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Is human hair a proper ^{210}Po and ^{210}Pb monitor of their increased activity in the human body?

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Abstract
The study focused on ^{210}Po and ^{210}Pb activity concentrations determination in human hair as well as investigation its utility as an easy and safe indicator of metal elicitation for natural ^{210}Po and ^{210}Pb, and finding differences in their concentrations in hair considering the age, gender, hair color or diet of people who donated the samples. Statistically analyzed results showed significant differences within age, hair color, and cigarette smoking groups. Our results showed that human hair could not be unambiguously used as ^{210}Po and ^{210}Pb body burden indicators.

Keywords ^{210}Po · ^{210}Pb · Natural radioactivity · Human · Bioaccumulation · Hair

Introduction

^{210}Po and ^{210}Pb radionuclides are a part of the ^{238}U decay chain. They are comparatively toxic to humans chemically and radiologically, principally α-emitting ^{210}Po [1, 2]. The overland air activity concentrations of ^{210}Po and ^{210}Pb range of 0.03–0.30 and 0.2–1.5 Bq m^{-3} respectively [2, 3]. The radon ^{222}Rn emanation is the main source of ^{210}Po and ^{210}Pb in the air, and this process gives globally about 22 PBq year^{-1} of ^{210}Po and ^{210}Pb [4]. The short-lived ^{222}Rn daughters (^{218}Po → ^{214}Pb → ^{214}Bi → ^{214}Po, ^{210}Tl) quickly attach to airborne particles, decay further as ^{210}Pb → ^{210}Bi → ^{210}Po and end up in the biosphere through dry and wet deposition on sea and ground what causes their uptake in plants and animals [2, 5, 6]. The atmospheric fallout of ^{210}Po and ^{210}Pb typically is assumed as constant supply at any location, determined on timescales of years [7]. The most important anthropogenic sources of these radionuclides are uranium mining and milling, burning of coal and other fossil fuels, superphosphate fertilizers and the sintering of ores in steelworks [8]. Lead is also widely distributed in the earth's crust, mainly as galena (PbS) and plattnerite (PbO_2) [9]. Heavy metals pollution has become a serious health care in recent years, and toxic heavy metals of greatest concern are lead, cadmium, and mercury [10].

Food and much less inhalation of contaminated aerosols are the main path for polonium ^{210}Po and lead ^{210}Pb incorporation in the human body [11]. The magnitude of radioisotopes intake depends on the place of residence (climate, geological- and agricultural conditions), local contamination quantity, diet habits, and food origin. Taking into consideration food origin, some products might be enriched with natural radionuclides when cultivated in soil with higher natural radioactivity background, e.g. Kerala and Madras (India), Ramsar (Iran), Yangjiang (China), Brazil, Sudan or Pakistan [7, 12]. Some studies proved, some fertilizers available for the agriculture can effect in higher radionuclides content in arable soil [13, 14]. The mineral (especially phosphate) fertilizers can impact on the uranium content and its daughter nuclides in the soil (e.g. ^{210}Po and ^{210}Pb), so plants, and next animals, are able to accumulate increased radioisotopes values [15].

It is known that the hair, nails, and teeth are tissues in which trace or heavy elements are sequestered and stored, and could be used to monitor their content. In this way, hair could be perfect as a bioindicator. It is easy to collect and store, and various trace elements can be determined with good precision and sensitivity [16, 17]. Mammalian hair consists of 45% carbon, 28% oxygen, 15% nitrogen, 7% hydrogen and 5% sulfur, and is preponderantly composed of keratin, thiols (cysteine sulfhydryl) rich protein which can bond different elements. Under normal conditions, hair

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contains 20–220 ppm Fe, 10–20 ppm Cu, 190 ppm Zn and 0.6 ppm I. The water content is about 12% at room temperature [18, 19]. The hair root is in continuous contact with the bloodstream, so it may incorporate metals flowing in the blood during growth.

Very early studies on ^{210}Pb accumulation in hair showed that its concentrations in the anagen (growing) hair was 7–137 times higher than in the telogen (resting) hair [20]. The studies on lead-binding in rat epidermis indicated the heaviest labeling after ^{210}Pb was found in hair follicles, though the upper epithelial and germinal layers, as well as deeper dermal regions and sebaceous glands were also clearly labeled [21]. As an implication, tissue metal concentrations can be reflected and hair may serve as a non-invasive monitor for body metal burden. Sanna and collaborators found a significant positive correlation between stable lead concentrations in blood and hair among groups of boys and girls from Sardinia (Italy) [22]. Some researchers suggested hair was an appropriate accumulative indicator of metal bioavailability and there was a significant correlation between metals and metalloids within the hair and other tissues like liver and kidney as well as environmental levels [18, 23].

Very often in radionuclides surveys, urine and feces samples were collected in order to analyze the body burden of radionuclides [24, 25]. It is well known some biological samples as urine and feces are remarkably difficult to sample, handle and store, also not easy to digest in the radiochemical preparations. Hair was suggested as a simple and more useful approach to study internal contamination, mainly because of the swiftness of sampling and less time consuming radiochemical analysis [6, 19, 26]. The results showed that hair could be used as an easy method to determine the total body content of radioactive polonium. Strumińska-Parulska et al. [27, 28], in their studies on dogs' fur, showed that ^{210}Po and ^{210}Pb activity concentrations in hair reflected their content in the surrounding.

