Partitioning and health risk dose assessment of polonium-210 in selected brands of cigarettes and types of tobacco consumed in Jordan

Mohammad S. Al-Hwaiti*

Environmental Engineering Department,
College of Engineering,
Al-Hussein Bin Talal University,
P.O. Box (20), Ma'an, Jordan,
Email: mohhwaiti@ahu.edu.jo
Email: mohhwaiti@gmail.com
*Corresponding author

Hanan H. Saleh

Department of Radiography,
College of Nursing and Health,
Al-Hussein Bin Talal University,
Ma'an, Jordan
Email: hanhas2002@gmail.com

Ma'mon Makhaleh and
Mufid Masadeh

Radiochemistry Laboratory,
Jordanian Atomic Energy Commission,
Amman, Jordan
Email: m.makahleh@jaec.gov.jo
Email: mufid.masadeh@jaec.gov.jo

Abstract: The aim of this study was the determination of Po-210 in cigarettes consumed in different parts of Jordan and determination of Po-210 in the four most frequently smoked brands (mixed brand cigarettes, cigarette brand – Gold Star, tobacco wrapped paper – Hishi and tobacco moassel). Po-210 in tobacco displays concentrations ranging from 4 to 29 mBq/g, depending upon the cigarette brand. The average percentages of Po-210 content in mixed brand cigarettes, cigarette brand (Gold Star), tobacco Hishi and tobacco moassel that were recovered by post-smoking filters, ash and smoke were 8.70%, 8.32%, 22.51% and 28.92%, respectively. Smokers, who are smoking cigarettes (mixed and gold coast) and tobacco (Hishi and moassel) per day, are inhaling on average ranged from 127 to 157 mBq/d and from 108 to 156 mBq/d, respectively, of Po-210 and Pb-210 each. The average annual effective doses due to Po-210 and Pb-210 intake by smoking one pack of cigarettes per day, during one year were 317 (0.37 mSv) and 480 (0.48 mSv), 257 (0.26 mSv) and 389 (0.39 mSv), 315 (0.32 mSv) and 469 (0.47 mSv), and 220 (0.22 mSv) and 332 (0.33 mSv), respectively.

Keywords: polonium-210; cigarette smoking; tobacco smoking; dose assessment; distribution; Jordan.

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Biographical notes: Mohammad S. Al-Hwaiti received his Bachelor's degree in Geology, Master's degree in Environmental Geochemistry from the University of Jordan, and PhD in Environmental Engineering from the University of Jordan/TU-Berlin. His expertise is in health risk assessment of heavy metals and radionuclides in water, soil, sediment, plant, human health, environmental radiation, and hazard waste management. He has published more than 50 papers in national and international journals.

Hanan H. Saleh graduated in Physics at the Yarmouk University, Jordan, obtained a Master's degree in Nuclear Physics at the University of Jordan and a PhD in in Radiation Physics/Medical Applications from the University of Jordan. She has expertise in medical and health physics and environmental radiation.

Ma'mon Makhaleh graduated in Applied Nuclear Physics from Sofia University in Bulgaria and obtained a Master's degree in Nuclear Technology and Nuclear Energy at the Sofia University in Bulgaria, and a PhD in Nuclear Electronics at the Sofia University in Bulgaria. He is Director of Radiation Protection and Calibration at Jordan Atomic Energy Commission (JAEC).

Mufid Masadeh graduated in Chemical Engineering from Turkey. He is superviser of radiochemistry laboratory at Jordan Atomic Energy Commission (JAEC). He has expertise in radioecology and analytical chemistry, with emphasis in radiochemistry.

1 Introduction

WHO has declared a tobacco epidemic, indicating the spread of smoking dependency, which affects 1.3 billion people worldwide and results in 5.4 million tobacco-related deaths each year. If this trend continues, there will have been10 million deaths by 2030 (Jha et al., 2002). Tobacco is used for smoking in many ways (e.g. cigarette, cigar, pipe and narghile) and the health consequences vary accordingly (Funck-Brentano et al., 2006). The cigarette is the most popular and worldwide consumed tobacco product. Narghile (hookah, shisha, water pipe) smoking is very popular in Middle East and North Africa countries and recently became fashionable worldwide (Khater et al., 2008).

