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^{210}Po inhalation due to smoking: a dose estimation

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Abstract Smoking is the second reason for developing lung cancer. Our goal was to determine how the amount of ^{210}Po in the tobacco is distributed among the cigarette parts and what percentage reaches the respiratory system, calculating the effective dose. ^{210}Po from tobacco, filter and ash samples were measured from seven Romanian cigarette brands by alpha spectrometry. The obtained average results were 13.97 ± 1.75 mBq/cigarette in the tobacco; 1.61 ± 0.25 mBq/cigarette in the filter and 3.33 ± 0.29 mBq/cigarette in the ash. The dose originating from active smoking was estimated to have an average of 8.36 ± 0.91 μSv/year, while the passive smoking dose reaching the respiratory system was 5.92 ± 0.49 μSv.

Keywords ^{210}Po · Tobacco dose estimation · Passive smoking · Active smoking

Introduction

Cigarettes are produced using as main ingredient various types of tobacco leaves. Many studies show that tobacco leaves contain radioactive ^{210}Po, an element harmful to human health [1–3, 5, 6, 8–13, 16–19, 24] ^{210}Po in tobacco comes from the decay of ^{222}Rn through airborne fallout, which is then caught by the fine hairs of the surface tobacco leaves (trichomes). Additionally, ^{210}Po enters the tobacco plant through the uptake of ^{226}Ra containing phosphate fertilizers [1] absorbed by the roots [2, 3]. Unlike other plants, which are always washed before consumption, tobacco leaves are directly dried in order to obtain quality cigarettes, so these will contain a great amount of ^{210}Po.

All polonium (atomic number 84) isotopes are radioactive (total of 33 with masses ranging from 188 to 220 [4, 5]. Polonium is a very rare natural element, being present in uranium ores in traces (100 μg per ton of ore) [6, 7], most of which have short half-lives. ^{210}Po is an alpha-emitting (5.297 MeV) and low abundance (1.06×10^{-5}) gamma-emitting (0.802 MeV) radionuclide, with a half time of 138 days. It is a member of the natural uranium-238 series, due to which it present in trace amounts in most plants and foodstuff as well as in human tissues.

Medical researches indicate that tobacco smoking has serious consequences on human health, some of these being lung cancer, respiratory infections and heart diseases [8, 9]. There are about 100 hazardous compounds in cigarette smoke, including ^{210}Po [10]. The ^{210}Po concentration in tobacco has a mean of 13 ± 2 Bq/kg [11], concentrations ranging from 2.8–37 Bq/kg varying with the cigarette brand due to the different varieties of tobacco used and different manufacturing procedures [3, 12]. Other studies mention ^{210}Po as one of the most powerful carcinogens in tobacco smoke [13] and exposure of the lungs to this element alone can cause lung cancer in rats and hamsters [14, 15]. Cigarette smoke is a complex aerosol consisting of a vapour and a particulate phase. The particles range from 0.1–1 μm and undergo a very fast coagulation [8, 16–18] at volatilising temperatures from 600 to 800 °C [19]. The tobacco leaves being consumed as cigarettes will contain ^{210}Po which will be deposited on the surface of the teeth, lungs and respiratory tract [20]. On average, 50 % of the ^{210}Po found in cigarette tobacco is transferred to the smoke, 35 % remains in the butt, the rest being found in the ash [21].

Smoking is common among the Romanian population, placing the country in a leading position regarding the per

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capita average cigarette consumption (tobaccoatlas.org). According to 24/7 Wall St. [22], Romania was an the 8-th place in the top 10 most smoking countries in 2012, with an overall adult smoking percenage of 34 % and yearly, a per capita cigarette consumption of 1404 [23].

Materials and methods

Active smokers

Seven popular cigarette brands have been chosen for this analysis, six of them having a cellulose filter and one having an active carbon filter. Also, five were worldwide known brands and two locally produced ones.

0.5 g of each cigarette tobacco, filter (before and after smoking) and ash have been added 0.5 ml of 100 mBq/ml ^{209}Po tracer. Samples have been put then to acidic digestion, using 3 × 20 ml 65 % HNO_3, 3 × 20 ml 35 % HCl and H_2O_2, until the reaction between the reagent and the sample takes place. Samples were then leached with 3 × 20 ml distilled water. The obtained solutions were poured in 100 ml balloons, which were filled with distilled water. Half of these were put into 50 ml Berzelius glasses. The ^{210}Po content of these solutions was spontaneously deposited on high nickel content stainless steel discs in an oven at 80 °C for 3 h. Interferents (Fe^{3+}) were eliminated using 0.5 g of ascorbic acid.

Measurements were carried out using a PIPS detector, having a resolution of 25–30 keV at an area of 900 mm^2 and the minimal detectable activity of 0.75 mBq. This detector type has a compact size, an excellent stability and a low sensibility towards gamma rays. The acquisition system is an Aspec 927 multichannel analyser and the spectra acquisition program is Maestro32.