The cardinal idea of this study was the investigation of the possibility of using hair as a monitor of ^{210}Po and ^{210}Pb activity level in the body content. The targets of presented research were to analyze activity concentrations of ^{210}Po and ^{210}Pb in human hair samples and to find differences in their concentrations in hair considering age, gender, hair type or diet of samples donors. In general, hair can reflect an internal contamination and may help to assess the environmental levels of certain radionuclides. This way, finding the relation of ^{210}Po and ^{210}Pb activity concentrations in hair to their activity level in soft tissues or organs, it may enable to use hair as an indicator to trace irregular amounts originating from their high intake.

Materials and methods

All analyzed hair samples were collected from 109 inhabitants of Pomerania (northern Poland) in 2009–2010 and were taken close to the scalp. Following the ethical standards all donors were asked for giving the hair samples and accepted our studies on ^{210}Po and ^{210}Pb. The donors were surveyed on their age, gender, hair color, cigarettes smoking and eating habits (consumption of more than 0.5 kg of fish per week) and all questionnaires were kept by Department Head.

The hair samples were cleaned carefully to remove fats and different forms of pollution: once in acetone, thrice in water and once in alcohol. During washing, the samples were left at room temperature for 10 min; after that the supernatant liquid was decantated and new portion of solvent was added. At the end, the analyzed hair was dried. All samples were spiked with 10 mBq of ^{209}Po. Mineralization was performed in a mixture of conc. HNO_3 and sometimes using conc. HCl with 30% H_2O_2 in the range of 50–90 °C and the temperature was limited by two factors: semi-closed mineralization system in glass beakers and acids boiling temperatures. After mineralization first polonium deposition was conducted on silver discs [4 h in 90 °C, sample dissolved in 0.5 M HCl and about 0.2 g of ascorbic acid ($C_6H_8O_6$) added] [27, 29]. The radiolead ^{210}Pb was analyzed indirectly through ingrowth of its daughter polonium ^{210}Po. For this purpose, the solution after polonium deposition was evaporated and the residue stored about 2 years in order for sufficient (5 half-lives) ^{210}Po ingrowth from ^{210}Pb [30]. After this period, each sample was treated with 10 mBq again and digested as previously. After that, the second polonium depositions on silver discs were performed [28–30]. In both analysis, polonium isotopes activities (^{209}Po and ^{210}Po) were measured using an alpha spectrometer (Alpha Analyst S470, Canberra-Packard, USA) and the single measurement took 1–3 days. The alpha spectrometer efficiency and energy calibration was done using certified solid source of ^{237}Np, ^{214}Am, ^{244}Cm (Isotrak). The activities of ^{210}Po and ^{210}Pb in analyzed hair samples were corrected for their decay to the day of autodeposition (time of separation ^{210}Po from ^{210}Pb).

The precision and accuracy of the radiochemical ^{210}Po and ^{210}Pb analysis were assessed using IAEA-414 reference material and were better than 5%. The analyzed radionuclides yield in hair samples ranged from 90 to 100% and the results were analyzed using statistical tests. Shapiro–Wilk of normality test showed there was non-normal distribution of the data ($p < 0.05$) and Levane test for equality of variance showed that variance was not equal among analyzed groups ($p < 0.05$) and we decided

to use non-parametric tests (mainly Mann–Whitney *U* test and Kruskal–Wallis one-way analysis of variance *H* test) in order to find significant differences between analyzed groups [31]. All tests were conducted with $\alpha = 0.05$.

Results and discussion

Gender

In the survey 17 women and 92 men participated. The ^{210}Po activity concentrations for men were in the range of 0.10 ± 0.01 and 12.8 ± 0.80 Bq kg^{-1} dry wt., while for women between 0.33 ± 0.02 and 5.89 ± 0.51 Bq kg^{-1} dry wt. (Table 1 and Fig. 1). The ^{210}Pb activity concentrations for men were from 0.44 ± 0.04 to 49.6 ± 1.48 Bq kg^{-1} dry wt., and for women from 0.53 ± 0.06 to 23.7 ± 1.91 Bq kg^{-1} dry wt. (Table 2 and Fig. 1). Mann–Whitney (also known as *U* test) for ^{210}Po showed there were statistically significant differences between gender groups ($p = 0.02$) and men hair contained more ^{210}Po than women (Table 1). But there were no statistically significant differences in the case of ^{210}Pb ($p = 0.81$). These observations were in line with previous studies on ^{210}Po and ^{210}Pb depending on gender in mammals' hair [18, 27, 32–36]. In the case of ^{210}Pb, some authors have reported differences in lead concentrations between boys and girls although results were not consistent and should be further investigated [37, 38]. Strumińska-Parulska et al. [28] and Tête et al. [39] who analyzed the fur of dog and mice respectively, concluded that males had higher amounts of radiolead and lead compared to females. Chojnacka et al. [40] showed that hair samples collected from males of south-western Poland had 280% more stable Pb than hair from females. In general, females have significantly more body fat than males but lower rates of renal clearance. Therefore females store more lipophilic metal ions (as Pb) to increase the contaminant concentration [41, 42].