Cigarette smokers inhale radionuclides that build up over time in the lungs and other parts of the body. Smokers are not the only ones affected by the radiation in cigarettes. Nearby non-smokers inhale the radionuclides as well (Fernando et al., 2006). Cigarettes made from this tobacco still contain these radioactive elements. Lead-210 and polonium-210 emit mostly alpha and gamma radiation. The radioactive particles settle in smokers'

lungs, where they build up as long as the person smokes. (Unfiltered cigarettes allow the greatest amount of radionuclides to enter the lungs.) Over time, the radiation can damage the lungs and help cause lung cancer (Robyn et al., 2009; WHO, 2010).

Polonium-210 is natural element found in nature. Po is directly produced during radioactive decay of the parent radionuclide ^{226}Ra, which is, in turn, a daughter of U decay. Lead-210 and polonium-210 are found at elevated concentrations in association with a Ra-226 source (Watson, 1985). Polonium-210 (which has a physical half-life time of 138 days) is a member of the natural uranium-238 series and one of the relatively long-lived radionuclides of radon decay products. It is an alpha-emitting radionuclide and is present in trace amounts in most plants and foodstuffs as well as in human tissues (Batarekh and Teherani, 1987).The polonium isotopes are among the most radiotoxic nuclides to human beings. The concentrations of ^{210}Po in cigarette tobacco are in the range of 2.8–37 Bq/kg and vary with the cigarette brand, probably due to the different varieties of tobacco used and to different manufacturing procedures (Skwarzec et al., 2001a,b).

Takizawa et al. (1994) reported that the range of ^{210}Po contained in the tobacco grands in Japan varied from 13.0 to 20.1 Bq kg^{-1} (mean 15.4 Bq kg^{-1}), 50% of ^{210}Po present in tobacco was transferred into the smoke and the other 50 % remained in the ash and butt. One pack-a-day smoker inhaled 24 mBq d^{-1} of ^{210}Po through smoking and the annual inhalation was 8.8 Bq. Peres and Hiromoto (2002) indicated that ^{210}Po in (dry) tobacco in Brazil ranged from 10.9 to 27.4 Bq kg^{-1} and ^{210}Pb from 11.9 to 30.2 Bq kg^{-1}. The collective committed effective dose resulting from the use of cigarettes produced in Brazil per year was estimated to be 1.5×10^4 man Sv, considering an annual production of 5×10^8 kg of cigarettes in Brazil and the committed effective dose of 0.16 mSv y^{-1} of cigarette smoking. Colangelo et al. (1992) measured ^{210}Po in tobacco in Argentina ranged from 10 to 80 Bq kg^{-1} and the lung dose due to the use of tobacco varied from 75 to 600 p, Sv y^{-1}. Khater (2004) estimated that the range of ^{210}Po in cigarette tobacco in Egypt ranged from 9.7 to 22.5 mBq per cigarette (average 16.6 mBq per cigarette). The average percentages of ^{210}Po content in fresh tobacco plus wrapping paper that were recorded by post-smoking filters, ash and smoke were 4.6, 20.7 and 74.7, respectively. Cigarette smokers, who are smoking one pack (20 cigarettes) per day, are inhaling on average 123 mBq d^{-1} of ^{210}Po and ^{210}Pb each. The mean values of the annual effective dose for smokers (one pack per day) were estimated to be 193 and 251 μSv y^{-1} from ^{210}Po and ^{210}Pb, respectively.

