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Distribution and enrichment of ^{210}Po in the environment of Kaiga in South India

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Abstract

Several soil and vegetation samples from the environment of Kaiga nuclear power plant site in the south western region of India were analysed for ^{210}Po. The vertical profile, particle-size distribution, seasonal variation and the dry deposition rate of ^{210}Po were measured employing the chemical method and α – counting technique. ^{210}Po activity in soil varies from 17.1 to 228.2 Bq kg^{-1} with a mean value of 83.3 Bq kg^{-1}. The activity of ^{210}Po is higher in the surface soil (0–5 cm) and decreases as depth increases to 20 cm and remains nearly constant thereafter. The activity concentration is almost uniform in the grain sizes of 350–177 μm and below 177 μm. *Pterobryopsis tumida* (Hook.) Dix, a plant of the moss family, shows a very high level of ^{210}Po activity — 2724 ± 13 Bq kg^{-1}. Seasonal variation studies show elevated levels of ^{210}Po in vegetation during winter. The annual dry deposition rate of ^{210}Po was 53.4 Bq m^{-2} yr^{-1}. © 2000 Elsevier Science Ltd. All rights reserved.

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1. Introduction

^{210}Po occurs widely in nature and is an important component of man's natural radiation background. Its presence in soils may be traced to the decay of

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radionuclides of the ^{238}U chain in the soil. This decay leads to the formation of ^{222}Rn. ^{222}Rn has a half-life of 3.82 d which allows time for its diffusion from soil to atmosphere. The fraction of ^{222}Rn escaping into the air can vary in the range of 18–87% depending upon soil type (Parfenov, 1974). In the atmosphere, ^{222}Rn decays into ^{210}Pb and ^{210}Bi. The radionuclides are no longer in the gaseous form and attach to airborne particles. These airborne particles are then carried back to the earth's surface through fallout resulting in the deposition of ^{210}Pb and ^{210}Bi. During the process of fallout, the airborne particles may be intercepted by plants or return to the top soil. In addition to this, ^{222}Rn can decay in the soil itself leading to the formation of ^{210}Po in the soil.

The ^{210}Po content of soil varies with soil type. According to Berger, Erhardth and Francis (1965), organic soils contain three times as much ^{210}Po as mineral soils. Ladinskaya (1971) found differences between the ^{210}Po contents of black earth and brown soils. A detailed study conducted by the US Atomic Energy Agency on the ^{210}Po contents of different types of soils of USA revealed $28.9 \sim 58.8$ Bq kg^{-1} of ^{210}Po (USAEC, 1980).

According to Mayneord, Turner and Radley (1960), approximately 84% of the α–activity of plants is due to ^{210}Po. It is reported that the ^{210}Po content in plants is the result of the direct deposition of ^{222}Rn daughters from atmospheric precipitation (Ermolaeva-Makovskaya, 1969; Berger, Erhardth & Francis, 1965; Hill, 1960). Plants may get radioactive nuclides in two ways (i) by the deposition of radioactive fallout on the plants directly and (ii) by absorption from the soil.

Therefore, a detailed study of ^{210}Po in soil and other environmental samples of a region constitutes an important aspect which assumes a special significance in the environment of a region chosen for building a nuclear power station, since such a study would help in the impact assessment of the nuclear power plant on the environment. In view of these points, a systematic study has been carried out on ^{210}Po in soil and vegetation samples of Kaiga (14°51′08″N, 74°26′40E) and its environs in the south-western part of India, where two nuclear power plants, each of 235 MWe capacity, are under construction. The vertical profile of ^{210}Po in soil, variation of activity with particle size, activity concentration in vegetation, seasonal variation of activity and dry deposition rate were studied.

2. Materials and methods

2.1. Sample collection

Samples of soil and vegetation were collected in the different seasons during May 1997–June 1998. For soil samples, undisturbed level surfaces situated sufficiently away from the public road and buildings were selected. The soil sampling stations are shown in Fig. 1. About 1 m^2 area was marked and the top layer of the soil which contains vegetation and roots was removed. The soil was then dug down to a depth of 5 cm, mixed thoroughly, and about 2 kg of the soil sample was collected in a polythene bag. In order to study the vertical distribution of radionuclides, samples were