Passive smokers

The passive smoking measurements were carried out in two popular pubs in Cluj-Napoca, Romania, using two pumps: an Alpha Pump with the capacity of 0.5 l/min and 60 μm paper filters, and a Leland Legacy SKC pump with the capacity of 7 l/min and 25 μm paper filters. Measurements were made for 3 and 5 h.

The filter papers have been measured using the same method mentioned in the previous section.

Results and discussion

Active smokers

After measuring the activity concentration for each cigarette tobacco, we got the result summarized in Table 1.

The measured average mass of the tobaccos was 0.64 ± 0.06 g, having an average activity concentration of 21.76 ± 2.88 mBq/g, resulting an average activity concentration per cigarette of 13.97 ± 1.75 mBq/cigarette.

The ^{210}Po concentration of the cigarette filters before smoking have been measured, but the activities were under the detection limit. The activity concentrations for cigarette filters after smoking are shown in Table 2.

The average mass of the cigarette filters has been measured to be 0.18 ± 0.02 g, having an average activity concentration of 8.67 ± 2.02 mBq/g, with an average cigarette filter activity of 1.61 ± 0.25 mBq/cigarette filter.

The activity concentration of cigarette ashes is summarized in Table 3.

The average mass of the cigarette ash has been 0.12 ± 0.01 g. The average activity concentration has been 26.16 ± 2.83 mBq/g and, respectively, 3.33 ± 0.29 mBq/cigarette ash.

After having these results, the activity concentration reaching the respiratory system was calculated using Eq. (1):

$$A_{RS} = A_T - (A_F + A_A), \quad (1)$$

where A_{RS} signifies the activity concentration reaching the lung, A_T the activity concentration of the tobacco, A_F the activity concentration of the filter and A_A the activity concentration of the ash. The obtained activity concentrations for the respiratory system and the percentage representing it from the tobacco concentrations are summarised in Table 4, showing that approximately 63.41 % of the tobacco ^{210}Po concentration reaches the respiratory system.

The effective dose reaching the respiratory system was calculated using the following formula: [24]

$$E_a = K_h \times A_{RS} \times F \times G \times \tau, \quad (2)$$

where K_h is the inhalational dose factor, for ^{210}Po being 3.3 × 10^{-6} (Sv/Bq) [25], A_{RS} is the activity concentration reaching the respiratory system (Bq/cigarette), F is the fraction of an ingested element absorbed directly into body fluids (equalling 0.2 in our case) [25], G is the consumption of cigarettes a year (for Romanians being 1404 cigarettes/year [23]) and τ is the consumption period, taken as a year.

The calculated effective doses are summarised in Table 5, the average effective dose of ^{210}Po reaching the respiratory system being 8.36 ± 0.91 μSv/year.

Passive smokers

The measured activity concentrations using the pumps are summarised in Table 6.

As measurements show, the 25 μm filter has captured aerosols in the same range as the bigger 60 μm filter. The air activity concentration (A_a) was measured using the following formula:

Table 1 Activity concentrations for ^{210}Po in tobacco

Code	Average mass (g)	Activity concentration (mBq/g)	Activity/cigarette tobacco (mBq/cigarette)
T1 w	0.64 ± 0.07	25.93 ± 3.02	16.43 ± 2.18
T2 w	0.68 ± 0.06	28.27 ± 3.23	19.24 ± 2.09
T3 w	0.57 ± 0.06	21.83 ± 2.28	13.02 ± 1.43
T4 w	0.75 ± 0.08	24.97 ± 3.17	18.75 ± 2.18
T5 w	0.61 ± 0.05	25.18 ± 3.09	14.98 ± 1.83
T6 l	0.62 ± 0.06	11.88 ± 2.31	7.18 ± 0.99
T7 l	0.58 ± 0.06	14.31 ± 3.10	8.21 ± 1.53

w worldwide known brand, *l* locally produced brand

Table 2 Activity concentrations for ^{210}Po in cigarette filters after smoking

Code	Average mass (g)	Activity concentration (mBq/g)	Activity/cigarette filter (mBq/filter)
F1 ce	0.15 ± 0.02	13.41 ± 2.04	1.91 ± 0.27
F2 ce	0.21 ± 0.02	9.23 ± 1.78	1.92 ± 0.37
F3 ac	0.31 ± 0.03	9.11 ± 1.90	2.76 ± 0.55
F4 ce	0.19 ± 0.02	7.88 ± 2.51	1.67 ± 0.55
F5 ce	0.17 ± 0.02	7.11 ± 2.18	1.06 ± 0.26
F6 ce	0.14 ± 0.01	8.28 ± 2.98	1.10 ± 0.36
F7 ce	0.15 ± 0.01	5.67 ± 0.78	0.87 ± 0.15

