Paper

^{137}Cs CONCENTRATION IN THE ENVIRONMENT OF KAIGA OF SOUTH WEST COAST OF INDIA

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Abstract—**This paper presents the results of ^{137}Cs activity in soil and vegetation obtained through a carefully planned pre-operational survey for the establishment of baseline data on background radiation level and distribution of radionuclides in the environment of Kaiga, in the south west coast of India, where two nuclear power reactors of 235 MWe each are under construction. The vertical profile in soil and the seasonal variation in the activity have been studied. Nine commonly available vegetation species of Kaiga region were analyzed for their ^{137}Cs activity, and the soil-to-plant transfer coefficients were evaluated. Measurements were made by gamma spectrometry method employing a 90 cc HpGe detector and a 3 × 3-inch well type NaI(Tl) detector. Results show significant levels of ^{137}Cs activity in soil samples—ranging from below detection limit (BDL) to 65.4 Bq kg^{-1}. The mean value of activity observed in 0–5 cm soil profiles of Kaiga environs is significantly higher when compared to the reported values for other environs of India. Depth profile studies show that the ^{137}Cs activity decreases with the increasing soil depth, and it is below detection limit for depths more than 25 cm. The mean value of effective dose commitment due to the presence of ^{137}Cs in soil was 167.2 μSv. Vegetation samples of the region show elevated levels of ^{137}Cs concentration. Epiphytic plants *Cymbidium aloifolium (Lo.)* Swartz. and *Petrobryopsis tumida (Hook.)* Dix. have been identified as bio-indicators to monitor the fallout of this radionuclide in the environment of Kaiga. Seasonal variation studies indicate higher fallout of this radionuclide along with rain.**

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INTRODUCTION

^{137}Cs is regarded as a most important constituent of world-wide radioactive fallout. Sixty percent of the collective effective dose equivalent commitment from external radiation associated with past atmospheric nuclear weapon testing can be attributed to ^{137}Cs (UNSCEAR 1988). In the case of an accidental release of fission products from a nuclear power plant, cesium isotopes are especially significant due to their volatility and the large inventory that builds up in the reactor over time (Miller et al. 1990). Therefore, measurement of ^{137}Cs levels is very much necessary in the environment of a proposed nuclear power plant site since data obtained from such a study would serve as the baseline data against which the long-term impact of the nuclear power plant, if any, on the environment can be assessed.

We have undertaken a systematic study on background radiation level and radionuclide distribution in the environment of Kaiga (14° 51′ 08″ N, 74° 26′ 40″E) in the south western part of India, where two nuclear power plants, each of 235 MWe capacity, are under construction. Extensive measurement of radioactivity levels (both natural and artificial origins) in various environmental matrices of Kaiga and surrounding regions were carried out under this study (Karunakara et al. 2000; Karunakara et al. 20001; Siddappa et al. 2000). The study has helped to establish the baseline background radiation levels prevailing in the region. This paper summarizes the results of measurements of ^{137}Cs activity concentration in soil and vegetation samples, its vertical profiles in soil, seasonal variation, and the soil-to-plant transfer coefficients.

MATERIALS AND METHODS

Study area

Kaiga, in the southwest coast of India, is situated on the banks of the river Kali in the North Kanara district of Karnataka state. It is about 60 km inland from the Arabian Sea where the Kali river debauches from deep gorges carved out of the steep west bank of the world famous Western Ghats. It is bound by steep hills with closed canopy forests nurtured by heavy seasonal precipitation. The average annual rainfall of the region during 1987–1997 is 3,786 mm. The climate is humid. The total duration of the rainy season is about 5 mo, from June to October. Detailed study of wind roses (for 50–400 m height) reported by Adiga et al. (1997) show that the wind pattern around the region is in the west-east direction. It is constrained by the hilly topography and

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also by the presence of the Kali river channel that is oriented in the west-east direction. Thus, seasonal variations in the wind direction are aberrated by the topography, forcing a west-east flow throughout the year. The soil in the study area is predominantly lateritic, dark brown in color, loamy textured with fine to medium grains, and rich in organic matter.

