Indian J. Phys. 83 (7), 1031-1037 (2009)



Analysis of ²²⁶Ra, ²³²Th and ⁴⁰K in soil samples for the assessment of the average effective dose

Rohit Mehra^{1*}, Surinder Singh² and Kulwant Singh²

¹Department of Applied Sciences, Malout Institute of Management and Information Technology, Malout-152 107, Punjab, India ²Department of Physics, Guru Nanak Dev University, Amritsar-143 005, Punjab, India

E-mail : rohit_mimit@rediffmail.com

: The activity concentrations of the natural radionuclides namely ²³⁸Ra, ²³²Th and ⁴⁰K are measured Abstract for soil samples collected from different locations of Faridkot and Mansa districts of Punjab. HPGe detector, based on high-resolution gamma spectrometry system is used for the measurement of activity concentration. The range of activity concentrations of ²²⁶Ra, ²³²Th and ⁴⁰K in the soil from the studied areas varies from 21.42 Bq kg⁻¹ to 40.23 Bq kg⁻¹, 61.01 Bq kg⁻¹ to 142.34 Bq kg⁻¹ and 227.11 Bq kg⁻¹ to 357.13 Bq kg⁻¹ with overall mean values of 27.17 Bq kg⁻¹, 95.22 Bq kg⁻¹ and 312.76 Bq kg⁻¹, respectively. Radium equivalent activities are calculated for the analyzed samples to assess the radiation hazards arising due to the use of these soil samples in the construction of dwellings. The absorbed dose rate calculated from activity concentration of ²²⁶Ra, ²³²Th and ⁴⁰K ranges between 9.87 and 18.55, 38.01 and 88.68 and 9.40 and 14.79 nGy h⁻¹, respectively. The total absorbed dose in the study area ranges from 61.10 nGy h⁻¹ to 112.86 nGy h⁻¹ with an average value of 84.80 nGy h⁻¹. The calculated values of external hazard index (H_{ev}) for the soil samples of the study area range from 0.36 to 0.68. Since these values are lower than unity, according to the Radiation Protection 112 (European Commission, 1999) report, soil from these regions is safe and can be used as construction material without posing any significant radiological threat to population. The corresponding average annual effective dose for indoor and outdoor measured in the study area are 0.42 mSv and 0.10 mSv respectively.

Keywords : Gamma ray spectrometry, HPGe detector, Ra_{eq} activities, annual effective dose, external hazard index.

PACS Nos. : 23.20Lv, 23.60.+e

1. Introduction

The natural radioactivity in soil primarily comes from U and Th series and natural K. The radiological implication of these radionuclides is due to the gamma ray exposure of the

^{*} Corresponding Author

body and irradiation of lung tissue from inhalation of radon and its daughters. Therefore, the assessment of gamma radiation dose from natural sources is of particular importance as natural radiation is the largest contributor to the external dose of the world population [1].

External gamma dose estimation due to the terrestrial sources is essential not only because it contributes considerably to the collective dose but also because of variations of the individual dose related to this pathway. These doses vary depending upon the concentrations of the natural radionuclides, ²³⁸U, ²³²Th, their daughter products and ⁴⁰K, present in the soils and rocks, which in turn depend upon the local geology of each region in the world [2,3].

The main objective of the present study is to study the level of radioactive element *viz.* radium, thorium and potassium in Malwa region of Punjab for health risk assessment.

2. Experimental procedure

2.1. Sampling :

In order to measure the natural radioactivity in soil, surface soil samples were collected from ten different locations of Mansa and Faridkot districts of Malwa region of Punjab on random basis. The soil was collected from an auger hole at a depth of about 0.75 meters from the ground so as to get the natural soil. After collection, samples were crushed into fine powder by using Mortar and Pestle. Fine quality of the sample was obtained using scientific sieve of 150 micron-mesh size. Before measurement samples were dried in an oven at a temperature of 383 K for 24 hours. Each sample was packed and sealed in an airtight PVC container and kept for about 4 weeks period to allow radioactive equilibrium among the daughter products of radon (²²²Ra), thoron (²²⁰Ra) and their short lived decay products. An average 0.25 kg of soil was used per sample.

2.2. Measurement of natural radioactivity :

Using HPGe detector based on high-resolution gamma spectrometry system, the activity of samples is counted. The detector is a co-axial *n*-type high purity germanium detector (make EG&G, ORTEC, Oak Ridge, US). The detector has a resolution of 2.0 keV and relative efficiency of 20% for 1.332 MeV gamma energy of Co-60. The output of the detector is analyzed using a 4K MCA system connected to PC. The spectral data is analyzed using the software "CANDLE" (Collection and Analysis of Nuclear Data using Linux Network) developed locally by Inter University Accelerator Centre, New Delhi. The detector is shielded using 4" lead on all sides to reduce the background level of the system [4]. The efficiency calibration for the system is carried out using secondary standard source of uranium ore in geometry available for the sample counting. Efficiency values are plotted against energy for particular geometry and are fitted by least squares method to an empirical relation that takes care of the nature of efficiency curve for the HPGe detector.

