

Natural radioactivity in Indian vegetation samples

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ABSTRACT

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Background: Vegetation (food stuff) is grown in soil that contains many radioactive elements such as ^{238}U (uranium), ^{232}Th (thorium) and ^{40}K (potassium), which may get deposited either due to radioactive fallout or/and by absorption from the soil and can pose serious health hazards. **Materials and Methods:** Natural radioactivity, radiological hazards and annual effective dose assessment was carried out in vegetation samples (vegetables, cereals and fruits) collected from fields and market. Gamma spectrometry using HPGe detector was used. **Results:** The measured specific activity concentration of ^{238}U (uranium), ^{232}Th (thorium) and ^{40}K (potassium) varied from 10.25 ± 0.94 Bq/kg to 29.13 ± 0.69 Bq/kg, 22.20 ± 2.46 Bq/kg to 58.21 ± 1.15 Bq/kg, and 1158.4 ± 26.05 Bq/kg to 1962.2 ± 18.17 Bq/kg respectively in various vegetable and cereal samples and varied from 2.5 ± 0.16 Bq/kg to 9.8 ± 0.15 Bq/kg, 7.4 ± 1.24 Bq/kg to 18.4 ± 1.39 Bq/kg, and 287.13 ± 11.23 Bq/kg to 815.72 ± 12.50 Bq/kg respectively in various fruit samples studied in the present work. From these values, hazard indices, the minimum and maximum values of absorbed dose and indoor and outdoor annual effective doses were calculated for various samples used in the present investigation. **Conclusion:** The various values obtained were found to be within the recommended limits. The absorbed dose and annual effective dose for the vegetable and cereal samples in which fertilizers were used to enhance the crop yield were higher than that in fruit samples.

Keywords: Radiological hazards, vegetation, radium equivalent activity.

INTRODUCTION

We live on and in a radioactive world and are exposed to ionizing radiation from natural sources. Natural radioactivity is wide spread in the earth's environment and it exists in various geological formations in soils, rocks, plants, water and air ⁽¹⁻³⁾. Our soil, in which our food stuff is grown, contains many radioactive elements. There are several radioactive elements in this category, such as ^{238}U (uranium), ^{232}Th (thorium) and ^{40}K (potassium), also termed as primordial radioisotopes, for they were present when the earth was formed.

Natural radioactivity in soils comes from ^{238}U and ^{232}Th series and natural ^{40}K . Uranium occurs in minerals such as pitchblende, uraninite etc. It is also found in phosphate rocks, lignite and monazite sands, whereas ^{40}K is present in mineral waters and brines, and in various minerals such as carnallite, feldspar, saltpeter, greens and sylvite ⁽⁴⁻⁶⁾. ^{238}U and ^{232}Th give rise to the radium and thorium atoms found in all humans, acquired from the food we eat and that food, of course, obtained these materials from the soil in which it grew or on which it grazed ⁽⁷⁾. Potassium is also in this category and ^{40}K - a naturally occurring radioactive isotope (isotope of interest in the present study) comprises a very

small fraction (about 0.0118%) of naturally occurring potassium; its concentration in the earth's crust is about 1.8 mg/kg, or 13 picocurie per gram (pCi/g) ⁽⁸⁾. It is the predominant radioactive component in human tissues and in most food ⁽⁹⁻¹³⁾ and is an important radionuclide in terms of the dose associated with naturally occurring radionuclides. The growing worldwide interest in natural radiation exposure has lead to extensive surveys in many countries. External gamma dose estimation due to terrestrial sources is essential not only because it contributes considerably (0.46mSv/y) to the collective dose but also because of the variations of the individual doses related to this pathways. The doses vary depending upon the concentration of the natural radionuclides, ²³⁸U, ²³²Th and their daughter products and ⁴⁰K, present in food stuffs, which in turn depend upon the local geology of each region in the world ⁽¹⁴⁻¹⁸⁾. The health hazard of potassium-40 is associated with cell damage caused by the ionizing radiation that results from radioactive decay, with the general potential for subsequent cancer induction. Thus measurement of radioactivity in potassium enriched food stuffs is very important from radiation protection point of view and in the present work we have reported the radioactivity in potassium enriched vegetation.