ce cellulose filter, *ac* active carbon filter

Table 3 Activity concentrations for ^{210}Po in cigarette ash

Code	Average mass (g)	Activity concentration (mBq/g)	Activity/cigarette ash (mBq/ash)
A1	0.14 ± 0.02	27.93 ± 1.97	3.87 ± 0.41
A2	0.12 ± 0.01	32.08 ± 3.07	3.79 ± 0.27
A3	0.12 ± 0.02	26.83 ± 3.17	3.25 ± 0.21
A4	0.12 ± 0.01	29.75 ± 3.75	3.61 ± 0.32
A5	0.14 ± 0.02	36.41 ± 4.12	4.85 ± 0.45
A6	0.12 ± 0.01	15.47 ± 2.33	1.83 ± 0.17
A7	0.13 ± 0.01	14.67 ± 1.41	2.14 ± 0.19

Table 4 Activity concentrations for ^{210}Po reaching the respiratory system

Sample	Respiratory system activity concentration (mBq/cigarette)	Quantity reaching the respiratory system (%)
1	10.65 ± 1.11	64.82
2	13.53 ± 1.08	70.32
3	7.01 ± 0.67	53.84
4	13.47 ± 1.31	71.84
5	9.07 ± 1.13	60.55
6	4.25 ± 0.46	59.19
7	5.20 ± 0.61	63.34

$$A_a = A_m \div PC,$$

where A_m is the measured activity of ^{210}Po for the exposure time (3, respectively 5 h) and PC is the pump capacity of each measuring device. The air activity varies between 60.02 and 72.78 μBq/l, having an average of 69.18 μBq/l.

The effective dose originating from passive smoking was calculated on the basis of the formula used at the active dose measurement:

$$E_p = L_{tv} \times r \times t \times \tau \times K_h \times F,$$

where L_{tv} is the lung tidal volume, meaning the amount of air inspired by an average person during normal relaxed

Table 5 The calculated effective doses for ^{210}Po reaching the respiratory system

Sample	Activity concentration in respiratory system (mBq/cigarette)	Recieved effective dose after the yearly average cigarette consumption (μSv/year)
1	10.65 ± 1.11	10.10 ± 1.31
2	13.53 ± 1.08	12.32 ± 1.18
3	7.01 ± 0.67	5.93 ± 0.63
4	13.47 ± 1.31	12.69 ± 1.28
5	9.07 ± 1.13	8.43 ± 0.92
6	4.25 ± 0.46	4.26 ± 0.49
7	5.20 ± 0.61	4.82 ± 0.53

Table 6 The measured activity concentrations in the aerosols captured by the filters and air

Nr.	Pump name	Activity after 3 h (mBq)	Activity after 5 h (mBq)	Pump capacity (l/min)	Air activity (μBq/l)
1	Alpha pump	–	9.07 ± 2	½	60.02
2	Leland legacy SKC pump	88.12 ± 2	147.85 ± 2	7	70.16
3	Leland legacy SKC pump	90.66 ± 3	154.13 ± 3	7	72.78

breathing; its value being 0.5 l [26], r is the average human respiratory rate, having an average of 16 breaths/min [26], t is the average, weekly residence time, taken as 5 h (estimation, considering that inside smoking is allowed in most closed spaces) and τ is the number of weeks in a year, taken as 54. Using this formula we got an average passive effective dose of 5.92 ± 0.49 μSv/year. Although this value was measured, the estimation of the filtered ^{210}Po is hard to make. There is no absolute certainty that the only ^{210}Po radionuclides were deposited on the applied filters and which other nuclides passed through. Presumably, the used filters do not filter the whole amount of ^{210}Po, so that the filtered amount can only be less than the present amount. This is why the effective dose originating from passive smoking is underestimated.

Conclusions

The research was started under the assumption, that not all activity concentration originating from the tobacco reaches the respiratory system. The average activity concentration for tobaccos was 13.97 ± 1.75 mBq, which can be divided into four parts: the part which first reaches the filter, where a small amount of the ^{210}Po is captured, then reaching the respiratory system and the ash originating from the burning of the tobacco and the smoke.

Measurements show that the filter is able to capture an average 1.61 ± 0.25 mBq (11.5 %), so only an average of 9.03 ± 0.91 mBq (63.41 %) activity concentration of the tobacco reaches the respiratory system. The ash has an average measured activity concentration of 3.33 ± 0.29 mBq (34.9 %), the smoke having the activity concentration of 6.9×10^{-6} mBq/m^3 air, representing less than 1 % of the tobaccos activity concentration. For a precise measurement of the passive dose, the retention efficiency of the filters should be determined.

Locally produced cigarettes have a significantly lower activity concentration in the tobacco, which is probably caused by the different manufacturing methods and the characteristics of the area where the tobacco plant has been grown. Also, the cigarette having an active carbon filter was able to retain twice as much ^{210}Po than the other filters made out of cellulose. Future investigations will be made both regarding the differences in the growing areas of the tobaccos and regarding the filter composition in comparison with the activity concentrations.

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