Sample collection

To start with, the region was divided into three zones: 8-km zone, 16-km zone, and 32-km zone, and various soil sampling stations were selected in these zones. For soil samples, undisturbed level surfaces situated sufficiently away from the public road and buildings were selected. Fig. 1 shows the locations of the 17 sampling stations chosen for the present study. About 1 m^2 area was marked and the top layer of the soil, which contained vegetation and roots, was removed. Soil samples were collected in depth increments of 0–5, 5–10, and 10–25 cm using an augur sampler at all sampling stations. At sampling station Kaiga School, samples were collected down to a depth of 70 cm with three more depth intervals of 25–40, 40–55, and 55–70 cm to study the distribution of ^{137}Cs in deeper profiles of soil. Care was taken in the extraction of soil sections to avoid mixing. To study the seasonal variation in the activity soil, samples (0–5 cm profiles) were also collected in pre-monsoon (May 1997) and monsoon seasons (August 1997) from four sampling stations.

For the determination of ^{137}Cs activity in vegetation, nine species of the region were selected. All the vegetation samples were collected from the sampling station Kaiga School in the monsoon season (August) of 1997. Leaf, branches, and bark samples of these species were collected and sealed in separate polythene bags. Leaves, well exposed to atmosphere, were collected from trees. A single composite sample of small and equal quantity of leaves belonging to the same species from the neighboring trees in a particular region was prepared so that this composite sample could be considered as representative of the region. About 2 kg of this sample was collected in a polythene bag and fresh weight was noted.

Apart from this, two most commonly observed tree species of the region, *Terminalia paniculata* Roth. and *Careya arborea* Roxb., were selected for studying the seasonal variation in ^{137}Cs activities. Leaf samples of tree species were collected in pre-monsoon (May 1997) and monsoon seasons (August 1997) from four sampling stations in the same way as just mentioned above.

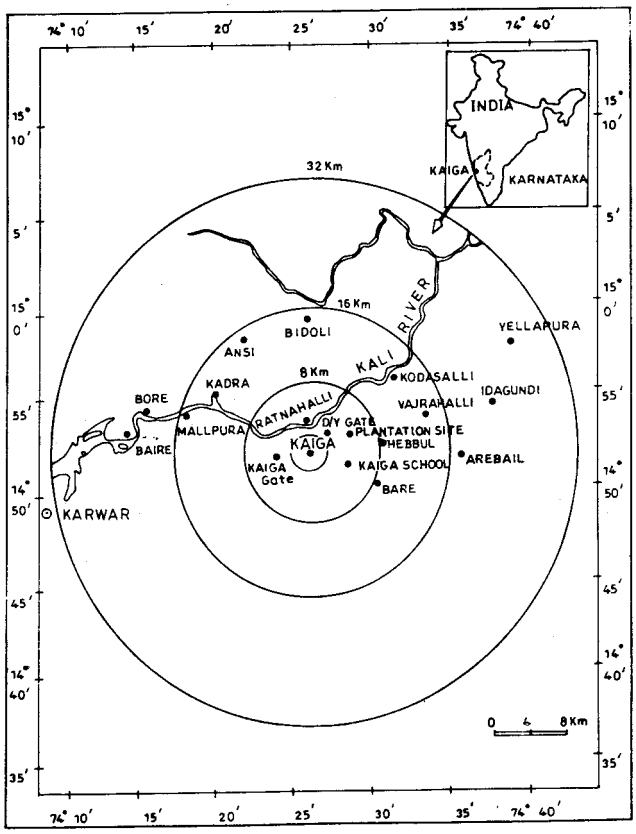

Fig. 1. Area covered under the investigation and sampling stations in Kaiga environment.