MATERIALS AND METHODS

Sample collection and preparation

In the present investigation, samples (commercially available in the market and from the fields) of different types of vegetation were collected and analyzed for the activity concentration of the natural radionuclides namely ²³⁸U, ²³²Th and ⁴⁰K using gamma spectrometry as carried out by other workers ⁽¹⁹⁾. Subsequently radium equivalent was calculated.

The samples were powdered, charred under a low flame, and then ashed at 450 °C to get a uniform white ash in muffle furnace. The samples were shaken in a sieve of 250

micron-mesh size and particles of size ≤ 250 microns were obtained. Vegetation samples were dried for 10–15 h at 110 °C in an electric oven (hot air oven) to obtain a constant dry weight. Sieved samples were packed and sealed in 300 ml air tight PVC container and kept for about four weeks period to allow radioactive equilibrium among the radon (²²²Rn), thoron (²²⁰Rn), and their short lived progenies. On an average 0.3 kg of ash was taken for each sample. For calibration of the low background counting system, a secondary standard was obtained, calibrated with the primary standard obtained from the International Atomic Energy Agency. The concentration of ²²⁶Ra was determined using a photon peak of 609 keV (46.1%) from ²¹⁴Pb. The 186 keV photon peak of ²²⁶Ra was not used because of interfering peak of ²³⁵U, with an energy of 185.7 keV. ²³²Th concentration was determined using the gamma transitions of 583 keV (86%) from ²⁰⁸Tl ⁽²⁰⁾. ⁴⁰K concentration was determined using the gamma transition of 1461 keV (10.7%).

Measurement technique

Using HPGe detector of high-resolution gamma spectrometry system available at inter university accelerator center (IUAC), New Delhi, the activity of samples is counted. The detector is a co-axial n-type high purity germanium detector (Make EG&G, ORTEC, Oak Ridge, USA). 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, the spectrum is analyzed using the locally developed software "CANDLE (Collection and Analysis of Nuclear Data using Linux network)". The detector is shielded using 4" lead on all sides to reduce the background level of the system ⁽²¹⁾. 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. The samples were counted for a period of 72000 seconds and the

spectra were analyzed of the photo peak of uranium, thorium daughter products and ^{40}K . The net count rate 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 radionuclides is calculated from the background subtracted area prominent gamma ray energies.

Formulas used in measurements

Measuring activity concentration of uranium, thorium and potassium

The concentrations of Uranium, Thorium and Potassium were calculated using the following equation:

$$\text{Activity (Bq)} = \frac{\text{CPS} \times 100 \times 100}{\text{B.I.} \times \text{Eff}} \pm \frac{\text{CPS}_{\text{error}} \times 100 \times 100}{\text{B.I.} \times \text{Eff}} \quad (1)$$

Where, CPS - Net count rate per second
B.I. - Branching Intensity, and
Eff - Efficiency of the detector.

(ii) Radium equivalent activity

The widely used radiation hazard index Ra_{eq} is called the radium equivalent activity; the radiation equivalent activity is a weight sum of activities of the three natural radionuclides ^{238}U , ^{232}Th and ^{40}K based on the estimation that 10 Bq/kg of ^{226}Ra , 7 Bq/kg of ^{232}Th and 130 Bq/kg of ^{40}K produce the same gamma ray dose rate (22).

The radium equivalent activity was calculated using the following equation

$$Ra_{eq} = C_U + 1.43C_{Th} + 0.077C_K \quad (2)$$

Where, C_U , C_{Th} and C_K are the specific activities of ^{238}U , ^{232}Th and ^{40}K in Bq/kg respectively.

Assessment of radiological hazards

As more than one radionuclide contributes towards the gamma doses (i.e. ^{226}Ra , ^{232}Th and ^{40}K), therefore radiological hazards have been presented in terms of a single quantity called 'hazard index' and the measured specific activity concentrations have been used to assess the

radiological hazards in terms of external hazard index (H_{ex}), Internal hazard index (H_{in}), Gamma index (I_γ) and Alpha index (I_α) using equations 3, 4, 5 and 6 respectively (22-24).

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (3)$$

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (4)$$

$$I_\gamma = \frac{A_{Ra}}{300} + \frac{A_{Th}}{200} + \frac{A_K}{3000} \quad (5)$$

$$I_\alpha = \frac{A_{Ra}}{200} \quad (6)$$

To limit the external gamma radiation dose from materials below 1.5 mGy/y, the external hazard index, H_{ex} should obey the following relation $H_{ex} \leq 1$ (25).