1.1 Cigarette smoking in Jordan

Jordan is one of the countries with a higher consumption of cigarettes on an international scale. Approximately half of the population (48%) had smoked a cigarette (Abughosh et al., 2012). Tobacco smoking is a very big health problem in view of the fact that studies have shown that the prevalence of smoking in adults is about 30% of men and 15% of women in 2003 (Burgan, 2003; Al-Matubsi et al., 2011), and for youth ages (13–15) in 2016 over 17% for males and 5% for females (WHO, 2017). The burden of smoking-related diseases in Jordan is increasingly evident.

During 2006, chronic, non-communicable diseases (NCDs) accounted for more than 50% of all deaths in Jordan (Belbeisi et al., 2009). In Jordan, however, the estimated prevalence of having ever smoked any form of tobacco among adolescents was 18% in 1999, 13% in 2004, 16% in 2007 (Belbeisi et al., 2009) and 26% in 2009 (EMR, 2010), whereas about 21% of Jordanian adolescents aged 13 to 15 currently smoke waterpipes, with higher prevalence rates among males (27%) than females (16%) (EMR, 2010). Mzayek et al. (2012) conducted a longitudinal study which followed 1702 seventh-grade students (13 years of age) in one of Jordan's northern governorates to assess the patterns in smoking initiation among youth for both cigarettes and waterpipes. They reported that the prevalence of having ever smoked water-pipe increased 1.8 times during the 2-year follow-up period (from 26% to 46%; $p < 0.01$), while current waterpipe smoking increased 1.4 times during the same period (from 13% to 19%; $p < 0.01$) among the study sample (Sukaina et al., 2013). Al-Kazwini et al. (2013) determined macro and trace elements in Moassel used in waterpipes in Jordan. The carcinogenic effect of ^{210}Po with respect to lung cancer is an important problem in many countries with very high cigarette consumption. Jordan has one of the highest consumptions of cigarettes in the world.

In Jordan, until now, no data are available about the activity concentration of ^{210}Po in cigarettes and tobacco. Thus, the determination of polonium-210 in different parts of cigarettes consumed in Jordan is of great concern. The aim of this study was the determination of polonium-210 in different parts of cigarettes consumed in Jordan and determination of ^{210}Po in four most frequently smoked brands [(mixture brands cigarettes, brand cigarette (Gold Star), tobacco wrapped paper (Hishi) and tobacco Hubble_Bubble (moassel)]. The annual committed effective dose from cigarettes was determined and compared with other results reported in literature.

2 Experimental work

2.1 Sampling

In the present study, ^{210}Po concentrations were determined for five brands of cigarettes consumed in Jordan [(mixture brands cigarettes, brand cigarette (Gold Star), tobacco wrapped paper (Hishi) and tobacco Hubble_Bubble (moassel)].These cigarettes for these studies were randomly selected from those available on the market. Each brand has several types of cigarettes, the most popular one is shown in Table 1.

2.2 Alpha spectrometer measurements

Alpha spectrometer analysis was carried out at the Jordanian Atomic Energy Commission, Radiochemistry Department, Amman. Alpha spectrometer analysis was performed on cigarettes and tobacco samples in order to determine the ^{210}Po in selected brands of cigarettes and types of tobacco consumed in Jordan. ^{210}Po analysis was conducted using alpha spectrometers (Canberra 4701), employing PIPS detectors, which combine high resolution and low backgrounds in a rugged alpha detector with active areas up to 1200 mm^2. Minimum detectable activity (MDA), of 1 mBq, was determined for the detection system and radiochemical procedures adopted in this study (Currie, 1968).

Table 1 Brands of Jordanian cigarettes and tobacco

Sample	*Type*	*Content*
Mixture brands cigarette	(Marlboro, Kent, Winston, LM, Gold coast)	20 cigarettes each pack
	Gold coast	10 packs
Cigarette brand (gold coast)	Fresh filter	200 filters
	Post filter	200 filters
Tobacco wrapping paper	(Hishi)	100 g
	Moassel	150 g
Tobacco Hubble-Bubble	Moassel ash	15 g
((Arguila)	Moassel water	1L

The average chemical recovery was 75%, and the individual values ranged from 50 to 100%.Analytical quality control measurements were regularly performed through reference samples analyses (e.g. IAEA-326 and IAEA-327), blank samples analyses and participation in IAEA inter-comparison exercises. The uncertainties of the reported results are evaluated considering counting statistics and calibration error only.