Sample processing

All samples were processed following the standard procedure (EML Procedure Manual 1983). Soils were well mixed after removing extraneous materials such as roots, mat portions, pieces of stones, and gravel. Samples were weighed and then dried overnight in an oven at 105°C and re-weighed to find the water content. After mixing thoroughly, the samples were shaken in a sieve shaker and particle sizes of $<$250 microns factions were obtained. The sieved samples were sealed in 300 mL plastic containers and subjected to gamma spectrometry to determine the activity. Organic matter content was estimated by weight loss on ignition at 550°C in a muffle furnace.

Vegetation samples were dried overnight at 110°C in an electric oven to obtain a constant dry weight. After drying, the samples were powdered and charred under low flame and then ashed at 400°C to get a uniform white ash. The ashed samples were then sealed in 2 cm diameter $\times$ 8 cm high plastic vials for the determination of ^{137}Cs activity.

Activity determination

A 90-cc p-type coaxial HpGe (PGT) detector with an efficiency of 18% and a resolution of 1.9–2 keV at 1.33 MeV (with associated electronics procured from EG&G ORTEC[§]) was employed for the measurement of ^{137}C concentration in soil samples. The detector was enclosed in a 10-cm-thick graded lead shield. The spectrum was acquired and analyzed by employing a PC based 8K multichannel analyzer[§] and associated

[§] EG&G ORTEC, 100 Midland Road, Oak Ridge, TN 37831-0895.

software. Detector efficiency calibration was performed using the IAEA quality assurance reference materials; RG U-238, RG Th-232, RG K-1 and SOIL-6 procured from IAEA. The standard material and the samples were taken in the same size and same type of containers so that detection geometry remained the same. Samples were counted long enough to reduce the counting error. ^{137}Cs concentration was inferred using the full absorption peak count rate at 662 keV after applying the Compton correction. The minimum detection limit (MDL) for the detector at 95% confidence level for a counting time of 43,200 s and for a sample weight of 275 g was 0.15 Bq kg^{-1}.

To determine the activity in ashed vegetation samples a 3 × 3 inch well type NaI(Tl) detector[‖] was employed. The detector was housed in a 12-cm graded lead shield. The gamma spectra were recorded using a 1K multichannel analyzer.[§] The efficiency calibration of the detector was performed by using the radioactive standards procured from IAEA, mentioned just above. Standards were prepared in 2 cm diameter × 8 cm height plastic vials. The ashed samples, which were sealed in plastic vials, were counted using this detector for 30,000 s. The spectrum was analyzed by simultaneous equations method (Abani 1994). The MDL for this spectrometer was 0.2 Bq kg^{-1} (at 95% confidence level for a counting time of 30,000 s and for a sample weight of 7 g).

[‖] Bicron, Saint-Gobain Industrial Ceramics, Inc., 12345 Kinsman Road, Newbury, OH 44065.

Inter-comparison measurements

Inter-comparison measurements were carried out to check the reliability of the measurements. After processing, 8 soil samples were sent to Environmental Assessment Division, Bhabha Atomic Research Centre (BARC), Mumbai, for determining the ^{137}Cs activity by gamma spectrometry. The detector used in BARC was a 54-cc HpGe with a relative efficiency of 15%. The results of these inter-comparison measurements showed a good agreement. The deviation in the results of two laboratories was found to be less than 10%.

RESULTS AND DISCUSSION

^{137}Cs in soil

Table 1 gives the results of ^{137}Cs activity in soil samples of three different depths (0–5, 5–10, and 10–25 cm) of Kaiga and surrounding environs. The range, mean, median, and standard deviation (SD) for each depth are also presented at the bottom of each column. The activity of ^{137}Cs in the surface soil ranges from BDL to 65.4 Bq kg^{-1} in the entire study region with an overall mean value of 26.5 Bq kg^{-1}. It is clear from the table that the activity in 0–5 cm soil profile is more or less uniform in the 8-km zone. But it varies widely in the 16- and

Table 1. Depth profiles of ^{137}Cs in soil.