1032

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. Gamma transitions of 1461 keV for ⁴⁰K, 186 keV and 609 keV of ²¹⁴Bi for ²²⁶Ra, 338, 463, 911, 968 keV for ²²⁸Ac, 727 keV for ²¹²Bi, 238 keV for ²¹²Pb were used for the laboratory measurement of activity concentration potassium, radium and thorium. The samples were counted for a period of 72000 seconds and the spectra are analyzed for the photo peak of radium, thorium daughter products and K-40. The net count rates under the most prominent photo peaks of radium and thorium daughter peaks are calculated by subtracting the respective count rate from the background spectrum obtained for the same counting time. Then the activity of the radionuclide is calculated from the background subtracted area prominent gamma ray energies. The concentrations of radionuclides are calculated using the following equation :

Activity
$$(Bq) = \frac{CPS \times 100 \times 100}{B.1 \times Eff} \pm \frac{CPS_{error} \times 100 \times 100}{B.1 \times Eff}$$

where, CPS = net count rate/second; B.I. = branching intensity; Eff = efficiency of the detector.

2.3. Radium equivalent activity :

The distribution of ²²⁶Ra, ²³²Th and ⁴⁰K in soil is not uniform. Uniformity with respect to exposure to radiation has been defined in terms of radium equivalent activity (Ra_{cq}) in Bq kg⁻¹ to compare the specific activity of materials containing different amounts of ²²⁶Ra, ²³²Th and ⁴⁰K. It is calculated through the following relation [5]:

$$Ra_{eg} = C_{Ra} + 1.43C_{Th} + 0.07 C_{K}$$

where C_{Ra} , C_{Th} and C_{K} are the activity concentrations of ²²⁶Ra, ²³²Th and ⁴⁰K in Bq kg⁻¹, respectively. While defining Ra_{eq} activity, it has been assumed that 370 Bq kg⁻¹ ²²⁶Ra or 259 Bq kg⁻¹ ²³²Th or 4810 Bq kg⁻¹ ⁴⁰K produces the same gamma dose rate.

2.4. Calculation of air-absorbed dose rate :

The external terrestrial γ -radiation absorbed dose rate in air at a height of about 1 meter about the ground are calculated by using the conversion factor of 0.0414 nGy h⁻¹/Bq kg⁻¹ for ⁴⁰K, 0.461 nGy h⁻¹/Bq kg⁻¹ for ²²⁶Ra, and 0.623 nGy h⁻¹/Bq kg⁻¹ for ²³²Th [5], assuming that ¹³⁷Cs, ⁹⁰Sr and the ²³⁵U decay series can be neglected as they contribute very little to the total dose from environmental background [6–8].

$$D (nGyh^{-1}) = 0.461 C_{Ra} + 0.623 C_{Th} + 0.0414 C_{K}$$

where, C_{Ra} , C_{Th} and C_{K} are the activity concentrations (Bq kg⁻¹) of radium, thorium and potassium in the samples.

2.5. Calculation of annual effective dose :

To estimate annual effective doses, account must be taken of (a) the conversion coefficient from absorbed dose in air to effective dose and (b) the indoor occupancy factor. Annual estimated average effective dose equivalent received by a member is calculated using a conversion factor of 0.7 SvGy⁻¹, which is used to convert the absorbed rate to human effective dose equivalent with an outdoor and indoor occupancy of 20% and 80% respectively.

The annual effective doses are determined as follows :

Indoor (nSv) = (Absorbed dose) $nGy^{-1} \times 8760h \times 0.8 \times 0.7 \text{ SvGy}^{-1}$

Outdoor (nSv) = (Absorbed dose) $nGy^{-1} \times 8760h \times 0.2 \times 0.7 \text{ SvGy}^{-1}$

2.6. External hazard index (H_) :

The external hazard index H_{ex} can be calculated by the following equation [9]:

$$H_{\rm ex} = C_{\rm Ra}/370 + C_{\rm Th}/259 + C_{\rm k}/4810 \le 1$$

where C_{Ra} , C_{Th} and C_{K} are the activity concentrations of ²²6Ra, ²³²Th and ⁴⁰K in Bq kg⁻¹, respectively. The values of this index must be less than unity in order to keep the radiation hazard to be significant. The radiation exposure due to the radioactivity from a construction material is limited to 1.5 mGy/Yr. The maximum value of H_{ex} equal to unity corresponds to the upper limit of Ra_{eq} (370 Bq/kg).