(iv) Estimation of absorbed and annual effective dose

The measured activity concentrations of ^{238}U , ^{232}Th and ^{40}K were converted into doses (nGy h^{-1} per Bq kg^{-1}) by applying the factors 0.462, 0.604 and 0.0417 for uranium, thorium and potassium, respectively (26). These factors were used to calculate the total absorbed gamma dose rate in air at one meter above the ground level using the following equation:

$$D (\text{nGy h}^{-1}) = (0.462 C_U + 0.604 C_{Th} + 0.0417 C_K) \quad (7)$$

Where, C_U , C_{Th} and C_K are the activity concentrations (Bq/kg) of uranium, thorium and potassium in the samples. 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 Sv/Gy, which is used to convert the absorbed dose rate to annual effective dose with an outdoor occupancy of 20% and 80% for indoors (27).

The annual effective doses are determined as follows:

$$\text{Indoor (mSv)} = (\text{Absorbed Dose}) \text{nGyh}^{-1} \times 8760 \text{h} \times 0.8 \times 0.7 \text{SvG}^{-1} \text{y}^{-1} \quad (8)$$

$$\text{Outdoor (mSv)} = (\text{Absorbed Dose}) \text{nGyh}^{-1} \times 8760 \text{h} \times 0.2 \times 0.7 \text{SvG}^{-1} \text{y}^{-1} \quad (9)$$

RESULTS

The concentration of the radionuclides, ^{238}U , ^{232}Th and ^{40}K , and radium equivalent activity calculated using equations 1 & 2 in the vegetable and cereal samples studied in the present investigation are given in table 1 and in fruit samples in table 2 respectively. From table 1, it is clear that the activity concentration for ^{238}U , ^{232}Th and ^{40}K varies from 10.25 ± 0.94 Bq/kg to 29.13 ± 0.69 Bq/kg, 22.20 ± 2.46 Bq/kg to 58.21 ± 1.15 Bq/kg, and 1158.4 ± 26.05 Bq/kg to 1962.2 ± 18.17 Bq/kg respectively in various vegetable and cereal samples studied in the present work. The radium equivalent activity varied from 177.78 Bq/kg to 252.07 Bq/kg in the vegetable and cereal samples used in the present investigation. The table 2 shows that the activity concentration for ^{238}U , ^{232}Th and ^{40}K varies from 2.5 ± 0.16 Bq/kg to 9.8 ± 0.15 Bq/kg, 7.4 ± 1.24 Bq/kg to 18.4 ± 1.39 Bq/kg, and 287.13 ± 11.23 Bq/kg to 815.72 ± 12.50 Bq/kg respectively in various fruit samples studied in the present work. The radium equivalent activity varied from 47.91 Bq/kg to 80.02 Bq/kg in fruit samples used in the present investigation.

The radiological hazards in terms of external hazard index (H_{ex}), Internal hazard index (H_{in}),

Gamma index (I_{γ}) and Alpha index (I_{α}) for the samples calculated using equations 3, 4, 5 & 6 are given in table 3 and 4. From table 3 and 4, it is clear that external hazard indices varies from 0.48 to 0.68 in various vegetable and cereal samples and varies from 0.13 to 0.22 in various fruit samples; the internal hazard index varies from 0.54 to 0.73 in various vegetable and cereal samples and varies from 0.14 to 0.24 in various fruit samples, the gamma index varies from 0.69 to 1.00 in various vegetable and cereal samples and varies from 0.19 to 0.32 in various fruit samples, the alpha index varies from 0.05 to 0.15 in various vegetable and cereal samples and varies from 0.01 to 0.05 in various fruit samples studied in the present work.

The radiation absorbed dose and annual effective dose from vegetable and cereal samples and from fruit samples calculated using equations 7, 8 & 9 are given in table 5 and table 6 respectively. The table 5 shows that the minimum and maximum values of absorbed dose, indoor annual effective dose and outdoor annual effective dose varied from 86.83 nGyh^{-1} to 125.18 nGyh^{-1} , from 0.425 mSv to 0.614 mSv and from 0.106 mSv to 0.153 mSv respectively in various vegetable and cereal samples under investigation. Table 6 shows that the calculated values of absorbed dose and annual effective dose (indoors and outdoors) varied from 23.39 nGyh^{-1} to 40.10 nGyh^{-1} , 0.114 mSv/y to 0.196 mSv/y and 0.028 mSv/y to 0.049 mSv/y , respectively in fruit samples.