Sampling Station Code	Name of the sampling station	Activity (Bq kg^{-1})		
		0–5 cm	5–10 cm	10–25 cm
8-km Zone				
S1	Dump Yard Gate	38.4 ± 1.2[a]	14.9 ± 0.6	9.2 ± 0.6
S2	Kaiga Gate	35.1 ± 1.1	24.8 ± 1.0	15.8 ± 0.9
S3	Kaiga School	38.4 ± 1.2	17.6 ± 0.9	15.9 ± 0.9
S4	Plantation Site	22.7 ± 0.8	19.9 ± 0.8	13.1 ± 0.8
S5	Ratnahalli	35.4 ± 0.9	28.5 ± 0.9	22.5 ± 0.8
	Median	35.4	19.9	15.8
16-km Zone				
S6	Ansi	65.4 ± 1.8	61.5 ± 2.0	23.2 ± 1.4
S7	Mallapura	37.0 ± 1.2	36.0 ± 1.2	12.4 ± 0.7
S8	Kodasalli	21.7 ± 0.9	9.6 ± 0.7	2.6 ± 0.6
S9	Vajrahalli	30.2 ± 1.6	21.7 ± 1.4	1.6 ± 0.6
S10	Bare	13.1 ± 0.8	11.3 ± 0.6	8.9 ± 0.6
S11	Bidoli	5.1 ± 0.7	2.0 ± 0.6	BDL[b]
S12	Hebbul	1.9 ± 0.6	BDL	BDL
	Median	21.7	11.3	2.6
32-km Zone				
S13	Bore	32.2 ± 1.2	10.7 ± 1.0	4.6 ± 0.7
S14	Baire	33.2 ± 1.0	14.7 ± 0.8	2.9 ± 0.7
S15	Arebail	6.3 ± 1.0	3.2 ± 0.8	2.5 ± 0.9
S16	Idagundi	8.3 ± 0.7	7.2 ± 0.7	5.3 ± 0.6
S17	Yellapura	BDL	BDL	BDL
	Median	8.3	7.2	2.9
	Range	BDL-65.4	BDL-61.5	BDL-23.2
	Mean	26.5[c]	18.9	10.0
	Median	30.2	14.7	5.3
	SD	17.4	15.4	7.7

[a] ± indicates the counting error.
[b] If the activity of the sample is less than the Minimum Detection Level (MDL) it is reported as BDL (Below Detection Level).
[c] BDL values were excluded when calculating mean values.

32-km zones. The median value of activity is highest in the 8-km zone and it decreases in the 16-km zone and further decreases in the 32-km zone. The region under the 8-km zone is surrounded by hills (ridges of Kali river) from all sides, and it is just like a bowl with Kaiga being at the bottom of the bowl. The hills and dense forest surrounding all the sides may just be acting as a trapping bowl for the aerosols resulting in the higher fallout in the 8-km zone.

The ^{137}Cs activity was also estimated in terms of Bq m^{-2}, and the same was found to vary from BDL to 4,251 Bq m^{-2} in the entire region with a mean value of 1,724.1 Bq m^{-2}. The effective dose commitment for the population due to external exposure, due to the presence of ^{137}Cs in soil, was also evaluated using the dose conversion factor (97 nSv Bq m^{-2}) given in UNSCEAR (1993). The activity observed in the 0–5 cm soil profile was employed for the dosimetric calculations. The effective dose commitment thus calculated for Kaiga region was found to have a mean value of 167.2 μSv.