Age

Every study on elements or toxic metal bioaccumulation in the human body should account for the age of the tested subjects. We divided all the collected samples into 5 age groups: 0–10, 10–20, 20–40, 40–60 and more than 60 years old; and the number of samples in each group were: 23, 9, 47, 22 and 5 respectively. Average and other significant values of ^{210}Po concentrations for each group, were presented in Table 1, while its distributions on Fig. 2. Similarly to Carvalho [43] research, the average value of ^{210}Po concentration in the hair increased with the donors' age. But *H* test showed slight statistically significant differences among analyzed age groups ($p = 0.09$).

The ^{210}Pb activity concentrations among analyzed age groups were presented in Table 2 and on Fig. 2. Used *H* test (Kruskal–Wallis) showed that there were statistically relevant differences among analyzed age groups ($p = 0.01$).

Table 1 ^{210}Po activity concentrations in hair samples of analyzed groups

Analyzed groups	Number of samples	^{210}Po activity concentrations (Bq kg^{-1} dry wt.) ± SD			
		Average	Median	Minimum value	Maximum value
Gender					
Women	17	1.73 ± 1.22	1.58	0.33 ± 0.02	5.89 ± 0.51
Men	92	2.76 ± 2.18	2.13	0.10 ± 0.01	12.8 ± 0.80
Age					
0–10	23	2.48 ± 1.45	2.33	0.26 ± 0.02	5.89 ± 0.51
10–20	9	2.42 ± 1.68	2.13	0.43 ± 0.03	5.82 ± 0.27
20–40	47	2.06 ± 1.47	1.66	0.10 ± 0.01	7.56 ± 0.51
40–60	22	3.54 ± 2.73	2.63	0.34 ± 0.03	12.8 ± 0.80
> 60	5	3.86 ± 3.63	2.86	0.36 ± 0.04	11.6 ± 0.26
Hair color					
Blonde	40	2.85 ± 2.10	2.22	0.64 ± 0.06	7.56 ± 0.51
Black	31	2.34 ± 1.75	1.66	0.27 ± 0.04	7.35 ± 0.16
Grey	11	3.78 ± 3.11	3.06	0.34 ± 0.03	12.8 ± 0.80
Brown	26	1.94 ± 1.38	1.60	0.10 ± 0.01	6.21 ± 0.49
Cigarettes smoking					
Smokers	25	3.40 ± 2.38	2.97	0.10 ± 0.01	11.6 ± 0.26
Non-smokers	84	2.34 ± 1.92	1.74	0.26 ± 0.02	12.8 ± 0.80
Fish consumption					
Fish consumers	14	3.71 ± 3.20	3.49	0.10 ± 0.01	11.6 ± 0.26
Non-fish consumers	95	2.47 ± 1.87	1.92	0.26 ± 0.02	12.8 ± 0.80