Table 1. Activity Concentration of uranium, thorium and potassium in vegetable and cereal samples.

Sr. No.	Sample Code	Activity Concentration (Bq/kg)			Radium Equivalent Activity (R_{eq}) (Bq/kg)
		^{238}U	^{232}Th	^{40}K	
1	VC-1	28.08 ± 1.28	42.31 ± 2.17	1158.4 ± 26.05	177.78
2	VC-2	15.55 ± 1.77	57.52 ± 2.34	1579.2 ± 17.58	219.40
3	VC-3	22.72 ± 1.63	47.32 ± 1.35	1268.5 ± 15.05	188.06
4	VC-4	29.13 ± 0.69	22.20 ± 2.46	1885.1 ± 28.03	206.03
5	VC-5	28.22 ± 1.62	26.48 ± 1.41	1590.9 ± 19.21	188.59
6	VC-6	10.25 ± 0.94	36.37 ± 1.20	1665.4 ± 17.63	190.49
7	VC-7	19.94 ± 0.40	49.17 ± 1.31	1820.6 ± 27.24	230.44
8	VC-8	17.74 ± 1.59	58.21 ± 1.15	1962.2 ± 18.17	252.07
9	VC-9	18.38 ± 1.15	50.82 ± 1.17	1698.5 ± 28.04	221.84
10	VC-10	11.40 ± 0.90	39.85 ± 2.32	1775.0 ± 26.48	205.06
11	VC-11	19.21 ± 1.61	26.53 ± 1.89	1625.2 ± 18.28	182.29

Table 2. Activity concentration of uranium, thorium, potassium in fruit samples.

Sr. No.	Sample Code	Activity Concentration (Bq/kg)			Radium Equivalent Activity (Ra _{eq}) (Bq/kg)
		²³⁸ U	²³² Th	⁴⁰ K	
1	FR-1	8.1 ± 0.15	12.3 ± 1.49	687.13 ± 12.23	78.60
2	FR-2	2.5 ± 0.16	15.1 ± 1.67	554.74 ± 14.09	66.81
3	FR-3	3.9 ± 0.25	13.0 ± 1.32	487.13 ± 11.23	60.00
4	FR-4	4.6 ± 0.23	09.6 ± 1.22	384.13 ± 9.23	47.91
5	FR-5	9.8 ± 0.15	11.4 ± 1.29	287.13 ± 11.23	48.21
6	FR-6	5.6 ± 0.15	13.4 ± 1.76	437.56 ± 12.39	58.45
7	FR-7	4.6 ± 0.29	08.3 ± 1.53	737.39 ± 9.37	73.25
8	FR-8	3.5 ± 0.27	07.4 ± 1.24	815.72 ± 12.50	76.89
9	FR-9	8.5 ± 0.12	18.4 ± 1.39	587.13 ± 16.23	80.02
10	FR-10 (Mixed)	7.4 ± 0.18	08.1 ± 1.34	511.25 ± 8.17	58.35

MADL (Minimum Activity Detection Limit) = 2Bq/kg, 2Bq/kg and 4Bq/kg for ²²⁶Ra, ²³²Th and ⁴⁰K respectively.

Table 3. External hazard index, internal hazard index, gamma index and alpha index in vegetable and cereal samples.

Sr. No.	Sample Code	H _{ex}	H _{in}	I _γ	I _α
1	VC-1	0.48	0.57	0.69	0.14
2	VC-2	0.59	0.64	0.87	0.08
3	VC-3	0.51	0.59	0.74	0.11
4	VC-4	0.56	0.54	0.84	0.15
5	VC-5	0.51	0.68	0.76	0.14
6	VC-6	0.51	0.73	0.77	0.05
7	VC-7	0.62	0.65	0.92	0.10
8	VC-8	0.68	0.58	1.00	0.09
9	VC-9	0.60	0.54	0.88	0.09
10	VC-10	0.55	0.57	0.83	0.06
11	VC-11	0.49	0.64	0.74	0.10

Table 4. External hazard index, internal hazard index, gamma index and alpha index in fruit samples.

