

^{210}Po radiation dose due to cigarette smoking

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The level of ^{210}Po in eight brands of cigarettes and four brands of bidis popular in and around Nagercoil town was determined to evaluate the annual effective dose. The ^{210}Po activity in a full cigarette ranged from 32.8 ± 3.6 to 68.4 ± 5.9 mBq and from 34.3 ± 3.5 to 62.9 ± 5.8 mBq in a bidi. In tobacco, the highest ^{210}Po content was recorded in the brand C4 (23.0 ± 1.2 mBq) whereas for bidis it was the highest in the brand B2 (21.1 ± 1.1 mBq). The activity in mainstream varied from 15.2 ± 0.75 to 36.8 ± 2.1 mBq in a cigarette and from 20.7 ± 3.1 to 39.8 ± 4.0 mBq in a bidi. With regard to ^{210}Po activity concentration, not much specificity was noted with respect to the tobacco brand. The data showed a relatively wide range of activity concentration of ^{210}Po in the different cigarette/bidi brands and even within the same brand. The bidis showed a higher activity when compared to cigarettes. The popular brands concentrated more activity than the fine brands. Smokers who smoke one pack (10 cigarettes/bidis) per day may inhale about $100\text{--}300$ mBq d^{-1} ($0.1\text{--}0.3$ Bq d^{-1}) of ^{210}Po . In this study, radiation dose values in the range of $153.5\text{--}372.9$ $\mu\text{Sv Y}^{-1}$ from cigarettes and from 209.2 to 402.7 $\mu\text{Sv Y}^{-1}$ from bidis was estimated for the whole body.

Keywords: Cigarettes, effective dose, polonium, radioactivity, tobacco.

TOBACCO is obtained by drying and processing the leaves of *Nicotiana tabacum* and *Nicotiana rustica*. Tobacco owes its activity to the alkaloid nicotine; its dual sedative and stimulating action provides a specific feeling of well-being to the smoker. But the constituents of tobacco are harmful to the health of the consumer, leading to a high risk of, among other things, cancer and cardiovascular disease. In India, one-fifth (19%) of tobacco consumed is in the form of cigarettes¹. Over half of all tobacco consumed is smoked as bidis (54%) and about one-fourth of tobacco consumption is in the smokeless form (27%). Bidis are sold 7–8 times more than cigarettes². It has been estimated that more than a 100 million people smoke bidis, about 25 million smoke cigarettes, and the number of smokeless tobacco users is fairly close to the total number of smokers^{1,3}. Tobacco contains minute quantities of radioactive isotopes from the uranium- and thorium-series (^{210}Pb , ^{210}Po and ^{226}Ra) that are carcinogenic and

could be found in smoke from burning tobacco. The long-term effects of radionuclide intake in the human body are important from the radiochemical and radiological points of view. With regard to internal exposure to humans, ^{210}Po is one of the most radiotoxic nuclides⁴. The maximum permissible human body burden for ingested ^{210}Po is only 1.1–10.3 Bq and the maximum allowable concentration for soluble polonium compounds in air is about 0.74 Bq m^3 (ref. 5). The main sources of ^{210}Po (and also ^{210}Pb) are food and tobacco smoke^{6–8}. The concentrations of ^{210}Po measured in cigarette tobacco were in the range of $2.8\text{--}37$ Bq kg^{-1} and varied with the cigarette brands, likely due to the different varieties of tobacco used and different manufacturing procedures^{7,9–12}. On an average, approximately 50% of the ^{210}Po in cigarette tobacco is transferred to the smoke, 35% remains in the butt and approximately 15% is found in the ash⁶. People who intentionally or passively inhale tobacco smoke are exposed to higher concentrations of radioactivity than non-smokers. Deposits of radioactive isotopes in the lungs of smokers that are delivered to sensitive tissues for a long periods of time generate localized radiation exposures and may induce cancer both alone and synergistically with non-radioactive carcinogens. Inhalation of some naturally occurring radionuclides via smoking has been considered to be one of the most significant causes of lung cancer. Finally, most of the ^{210}Po and ^{210}Pb sublimates from tobacco to smokers' lungs. The study of ^{210}Po and ^{210}Pb contents of tobacco has assumed great importance because of the increase in the incidence of lung cancer amongst smokers^{10,13,14}. More recently, additional reviews and evaluations by the Environmental Protection Agency and others have led to the conclusion that the highly carcinogenic alpha-particles from ^{210}Po have a major synergistic effect with the chemical carcinogens in cigarette smoke, causing the lifetime risk of lung cancer in smokers to be increased by a factor of more than 8, compared with non-smokers. In the United States, more than 160,000 people (44% women) died of lung cancer during 2008 and of these, an estimated 85–90% (i.e. 140,000) deaths were caused by cigarettes¹⁵. Based on this scenario, the level of ^{210}Po in different brands of tobacco products popular around Nagercoil town was determined to estimate the effective dose via smoking.