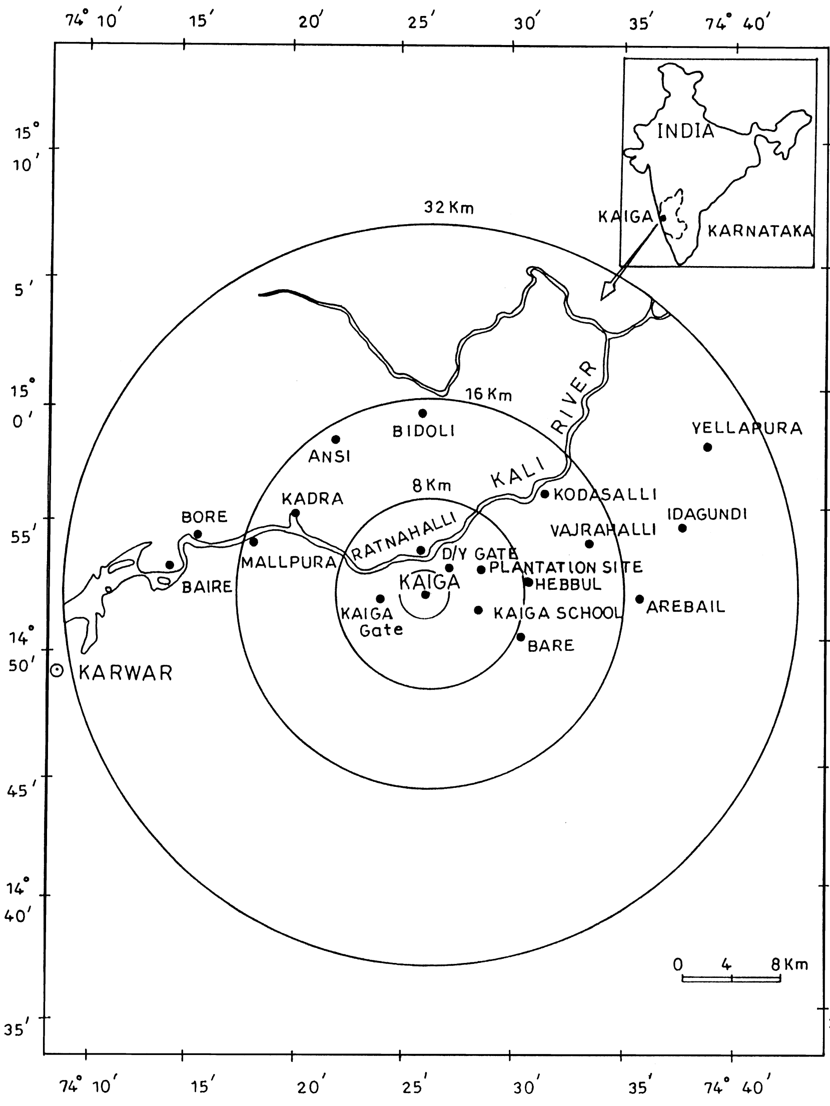

Fig. 1. Area covered by the investigation and sampling stations in the Kaiga environment.

collected from different soil depths, viz. 5–10 and 10–25 cm, at all the sampling stations using a conventional augur sampler. At Kaiga School sampling station, samples were collected down to a depth of 70 cm with three more depth intervals viz. 25–40, 40–55 and 55–70 cm. To find the difference in the activity concentration between cultivated and uncultivated soils, samples were also collected in the cultivated land at Kaiga School, Plantation Site and Dump Yard Gate sampling stations.

For the determination of ^{210}Po in the vegetation of the Kaiga environment, 11 species were selected. The botanical names of these plant species along with their popular names are given in the first column of Table 4. All the vegetation samples were collected from the Kaiga School sampling station in the monsoon season (August) of 1997. Leaves, branches and bark samples of these species were collected and sealed in separate polythene bags. Leaves well exposed to the atmosphere were collected from the trees. A single composite sample of small and equal quantities 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 were collected in polythene bags and fresh weights were determined.

Apart from this, the two most commonly observed tree species of the region, *Terminalia Paniculata* Roth. and *Careya arborea* Roxb., were selected to study the seasonal variation in ^{210}Po activities. The sampling stations selected for the seasonal variation studies are given in the first column of Table 5. Leaf samples of tree species were collected in summer (May, 1997), monsoon (August, 1997) and winter seasons (December, 1997).