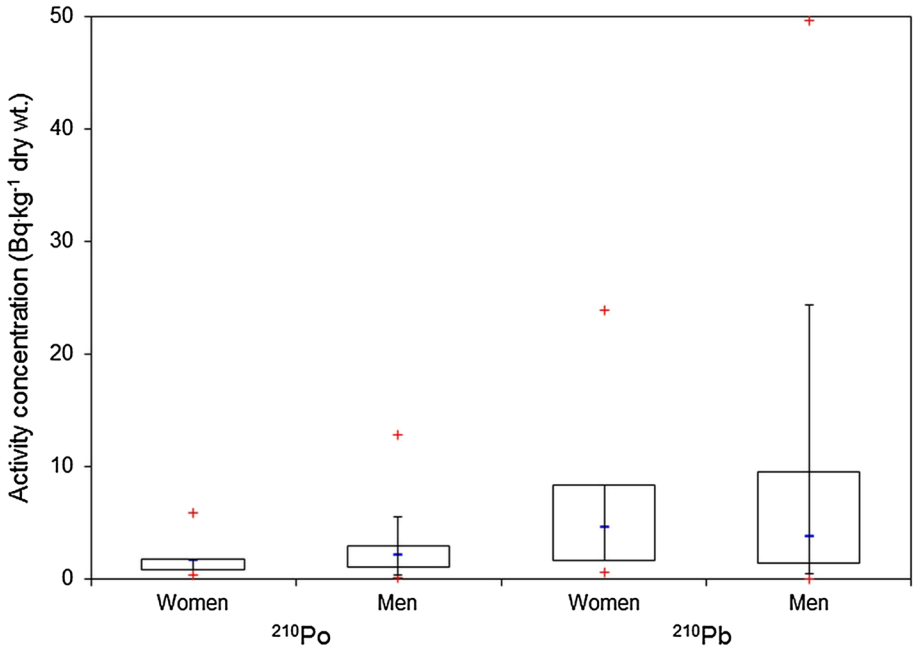

Fig. 1 ^{210}Po and ^{210}Pb activity concentrations in analyzed gender groups

Table 2 ^{210}Pb activity concentrations in hair samples of analyzed groups

Analyzed groups	Number of samples	^{210}Pb activity concentrations (Bq kg^{-1} dry wt.) ± SD			
		Average	Median	Minimum value	Maximum value
Gender					
Women	17	6.84 ± 6.42	4.57	0.53 ± 0.06	23.7 ± 1.91
Men	92	8.36 ± 10.3	3.75	0.44 ± 0.04	49.6 ± 1.48
Age					
0–10	23	5.46 ± 6.96	2.79	1.08 ± 0.11	31.7 ± 2.29
10–20	9	13.9 ± 9.32	14.9	1.30 ± 0.19	34.9 ± 2.75
20–40	47	6.33 ± 9.29	3.05	0.44 ± 0.04	29.8 ± 2.30
40–60	22	10.4 ± 8.86	6.22	1.26 ± 0.06	28.9 ± 2.07
> 60	5	19.9 ± 16.2	15.5	3.75 ± 0.26	49.6 ± 1.48
Hair color					
Blonde	40	9.43 ± 10.9	3.78	0.89 ± 0.07	49.6 ± 1.48
Black	31	6.13 ± 6.25	2.97	0.50 ± 0.04	25.6 ± 0.89
Grey	11	13.6 ± 8.81	15.0	2.52 ± 0.20	28.9 ± 2.07
Brown	26	6.80 ± 10.6	3.53	0.44 ± 0.04	26.8 ± 1.55
Cigarettes smoking					
Smokers	25	11.7 ± 14.0	4.84	1.40 ± 0.11	49.6 ± 1.48
Non-smokers	84	7.35 ± 8.10	3.51	0.44 ± 0.04	34.9 ± 2.75
Fish consumption					
Fish consumers	14	14.7 ± 17.5	4.62	1.40 ± 0.11	49.6 ± 1.48
Non-fish consumers	95	7.53 ± 8.1	3.78	0.44 ± 0.04	34.9 ± 2.75

Dunn's test indicated relevant differences in 2 age groups: 20–40 and > 60 years old ($p = 0.001$). People older than 60 years had the highest average ^{210}Pb activity concentration in hair samples (Table 2). This was exactly the opposite of what Carvalho et al. [43] reported. They did not find a correlation between ^{210}Pb in hair and the age of donors and stated ^{210}Pb concentrations in hair were independent of the age and seemed to be constant [43]. Although there were more studies that ^{210}Pb was age dependent. Strumylaite et al. [35] revealed that Pb concentration in hair was related to age. They observed a positive significant association between Pb in hair and age. Similar results were presented by Nowak [37]. According to his study, people over 30 years had higher lead concentrations in their hair than those less