Three packets (in triplicate) each of Indian-made fine branded cigarettes and four brands of country-made cigarettes (bidis) were bought from local shops at Nagercoil town, Kanyakumari district. Fifteen samples were selected randomly from each packet, out of which five samples were analysed individually for ^{210}Po in different parts of the cigarettes, i.e. tobacco, wrapping paper and mainstream. Five samples were analysed as a whole and the other five samples were allowed to be smoked by volunteers to collect the ash and post-smoking filter/butt.

The samples were transferred to beakers and digested using $\text{HNO}_3:\text{HCl}$ and evaporated to near dryness on a

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Table 1. ^{210}Po activity (mBq per cigarette) in different brands of cigarettes and bidis

Brands	Whole cigarettes	Tobacco	Wrapping paper	Mainstream	Ash	Post smoking filter/butt	Smoke
Cigarettes							
C1	41.0 ± 4.1	12.1 ± 0.56	3.4 ± 0.15	15.2 ± 0.75	4.3 ± 0.17	1.3 ± 0.11	10.8 ± 0.45
C2	50.0 ± 4.5	18.8 ± 0.88	3.0 ± 0.16	36.8 ± 2.1	4.4 ± 0.2	2.9 ± 0.19	32.4 ± 1.5
C3	34.9 ± 3.7	8.8 ± 0.4	6.3 ± 0.33	18.5 ± 1.9	4.5 ± 0.25	2.2 ± 0.17	14.0 ± 0.70
C4	46.9 ± 4.6	23.0 ± 1.2	4.1 ± 0.26	24.9 ± 1.9	6.2 ± 0.31	1.0 ± 0.10	18.7 ± 0.6
C5	47.6 ± 4.9	8.4 ± 0.43	3.9 ± 0.29	28.2 ± 2.1	3.6 ± 0.17	1.8 ± 0.14	24.5 ± 1.2
C6	32.8 ± 3.6	12.7 ± 0.57	2.5 ± 0.1	16.6 ± 0.81	5.7 ± 0.19	1.5 ± 0.15	10.9 ± 0.52
C7	43.5 ± 4.3	14.4 ± 0.71	4.2 ± 0.23	28.6 ± 1.8	3.7 ± 0.14	0.8 ± 0.10	24.9 ± 1.2
C8	68.4 ± 5.9	20.2 ± 1.1	4.1 ± 0.25	20.0 ± 2.0	3.2 ± 0.12	1.7 ± 0.15	16.8 ± 0.56
Bidis							
B1	34.3 ± 3.5	19.2 ± 0.98	4.4 ± 0.28	20.7 ± 3.1	2.7 ± 0.12	1.6 ± 0.13	18.0 ± 0.9
B2	48.9 ± 4.9	21.1 ± 1.1	3.7 ± 0.18	29.8 ± 3.8	3.2 ± 0.14	2.5 ± 0.18	26.7 ± 0.6
B3	62.9 ± 5.8	13.9 ± 0.67	5.2 ± 0.36	39.8 ± 4.0	5.7 ± 0.15	1.8 ± 0.16	34.0 ± 1.7
B4	50.8 ± 5.1	16.0 ± 0.85	4.5 ± 0.29	35.1 ± 3.6	2.7 ± 0.11	1.0 ± 0.10	32.4 ± 1.6

