	Potassium concentration $C_{Potassium}$ (Bqkg^{-1})
1	Faridkot city	43.2± 0.4	67.9± 1.6	428.0± 5.4
2	Kotkapura	34.2± 0.6	65.5±1.6	320.2± 5.0
3	Ramana	28.4± 0.5	57.6± 1.0	400.0± 5.3
4	Jaito	24.4± 0.4	68.9± 1.6	320.6± 3.3
5	Bhagtuana	30.8± 0.5	43.2± 0.6	268.2± 4.0
6	Karirwali	30.0± 0.5	40.2± 1.0	415.4± 5.4
7	Machaki	26.7± 0.4	77.9± 2.1	318.5± 4.4
8	Sadik	29.9± 0.5	65.5± 1.5	296.1± 4.0
9	Mallan	24.3± 0.4	42.4± 0.6	319.6± 4.5
10	Kauni	30.4± 0.5	56.4± 0.8	408.5± 5.2
11	Mukatsar city	41.4± 0.9	78.3± 2.2	434.8± 5.2
12	Marh Mallu	33.0± 0.6	90.2± 2.6	430.3± 5.2
13	Rupana	42.1± 1.0	85.6± 1.8	394.2± 5.0
14	Aulakh	45.5± 0.4	45.0± 1.0	380.1± 4.8
15	Pind Malout	16.8± 0.4	32.2± 0.6	317.7± 4.1
16	Malout City	33.1± 0.6	86.8± 1.7	411.1± 5.3
17	Badal	39.0± 0.8	70.2± 1.6	401.1± 5.3
18	Kabbarwal	26.9± 0.4	49.0± 1.2	337.5± 4.2
19	Balluana	55.2± 1.6	140.3± 2.0	312.9± 3.5
20	Abohar	43.7± 1.1	66.0± 1.5	340.2± 3.5
21	Nihal Khera	29.7± 0.4	60.7± 1.4	225.8± 2.6
22	Fazilka	39.0± 1.0	57.6± 1.2	531.0± 5.6
23	Behakbobla	44.8± 1.2	30.8± 0.6	470.2± 5.5
24	Bambha Battu	25.6± 0.4	30.3± 0.5	255.0± 3.4
25	Bagge Ke	32.5± 0.5	45.0± 1.0	237.0± 3.5
26	Jalalabad	48.8± 1.1	82.0± 2.2	388.3± 4.4
27	Jiwan Arain	12.5± 0.4	30.8± 0.6	212.8± 4.0
28	Pindi	30.3± 0.4	30.4± 0.6	315.6± 4.4
29	Lakho ke	30.8± 0.5	35.4± 0.7	306.1± 4.2
30	Khai Kheme Ki	41.8± 1.1	39.5± 1.0	194.4± 2.4
31	Ferozepur city	42.6± 1.0	102.7± 2.0	289.9± 2.4
32	Khosa Dal Singh	20.8± 0.4	40.7± 0.8	222.6± 2.0
33	Zira	39.0± 0.8	44.7± 1.0	188.2± 2.2
34	Khui Khera	28.3± 0.4	45.8± 1.0	245.0± 3.0
35	Bhadana	10.0± 0.4	33.0± 0.6	230.4± 2.4
36	Makhu	40.1± 1.2	77.5± 1.6	514.2± 5.2
Range		10.0-55.2	30.3-140.3	188.2-531.0
Average		32.7	58.8	330.0

Table 5.4 Radium equivalent**,** Air absorbed dose rates, annual effective dose and external hazard index (H_{ex}) corresponding to ^{226}Ra, ^{232}Th, ^{40}K activity in the soil samples from different locations in Faridkot, Muktsar and Ferozepur districts, Punjab, India