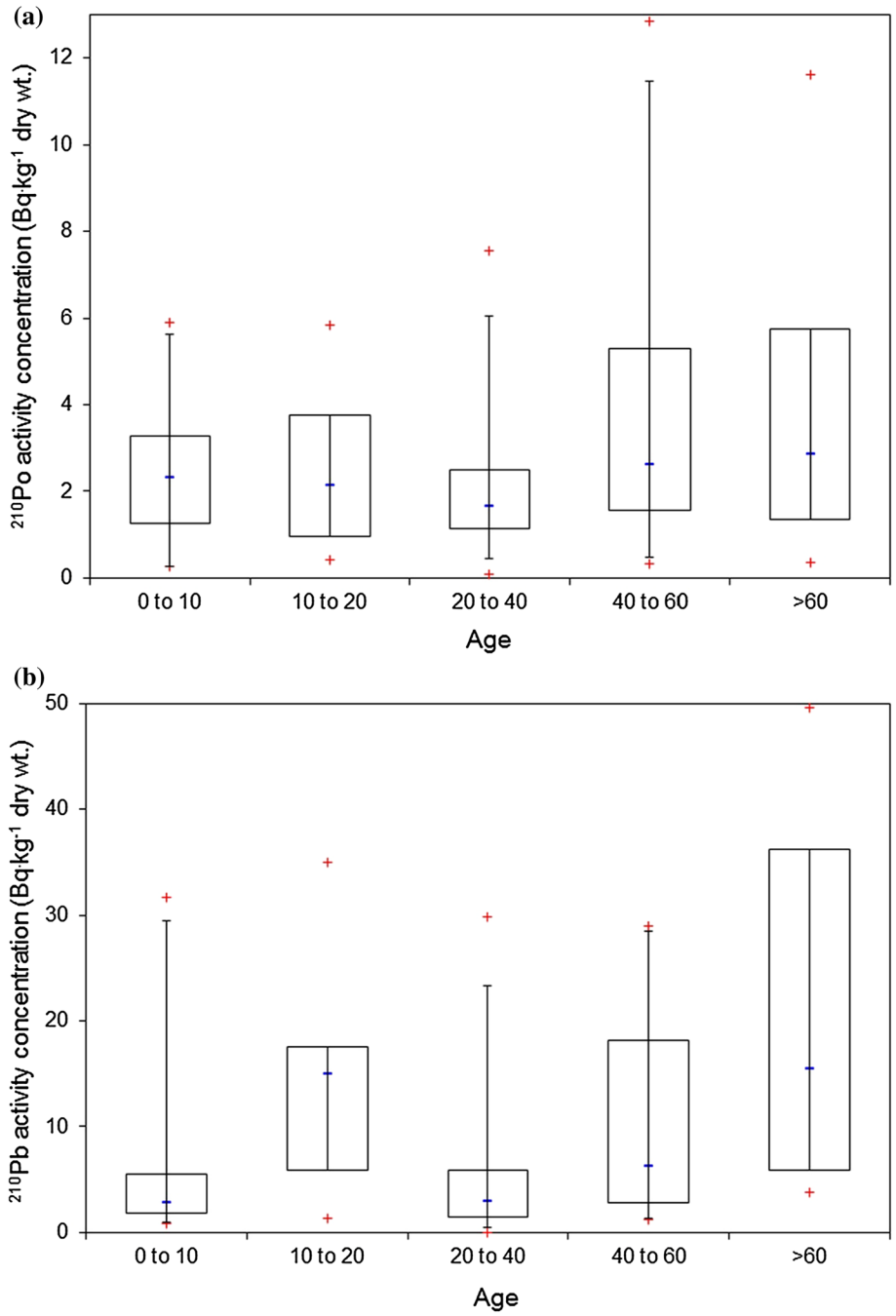

Fig. 2 ^{210}Po and ^{210}Pb activity concentrations in analyzed age groups

than 30. Zhou et al. [42] showed people of age 51–65 had higher hair As, Cd and Pb concentrations than younger groups, especially among males. Generally, people have lower food consumption with age, thus lower heavy metals intake and they tend to develop trace elements deficiencies (i.e. Fe^{2+}) [44]. This might lead to higher rates of absorption and accumulation of other ingested divalent cations in the internal organs and hair [41, 45].

In this paper we tried to find out if hair could be a good indicator of human exposure to ^{210}Pb and ^{210}Po; would reflect their environmental occurrence. Meanwhile the problem of the analyzed isotopes sources was born. ^{210}Pb, and further ^{210}Po, could come not only from indirect fresh intake with food and air but also from ^{226}Ra accumulated in bones, which content increases with age. However, considering ^{210}Po and ^{210}Pb additional sources as their parent nuclide, ^{226}Ra half-life (half-life 1600 years), its potential release into bloodstream and excretion through hair indicates it could have a small impact on their content. The more probable source would be ^{222}Rn (half-life 3.82 days) present in the air, or ^{210}Pb, decaying to their short-lived

nuclides, and further their released to the bloodstream and built up in hair [7].

Hair color

In order to evaluate the possible impact of hair color (eumelanin and pheomelanin) on ^{210}Po and ^{210}Pb accumulation, we asked the donors to mention their hair color. From 109 surveyed people 40 had blonde, 31 black, 26 brown and 11 grey hair. The obtained ^{210}Po activity concentrations were in range of 0.64 ± 0.06 and 7.56 ± 0.51 Bq kg^{-1} dry wt. for blonde hair, 0.27 ± 0.04 and 7.35 ± 0.16 Bq kg^{-1} dry wt. for black hair, 0.34 ± 0.03 and 12.8 ± 0.80 Bq kg^{-1} dry wt. for grey color, and 0.10 ± 0.01 and 6.21 ± 0.49 Bq kg^{-1} dry wt. for brown hair (Table 1 and Fig. 3). The highest average ^{210}Po activity concentration was calculated for grey hair (3.78 ± 3.11 Bq kg^{-1} dry wt.; Table 1) and *H* test indicated there were statistically significant differences between the hair color groups ($p = 0.03$). The only studies on hair color and ^{210}Po concentrations were done in dogs' fur and did not show ^{210}Po was hair color dependent as well [27]. It let us suppose ^{210}Po would not depend on the hair saturation with melanin, oppositely to zinc where the lighter the hair color the lower zinc concentration in the hair [46, 47]. We might think, the keratin-rich hair structure and altogether with cysteine and sulfhydryl groups (–SH) would bind to polonium similarly as lead and cadmium [48, 49].

The ^{210}Pb activity concentrations ranged of 0.89 ± 0.07 and 49.6 ± 1.48 Bq kg^{-1} dry wt. for blonde hair, 0.55 ± 0.04 and 25.6 ± 0.89 Bq kg^{-1} dry wt. for black hair, 2.52 ± 0.20 and 28.9 ± 2.07 Bq kg^{-1} dry wt. for grey hair and 0.44 ± 0.04 and 52.9 ± 4.45 Bq kg^{-1} dry wt. for brown color (Table 2 and Fig. 3). Similarly to ^{210}Po concentrations, the highest average ^{210}Pb activity concentration was calculated for grey hair (13.6 ± 8.81 Bq kg^{-1} dry wt.; Table 2). Applied *H* test indicated there were straight statistical differences between the hair color groups ($p = 0.01$). Post hoc Dunn's tests revealed that statistically different were colors: black and grey ($p = 0.02$) and brown and grey ($p = 0.03$). Years ago Nowak [37] measured higher Pb concentrations in dark hair. Chojnacka and collaborators [40] reported higher Pb results in auburn, dark and grey hair colors (with highest concentrations for dark and grey hair) compared to blonde and colored hair. Black and brown hair contains eumelanin. Melanin is known to preferentially bind to cadmium, lead, and copper [50]. In our survey, grey hair was characterized by the highest ^{210}Pb activity concentrations (Table 2) but all grey hair samples were donated by males. Schroeder and Nason [51] found lower levels of Pb in grey-haired females but not in males. Grey hair is usually a feature of an older age. Obviously melanin content in the hair itself is not enough to correlate ^{210}Pb concentrations.