hot plate at a temperature of about 80–90°C. The sample residue was treated with two portions of 10 ml of conc. HCl and evaporated to near dryness, until a white residue was obtained. Finally, the samples were dissolved in 100 ml of 0.5 M HCl and polonium was spontaneously plated from the solution at the temperature of 70–80°C on a rotating silver planchet¹⁶. After complete plating, the planchet was taken out, rinsed with distilled water, acetone-dried and kept in an alpha counting system for 6000 s to measure the activity. The activity was determined using a radiation counting system (Nucleonix, RC 605 A) with an alpha probe of ZnS solid scintillation detector having a minimum detectable limit (MDL) of 0.31 mBq g⁻¹. ²⁴¹Am (Americium-241), with an activity of 12.6 dps (disintegration per second), was used as the standard source for calibration of the instrument, with an average counting efficiency of 32.14%. ²⁰⁸Po tracer yielded a recovery of 98 ± 2%. The activity in cigarettes was reported as mBq per cigarette (in (g) dry wt).

For quality assurance, ²⁰⁸Po tracer obtained from National Physical Laboratory, UK was added to the sample before digestion. The recovery was to the tune of 98 ± 2%. Analytical quality control measurements were regularly performed through running blank samples and intercomparison at Environmental Survey Laboratory, Health Physics Division, BARC established at Kudankulam and also with reference material (IAEA-375 sediment). The intercomparison showed an error <2% with a similar type of alpha counter.

The average activity concentrations of ²¹⁰Po in eight brands of cigarettes and four brands of bidis are presented in Table 1 and Figure 1. In a full cigarette, the activity ranged from 32.8 ± 3.6 mBq in brand C6 to 68.4 ± 5.9 mBq in brand C8. In a full bidi, the activity varied between 34.3 ± 3.5 mBq for brand B1 and 62.9 ± 5.8 mBq for brand B3. In tobacco, the highest ²¹⁰Po content was recorded in the brand C4 (23.0 ± 1.2 mBq). In other brands, the activity ranged from 8.4 ± 0.43 to 20.2 ± 1.1 mBq.

Among bidis, the activity was the highest in the brand B2 (21.1 ± 1.1 mBq). In cigarettes, the level of ²¹⁰Po in the wrapping paper varied between 2.5 ± 0.1 and 6.3 ± 0.33 mBq. In bidis, it ranged from 3.7 ± 0.18 to 5.2 ± 0.36 mBq. The ²¹⁰Po activity in the mainstream of cigarettes and bidis ranged from 15.2 ± 0.75 to 36.8 ± 2.1 mBq and 20.7 ± 3.1 to 39.8 ± 4.0 mBq respectively. In cigarette ash, the lowest activity was recorded in the brand C8 and the highest in brand C4. In the post-smoking filter/butt, the activity ranged from 0.8 ± 0.10 to 2.9 ± 0.19 mBq for cigarettes and 1.0 ± 0.10 to 2.5 ± 0.18 mBq for bidis. Higher ²¹⁰Po was observed in the smoke of the cigarette brand C2 (32.4 ± 1.5 mBq) and the bidi B3 (34.0 ± 1.7 mBq). The ²¹⁰Po content in the bidi samples was higher compared to that in cigarettes. The tobacco contained in cigarettes may be fried during processing and there is a chance of sublimation of ²¹⁰Po. There is no chance for sublimation in the case of bidis, and hence the higher concentration of ²¹⁰Po in bidis than in cigarettes. The presented data show a relatively wide range of activity concentration of ²¹⁰Po in the different cigarette brands and even within the same brand. The popular brands concentrated more ²¹⁰Po than the fine brands. The percentage contribution of ²¹⁰Po in different parts of cigarettes is shown in Figure 2. All the cigarette brands examined, except C1 and C2, are filter-tipped. The risk associated with cigarette smoking is not only due to the high concentration of toxic substances, but also due to the poor efficiency of the filters, which do not sufficiently reduce the quantities of carcinogenic substances present in the smoke. Volatilization of polonium was evidenced by the low ²¹⁰Po activity measured in cigarette ash as compared with that measured in unburned cigarettes. The ²¹⁰Po content in the ash was quite low for most of the analysed brands, ranging from 3.2 ± 0.14 mBq in C8 to 6.2 ± 0.31 mBq in C4. The marked difference in the ²¹⁰Po content in the ash in comparison with its content in tobacco is due to the different tobacco-burning temperatures of