2.3 Calculation of committed annual effective dose

Daily inhalation of ^{210}Po was calculated. The dose conversion factor for adults was 3.7μSv Bq^{-1} for ^{210}Po (Mennah, 2011). The committed annual effective dose contribution to smokers, considering the ^{210}Po concentration, was calculated using the following formula:

$$E = F1 \times F2 \times K \times G \times C \times t \quad (1)$$

where E is the committed effective dose from inhalation (μSv), $F1$ the average transfer factor from tobacco to smoke (1.5), $F2$ the inhaled smoke per total smoke ratio (0.5), K the inhalation dose conversion factor of ^{210}Po (3.7 μSv Bq^{-1}), G the number of cigarettes smoked (10 cigarettes day^{-1}) to calculate the average number of cigarettes smoked by the individual's daily through the questionnaire and the study was on 25 per person is about 87% of them smoked 10 cigarettes per day, C the concentration of ^{210}Po (Bq/cigarette) and t the duration of smoking (365 days) (Godwin et al., 2010).

3 Results and discussion

The activity concentrations of ^{210}Po in a mixture cigarettes tobacco, cigarettes tobacco gold coast, fresh filter, post filter, cigarettes Hishi tobacco, Moassel tobacco, Moassel ash, Moassel water of the J cigarettes is presented in Table 2. The average activity concentrations of ^{210}Po in mixture cigarettes tobacco, cigarettes tobacco gold coast, cigarettes Hishi tobacco, Moassel tobacco, were 18.16 ± 0.88, 13.82 ± 0.44, 20.08 ± 0.88, and 15.25 ± 1.32 mBq/cigarette, respectively (Figure 1). Because the analysed cigarette brands (gold coast) represent the most frequently smoked cigarettes and about 75% of the Jordan cigarette market, the average activity concentration of ^{210}Po in the tobacco of the Jordan cigarettes is 13.82 ± 0.44 mBq/cigarette(19.75 ± 0.63 mBq/g). Whereas, the

highest analysed cigarette brands (Hishi) represent the lowest frequently smoked cigarettes and about 5% of the Jordan cigarette market, the average activity concentration of ^{210}Po in the tobacco of the Jordan cigarettes is 20.08 ± 0.88mBq/cigarette (28.68 ± 1.25 mBq/g).

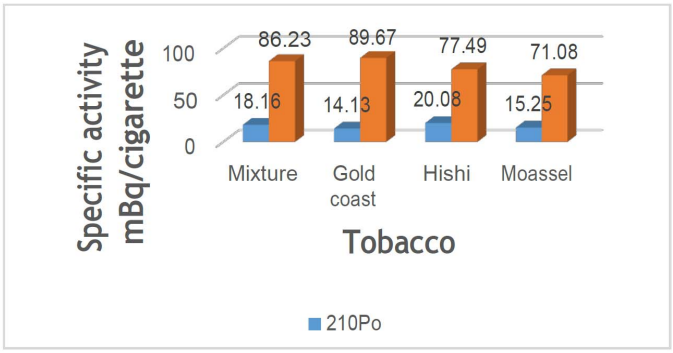
Table 2 Descriptive statistical analysis of activity concentrations of ^{210}Po in Jordan cigarettes smoking