2.2. Sample processing

All samples were carefully processed following the standard procedure (Volchok & de Planque, 1983). Soils were well mixed after removing extraneous materials such as roots, mat portions, pieces of stones and gravel. They were then transferred to porcelain dishes and dried in an oven at 110°C till a constant dry weight was obtained. From the fresh and dry weights, the moisture percentages of the samples were determined. The samples were then crushed into fine powder and sieved through different meshes to obtain different grain sizes. Vegetation samples were dried and powdered and a definite weight of the sample was taken for activity measurement.

2.3. Activity measurement

The electrochemical deposition method was employed for the determination of ^{210}Po activity (Khandekar, 1977; Iyengar, Rajan, Ganapathy & Kamath, 1980). About 20 g of soil was leached with 4 M HNO_3 and then the organic matter present in the sample was destroyed by digestion adding $HNO_3 + H_2O_2$ mixture in small increments to get a white residue. The sample was then converted into 0.5 M HCl medium and ^{210}Po in the solution was deposited onto a silver disc shaking at 97°C for 6 h. The silver disc α-activity was then counted using a ZnS(Ag) detector of 32% counting efficiency. In the case of vegetation, dried samples were digested directly with $HNO_3 + H_2O_2$ mixture and converted into 0.5 M HCl medium. ^{210}Po was then deposited onto a silver disc and counted in the same way.

The average chemical recovery of ^{210}Po by this method was $94 \pm 2\%$. All the samples were processed and analysed within 20 d from the date of collection.

2.4. *Determination of dry deposition rate of ^{210}Po*

In order to determine the dry deposition rate of ^{210}Po, dry fallout samples were collected during the period May–June, 1998. Four surrogate collectors (Al trays of 1 m^2 area and 5 cm depth) were exposed in the open field at Kaiga. The collectors were kept 2 m above the ground level to avoid any soil particles being thrown onto the collector from the ground (Volchok & de Planque, 1983; Anand & Rangarajan, 1990). Two sets of trays were kept at each sampling station which are 4 km apart. A layer of grease was maintained to prevent the loss of deposited aerosols by breeze. The trays were exposed for a period of 40 d. At the end of the collection period, the trays were washed with distilled water and the washings were collected separately. Once washing was over, the samples were acidified with a few drops of 8 M HCl. Samples were first evaporated and then subjected to electrochemical separation in the way described before and the ^{210}Po activity was measured. From the measured values, the average annual ^{210}Po deposition per m^2 was estimated. For the purpose of comparison, two surrogate collectors were also exposed simultaneously in the premises of Mangalore University Campus and were processed similarly.

3. Results and discussion

3.1. *Activity of ^{210}Po in soil*

Table 1 gives the results for ^{210}Po activity in soil samples at three different depths (0–5, 5–10 and 10–25 cm). Results are presented in zones, viz. 8 km, 16 km and 32 km zones along with the respective mean values of activity concentration. The range, mean, median, standard deviation and the coefficient of variance for the entire study region are presented at the bottom of the table.

It can be observed from Table 1 that the ^{210}Po activity in surface soils (0–5 cm depth) collected from the 8 km zone (Kaiga plant site region) fall within $\pm$ 20% of the respective mean value (111.2 Bq kg^{-1}) and, consequently, the distribution of ^{210}Po may be regarded as nearly uniform in the surface soil of the 8 km zone. The surface soils collected from the 16 km zone and the 32 km zone show wide variation in their ^{210}Po activities and their respective mean values are lower than the mean value for the 8 km zone.

It is interesting to note from Table 1 that the ^{210}Po concentration decreases with increasing soil depth in all the sampling stations. To study the variation of ^{210}Po activity in deeper layers of the soil ($>$ 25 cm), samples were collected up to a depth of 70 cm with 3 more depth intervals, 25–40, 40–55 and 55–70 cm, from the Kaiga School sampling station and analysed. The results are plotted in Fig. 2. A sharp decrease in the activity is observed with increasing depth down to 20 cm, remaining constant thereafter. This observation shows that the main source of ^{210}Po in surface soil is from the deposition of ^{222}Rn daughters. The results also indicate that ^{210}Po which is deposited on the soil from the atmosphere is able to move down to a maximum depth