It is interesting to note from Table 1 that the ^{137}Cs concentration decreases with increasing soil depth. To study the variation of ^{137}Cs activity in deeper layers of the soil (>25 cm) samples were also collected down to a depth of 70 cm with 3 more depth intervals 25–40, 40–55, and 55–70 cm from the sampling station Kaiga School and analyzed. The results show that the activity decreases with the increasing soil depth, and it is below detection level in 25–40 cm soil profile and in subsequent profiles. This shows that the ^{137}Cs deposited on surface soil through fallout is able to move down to a maximum depth of 25 cm in Kaiga soil. Numerous reports suggest that the ^{137}Cs deposited on soil through fallout is strongly fixed on the surface soil and has small mobility and would normally be able to move down to a depth of 15 cm (Durrance 1986; Russell 1965). A study conducted by Livens and Baxter (1988) on soil of enhanced ^{137}Cs concentration showed that ^{137}Cs is held on the top 15 cm of soil profiles, suggesting small mobility.

The results of ^{137}Cs activity obtained in the present study for the soil samples of Kaiga region are compared with the literature values reported for other environs in Table 2. Kamath et al. (1996) have reported results of ^{137}Cs activity in soils collected from 19 different cities of India and the reported activity range was from BDL–6.7 Bq kg^{-1}. It is clear from Table 2 that the ^{137}Cs activity observed in the soils of Kaiga environs is significantly higher when compared to the literature values reported by Kamath et al. (1996) and by other investigators for different environs of India.

Kaiga region has a humid climate with a moisture index of greater than 20 (ICAR 1992). The region also experiences a high precipitation rate. It is known that the presence of ^{137}Cs in soil is directly proportional to the amount of rainfall as 80 to 90% of ^{137}Cs is water soluble. As already mentioned, the average annual rainfall in Kaiga for the period of 1987–1997 is 3,786 mm (Adiga et al. 1997). This rainfall is significantly higher when compared to the rainfall of surrounding region. Therefore, a continuous supply of ^{137}Cs through rain must be the reason for the observed higher levels of this radionuclide in the region. Studies conducted by Kamath et al. (1996) in Mumbai region

Table 2. Comparison of ^{137}Cs activity in soil.

Activity (Bq kg^{-1})			
Present work (Kaiga region)	Literature values	Region	Reference
BDL-65.4 (26.5)[a]	BDL-14.43	Kalpakkam, India	Iyengar et al. (1979)
	BDL-6.7[b]	All India	Kamath et al. (1996)
	5.2–9.5	Mumbai, India	Shukla et al. (1987)
	1.3	Trichirappali, India	Shukla et al. (1987)
	BDL-21.6	Coastal Karnataka, India	Siddappa et al. (2000)
	0.01–22.6	World wide range	Cox and Barry (1984)

[a] Value given in the parenthesis is the mean value.
[b] Activity range for samples collected from 19 cities of India.

Table 3. Seasonal variation of ^{137}Cs activity in soil.

		Activity (Bq kg^{-1})	
Location	Soil depth	Pre-monsoon[a]	Monsoon[b]
Mallpura	0–5 cm	23.9 ± 1.2[c]	32.4 ± 1.2
Kaiga Gate	0–5 cm	26.7 ± 1.1	38.6 ± 1.1
Kaiga School	0–5 cm	34.1 ± 1.1	39.2 ± 1.2
Plantation Site	0–5 cm	15.1 ± 0.8	16.8 ± 0.8
	Mean	25.0	31.8

[a] Pre-monsoon samples were collected in the month of May.
[b] Monsoon samples were collected in the month of August.
[c] ± indicates the counting error.

showed a clear increase in the activity of ^{137}Cs in rainy season. Cox and Barry (1984) have reported a positive correlation between the ^{137}Cs activity in soil and rainfall for Hawaii.

In order to verify the possibility of higher fallout of ^{137}Cs along with rain in Kaiga region seasonal variation studies were carried out. Table 3 presents the variation of ^{137}Cs activity in 0–5 cm soil profile collected in pre-monsoon and monsoon seasons. The pre-monsoon samples were collected in May 1997, and monsoon samples were collected in August 1997. It is obvious from the results of each sampling station as well as from the mean values presented at the bottom of the table that monsoon samples show relatively higher activity when compared to the pre-monsoon samples. This confirms the higher fallout of ^{137}Cs along with rain in the rainy season.