Cigarettes smoking

Tobacco leaves are well known to contain high amounts of ^{210}Po and ^{210}Pb [5]. There have been many surveys conducted on ^{210}Po and ^{210}Pb in cigarettes [52–55]. It has been estimated about 10% of ^{210}Pb and 20% of ^{210}Po present in the cigarette might enter the lungs with the main smoke stream [56]. As was estimated, the cigarette smoke can contain up to 75% of the ^{210}Po initial amount in the cigarette. Close to 50% of the smoke aerosol might be inhaled into a smoker's lungs. This leads to the conclusion that on average 37% of the ^{210}Po contained in cigarettes is inhaled via smoking. Both ^{210}Po and ^{210}Pb have similar burning behavior below

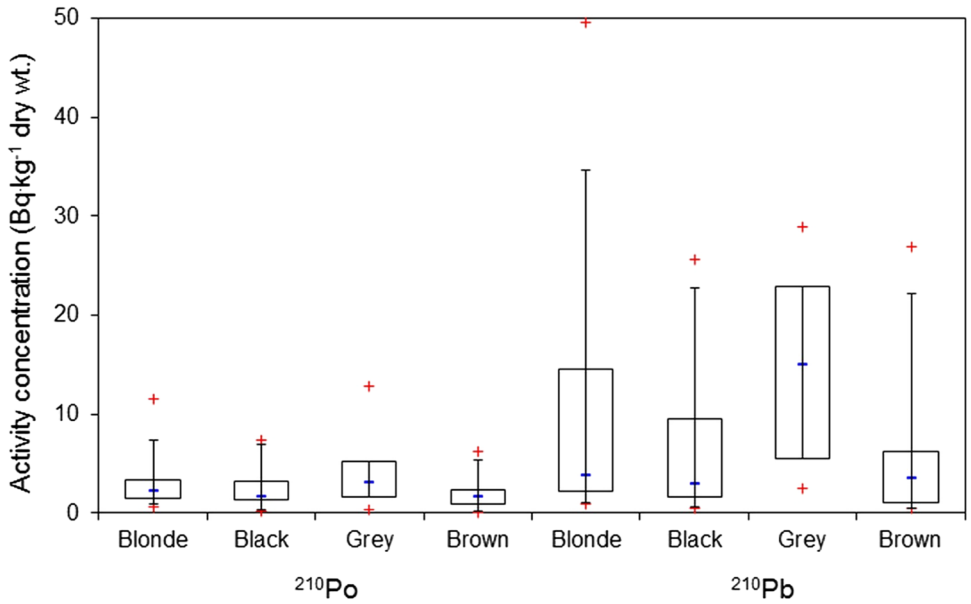

Fig. 3 ^{210}Po and ^{210}Pb activity concentrations in analyzed hair color groups

500 °C so we can assume the same percentage value of ^{210}Pb inhaled via smoking [52, 54, 55]. As presented earlier, Polish who smoke 20 cigarettes per day might inhale from 20 to 215 mBq of ^{210}Po and ^{210}Pb each (average value 96 mBq) [54].

In the study, 25 people declared to smoke cigarettes while 86 were non-smokers. The obtained ^{210}Po activity concentrations for both groups were in the range of 0.10 ± 0.01 and 11.6 ± 0.26 Bq kg^{-1} dry wt. for smokers, and 0.26 ± 0.02 and 12.8 ± 0.80 Bq kg^{-1} dry wt. for non-smokers (Table 1; Fig. 4). Applied *U* test showed statistically relevant differences between these groups ($p = 0.02$). Many types of research were done and proved that cigarette smoking might increase the polonium load to humans [36, 43, 57, 58]. Polonium taken from a cigarette could retain in the blood and be reflected in the hair, especially in the presence of many body factors increasing ^{210}Po mobility [e.g. the pH of the intestinal juice (7.7) and blood (7.4)] and allowing its higher accumulation in the hair [36].

The obtained ^{210}Pb activity concentrations for both groups were in the range of 1.40 ± 0.11 and 49.6 ± 1.48 Bq kg^{-1} dry wt. for smokers, and 0.44 ± 0.04 and 34.9 ± 2.75 Bq kg^{-1} dry wt. for non-smokers (Table 2, Fig. 4). Applied Mann–Whitney *U* test showed only slight statistically significant differences between these groups ($p = 0.08$), but in the case of $\alpha = 0.05$ (95% of confidence) they could not be treated as statistically significant. Yamamoto et al. [34] did not observe any differences in ^{210}Po and ^{210}Pb activity concentrations in hair of smokers and non-smokers, while Strumylaite et al. [35] did. The researchers found a positive association between lead content in hair and smoking—one more cigarette smoked per day gave 0.02 μg g^{-1} increase in Pb in hair [35].