	mBq/g			*mBq/cigarette*		
	Min	*Max*	*Average*	*Min*	*Max*	*Average*
Mixture brands cigarette						
Mixture cigarette	23,88	28.11	25.94 ± 1.26	17.02	19.75	18.16 ± 0.88
Ash	28.54	33.45	30.25	1.88	2.56	1.58 ± 0.12
Fresh filter	3.64	5.38	4.30 ± 0.23	0.40	0.82	0.30 ± 0.04
Post filter	7.84	10.42	8.50 ± 0.60	1.06	1.48	1.22 ± 0.08
Brand gold coast						
Cigarette	19.00	20,69	19.75 ± 0.63	13.22	14.84	13.82 ± 0.44
Ash	21.10	23.12	21.85 ± 1.00	0.83	1.52	1.15 ± 0.04
Fresh filter	1.82	2,69	2.15 ± 0.23	0.20	0.41	0.30 ± 0.04
Post filter	3.92	5.12	4.25 ± 0.60	0.53	0.74	0.61 ± 0.04
Tobacco wrapping paper						
Tobacco (Hishi)	26.92	31.14	28.68 ± 1.25	19.01	23.23	20.08 ± 0.88
Ash	8.02	10.92	9.32 ± 1.28	4.40	4.70	4.52 ± 0.04
Tobacco Hubble-Bubble (Arguila)						
Moassel	4.18	5,59	4.91 ± 0.43	13.48	16.43	15.25 ± 1.32
Moassel ash	7.91	10.89	9.32 ± 1.28	3.46	5.37	4.41 ± 0.41
Moassel water	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.

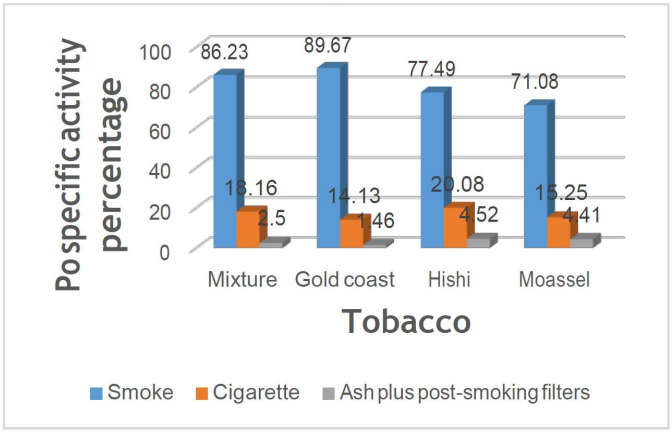
Note: b.d.l. = below detection limit.

The activity concentrations of ^{210}Po in mBq/cigarette present in the cigarette tobacco, ash and post-smoking filters, and the smoke, and the percentages of ^{210}Po recovered in cigarettes ash, post-smoking filters and smoke are given in Table 2. The efficiency of cigarettes filters to reduce the smoke content of polonium is proved to be quite low in mixture bands and gold coast brand. The average values are 5.06% and 2.24% of the ^{210}Po contained in the in mixture bands and gold coast brand cigarettes, respectively. Skwarzec et al. (2001a,b) reported that the risks associated with cigarette smoking is due not only to high concentrations of toxic substances, but also to the poor efficiency of the filters, which do not reduce sufficiently the quantities of carcinogenic substances contained in cigarette smokes. The average ^{210}Po activity concentration percentages recovered in mixture cigarettes tobacco, cigarettes tobacco gold coast, cigarettes Hishi tobacco, Moassel tobacco brands cigarette ash were 8.70%, 8.32%, 22.51% and 28.92%, respectively (Figure 1). These results indicated that the activity concentrations of ^{210}Po in cigarettes Hishi tobacco and Moassel tobacco brands of cigarettes are higher in tobacco and smoke than those in mixture cigarettes brands and gold coast brands of cigarettes.