Once deposited on the soil through fallout, the movement and leaching of ^{137}Cs is controlled by the chemical composition of the soil and its physical properties. The sampling stations shown in Table 1 can be classified into two categories depending upon their organic matter content. Soils collected from sampling stations S1 to S9, S13 and S14 (all from dense, closed canopy, forests region) were rich in their organic matter content. Soils in these sampling stations were covered by a layer of dead leaf litter and the organic matter content of 0–5 cm soil profile varied in the range 121–197 g kg^{-1}. Soils collected in the remaining stations showed a lesser organic matter content, varying in the range 20–72 g kg^{-1}. It is interesting to note from Table 1 that the soils belonging to the category that are rich in their organic matter contents show significantly higher ^{137}Cs activity when compared to the other samples. The higher level of organic matter in soil results in a higher negative pH in surface horizons. Further, the higher levels of organic matter in soil also results in higher cation exchange capacity of soil. Soil, which has higher negative pH and cation exchange capacity, tends to fix ^{137}Cs more strongly. This type of fixation resembles the well-known fixation by soils and clays of the ions K^+, NH_4^+, Rb^+, and Cs^+ (Marel 1954). The radii of these cations approach most closely the radii of the gaps in the lattice of the clay minerals present in soils. A detailed study reported by Miller et al. (1990) showed that soils collected from forest areas showed significantly higher activity when compared to the soils of field areas, and the higher activity in forest soil was attributed to the higher organic matter content (2–5 times higher than the soils from field areas). Similar findings were reported by other investigators (Rommelt et al. 1990; Bergeijk et al. 1992; Durrance 1986; Russell 1965; Rogowski and Tamura 1965; Menzel 1965; Livens and Baxter 1988; Gersper 1970; Lowe 1978).

All the soil samples also were analyzed for the ^{210}Po activity concentration. The results showed significantly higher concentrations of ^{210}Po (ranging from 17.1 to 228.2 Bq kg^{-1} with a mean value of 83.3 Bq kg^{-1}). The details of the measurement and results are published elsewhere (Karunakara et al. 2000). The study also showed that the reason for higher activity of ^{210}Po in

Table 4. ^{137}Cs activity in vegetation.

Species	Plant part	Activity (Bq kg^{-1} dry wt)	Transfer factor (TF)
Terminalia paniculata Roth. [Banpu][a]	Bark	3.0–6.5 (3.1)[b]	0.08–0.17 (0.08)
	Branches	BDL[c]-3.5 (2.4)	BDL-0.09 (0.06)
	Leaves (50 cm^2)[d]	3.8–4.7 (4.0)	0.10–0.12 (0.10)
Careya arborea Roxb. [Daddala]	Bark	BDL-5.0 (2.9)	BDL-0.13 (0.07)
	Branches	BDL-4.9 (2.8)	BDL-0.13 (0.07)
	Leaves (90 cm^2)	BDL-4.0 (3.9)	BDL-0.11 (0.05)
Dillenia pentagyna Roxb. [Kanagilu]	Leaves (1,000 cm^2)	BDL	BDL
Microcos paniculata L. [—]	Leaves (30 cm^2)	BDL	BDL
Calycopteris floribunda (Roxb.) Poir [Enjir]	Leaves (30 cm^2)	6.2 ± 0.7[e]	0.16
Tamarindus indica L. [Hunase]	Leaves (1 cm^2)	3.3 ± 0.6	0.08
Tectona grandis L.F. [Saguvani]	Bark	BDL	BDL
	Leaves (600 cm^2)	4.8 ± 0.4	0.12
Cymbidium aloifolium (Lo) Swartz. [Kharana] {3}[f]	Whole plant	31.3 ± 1.2	0.8
Petrobryopsis tumida (Hook) Dix. [Tree Moss] {3}	Whole plant	15.7 ± 1.1	0.4