Table 1
Depth profiles of ^{210}Po in Kaiga soil

Location	Activity (Bq kg^{-1})		
	0–5 cm	5–10 cm	10–25 cm
8 km Zone			
Kaiga gate	92.0 ± 1.5[a]	23.7 ± 0.7	11.8 ± 0.4
Plantation site	116.3 ± 1.8	63.9 ± 1.5	42.1 ± 1.2
Dump yard gate	100.3 ± 1.7	44.4 ± 1.0	15.4 ± 0.5
Kaiga school	126.9 ± 2.2	26.7 ± 1.0	11.4 ± 0.6
Ratnahalli	120.5 ± 1.6	87.0 ± 1.6	67.0 ± 1.2
Mean	111.2	49.1	29.5
16 km Zone			
Ansi	228.2 ± 3.9	142.4 ± 2.6	26.2 ± 1.1
Bare	52.1 ± 1.5	51.0 ± 1.5	39.7 ± 1.4
Bidoli	59.7 ± 1.5	32.8 ± 1.1	16.7 ± 0.8
Mallapura	90.9 ± 1.7	37.2 ± 1.1	18.2 ± 0.8
Kodasalli	52.4 ± 2.1	47.8 ± 2.0	35.3 ± 1.5
Vajrahalli	46.5 ± 1.8	7.3 ± 0.7	4.2 ± 0.5
Mean	88.8	53.1	23.4
32 km Zone			
Arebail	35.8 ± 1.3	20.0 ± 0.9	14.5 ± 0.9
Baire	111.3 ± 1.6	54.1 ± 0.6	21.8 ± 0.7
Bore	51.7 ± 1.4	24.9 ± 0.8	20.2 ± 0.6
Idagundi	31.8 ± 1.3	25.0 ± 1.2	12.0 ± 0.8
Yellapura	17.1 ± 0.8	12.4 ± 0.7	10.2 ± 0.7
Mean	49.5	27.3	15.7
Range	17.1–228.2	7.3–142.4	4.2–67.0
Mean	83.3	43.8	22.9
Median	75.3	35.0	17.5
SD	52.1	33.3	16.0
CV (%)	62.5	76.0	69.9%

[a] ± indicates the counting error.

of about 20 cm in the soils of the Kaiga environs. The activity in the deeper layers is purely due to the decay of ^{222}Rn and its daughters in the soil itself.

To find the difference in ^{210}Po activities between the forest soil and the surrounding cultivated soil, samples were also collected from the cultivated land of Kaiga school, plantation site and dump yard gate and analysed. The samples from the cultivated soil (0–5 cm depth) showed significantly lower activity (21.8 ± 1.3 Bq kg^{-1} at plantation site, 38.7 ± 1.6 Bq kg^{-1} at Dump yard gate and 53.5 ± 2.1 Bq kg^{-1} at Kaiga school) as compared to the forest soil which are shown in Table 1. The lower activity in the cultivated soils may be attributed to the mixing of soil during the cultivation process and also to the washout of ^{210}Po from the surface soil. Reduction in the activity of

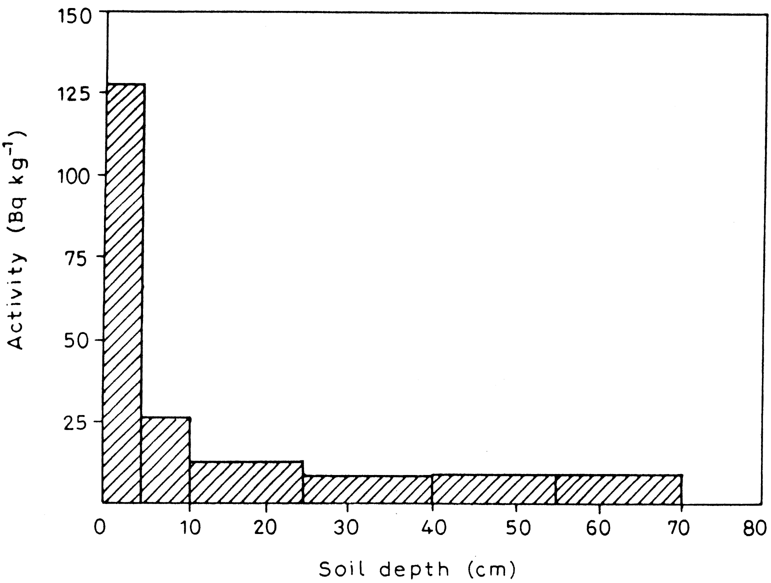

Fig. 2. Variation of ^{210}Po activity with soil depth.