Sr. No.	Sample Code	H _{ex}	H _{in}	I _γ	I _α
1	FR-1	0.21	0.23	0.32	0.04
2	FR-2	0.18	0.19	0.27	0.01
3	FR-3	0.16	0.17	0.24	0.02
4	FR-4	0.13	0.14	0.19	0.02
5	FR-5	0.13	0.16	0.19	0.05
6	FR-6	0.16	0.17	0.23	0.03
7	FR-7	0.20	0.21	0.30	0.02
8	FR-8	0.21	0.22	0.32	0.02
9	FR-9	0.22	0.24	0.32	0.04
10	FR-10 (Mixed)	0.16	0.18	0.24	0.04

Table 5. Radiation absorbed dose and annual effective dose from vegetable and cereal samples.

Sr. No.	Sample Code	Absorbed Dose Rate (nGy ⁻¹)	Annual Effective Dose (mSv)	
			Indoor	Outdoor
1	VC-1	86.83	0.425	0.106
2	VC-2	107.78	0.528	0.132
3	VC-3	91.97	0.451	0.112
4	VC-4	105.48	0.517	0.129
5	VC-5	95.37	0.467	0.117
6	VC-6	96.15	0.471	0.118
7	VC-7	114.83	0.563	0.141
8	VC-8	125.18	0.614	0.153
9	VC-9	110.01	0.539	0.135
10	VC-10	103.35	0.507	0.126
11	VC-11	92.67	0.454	0.113

Table 6. Radiation absorbed dose and annual effective dose from fruit samples.

Sr. No.	Sample Code	Absorbed Dose Rate (nGy ⁻¹)	Annual Effective Dose (mSv)	
			Indoor	Outdoor
1	FR-1	39.82	0.195	0.048
2	FR-2	33.41	0.163	0.041
3	FR-3	29.97	0.147	0.036
4	FR-4	23.94	0.117	0.029
5	FR-5	23.39	0.114	0.028
6	FR-6	28.93	0.141	0.035
7	FR-7	37.89	0.185	0.046
8	FR-8	40.10	0.196	0.049
9	FR-9	39.52	0.193	0.048
10	FR-10 (Mixed)	29.63	0.145	0.036

DISCUSSION

From the results obtained it is clear that the concentration of Radium, Thorium and Potassium and the radium equivalent activity varied considerably in different samples depending on the quantity and type of fertilizer used in the fields. From the data, it reveals that the activity concentration and the radium equivalent activity in the fruit samples in which no fertilizer/less fertilizer was used, is significantly lower than that in the vegetable and cereal samples collected from market and crop fields where fertilizers were used to enhance the crop yield. Our findings are in good agreement with the findings of other researchers reported in the literature ^(26, 28-33). The concentration of the radionuclide ⁴⁰K is higher in all the vegetable and cereal samples than fruit samples. It is inferred that for all the samples analyzed, the radium equivalent activity value is well within the permissible limits of 370Bq/kg ^(26,34).

The external hazard index and internal hazard index for the studied samples is less than unity and therefore these vegetations are safe to be used for consumption. Value of gamma index $I_\gamma \leq 2$ corresponds to a dose rate criterion of 0.3 mSv/y, whereas $2 \leq I_\gamma \leq 6$ corresponds to a criterion of 1 mSv/y ^(23, 35). Thus the vegetation with $I_\gamma > 6$ should be avoided to be used, since these values correspond to the dose rates higher than 1 mSv/y which is higher than the recommended safe limit values ⁽²⁶⁾. All the current ' I_γ ' values of the studied samples follow the criterion ($I_\gamma \leq 2$) therefore it may be concluded that the samples are safe from health and hygiene point of view and don't pose any significant health hazards to the consumers. The recommended limit for concentration of ²²⁶Ra is 200 Bq/kg, for which $I_\alpha = 1$ ⁽³⁶⁾. The observed values are less than unity showing that the samples are safe from the health and hygiene point of view and don't pose any environmental radiation hazards.

In all the samples, the indoor annual effective dose was less than the recommended safety limit of 1 mSy/y as recommended for general public ⁽³⁷⁾. The positive correlation was observed between the uranium activity and the

absorbed dose. The absorbed dose and annual effective dose for the vegetable and cereal samples in which fertilizers are used to enhance the crop yield are higher than that in fruit samples.