[a] In bracket shows the common name of each species.
[b] Value given in the parenthesis is the mean value of 4 measurements.
[c] If the activity of the sample is less than the Minimum Detection Level (MDL) it is reported as BDL (Below Detection Level).
[d] Values given in the parenthesis just below the word 'leaves' are the average leaf surface area per leaf.
[e] ± indicates the counting error.
[f] Values given in the braces are the number of samples analyzed.

Table 5. Seasonal variation of ^{137}Cs in vegetation.

Location	Vegetation species	Activity (Bq kg^{-1})	
		Pre-monsoon[a]	Monsoon[b]
Kaiga School	*Terminalia paniculata* Roth.	4.3 ± 0.5[c]	4.7 ± 0.6
	Careya arborea Roxb.	BDL[d]	BDL
Kaiga Gate	*Terminalia paniculata* Roth.	3.7 ± 0.5	4.2 ± 0.4
	Careya arborea Roxb.	1.8 ± 0.6	BDL
Mallpura	*Terminalia paniculata* Roth.	4.1 ± 0.6	4.2 ± 0.4
	Careya arborea Roxb.	1.5 ± 0.3	4.0 ± 0.4
Plantation Site	*Terminalia paniculata* Roth.	1.9 ± 0.3	3.8 ± 0.4
	Careya arborea Roxb.	0.7 ± 0.3	3.5 ± 0.3
	Terminalia paniculata Roth.		
	Mean	3.5	4.2
	Median	2.8	4.0
	Range	1.9–4.3	3.7–4.8
	Careya arborea Roxb.		
	Mean	1.3	3.8
	Median	1.5	3.9
	Range	BDL-1.8	1.9–4.3

[a] Pre-monsoon samples were collected in the month of May.
[b] Monsoon samples were collected in the month of August.
[c] ± indicates the counting error.
[d] If the activity of the sample is less than the Minimum Detection Level (MDL) it is reported as BDL (Below Detection Level).

Kaiga environs is the higher atmospheric deposition. The correlation plot (Fig. 2) of ^{137}Cs and ^{210}Po distribution in the 0–5 cm soil profile shows a good correlation, the correlation coefficient being $r = 0.85$. It is known that the major source of ^{210}Po in the surface soil is the atmospheric deposition of ^{222}Rn progeny. A good correlation observed in the distribution of ^{137}Cs and ^{210}Po indicates that the reason for the higher activity of these radionuclides in soils of Kaiga is the higher fallout rate.

^{137}Cs in plants

Nine predominant tree species, one orchid species, and one moss species of Kaiga environs were analyzed for their ^{137}Cs activity, and the results are presented in Table 4. The botanical names of the plant species along with their popular names are given in column 1 of Table 4. Tree species were selected depending upon the surface area of their leaves. The average surface area per leaf varied from 1 cm^2 to 1,000 cm^2. All the samples were collected in the monsoon season (August) of year 1997. Further, all species selected for the present study, except orchid and moss, have similar growing habits like weathering and shedding in the same season.