Table 2
Comparison of ^{210}Po activity in the surface soils with previous data

Activity (Bq kg^{-1})	Region	Reference
17.1–228.2	Kaiga, India	This work
44.4	Kalpakkam, India	Iyengar et al. (1980)
7.6–37.3	Mysore, India	Nagaiah, Malini, Paramesh, Venkataramaiah & Raghavayya (1995)
1.3–13.7	Ullal, India	Radhakrishna, Somashekarappa, Narayana & Siddappa (1993)
3.6–45.2	Coastal Karnataka, India	Siddappa, Balakrishna, Radhakrishna, Somashekarappa & Narayana (1994)
28.86–58.83	Colorado, Iowa, Wisconsin USA	US Atomic Energy Agency (1980)
78.1	Wyoming, USA	Ibrahim and Whicker (1987)
8.1–128.3	USA (Country wide)	Myrick, Berven & Haywood (1983)
33.3–207.2	Black forest, Germany	Schuttelkopf and Kiefer (1982)
32.07–70	CIPC, Brazil	Santos, Gouvea, Dutta & Gouvea (1990)
8.14–219	World range	Parfenov (1974)

^{210}Po in the upper soil strata has been reported by Schuttelkopf and Kiefer (1982). Also, the forest soil is covered with a layer of dead leaf litter and other decayed matter which prevents the surface soil from being exposed to weathering.

In Table 2 the results of ^{210}Po activity in the soils of Kaiga environs are compared with the literature values reported for other environs. From Table 2 it is clear that the

^{210}Po concentration in Kaiga soil is higher than in the samples from other Indian environs and also in the samples from the United States of America. The ^{210}Po activity of Kaiga soil is also high when compared to the results reported for samples from some of the high background areas of CIPC, Brazil and the Black Forest of Germany. The activities in some soil samples of Kaiga exceed the world range.

All the soil samples were also analysed for ^{226}Ra by γ–ray spectrometry employing a 90 cm^3 HpGe detector. The ^{226}Ra activity was found to be normal (varying in the range 15.5–61.2 Bq kg^{-1} with a mean value of 34.3 Bq kg^{-1}) in the Kaiga region. The details of the measurement and results are published elsewhere (Karunakara, Avadhani, Mahesh, Somashekarappa, Narayana and Siddappa, 1998). The study also showed that there exists no correlation between the activities of ^{226}Ra and ^{210}Po, suggesting higher atmospheric deposition of ^{222}Rn daughters. The higher deposition could be due to the special geographical terrain of the Kaiga region. The region (especially in the 8 km zone) is surrounded by hills on all sides and is just like a bowl with Kaiga being at the bottom of the bowl. The hills and dense forest surrounding on all sides may just be acting as a trapping bowl for the aerosols.

Table 3 presents the results for the ^{210}Po concentrations in different grain sizes of the soil samples from the Kaiga environs. It is evident that the ^{210}Po activity fluctuates around the mean value for all the three grain sizes and there is no definite correlation with the grain size of the soil. The results confirm the findings of the depth profile studies (Table 1), viz. the activity is highest in the surface soil and decreases with increasing depth.

3.2. ^{210}Po activity in plants

Nine predominant plant species, 1 orchid and 1 moss species from the Kaiga environs were analysed for ^{210}Po activity. These species were selected depending on the surface area of their leaves. The average surface area per leaf varies from 1 to 1000 cm^2. All the samples were collected in the monsoon season (August) of year 1997 from the Kaiga School sampling station. Further, all species selected for the present study, except the orchid and moss, have similar growth habits like weathering and shedding in the same season. The results are presented in Table 4.

It is observed that the leaves exhibit the highest activity. In branch and bark parts, the activity is significantly lower and is almost the same amongst the different plants species. Since leaves are directly exposed to the natural fallout, the observed high activity concentration proves the higher contribution of atmospheric precipitation to the ^{210}Po activity. An attempt was made to find the correlation between the ^{210}Po concentration in leaves and their surface area. The relation between the leaf surface area and the ^{210}Po activity is shown in Fig. 3. The correlation coefficient is found to be 0.83 which is significant at 95% confidence level. Numerous reports have demonstrated that fallout radionuclide concentrations in plants are from materials deposited directly upon, entrapped by, or absorbed by their exposed aerial surfaces (Osburn, 1965; Hill, 1965). According to Parfenov (1974), the content of ^{210}Po in a plant depends mainly on its leaf surface area. Also, Santos, Gouvea, Dutta and Gouvea (1990) reported that the parts directly exposed to natural fallout contain the greatest