CONCLUSION

The present investigations showed the inborn radioactivity in vegetation samples was modified during technological enhancement (use of fertilizers to enhance the crop yield) but all the samples were found to satisfy the safety criteria. Efforts should be made at national and international level to reduce ²²⁶Ra activity in the fertilizers, like extracting uranium from phosphoric acid by solvent extraction method, so that the fertilizers are more eco-friendly and the radioactivity in the soil itself is not technologically enhanced.

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Conflicts of interest: none to declare.

REFERENCES

1. Ibrahim NM, Abdel-Ghani AH, Shawky SM, Ashraf EM, Farouk MA (1993) Measurement of radioactivity levels in soil in the Nile Delta and Middle Egypt. *Health Physics*, **64**: 620–627.
2. Aly Abdo AA, Hassan MH, Huwait MRA (1999) Radioactivity assessment of fabricated phosphogypsum mixtures. In: *Fourth Radiation Physics Conference, 15–19 November, Alexandria, Egypt*, pp. 632–640.
3. Malanca A, Gaidolfi L, Pessina V, Dallara G (1996) Distribution of ²²⁶Ra, ²³²Th and ⁴⁰K in soils of Rio Grande do Norte, Brazil. *J Environ Radioact*, **30**: 55–67.
4. Beck HL (1980) Exposure rate conversion factors for radionuclides deposited on the ground. US Department of Energy, EML-378, New York.