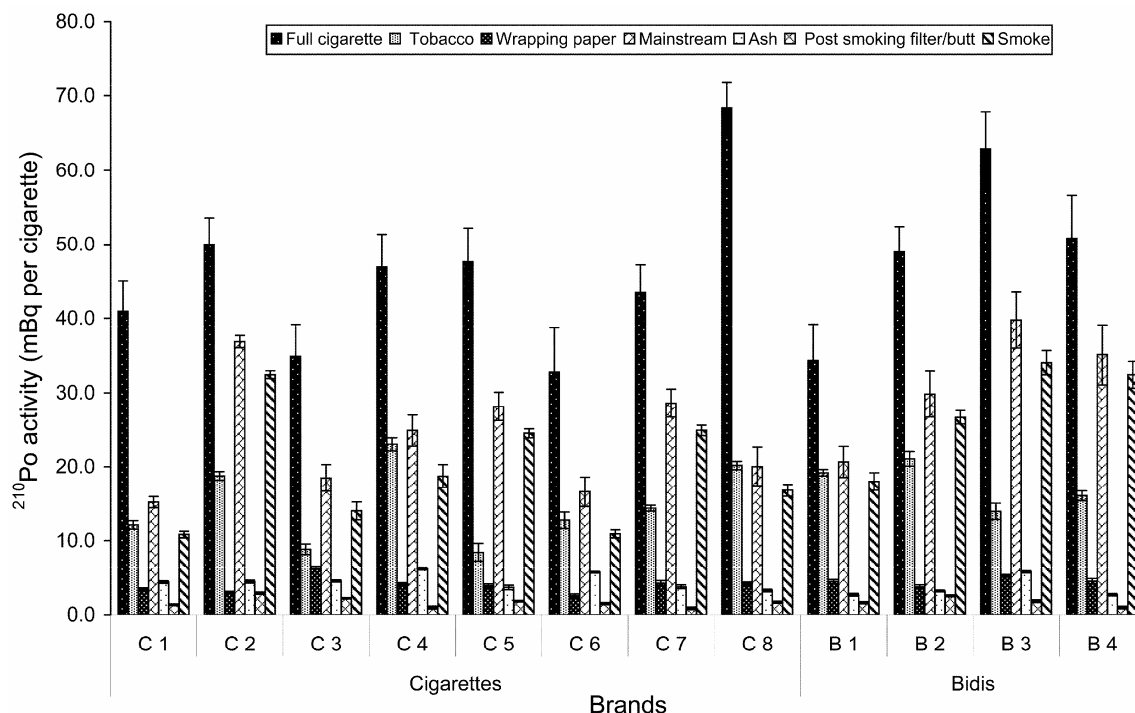


Figure 1. ²¹⁰Po activity in different parts of cigarettes/bidis.

Table 2. ²¹⁰Po activity in cigarettes from different countries

Country	No. of brands measured	²¹⁰ Po range/mean (mBq per cigarette)
Canada ²⁷	2	8
China ^{28,29}	1	13
Egypt ^{22,27}	12	18–29
England ²⁷	1	14
Finland ^{2,27}	10	10–22
France ²⁷	7	9–23
Germany ^{27,30}	2	10–12
Hungary ²³	8	8–14
Czechoslovakia ³¹	1	23
Brazil ³¹	3	15–22
Bulgaria ³¹	1	19
Italy ²¹	29	10–33
Japan ^{27,29,32}	–	11.7
New Zealand ³³	–	16.9
Norway ²⁷	–	14.0
Philippines ²⁷	17	7–17
Poland ¹²	4	17–33
Russia ²⁷	12	12–28
Saudi Arabia ²²	8	10–15
Turkey ¹¹	8	9–17
United States ^{27,30,34}	1	9
India ³¹	1	12
Present study	8	14–22
Worldwide range ³¹	–	3.3
		15.2–36.8
		4.0–23.2