Table 3
Grain size analysis of ^{210}Po activity in soil samples

Location	Grain size (μm)	Activity (Bq kg^{-1})		
		0–5 cm	5–10 cm	10–25 cm
Ansi	350–250	287.7 ± 5.4[a]	128.3 ± 2.1	11.6 ± 0.8
	250–177	234.4 ± 5.1	109.0 ± 3.2	17.7 ± 1.3
	< 177	242.1 ± 4.5	116.8 ± 3.7	15.3 ± 1.0
	Mean	254.7	118.0	14.9
Arebail	350–250	47.5 ± 2.0	19.7 ± 1.2	12.0 ± 0.9
	250–177	38.8 ± 1.8	19.9 ± 1.5	10.5 ± 1.0
	< 177	30.1 ± 1.3	19.2 ± 1.0	7.6 ± 0.8
	Mean	38.8	19.6	10.0
Bare	350–250	46.6 ± 1.7	39.4 ± 1.4	27.4 ± 1.2
	250–177	46.2 ± 1.6	45.2 ± 1.7	34.8 ± 1.5
	< 177	57.4 ± 1.8	55.1 ± 1.9	39.6 ± 1.6
	Mean	50.1	46.6	33.9
Bidoli	350–250	65.9 ± 2.2	39.1 ± 1.9	21.7 ± 1.5
	250–177	59.9 ± 2.5	29.4 ± 1.9	14.5 ± 1.3
	< 177	98.9 ± 3.2	51.8 ± 2.5	19.7 ± 1.4
	Mean	74.9	40.1	18.6
Idgundi	350–250	26.4 ± 1.7	11.8 ± 1.4	6.4 ± 0.9
	250–177	32.6 ± 2.1	13.1 ± 1.2	5.2 ± 0.9
	< 177	19.5 ± 1.5	10.7 ± 1.0	4.2 ± 0.7
	Mean	26.2	11.9	5.3
Kaiga	350–250	92.6 ± 1.7	30.2 ± 1.2	18.3 ± 0.9
	250–177	79.5 ± 1.4	24.2 ± 0.9	16.8 ± 0.8
	< 177	84.4 ± 1.8	18.7 ± 0.8	14.8 ± 0.8
	Mean	85.5	24.4	16.6
Ratnahalli	350–250	120.5 ± 1.6	87.0 ± 1.6	67.0 ± 1.3
	250–177	133.9 ± 2.0	87.6 ± 1.6	56.7 ± 1.2
	< 177	105.3 ± 1.6	61.0 ± 1.4	56.5 ± 1.2
	Mean	119.9	78.5	60.1
Vajrahalli	350–250	39.1 ± 1.9	18.4 ± 1.5	9.6 ± 1.0
	250–177	48.3 ± 2.7	26.9 ± 2.1	18.2 ± 1.7
	< 177	37.1 ± 1.8	24.8 ± 2.0	12.8 ± 1.0
	Mean	41.5	23.4	13.5
Yellapura	350–250	22.0 ± 1.6	18.5 ± 1.6	7.4 ± 1.0
	250–177	11.0 ± 2.0	14.6 ± 1.3	8.9 ± 1.0
	< 177	15.2 ± 1.3	12.6 ± 1.2	8.6 ± 1.5
	Mean	16.1	15.2	8.3

[a] ± indicates the counting error

Table 4
^{210}Po activity in vegetation

Species	Plant part	Activity(Bq kg^{-1})
Terminalia paniculata Roth [Banpu][a]	Leaves (50 cm^2)[b]	65.7 ± 1.4[c]
	Branches	9.0 ± 0.2
	Bark	15.3 ± 0.3
Careya arborea Roxb. [Daddala]	Leaves (90 cm^2)	58.3 ± 0.8
	Branches	14.8 ± 0.3
	Bark	11.6 ± 0.3
Dillenia pentagyna Roxb. [Kanagilu]	Leaves (1000 cm^2)	124.9 ± 2.0
Microcos paniculata L. [—]	Leaves(30 cm^2)	66.8 ± 1.8
	Branches	12.3 ± 0.3
	Stem	14.8 ± 0.3
Mangifera indica L. [Mavu]	Leaves (60 cm^2)	68.9 ± 1.2
	Branches	10.5 ± 0.2
	Bark	12.1 ± 0.2
	Flower	18.0 ± 0.5
Clerodendrum viscosum Vent.	Leaves (90 cm^2)	82.4 ± 1.8
[Panchami pool, Ittovu]	Branches	4.5 ± 0.1
Calycopteris floribunda (Roxb.) Poir	Leaves (30 cm^2)	54.2 ± 1.1
[Enjir]	Branches	11.9 ± 0.2
Tamarindus indica L.	Leaves (1 cm^2)	18.3 ± 0.2
[Hunase]	Branches	16.4 ± 0.2
	Bark	12.3 ± 0.1
Tectona grandis L.F.	Leaves (600 cm^2)	90.3 ± 1.0
[Saguvani]	Branch	12.7 ± 0.2
	Bark	13.1 ± 0.2
Cymbidium aloifolium (L.) Swartz [Kharana]	Whole plant	148.8 ± 1.5
Pterobryopsis tumida (Hook.) Dix. [Tree Moss] {2}[d]	Whole plant	2724 ± 13