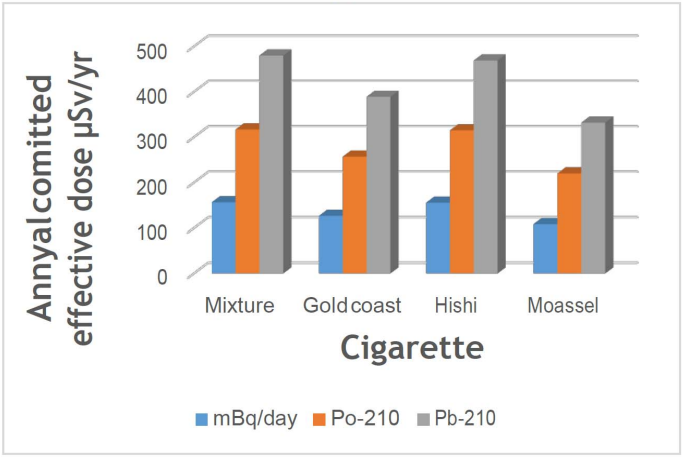
Figure 1 Activity concentration of ^{210}Po and tobacco content in cigarette (A), (B) ^{210}Po activity percentage released in smoke and remained in ash and filter (C) and annual committed effective dose due to ^{210}Po and ^{210}Pb intake via smoking



A



B



C

Radford and Hunt (1964) have measured the relatively low ^{210}Po activity in the analysed cigarette ash is due to volatilisation of polonium at the cigarette burning temperature (600–800°C), which is partially inhaled by the smoker. Baker and Dixon (2006) found that the bulk of studies covering more than one century indicate that, "on average, 60-80% of the mainstream smoke particulate matter is retained in the lungs after inhalation". About 75% of the of the total polonium in the cigarette tobacco was contained in the cigarette smoke, which is partially inhaled and deposited in the lung tissues and about 25% was retained in the cigarette filter and ash (Khater, 2004).

In this study, the average ^{210}Po activity concentration percentages retained in the cigarette filter and ash in mixture cigarettes tobacco and cigarettes tobacco gold coast brands cigarette ash were 13.77%, 10.33%, 22.51% and 28.92%, respectively. About 86.23%, 89.67%, 77.49%, and 71.08%, respectively, of the polonium content in the cigarette tobacco was contained in the cigarette smoke, which is partially inhaled and deposited in the lung tissues.

Average activity concentrations for ^{210}Po (in mBq/cigarette) in Jordan cigarettes compared with other countries are presented in Table 3. The values of activity concentration of Po found in Jordanian cigarette are within the range found in literature (Table 4). The activity concentrations of ^{210}Po in Europe cigarette tobacco (Black and Brethauer, 1968; Parfenov, 1974; Musseal o and Jaakkola, 1985; Skwarzec et al., 2001a,b) ranged from 8.3 mBq/cigarette to 23.2 mBq/cigarette. For comparison two countries are mentioned here, France that produced tobacco with relatively high ^{210}Po concentrations (23.2 mBq/cigarette) and India that produced tobacco with relatively low concentrations 3.3 mBq/g (about 4 mBq/cigarette, based on a normal value for cigarette weight). The average activity concentration of ^{210}Po in Egyptian cigarette tobacco (Khater, 2004) is 16.3 mBq/cigarette, while ^{210}Po activity concentrations in Jordan is 13.8 mBq per cigarette. Since 40 years ago, there is no significant difference between the results obtained by authors (Table 3), indicating that the modern tobacco processing methods and filter materials used and developed have not been sufficient to reduce the ^{210}Po concentrations in cigarette.

Table 3 The average activity concentrations of ^{210}Po (mBq/cigarette) in tobacco plus wrapping paper, ash plus post-smoking filters, and the smoke. (b) Percentages of ^{210}Po activity concentrations recovered after cigarette smoking in cigarette ash, post-smoking filters and smoke

Brands	*Mixture cigarettes*	*Gold coast cigarette*	*Tobacco Hishi*	*Tobacco Moassel*
Tobacco	18.16 ± 0.88	14.13 ± 0.44	20.08 ± 0.88	15.25 ± 1.32
Ash plus post-smoking filters	2.50 ± 0.92	1.46 ± 0.48	4.52 ± 0.04	4.41 ± 0.41
Smoke	15.66 ± 1.80	12.67 ± 0.92	15.56 ± 0.92	10.84 ± 1.73
^{210}Po % (Smoke)				
Ash	8.70	8.32	22.51	28.92
Post-smoking filters	5.06	2.24	–	–
Smoke	86.23	89.67	77.49	71.08