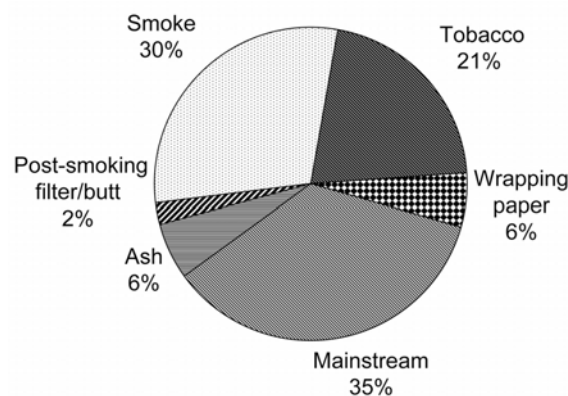


Figure 2. ²¹⁰Po content (%) in different parts of cigarettes.

smoking (between 500°C and 700°C), which cause ²¹⁰Po to sublime into the smoke which is inhaled by the smoker¹⁷. On an average, about 7% of the total polonium in the cigarette tobacco is retained in the cigarette filter and ash (Figure 3). About 51% of the polonium content in the cigarette tobacco was contained in the cigarette smoke, which is partially inhaled and deposited in lung tissues. The polonium activity in cigarettes and bidis was comparable with values recorded in other countries (Table 2).

Long-term tobacco storage, before production and sale of cigarettes (often over 2 years), cause the ²¹⁰Po and ²¹⁰Pb present in the tobacco to exist practically in radioactive equilibrium and the activities of the analysed radionuclides to be equal at the time of smoking^{18–20}.

Table 3. Inhalation and effective dose due to ²¹⁰Po via smoking different brands of cigarettes and bidis

Brand	²¹⁰ Po activity (Bq Cig ⁻¹)	Inhalation (Bq d ⁻¹)	Inhalation (Bq y ⁻¹)	Effective dose (μSv d ⁻¹)	Effective dose (μSv y ⁻¹)
Cigarettes					
C1	0.015	0.1	41.5	0.4	153.5
C2	0.037	0.3	100.8	1.0	372.9
C3	0.018	0.1	50.6	0.5	187.2
C4	0.025	0.2	68.1	0.7	252.1
C5	0.028	0.2	77.1	0.8	285.2
C6	0.017	0.1	45.4	0.5	168.0
C7	0.029	0.2	78.3	0.8	289.8
C8	0.020	0.2	54.8	0.6	202.8
Bidis					
B1	0.021	0.2	56.5	0.6	209.2
B2	0.030	0.2	81.6	0.8	302.0
B3	0.040	0.3	108.8	1.1	402.7
B4	0.035	0.3	96.0	1.0	355.2

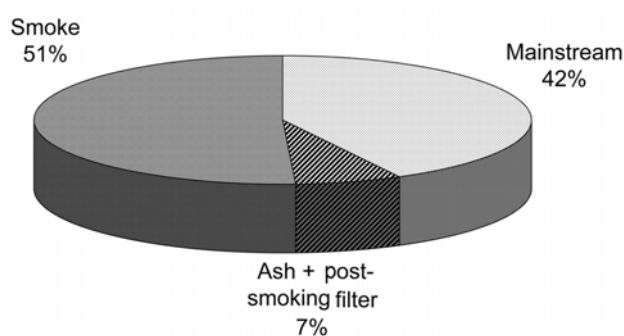


Figure 3. ²¹⁰Po activity content (%) and transfer from mainstream to smoke.

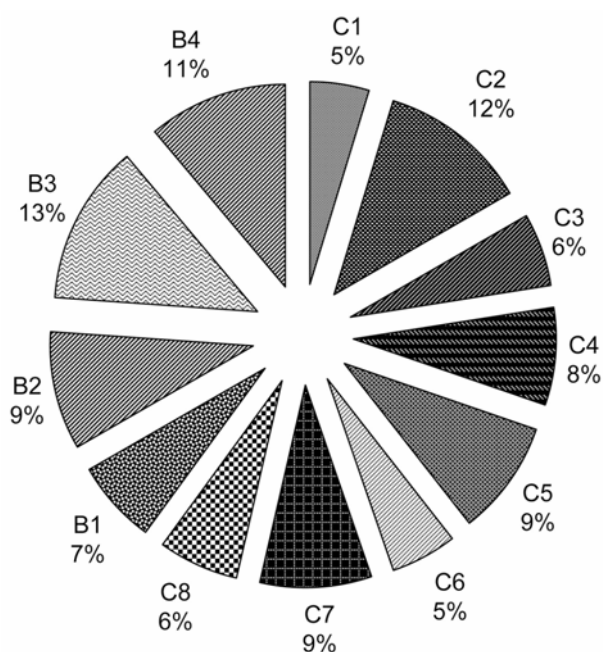


Figure 4. Inhalation and effective dose due to ²¹⁰Po (%) in different brands of cigarettes.