Fish consumption

Many studies confirmed that seafood diet might influence on ^{210}Pb and ^{210}Po radionuclides incorporation into the body. People who consume higher amounts of fish might have higher ^{210}Po and ^{210}Pb whole body burden [34, 59]. It has been reported, ^{210}Po in marine organisms had higher affinity for organic matter than ^{210}Pb [60]. ^{210}Po accumulated in marine food chains contributes more to the total ^{210}Po ingestion (about 80%) than the terrestrial food [59]. In our survey, 14 people declared to eat more than 0.5 kg of fish during a week while 95 claimed to eat less or not at all. The obtained ^{210}Po activity concentrations for both groups ranged of 0.10 ± 0.01 and 11.6 ± 0.26 Bq kg^{-1} dry wt. for fish consumers, and 0.26 ± 0.02 and 12.8 ± 0.80 Bq kg^{-1} dry wt. for a group called non-fish consumers (Table 1, Fig. 5). *U* test showed no statistically relevant differences between these groups ($p = 0.34$). This data are opposite to previously reported [25, 34, 36] but we studied Polish inhabitants hair samples and statistical Pole eats 5 kg of fish per year. Also Polish diet is not rich in other seafood products as shellfish or crustaceans and their influence on ^{210}Po intake is much smaller. It should be clear, the lack of statistical difference between both groups is probably related to a small sample size (number of people eating much more seafood products than statistical amount). Some previous studies showed there are some food products estimated as insignificant, that might be an important source of ^{210}Po and ^{210}Pb [61–66]. The

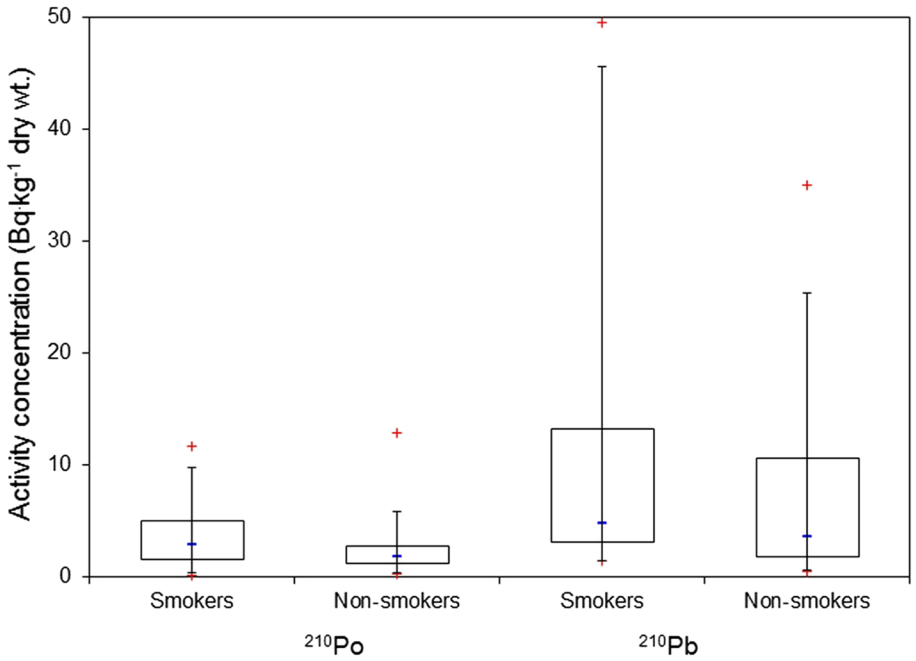

Fig. 4 ^{210}Po and ^{210}Pb activity concentrations in analyzed cigarettes smoking groups

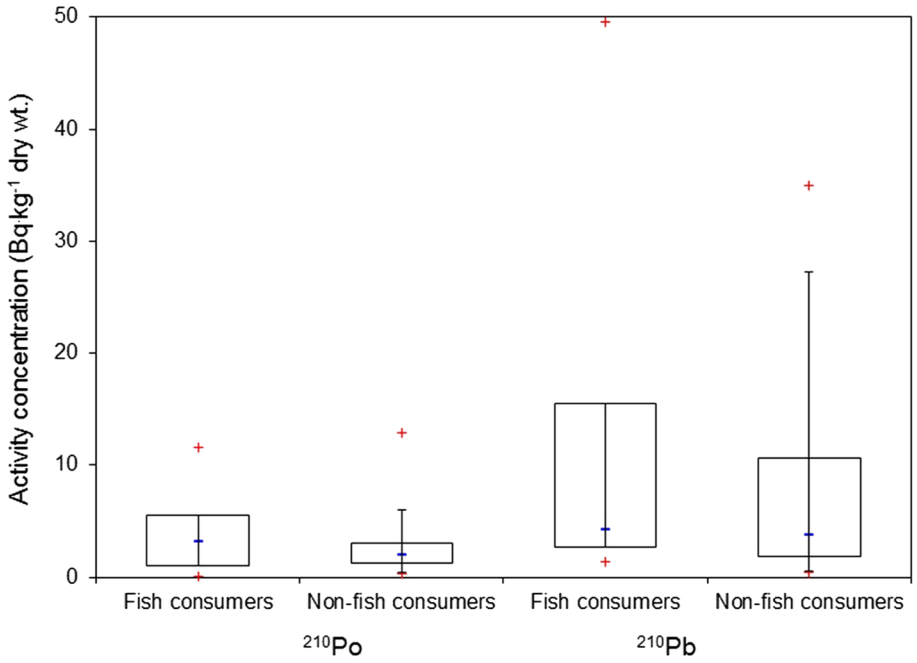

Fig. 5 ^{210}Po and ^{210}Pb activity concentrations in analyzed fish consumption groups

activity concentrations of ^{210}Pb for analyzed groups were in the range of 1.40 ± 0.11 and 49.6 ± 1.48 Bq kg^{-1} dry wt. for fish consumers, and 0.44 ± 0.04 and 34.9 ± 2.75 Bq kg^{-1} dry wt. for non-fish consumers (Table 2, Fig. 5). Applied Mann–Whitney *U* test showed no statistically relevant differences between these groups as well ($p = 0.20$).