S. No	Location	Radium Equivalent ($Bqkg^{-1}$)	Absorbed dose rate ($nGyh^{-1}$)	Annual effective dose (mSv)			External Hazard Index 'H_{ex}'
				Indoor	Outdoor	Total	
1	Faridkot city	137.85	61.24	0.30	0.08	0.38	0.37
2	Kotkapura	152.48	68.70	0.34	0.08	0.42	0.41
3	Ramana	141.51	64.57	0.32	0.08	0.40	0.38
4	Jaito	147.61	66.26	0.33	0.08	0.41	0.40
5	Bhagtuana	113.29	51.53	0.25	0.06	0.32	0.31
6	Karirwali	119.49	55.47	0.27	0.07	0.34	0.32
7	Machaki	162.62	72.67	0.36	0.09	0.45	0.44
8	Sadik	146.30	65.69	0.32	0.08	0.40	0.40
9	Mallan	109.59	50.18	0.25	0.06	0.31	0.30
10	Kauni	142.46	65.12	0.32	0.08	0.40	0.38
11	Mukatsar city	186.92	84.58	0.41	0.10	0.52	0.50
12	Marh Mallu	195.05	87.64	0.43	0.11	0.54	0.53
13	Rupana	194.80	87.57	0.43	0.11	0.54	0.53
14	Aulakh	139.15	64.06	0.31	0.08	0.39	0.38
15	Pind Malout	87.26	40.44	0.20	0.05	0.25	0.24
16	Malout City	188.79	84.82	0.42	0.10	0.52	0.51
17	Badal	170.31	77.16	0.38	0.09	0.47	0.46
18	Kabbarwal	122.96	56.10	0.28	0.07	0.34	0.33
19	Balluana	280.01	123.33	0.61	0.15	0.76	0.76
20	Abohar	164.27	74.24	0.36	0.09	0.46	0.44
21	Nihal Khera	133.85	59.78	0.29	0.07	0.37	0.36
22	Fazilka	162.26	74.95	0.37	0.09	0.46	0.44
23	Behakbobla	125.05	58.91	0.29	0.07	0.36	0.34
24	Bambha Battu	88.58	40.77	0.20	0.05	0.25	0.24
25	Bagge Ke	115.13	52.09	0.26	0.06	0.32	0.31
26	Jalalabad	195.96	88.27	0.43	0.11	0.54	0.53
27	Jiwan Arain	72.91	33.24	0.16	0.04	0.20	0.20
28	Pindi	98.07	45.52	0.22	0.06	0.28	0.26
29	Lakho ke	104.93	48.35	0.24	0.06	0.30	0.28
30	Khai Kheme Ki	113.25	51.28	0.25	0.06	0.31	0.31
31	Ferozepur city	211.67	93.75	0.46	0.11	0.57	0.57
32	Khosa Dal Singh	96.14	43.47	0.21	0.05	0.27	0.26
33	Zira	117.41	52.87	0.26	0.06	0.32	0.32
34	Khui Khera	112.70	50.97	0.25	0.06	0.31	0.30
35	Bhadana	74.91	61.03	0.30	0.07	0.37	0.20
36	Makhu	190.53	58.28	0.29	0.07	0.36	0.51
Range		72.91-80.01	33.24-23.33	0.16-0.61	0.04-0.15	0.20-0.76	0.20-0.76
Average		142.11	64.30	0.32	0.08	0.39	0.38

Table 5.5 Comparison of natural radionuclide content in soil calculated in the present study for different locations in Punjab, Northern India with global data from UNSCEAR (2000)