²¹⁰Po activity in the total smoke was found to be 51% (Figure 3). Many authors^{11,12,21,22} have reported a range of 67–75% of ²¹⁰Po in the smoke. Some authors^{23,24} have reported that 33–37% of the ²¹⁰Po will be inhaled. According to these results, and assuming that 50% of the total smoke is inhaled, the daily inhalation of ²¹⁰Po by smokers was calculated and the results are presented in Table 3. Smokers who smoke one pack (10 cigarettes/bidis) per day may inhale about 100–300 mBq d⁻¹ (0.1–0.3 Bq d⁻¹) of ²¹⁰Po. Smokers who smoke 10 cigarettes/bidis a day would inhale about 41.5–108.8 Bq Y⁻¹ of ²¹⁰Po. This is possible because a large number of smokers smoke two or sometimes more packs of cheap cigarettes. These results indicate that cigarettes are an important source of ²¹⁰Po to smokers. The daily inhalation of ²¹⁰Po by smokers is on an average about 30 times higher than the daily inhalation of atmospheric ²¹⁰Po by non-smokers. A similar relationship was observed in the Portuguese population¹⁹. The inhalation of ²¹⁰Po from cigarette smoke in Nagercoil is appreciably comparable with that in other areas^{6,7,9,19,25} and is similar to that in Turkey¹¹. The percentage contribution of different categories of cigarettes to the annual inhalation (Bq Y⁻¹) is shown in Figure 4.

Assuming that 50% of the total smoke is inhaled¹², the daily inhalation of ²¹⁰Po was calculated. The dose conversion factor for adults was 3.7 μSv Bq⁻¹ for ²¹⁰Po (ref. 28). The committed annual effective dose contribution to smokers, considering the ²¹⁰Po concentration, was calculated using the following formula:

$$E = F_1 \times F_2 \times K \times G \times C \times t,$$

where *E* is the committed effective dose from inhalation (μSv), *F*₁ the average transfer factor from tobacco to smoke (1.5), *F*₂ the inhaled smoke per total smoke ratio (0.5), *K* the inhalation dose conversion factor of ²¹⁰Po

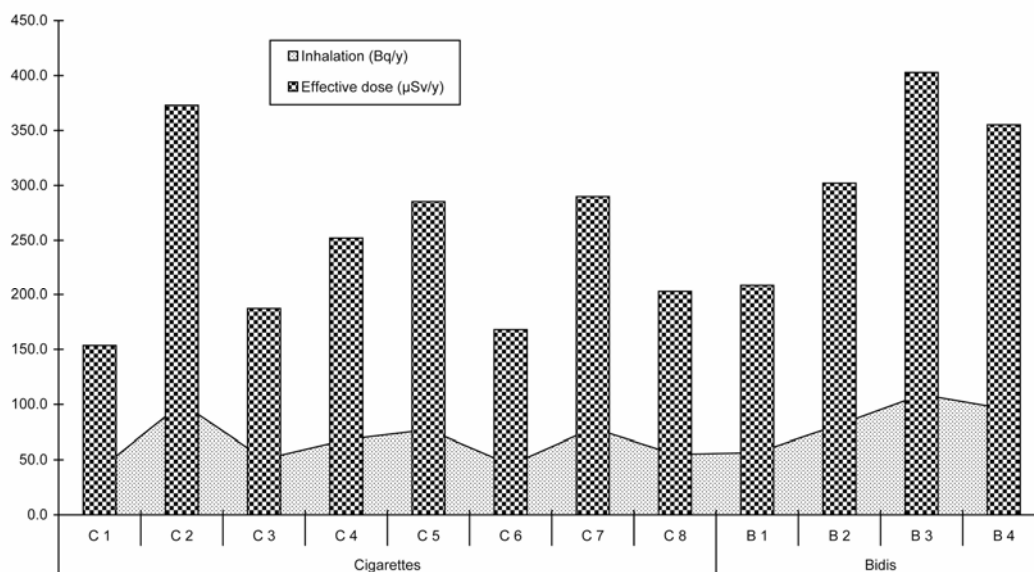


Figure 5. Inhalation and effective dose due to ²¹⁰Po in cigarettes.