Comparison with other studies

In this study, for all hair samples, we received ^{210}Po activity concentrations between 0.10 ± 0.01 and 12.8 ± 0.80 Bq kg^{-1} dry wt. with an average value of 2.60 ± 2.09 Bq kg^{-1} dry wt and these results are comparable to the other research available. According to Parfenov [56], the ^{210}Po contents in the human hair of the general population in various areas ranged from 1.4 to 18.5 Bq kg^{-1}. In Japan, the mean value of ^{210}Po concentrations in hair samples was 18.2 ± 12.2 Bq kg^{-1} (range 5.0–33.2 Bq kg^{-1}) [34]. Carvalho et al. [25] showed ^{210}Po concentration in analyzed human hair from Portugal ranged of 7.4–27.5 Bq kg^{-1} (with its highest values for Portuguese uranium miners). Rathi et al. [36] gave the ^{210}Po activity concentrations in hair samples from Kanyakumari district (India) with a high natural background in a range of 9.89–58.8 Bq kg^{-1}. Al-Afiri et al. [58] measured ^{210}Po in Saudi inhabitants hair at a range of 1.9 and 6.5 Bq kg^{-1} and stated ^{210}Po activity concentration followed the same trend within smokers and non-smokers group: hair $\gg$ blood $>$ urine.

For all samples, the obtained ^{210}Pb activity concentrations were between 0.44 ± 0.04 and 52.9 ± 4.45 Bq kg^{-1} dry wt. with an average value of 8.33 ± 9.91 Bq kg^{-1} dry wt. Ladinskaya et al. [67] gave the mean concentration of ^{210}Pb in human hair at 1.48 Bq kg^{-1}. In Japan, ^{210}Pb concentrations in hair samples from the general public were assessed by Yamamoto et al. [34] and the mean concentration was 2.3 Bq kg^{-1} (range 0.7–6.5 Bq kg^{-1}) and high values were explained by the fact that in Japanese culture a lot of seafood is consumed. Gotchy and Schiager [68] reported maximum value of 341 Bq kg^{-1} of ^{210}Pb in samples from miners from Colorado. Santos et al. [69] analyzed ^{210}Pb activity concentrations in hair samples from uranium mine workers and received values between 3.25 and 5.25 Bq kg^{-1} while for control group the range was from 2.63 to 10.12 Bq kg^{-1}. Phosphate industry workers are also endangered for higher ^{210}Pb intake. Average ^{210}Pb activity concentrations in Brazilian farmers using phosphate fertilizers was 4.6 Bq kg^{-1} while for the control group it was 3.9 Bq kg^{-1} [70]. Higher ^{210}Pb activity concentrations for this study might be explained by the fact that Gdańsk agglomeration is an industrial area with shipyards and phosphate industry that may increase the bioavailable amounts of ^{210}Pb. Generally, the highest concentrations of ^{210}Po and ^{210}Pb were found in bone and hair, almost 10 times higher than in other organs; while the main route of their excretion was feces, estimated at 15 times higher than urine [24].

Conclusions

Hair samples are easy to collect, simple and non-lethal technique in different elements of analysis that can be used to determine the total body content of many elements but

also radionuclides. The ethical benefits are obvious. We received significant statistical differences between age groups and elderly people have higher ^{210}Pb body burden. We have not confirmed the relation between gender and ^{210}Pb activity concentrations probably due to the small female group. Melanin content in hair (hair color), without considering other possible ^{210}Po and ^{210}Pb intake sources and accumulation processes, did not give sufficiently clear results as objects with bright hair color had their highest activity concentrations. Although we received some relevant statistical differences, especially within cigarettes smoking groups, we have to consider other, less evident sources that can increase ^{210}Po and ^{210}Pb intake—occupational hazard, living habits, specific diet. Additionally, some people could be endangered to an acute intake of ^{210}Pb what was not considered in this study.

In conclusion, our results showed that northern Poland geological conditions and its low natural background radiation, unknown specific occupational and environmental surveys for various populations it is difficult to use as unambiguous ^{210}Po and ^{210}Pb body content monitor.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical standards Following the ethical standards the research ethics committee (Prof. B. Skwarzec, Dr. K. Kabat, O. Bławat) reviewed and approved the research. In the study all donors were asked for giving the hair samples and next accepted our studies on ^{210}Po and ^{210}Pb. They were surveyed on the analyzed factors and all questionnaires were kept by Department Head. According to minor participants (under 18 years of age) their parents filled the questionnaires.

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