5. Leung KC, Lau SY, Poon CB (1990) Gamma radiation dose from radionuclides in Hong Kong soil. *J Environ Radioact*, **11**: 279–290.
6. Fong SH and Alvarez JL (1997) Data quality objectives for surface soil cleanup operation using in situ Gamma Spectrometry for concentration measurements. *Health Phys*, **72**: 286–295.
7. International Atomic Energy Agency (IAEA) (2002) Natural and induced radioactivity in food. IAEA-TECDOC-1287, ISSN 1011–4289, IAEA, Vienna, Austria.
8. Argonne National Laboratory (ANL) (2005) EVS, Environmental Science Division, Radiological and chemical fact sheets to support health risk analyses for contaminated areas, Prepared by John Peterson, Margaret MacDonell, Lynne Haroun, and Fred Monette, Human Health Fact Sheet, August 2005.
9. Elstner EF, Rita F, Holl W, Lengfelder E, Ziegler H (1987) Natural and Chernobyl-caused radioactivity in mushrooms, mosses and soil-samples of defined biotops in SW Bavaria. *Oecologia (Berlin)*, **73**: 553–558.
10. Kalac P (2001) A review of edible mushroom radioactivity. *Food Chemistry*, **75**: 29–35.
11. Karunakara N, Somashekarappa HM, Narayana Y, Avadhani DN, Mahesh HM, Siddappa K (2003) ^{226}Ra , ^{40}K , and ^7Be activity concentration in plants in the environment of Kaiga, India. *J. Environ Radioact*, **65**: 255–266.
12. Rao C, Prabhu U, Karunakara N, Somashekarappa HM, Nayak PD, Ravi PM (2008) Site-specific Transfer factors of ^{226}Ra , ^{228}Ra , ^{40}K , and ^{137}Cs for vegetables in Kaiga region. In: Proc. 28th Indian Association for Radiation Protection National Conference (IARPNC-2008), Jodhpur, India, Nov. 19–21, 2008.
13. Changizi V, Jafarpour Z, Naseri M (2010) Measurement of ^{226}Ra , ^{228}Ra , ^{137}Cs and ^{40}K in edible parts of two types of leafy vegetables cultivated in Tehran Province-Iran and resultant annual ingestion radiation dose. *Iran J Radiat Res*, **8**: 103–110.
14. Radhakrishna AP, Somashekarappa HM, Narayana Y, Siddappa K (1993) A new natural background radiation area on the southwest coast of India. *Health Phys* **65**: 390–395.
15. Becker RL (1979) A determination of the radioactivity induced in food as a result of irradiation by electrons of energy between 10 and 16 MeV. Contact No. DAAK60-78-R-0007. US Army Natick Research and Development Command, Natick, Massachusetts 01760.
16. National Commission on Radiological Protection (NCRP) (1984) Exposure from the uranium series with emphasis on radon and its daughters. NCRP Publication no. 77, Bethesda, MD.
17. National Commission on Radiological Protection (NCRP) (1987) Exposure of the population in the United States and Canada from natural background radiation. NCRP Publication no. 94, Bethesda, MD.
18. BEIR IV (1988) Report of the committee on the biological effects of ionizing radiation. Health risks of radon and other internally deposited alpha emitters. Natl. Acad. of Sciences. Natl. Acad. Press, Washington, DC.
19. Ramachandran TV and Mishra UC (1989) Measurement of natural radioactivity levels in Indian foodstuffs by gamma spectrometry. *Appl. Radiat Isot*, **40(8)**: 723–726.
20. Canet A and Jacquemin R (1990) Methods for measuring radium isotope: gamma spectrometry. In: The Environmental Behaviour of Radium, (Vienna: IAEA), Technical Report Series No. 310, Vol. I1, pp.189.
21. Kumar A, Narayani KS, Sharma DN, Abani MC (2001) Background spectrum analysis: a method to monitor the performance of a gamma ray spectrometer. *Radiat Prot Environ*, **24**: 195–200.
22. Beretka J and Mathew PJ (1985) Natural radioactivity of Australian building materials, industrial wastes and by-products. *Health Phys*, **48**: 87–95.
23. European Commission (EC) (1999) Radiation Protection 112-radiological protection principles concerning the natural radioactivity of building materials Directorate- General Environment. Nuclear safety and civil Protection.
24. Righi S and Bruzzi L (2006) Natural radioactivity and radon exhalation in building materials used in Italian dwellings. *J Environ Radioact*, **88**: 158–170.
25. Krieger VR (1981) Radioactivity of construction materials. *Betonwerk Fertigteil Tech*, **47**: 468–473.
26. UNSCEAR (2000) Sources and Effects of Ionizing Radiation. United Nations Scientific Committee on the Effects of Atomic Radiation, United Nations Publication, New York, USA.
27. UNSCEAR (1993) United Nations Scientific Committee on the Effects of Atomic Radiation. Report to the General Assembly, United Nations, New York.
28. Boukhenfouf W and Boucenna A (2011) The radioactivity measurements in soils and fertilizers using gamma spectrometry technique. *J Environ Radioact*, **102**: 336–339.
29. Rafat MA, Mansy M, Eissa MF, Eissa HM, Shahin FM (2008) Assessment of natural radioactivity and radon exhalation rate in Sannur cave, eastern desert of Egypt. *J Radiol Prot*, **28**: 213–222.
30. Singh S, Rani A, Mahajan RK (2005) ^{226}Ra , ^{232}Th and ^{40}K analysis in soil samples from some areas of Punjab and Himachal Pradesh, India using gamma ray spectrometry. *Radiat Meas*, **39**: 431–439.
31. Sonkawade RG, Kant K, Muralithara S, Kuma R, Ramola RC (2008) Natural radioactivity in common building construction and radiation shielding materials. *Atmos Environ*, **42**: 2254–2259.
32. Kant K, Upadhyay SB, Sonkawade RG, Chakravarti SK (2006) Radiological risk assessment of use of phosphate fertilizers in soil. *Iranian J Rad Res*, **4(2)**: 63–70.
33. Karunakara N, Somashekarappa HM, Narayana Y, Avadhani DN, Mahesh HM, Siddappa K (2003) ^{226}Ra , ^{40}K and ^7Be

- activity concentrations in plants in the environment of Kaiga, India. *J Environ Radioact*, **65**: 255-266.
34. 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.
35. Anjos RM, Veiga R, Soares T, Santos AMA, Aguiar JG, Frasca MHBO, Brage JAP, Uzeda D, Mangia L, Facure A, Mosquera B, Carvalho C, Gomes PRS (2005) Natural radionuclide distribution in Brazilian commercial granites. *Radiat Meas*, **39**: 245-253.
36. The Radiation Protection in Denmark, Iceland, Norway and Sweden (2000) Naturally occurring Radiation in the Nordic Countries- recommendations The Flag-Book Series (Reykjavik).
37. ICRP 60 (1991) The 1990-91 Recommendations of the International Commission on Radiological Protection. ICRP Publication 60. Annals of the ICRP, Pergamon Press, Oxford, UK.