Region/country	Concentration in soil **(Bqkg^{-1})**					
	^{226}Ra		**^{232}Th**		**^{40}K**	
	Mean	**Range**	**Mean**	**Range**	**Mean**	**Range**
Malaysia	67	38–94	82	63–110	310	170–430
Egypt	17	5–64	18	2–96	320	29–650
United States	40	8–160	35	4–130	370	100–700
China	32	2–440	41	1–360	440	9–1800
Hong Kong SAR	59	20–110	95	16–200	530	80–1100
India	**29**	**7–81**	**64**	**14–160**	**400**	**38–760**
Japan	33	6–98	28	2–88	310	15–990
Thailand	48	11–78	51	7–120	230	7–712
Iran	28	8–55	22	5–42	640	250–980
Denmark	17	9–29	19	8–30	460	240–610
Belgium	26	5–50	27	5–50	380	70–900
Luxembourg	35	6–52	50	7–70	620	80–1800
Switzerland	40	10–900	25	4–70	370	40–1000
Bulgaria	45	12–210	30	7–160	400	40–800
Poland	26	5–120	21	4–77	410	110–970
Romania	32	8–60	38	11–75	490	250–1100
Greece	25	1–240	21	1–190	360	12–1570
Portugal	44	8–65	51	22–100	840	220–1230
Spain	32	6–250	33	2–210	470	25–1650
Hungary	33	14–76	28	12–45	370	79–570
Present Study	**32.7**	**10.0-55.2**	**58.8**	**30.3-140.3**	**330.0**	**188.2-531.0**

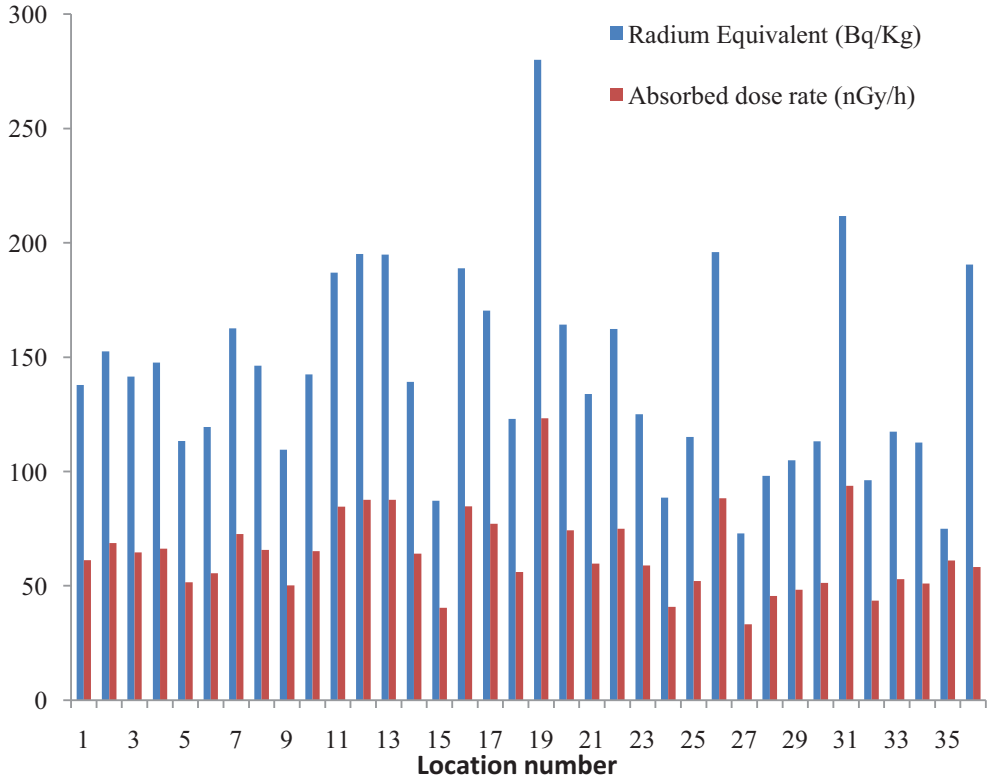

Figure 5.2 Graphical representation of radium equivalent and Air absorbed dose rate values for 36 locations

Radium Equivalent (Ra_{eq}) for the 36 samples of gamma spectrometric analysis averaged at 142.11 $Bqkg^{-1}$ and ranged as 72.91- 280.01 $Bqkg^{-1}$. The values of radium equivalent activity for all the soil samples of the study area has been calculated to be less than the guideline limit of 370 $Bqkg^{-1}$ (OECD, 1979). Figure 5.2 is a graphical representation of Radium Equivalent and Air absorbed dose rate values for 36 locations from Table 5.3.