Table 4 The average activity concentrations of ^{210}Po (in mBq/cigarette) in Jordan cigarettes compared with other countries

Country	*^{210}Po*	*References*	*Country*	*^{210}Po*	*References*
Jordan	13.8	This study	England	17.3	Black and Brethauer (1968)
Jordan	18.2	This study	Czechoslovakia	11.7	Parfenov (1974)
Egypt	16.3	Khater (2004)	Bulgaria	14.0	Parfenov (1974)
Brazil	16.9	Parfenov (1974)	Finland	11.1	Musseal o and Jaakkola (1985)
Canada	7.9	Black and Brethauer (1968)	Poland	13.3	Skwarzec et al. (2001a,b)
Japan	22.4	Black and Brethauer (1968)	Germany	19.2	Black and Brethauer (1968)
Philippines	10.7	Black and Brethauer (1968)	France	23.2	Black and Brethauer (1968)
Russia	14.1	Black and Brethauer (1968)	Norway	8.6	Black and Brethauer (1968)
India	3.3[a](3.96)[b]	Sinh and Nilekani (1976)	Turkey	14.3	Karali et al. (1996)

Notes: [a]In mBq/g.

[b]Assuming 1.2 g tobacco per cigarette

The daily and annual ^{210}Po concentration inhaled via smoking, and annual committed effective dose due to inhaled ^{210}Po and ^{210}Pb are given in Table 5 and shown in Figure 1. There is a clear correlation between the concentrations of ^{210}Po and ^{210}Pb, because of the assumed secular equilibrium between them, and the tobacco concentrations (Godoy et al., 1992; Carvalho, 1995; Skwarzec et al., 2001b; Peres and Hiromoto, 2002). Khater (2004) has reported that 50% of the total ^{210}Po and ^{210}Pb activity concentrations in cigarette smoke is inhaled during smoking, it means that for a smoker consuming one pack (20 cigarettes) per day.

Table 5 Activity concentration of ^{210}Po in Jordan cigarette tobacco (mBq/cig.) and inhaled via smoking per day (mBq/d) and year (mBq/yr) and annual committed effective dose (μSv/yr) due to ^{210}Po and ^{210}Pb inhalation via smoking

	Po-210 activity concentration			*Annual committed effective dose (μSv/yr)*		
	mBq/cig.	*mBq/day*	*Bq/yr*	*Po-210*	*Pb-210d*	*Total*
Mixture cigarettes	15.66	156.6	57.2	317	480	797
Cigarette gold coast	12.67	126.7	46.3	257	389	646
Tobacco (Hishi)	15.56	155.6	56.8	315	469	784
Tobacco Moassel	10.84	108.4	39.6	220	332	552

Notes: F1, the average transfer factor from tobacco to smoke (1.5),

F2, the inhaled smoke per total smoke ratio (0.5),

K,3.7 μSv/Bq, ^{210}Po dose conversion factor

G, 20 cigarette/day and 50% of ^{210}Po (^{210}Pb) in smoke inhaled.

C the concentration of ^{210}Po (Bq/cigarette) and *t* the duration of smoking (365 days).

D, assuming ^{210}Po and ^{210}Pb are in secular equilibrium & ^{210}Pb dose conversion factor = 5.6 μSv/Bq.