($3.7 \mu\text{Sv Bq}^{-1}$), G the number of cigarettes smoked (10 cigarettes day⁻¹), C the concentration of ²¹⁰Po (Bq per cigarette) and t the duration of smoking (365 days). Based on the daily inhalation of ²¹⁰Po from cigarette smoke, the average annual effective dose estimated for adult smokers is given in Table 3. The values of the annual effective dose for smokers who smoke one pack of cigarettes/bidis per day ranged from 153.5 to 402.7 $\mu\text{Sv Y}^{-1}$ (Figure 5). But for persons who smoke one pack of a brand of cigarette with higher ²¹⁰Po concentration (C2 and B3) per day, the annual effective dose was significantly higher (372.9 and 402.7 μSv). In this study, a radiation dose of 402.7 μSv was calculated for the whole body, but in the smokers' lungs it would be much higher. Singh and Nikelani¹³ estimated a daily radiation dose to the bronchial epithelium of 240 mSv for persons who smoke 30 cigarettes per day. Cigarette smoking and the connected inhalation of radionuclides, dioxins, nicotine and polycyclic aromatic hydrocarbons (PAH) are probably the reasons for the high incidence of cancers in lungs, oesophagus, larynx and other organs of the respiratory system principally amongst smokers²⁶. It has been reported that ²¹⁰Po preferentially gets deposited in the bronchial epithelium and would contribute an estimated annual dose of 160 mSv to lungs. Even so, due to some losses during processing of the sample, the estimated dose rate was thought to be lower than that actually received. The contribution of cigarette categories to the annual effective dose is shown in Figure 5. The higher ²¹⁰Po activity reported in the present study relative to the cigarettes of other countries demonstrates that in India, smoking is a large source of ²¹⁰Po intake.

Cigarette smoking increases the internal intake of ²¹⁰Po which is contained in cigarette tobacco in relatively high

concentrations. Polonium-210 inhaled and deposited in the lung tissues will contribute to an increase in the internal radiation dose and in the number of lung cancer incidences observed among smokers. The results of ²¹⁰Po activity determinations indicate that bidis and cigarettes are comparable to the values reported in other countries. Inhalation of cigarette smoke increases the lung exposure to ²¹⁰Po by about 30 times, when compared to atmospheric polonium¹². However, the contributions of cigarette smoke to the total ²¹⁰Po absorbed by the internal tissues will be higher when compared with the radionuclide intake from the diet. For persons who smoke the most popular cigarette brands containing higher radionuclide concentrations, the effective dose will be much higher than the intake through food and water.

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Artificial seed production from encapsulated PLBs regenerated from leaf base of *Vanda coerulea* Griff. ex. Lindl. – an endangered orchid

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Artificial seeds were produced from encapsulated protocorm-like bodies (PLBs) obtained from six-month-old axenic leaf explants of *Vanda coerulea* Griff. ex. Lindl. The percentage of germination of encapsulated PLBs was influenced by the concentrations of sodium alginate and calcium chloride ($\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$) used. It was found that among the different concentrations tested, 3% sodium alginate and exposure to 100 mM $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ solution for 30 min produced firm, clear, round and uniform optimal beads which were suitable for handling. It was also observed that PLBs obtained from optimization of encapsulation matrix showed the highest percentage of germination (94.9%) when beads were innoculated immediately after formation. Encapsulated PLBs stored at 4°C retain their viability up to 100 days. The findings suggest that the encapsulation method for PLB obtained from leaf explants of *V. coerulea* can be useful as an alternative tool for conservation of this endangered species.

Keywords: Encapsulation, ecorehabilitation, *in vitro*, protocorm-like bodies.

THE production of synthetic seeds in orchids is useful since orchids produce tiny and non-endospermic seeds.

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