In a similar study, Singh *et al.* (2005) analysed ^{226}Ra, ^{232}Th and ^{40}K in soil samples from some areas of Punjab and Himachal Pradesh using gamma ray spectrometry and reported comparatively higher values of ^{226}Ra in soil, ranging from 18.22 to 90.30 $Bqkg^{-1}$. The authors measured activity concentration of ^{226}Ra (57 $Bqkg^{-1}$) and ^{232}Th (87 $Bqkg^{-1}$) in soil to be higher and lower for ^{40}K (181.41 $Bqkg^{-1}$) than the world average. The radium equivalent activity was however, reported lower than the OECD value in all the soil samples as in the present study.

Natural radioactivity in soil samples from the neighboring mineral rich Rajsthan state have been reported (Nageswara Rao *et al*., 1996). In their analysis, they reported higher concentrations of ^{226}Ra (upto 77.9 $Bqkg^{-1}$) and ^{232}Th (up to 106.2 $Bqkg^{-1}$). Several important minerals of economic importance occur in this sand and alluvium covered state. But these values can further be compared with the much higher concentrations (due to presence of monazite mineral in beach sands) of ^{232}Th (15-776 $Bqkg^{-1}$) and ^{40}K (200-854 $Bqkg^{-1}$) in the coastal sands of Kalpakkam in India (Kannan *et al*., 2002).

External exposure rates from terrestrial gamma radiation (absorbed dose rates) in air inferred from obtained concentrations of ^{226}Ra, ^{232}Th, ^{40}K radionuclides in soil samples varied as 33.24-123.33 and averaged at 64.30 in the units $nGyh^{-1}$. When compared with national average 56 $nGyh^{-1}$ (range 20-1100) (UNSCEAR, 2000), average absorbed dose rate for the study region is greater by 14.8%.

The range 33.24-123.33 $nGyh^{-1}$ obtained for terrestrial gamma exposure is very much normal when compared with the areas of high natural radiation background reported world-wide. For example value as high as 90, 000 $nGyh^{-1}$ is reported by Pfeiffer *et al.* (1981) for the Brazilian coastal areas composed of Monazite sands.

Similarly another example of area with high natural radiation background is Granitic area known for uranium minerals (Delpoux *et al.*, 1997). The coastal belt of Karunagopapally (Kerala state) in India is another example of high background radiation area due to thorium-containing monazite sand, with outdoor radiation level as high as 70 $mGyy^{-1}$ (Nair *et al*., 2009). Examples of areas of high natural radiation background around the world are given elsewhere (UNSCEAR, 2008).

Finally, annual total average effective dose equivalent received by the population has been calculated taking account of a conversion factor of 0.7 $SvGy^{-1}$ and outdoor and indoor occupancy factors of 20% and 80% respectively (UNSCEAR, 2008). Annual total average effective dose averaged at 0.39 mSv for the present study region with range 0.20-0.76 mSv. This values did not differ from the typical values (average=0.48 mSv and range: 0.3-1.0 mSv) of external terrestrial radiation reported by UNSCEAR in its 2008 report. The values external hazard index (Hex) for all the soil samples was found to be less than 1, varied as 0.20-0.76 with mean value 0.38.

5.5 Conclusions

1. From the analysis of 36 soil samples using Gamma Spectrometry ^{226}Ra content for the study region has been found to be up by 12.8% than national average. However, ^{232}Th and ^{40}K are lower in content by 8.13% and 7.5% respectively.
2. In terms of radium equivalent activity, activity content of the region is within guideline limit of 370 $Bqkg^{-1}$.
3. With calculated average 64.30nGy/h, average absorbed dose rate for the study region is greater than national average 56 $nGyh^{-1}$ by 14.8%.
4. The values of external hazard index (Hex) for all the soil samples were found to be less than 1.