The activity concentrations of ^{210}Po, inhaled via smoking per day (mBq/d) and year (mBq/yr) in mixture cigarettes tobacco, cigarettes tobacco gold coast, cigarettes Hishi tobacco, Moassel tobacco, were156.6 and 57.2, 126.7 and 46.3, 15.56 and 56.8, and 108.4 and 39.6, respectively, and annual committed effective dose (μSv/yr) due to ^{210}Po and ^{210}Pb inhalation via smoking were317 and 480, 257 and 389, 315 and 469, and 220 and 332, respectively. This can be concluded that ^{210}Po inhalation via smoking (Hishi) per day with higher concentration was 15.56(mBq/d), and the annual effective dose was significantly higher 317 μSv/yr are shown in Table 4. This result is comparable with result in Egypt (Khater, 2004) was estimated popular brand cigarettes to be inhaled via smoking per day 144 (mBq/d) and 53 (mBq/yr) and annual committed effective dose (μSv/yr) due to ^{210}Po and ^{210}Pb were 226 and 295 inhalation via smoking. Addition, the estimated ^{210}Po via moassel to be inhaled via smoking per day 242 (mBq/d) and 89 (mBq/yr) and the calculated annual committed effective dose, μSv/yr, due to inhalation of both ^{210}Po and ^{210}Pb, via moassel were 381 and 496, respectively (Khater et al., 2008). Peres and Hiromoto (2002) the average annual committed effective dose is estimated to be an average 193 and 251(μSv/yr) due to cigarettes smoking for ^{210}Po and ^{210}Pb, respectively. The average values of the annual effective dose for Polish smokers who smoke one pack of cigarettes per day were estimated at 35 and 70 (μSv/yr) from ^{210}Po and ^{210}Pb, respectively (Skwarzec et al., 2001b).These values may variable depending on the number and size of puffs per cigarette (smoking habits), and ^{210}Po and ^{210}Pb concentrations in the non-inhaled side smoke. By applying the dose conversion factor for adults of 5.6 μSv/Bq for ^{210}Pb and 4.3 μSv/Bq for ^{210}Po (Battig et al., 1982; Peres and Hiromoto, 2002; Al-Arifi, 2005).

Overall assessment, the study of ^{210}Po contents of tobacco has assumed great importance because of the increase in the incidence of lung cancer amongst smokers (Watson, 1985; Sinh and Nikelani, 1976). 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 life time risk of lung cancer in smokers to be increased by a factor of more than 8, compared with non-smokers. Cigarette smoking increases the internal intake of ^{210}Po 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.

4 Conclusions

The carcinogenic effect of ^{210}Po with respect to lung cancer is an important problem in many countries with very high cigarette consumption. Jordan has one of the highest consumptions of cigarettes in the world. The results of this work indicate that the average activity concentration of ^{210}Po in mixture cigarettes tobacco, cigarettes tobacco gold coast, cigarettes Hishi tobacco, Moassel tobacco, were 18.16 ± 0.88, 13.82 ± 0.44, 20.08 ± 0.88, and 15.25 ± 1.32 mBq/cigarette, respectively. The activity concentrations of ^{210}Po in Hishi brand cigarette tobacco and smoke are higher than that in other brands of cigarette tobacco. The efficiency of cigarettes filters to reduce the smoke content of polonium is proved to be quite low in mixture brands and gold coast brand. The average values are 5.06% and 2.24% of the ^{210}Po contained the in mixture brands and gold coast

brand cigarettes, respectively. The average recovery percentages of the ^{210}Po contained in cigarette tobacco to cigarette ash and smoke are 8.70%, 8.32%, 22.51% and 28.92%, respectively. The activity concentrations of ^{210}Po activity contained in inhaled cigarette smoke (mBq/d) were 156.6 and 57.2, 126.7 and 46.3, 15.56 and 56.8, and 108.4 and 39.6, respectively, the average committed effective doses due to ^{210}Po and ^{210}Pb intake by smoking one pack of cigarettes per day, during 1 yr were 317 (0.37 mSv) and 480 (0.48 mSv), 257 (0.26 mSv) and 389 (0.39 mSv), 315 (0.32 mSv) and 469 (0.47 mSv), and 220 (0.22 mSv) and 332 (0.33 mSv), respectively.

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