It can be seen from Table 4 that the ^{137}Cs activity in leaves in different annual terrestrial plants varies from BDL to 6.5 Bq kg^{-1}. It is interesting to note that the activity in orchid *Cymbidium aloifolium* (Lo.) Swartz. and moss *Pterobryopsis tumida* (Hook.) Dix. (both are epiphytic plants), is an order of magnitude higher than that in the annual terrestrial plants. These orchid and moss species grow on other trees, and they depend on the host tree only for support and not for their nutrients. They derive the nutrients from atmospheric moisture and dust particles by continuously absorbing them. As a result of this, the ^{137}Cs that is attached to the dust particles are absorbed and accumulated by these plants over a period of time resulting in the higher activity. The present results regarding the orchid and moss family supports the findings reported by Hasanen (1972) that moss and lichen have a strong ion exchange capacity and are able to hold, in addition to nutrients, the nuclides that are transported through rain water and moisture. Many authors have reported higher levels of ^{137}Cs in moss and lichen (Kljaic et al. 1982; Holm et al. 1982; Dean et al. 1982; Schuettelkopf and Kiefer 1982). Svensson and Liden (1965) suggested the use of moss and lichen as a natural integrating fallout meter. Therefore, the orchid species *Cymbidium aloifolium* (Lo.) Swartz. and the moss species *Pterobryopsis tumida* (Hook.) Dix. can be

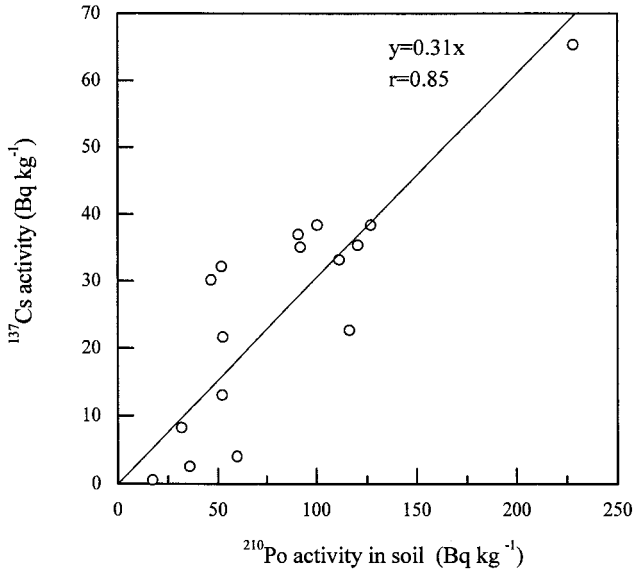

Fig. 2. Correlation between ^{210}Po and ^{137}Cs.

used as bio-indicators in the environment of Kaiga to monitor the release of ^{137}Cs, if any, from the nuclear power station operating in Kaiga.

From the results of the ^{137}Cs activity concentration in soil (Table 1) and vegetation (Table 4) the soil-to-plant transfer coefficients, which are defined as the ratio of ^{137}Cs activity in plant (Bq kg^{-1} in dry weight) to that in soil, were calculated and the results are presented in the last column of Table 4. It can be seen from the table that leaves and bark of different plants show a similar range of transfer coefficients.

Table 5 presents the results of seasonal variation studies in leaf samples of two predominant tree species *viz. Terminalia paniculata* Roth. and *Careya arborea* Roxb. The mean values of activity concentration for each species given at the bottom of Table 5 indicate that the samples collected in the monsoon season show higher activity when compared to pre-monsoon samples which confirms the higher fallout of ^{137}Cs along with rain.

CONCLUSION

The activity concentration of ^{137}Cs in soil samples of Kaiga region is significantly higher when compared to the literature values reported for other parts of India. This is traced to the higher fallout rate due to special geographical terrain, heavy rain fall, dense vegetation, and retention of deposited ^{137}Cs by soil organic matter. Vertical profiles of ^{137}Cs show a sharp decrease in the activity concentration with the increasing soil depth and the activity is below detection limit for soil depth more than 25 cm. The epiphytic plants *Cymbidium aloifolium* (Lo.) Swartz. and *Petrobryopsis tumida* (Hook.) Dix. show higher levels of ^{137}Cs. These two species, which are abundant in Kaiga environs, can be used as bio-indicators to monitor the fallout radionuclides in the environment of Kaiga. Soil samples collected in the monsoon season show relatively higher levels of ^{137}Cs when compared to pre-monsoon season suggesting deposition of ^{137}Cs along with rain.

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