[a]Common name of each species is shown in bracket.
[b]Values given in parentheses are the average leaf surface areas per leaf.
[c] ± indicates the counting error.
[d]Values given in the flower brackets are the number of samples analysed.

activities. A similar observation was reported by Berger, Erhardth and Francis (1965). The results of the present study clearly support these earlier findings.

It is interesting to note that the moss species *Pterobryopsis tumida* (Hook.) Dix. shows a significantly higher level of ^{210}Po activity. The orchid species *Cymbidium aloifolium* (L.) Swartz also shows a markedly higher level of ^{210}Po activity when compared to tree species. These moss and orchid species grow on other trees and they depend on the host tree only for support and not for nutrients. They derive their nutrients from atmospheric moisture and dust particles. As a result of this, the ^{222}Rn daughters which are attached to the dust particles are absorbed and accumulated by the moss and orchid species over a period, resulting in a higher activity level. The present results regarding the moss family *Pterobryopsis tumida* (Hook.) Dix. support the findings reported by Hasanen (1972) that moss and lichen have a strong ion

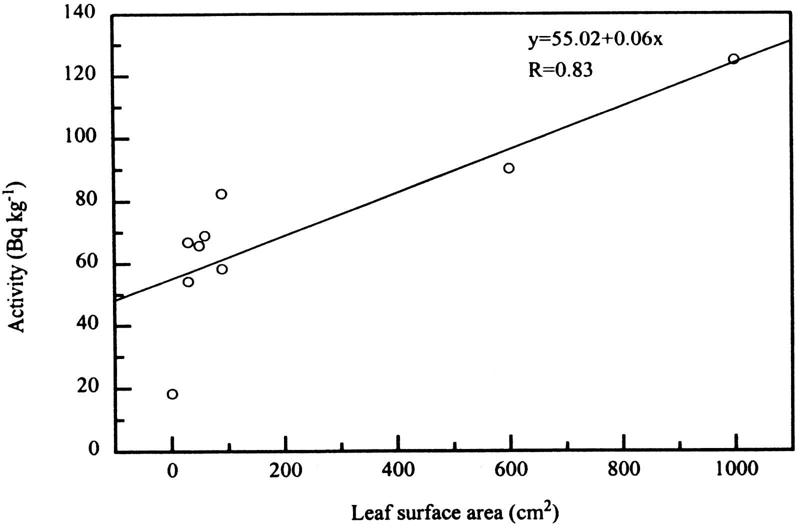

Fig. 3. Correlation between leaf surface area and ^{210}Po activity.

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 ^{210}Po in moss and lichen (Kljaic, Milosevic, Horsic & Bauman, 1982; Holm, Samulsson & Persson, 1982; Dean, Chiv, Neame & Bland, 1982; Schuttelkopf & Kiefer, 1982). Svensson and Liden (1965) suggested the use of moss and lichen as a natural integrating fallout meter. The results of the present study confirm the earlier findings and the moss species *Pterobryopsis tumida* (Hook.) Dix. and the orchid species *Cymbidium aloifolium* (L.) Swartz can be used as bio-indicators in the environment of Kaiga to monitor ^{210}Po activity.