3. Results and discussion

Table 1 summarizes the results of measurements of natural radionuclide (226 Ra, 232 Th and 40 K) concentrations in the collected soil samples. World average concentrations are 35 Bq kg⁻¹, 30 Bq kg⁻¹ and 400 Bq kg⁻¹ for 226 Ra, 232 Th and 40 K respectively.

Table 1 shows that, in general, the average and ranges of activity concentration of 232 Th in soil of these areas are higher than the world Figures [10]. However, the concentration for 226 Ra is very much comparable and a concentration for 40 K is lower as compared with world figures. The range of activity concentrations of 226 Ra, 232 Th and 40 K in the soil from the studied areas varies from 21.42 Bq kg⁻¹ to 40.23 Bq kg⁻¹, 61.01 Bq kg⁻¹ to 142.34 Bq kg⁻¹ and 227.11 Bq kg⁻¹ to 357.13 Bq kg⁻¹ with overall mean values of 27.17 Bq kg⁻¹, 95.22 Bq kg⁻¹ and 312.76 Bq kg⁻¹ respectively. Comparatively high values of 226 Ra and 232 Th in soil samples as compared to world average from the study area may be correlated with the presence of uranium in the soil of this area which is also reported in earlier studies [11]. Our values for radium content in soil lie in the range (2.5–207.0 Bq kg⁻¹), reported for Indian soils [12] using gamma ray spectrometry and are less than the permissible value (370 Bq kg⁻¹), which is acceptable as safe limit [13]. These values reported for radium content in soils of study area are generally low as compared to the values reported by Sharma *et al* [14] for radium concentration in soils of Kangra, Himachal Pradesh. These values of radium concentration are comparable with those reported

1034

Sr. no.	Sample location (village)	Redium concentration in soil	Thorium concentration in soil	Potassium concentration in soil	Radium equivalent activity
	(village)	C _{Radium} (Bq kg ⁻¹)	C _{Thorium} (Bq kg ⁻¹)	C _{Potassium} (Bq kg ⁻¹)	Ra _{eq} (Bq kg ⁻¹)
Faridkot					
1	Faridkot	22.12	66.61	227.11	133.27
2	Sadik	23.43	64.48	294.2	136.23
3	Kot Kapura	33.41	61.01	318.44	142.95
4	Khara	40.23	70.07	301.3	161.52
5	Jaiton	27.13	69.28	326.32	149.04
Mansa					
1	Budlada	22.31	94.8	301.01	178.94
2	Mansa	26.13	111.23	341.13	209.07
3	Buri Harike	33.43	133.02	323.43	246.29
4	Bhiki	22.13	142.34	337.57	249.31
5	Bareta	21.42	139.39	357.13	245.75

Table 1. The values of $^{226}Ra,~^{232}Th$ and ^{40}K activity content using Gamma ray spectrometry and Ra_{eq} activity in the soil samples from Malwa Region of Punjab.

Table 2. Air-absorbed dose rates and annual effective doses at various locations of Malwa Region of Punjab.

Sr. no.	Sample location (village)	Absorbed dose (nGy h ⁻¹)			External hazard	Annual	Annual effective	
		²³⁶ Ra	²³² Th	⁴⁰ K	Total	index (H _{ex})	Indoor	Outdoor
Faridkot								
1	Faridkot	10.2	41.5	9.4	61.1	0.36	0.3	0.07
2	Sadik	10.8	40.17	12.18	63.15	0.37	0.31	0.08
3	Kot Kapura	15.4	38.01	13.18	66.59	0.39	0.33	0.08
4	Khara	18.55	43.65	12.47	74.67	0.44	0.37	0.09
5	Jaiton	12.51	43.16	13.51	69.18	0.41	0.34	0.08
Mansa								
1	Budlada	10.28	59.06	12.46	81.81	0.49	0.4	0.1
2	Mansa	12.05	69.3	14.12	95.47	0.57	0.47	0.12
3	Buri Harike	15.41	82.87	13.39	111.67	0.67	0.55	0.14
4	Bhiki	10.2	88.68	13.98	112.86	0.68	0.55	0.14
5	Bareta	9.87	86.84	14.79	111.5	0.67	0.55	0.14

by Singh *et al* [15] for Bathinda district of Punjab. The values of activity concentrations of ²²⁶Ra and ²³²Th are less and value of activity concentrations of ⁴⁰K is on the higher side than those reported earlier in Kullu area by Narayan Das *et al* [16] and Kaul *et al* [17]. However, a detailed investigation is required to reach some conclusion.