Table 5 presents the results of the seasonal variation studies in the vegetation. To analyse the seasonal variation, only leaf samples of the 2 predominant tree species *Terminalia Paniculata* Roth. *and Careya arborea* Roxb. were chosen. The results show a 2-fold increase in the activity from summer (May) to winter (December). The variation in *Careya arborea* Roxb. is more prominent. Both species have similar growth habits and shed their leaves at the end of every growing season, i.e. during the last days of winter (second or third week of January). Leaves start growing during the last days of summer (second or third week of May). The activity level was found to follow the growth of the leaves: activities increase with the age of the leaves and with increase in their surface area. The samplings in summer were done when these leaves were not fully grown and this could be the reason for the lower level of activity in summer. These results suggest that the ^{210}Po content in vegetation depends on the duration of the vegetative period and also on the leaf surface area. In addition to this, a higher level of atmospheric deposition of ^{222}Rn daughters, which decays to ^{210}Po, in monsoon and winter may also contribute to the elevated level of ^{210}Po in winter.

Table 5
Seasonal variation of ^{210}Po in vegetation

Location	Vegetation species	Activity (Bq kg^{-1})		
		Summer (May)	Monsoon (August)	Winter (December)
Kaiga School	*Terminalia paniculata* Roth.	46.7 ± 0.9[a]	65.7 ± 1.4	87.4 ± 0.7
	Careya arborea Roxb.	29.3 ± 0.9	58.3 ± 0.8	92.6 ± 1.5
Kaiga Gate	*Terminalia paniculata* Roth.	27.7 ± 0.8	40.3 ± 0.9	52.9 ± 0.6
	Careya arborea Roxb.	28.7 ± 0.9	63.2 ± 0.8	134.9 ± 1.7
Mallapura	*Terminalia paniculata* Roth.	30.3 ± 1.0	29.6 ± 0.8	203.1 ± 1.5
	Careya arborea Roxb.	22.3 ± 0.9	68.8 ± 1.1	112.9 ± 1.0
Plantation site	*Terminalia paniculata* Roth	33.5 ± 0.9	36.2 ± 0.5	52.5 ± 1.0
	Careya arborea Roxb.	43.2 ± 1.2	46.6 ± 0.4	129.0 ± 1.5
Terminalia paniculata Roth.				
Range		27.7–46.7	29.6–65.7	52.5–203.1
Mean		34.6	43.0	99.0
Median		31.9	38.3	70.1
Careya arborea Roxb.				
Range		22.3–43.2	46.6–68.8	92.6–134.9
Mean		30.9	59.2	117.4
Median		29.1	60.8	121.0

[a] ± indicates the counting error.

3.3. *Dry deposition rate of* ^{210}Po

In order to find the reason for the higher ^{210}Po activity in soil and vegetation of the Kaiga region, the extent of ^{210}Po deposition from atmospheric precipitation (dry deposition rates) were measured. The results show an average deposition rate of 53.4 Bq m^{-2} yr^{-1} in the 8 km zone of the Kaiga environs. Samples collected from the Mangalore University campus show an average deposition rate of 26.4 Bq m^{-2} yr^{-1}. Literature values for the deposition rate of ^{210}Po are 14.8 and 27.75 Bq m^{-2} yr^{-1} for the Harwell (England) and Leningrad (former USSR) regions, respectively (Burton & Stewart, 1960; Ermolaeva-Makovskaya, 1969). The results obtained in the present study for Kaiga are higher than these literature values. The deposition rate at Kaiga is also higher than in the University premises. This confirms that the source of the higher levels of ^{210}Po activity observed in the environs of Kaiga is the deposition of ^{222}Rn daughters through atmospheric precipitation. The higher deposition rate in the Kaiga region may be due to the special geographical terrain of the region, as discussed previously.

4. Conclusions

The ^{210}Po activities in soil samples from the Kaiga environs are higher than in other normal background regions. Depth profile studies show a decreasing trend in activity level as the soil depth increases up to 20 cm remaining constant thereafter. ^{210}Po contents in the three grain sizes, *viz*. 350–250, 250–177 and below 177 μm, are almost uniform.

The ^{210}Po content in plant leaf depends on leaf surface area and also on the vegetative period. Activity shows an increasing trend with increasing age of the leaf. ^{210}Po activity in the plant bark and branches remains almost the same irrespective of the plant species. Moss species *Pterobryopsis tumida (Hook.)* Dix. show very high levels of ^{210}Po activity. Orchid species also show a markedly high activity when compared to tree species. Therefore these two natural species could be used as bio-indicators in the environment of Kaiga for monitoring the ^{210}Po activity.

Dry deposition rate measurements show higher levels of ^{210}Po fallout through atmospheric deposition in the Kaiga region. The observed elevated levels of ^{210}Po in the Kaiga environs may therefore be traced to the atmospheric precipitation of ^{222}Rn daughters.

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