The radium equivalent activity (Ra_{eq}) in these soil samples ranges from 133.27 Bq kg⁻¹ to 249.31 Bq kg⁻¹ with mean value of 185.24 Bq kg⁻¹ which is less than the safe limit (370 Bq kg⁻¹) recommended by OECD, 1979 [13]. No regular trend in the variation of the terrestrial radioactivity has been observed from the study area. A detailed analysis of the results indicates that there is some degree of positive correlation between the activity concentrations of ²³²Th and ⁴⁰K (0.62) in the soil samples. The respective correlation coefficient is comparable in values with those reported for soils from Rajasthan [12].

The calculated total absorbed dose and annual effective dose rates of samples are shown in Table 2. The International Commission on Radiological Protection (ICRP) has recommended the annual effective dose equivalent limit of 1 mSvY⁻¹ for the individual members of the public and 20 mSvY⁻¹ for the radiation workers [18].

From Table 2 it is observed that the absorbed dose rate calculated from activity concentration of 226 Ra, 232 Th and 40 K ranges between 9.87 and 18.55, 38.01 and 88.68, and 9.40 and 14.79 nGy h⁻¹, respectively. The total absorbed dose in the study area ranges from 61.10 nGy h⁻¹ to 112.86 nGy h⁻¹ with an average value of 84.80 nGy h⁻¹.

The corresponding indoor and outdoor annual effective doses range from 0.30 to 0.55 mSv and 0.07 to 0.14 mSv with an average value of 0.417 and 0.10 mSv respectively, while the world wide average annual effective dose is approximately 0.5 mSv and the results for individual countries being generally within the 0.3–0.6 mSv range for indoors. Generally similar type of trend is observed in all the samples and no regular trend in the variation in the annual effective dose and absorbed dose rare is observed from the soil samples. Our results for average annual effective dose are within the range of world wide average value.

The calculated values of H_{ex} for the soil samples studied range from 0.36 to 0.68 (Table 2). Since these values are lower than unity, according to the Radiation Protection 112 report [19], soil from these regions is safe and can be used as a construction material without posing any significant radiological threat to population.

4. Conclusions

- (i) The concentration of ²³²Th in soil samples of Malwa region of Punjab are higher than the world figures reported in UNSCEAR, 2000. However, the concentrations for ²²⁶Ra is very much comparable and concentration of ⁴⁰K are lower than world figures.
- (ii) The results obtained have shown that the indoor and outdoor effective dose due to natural radioactivity of soil samples is lower than the average national and world recommended value of 1.0 mSvY⁻¹.
- (iii) These values reported for radium content in soils of study area are generally low as compared to the values reported for radium concentration in soils of Himachal Pradesh.

1036

References

- [1] UNSCEAR : United Nations Scientific Committee on the Effect of Atomic Radiation (New York : United Nations) (1988)
- [2] A P Radhakrishna, H M Somasekarapa, Y Narayana and K Siddappa Health Physics 65 390 (1993)
- [3] L S Quindos, P L Fernandez, J Soto, C Rodenos and J Gomez Health Physics 66 194 (1994)
- [4] A Kumar, B Singh and S Singh Indian J. Pure Appl. Phys. 39 761 (2991)
- [5] K N Yu, Z J Guan, M J Stoks and E C Young J. Environmental Radioactivity 17 31 (1992)
- [6] D C Kocher and A L Sjoreen Health. Physics 48 p193 (1985)
- [7] P Jacob, H G Paretzke, H Rosenbaum and M Zankl, Radiat. Prot. Dosim. 14 299 (1986)
- [8] K C Leung, S Y Lau and C B Poon J. Environmental Radioactivity 11 279 (1990)
- [9] J Beretka and P J Mathew Health Physics 48 87 (1985)
- [10] UNSCEAR : United Nations Scientific Committee on the Effects of Atomic Radiation (New York : United Nations) (2000)
- [11] R Mehra, S Singh and K Singh Indoor and Built Environment 15 499 (2006)
- [12] M V Nageswara Rao, S S Bhatti, P Rama Seshu and A R Reddy Radiat. Prot. Dosim. 63 207 (1996)
- [13] Organization for Economic Cooperation and Development (Paris, France : OECD) (1979)
- [14] D K Sharma, A Kumar, M Kumar, S Singh, Radiation Measurements 36 363 (2003)
- [15] S Singh, R Mehra, K Singh Journal of Environment Science and Engineering 47/02 85 (2005)
- [16] D R Narayan Dass, T N Parthasarthy and A C Taneja J. Geological Society of India 20 95 (1979)
- [17] R Kaul, K Umamaheshwar, S Chandrashekharan, R D Deshmukh and B M Swarmukar J. Geological Society of India 41 243 (1993)
- [18] ICRP : International Commission on Radiological Protection ICRP publication 65 (Oxford : Pergamon Press) (1993)
- [19] European Commission. Radiation Protection 112, Radiological protection principles concerning the natural radioactivity of building materials (Brussels : European Commission) (1999)