Radiological hazards of Narghile (hookah, shisha, goza) smoking: activity concentrations and dose assessment

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A R T I C L E   I N F O

Article history:
Received 6 March 2008
Received in revised form 13 June 2008
Accepted 20 July 2008
Available online 2 September 2008

Keywords:
Narghile
Hookah
Shisha
Tobacco
Smoking
Radionuclides
Dose assessment
Moassel

A B S T R A C T

Narghile (hookah, shisha, goza, “water-pipe”) smoking has become fashionable worldwide. Its tobacco pastes, known as moassel and jurak, are not standardized and generally contain about 30–50% (sometimes more) tobacco, molasses/juice of sugarcane, various spices and dried fruits (particularly in jurak) and, in the case of moassel, glycerol and flavoring essences. Tobacco contains minute amounts of radiotoxic elements such as\(^{210}\text{Pb},^{210}\text{Po}\) and uranium, which are inhaled via smoking. Only very few data have been published on the concentrations of natural radionuclides in narghile tobacco mixtures. Consequently, the aim of this study was to draw first conclusions on the potential hazards of radioactivity in moassel tobacco in relation to narghile smoking. The results indicate the existence of a wide range in the radioactivity contents where the average (range) activity concentrations of\(^{238}\text{U},^{234}\text{Th}\), \(^{226}\text{Ra}\), \(^{210}\text{Pb}\), \(^{210}\text{Po}\), \(^{232}\text{Th}\) and \(^{40}\text{K}\), in Bq/kg dry weight were 55 (19–93), 11 (3–23), 3 (1.2–8), 14 (3–29), 13 (7–32), 7 (4–10) and 719 (437–1044) Bq/kg dry weight, respectively. The average concentrations of natural radionuclides in moassel tobacco pastes are comparable to their concentration in Greek cigarettes and tobacco leaves, and lower than that of Brazilian tobacco leaves. The distribution pattern of these radionuclides after smoking, between smoke, ash and filter, is unknown, except for \(^{210}\text{Po}\) during cigarette smoking and from one existing study during moassel smoking. Radiological dose assessment due to intake of natural radionuclides was calculated and the possible radio-toxicity of the measured radionuclides is briefly discussed.

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1. Introduction

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.

A narghile is a sophisticated pipe of 0.5–1.5 m in height. A suction hose of the same length is attached to a (glass) base partially filled with a quantity of 0.5–1 L of water. The user draws the smoke to his mouth by forcing it to go down – from the bowl containing the smoking mixture at the very top of the pipe – through a hollow vertical tube and then bubble through water inside the airtight base before entering the hose.

It has been claimed and repeated in the open peer-reviewed scientific literature that more than 100 million people worldwide smoke narghile daily (Maziak et al., 2007). However, the origin of such an estimate cannot be traced in any scientific database. As for the historical background of the narghile, it is not Indian as often stated but more probably African (Chaouachi, 2006).

There are different names and types of narghile (shisha, hookah, goza, madâ’a, etc.) that vary in size, shape, structure, etc. The word “water-pipe” is arbitrarily used in some of the available literature. Certainly, it would be easier, for modern scientific information management, to have only one word describing a given apparatus. Unfortunately, each of the existing different names generally refers to different devices with different shapes, sizes, common tobacco-based mixtures, smoking patterns, etc. In these conditions, reducing such a striking physical, social and cultural diversity under a functionalist arbitrary neologism like “water-pipe” (Maziak et al., 2007) has unavoidably led researchers to a great confusion (Chaouachi, 2007b).

Tobacco used for narghile smoking has three main forms: moassel (“mu’assel” as a proper transliteration, meaning “honeyed” in Arabic – although we will use “moassel” in this
study), jurak and tumbak. Their compositions are variable and not well standardized. Moassel contains about 30% tobacco and up to 70% honey or molasses/sugar cane, in addition to glycerol and flavoring essences. The nicotine content varies significantly with quantities of tobacco than ours [i.e. in Europe] in our countries’’ (Guillerm et al., 1961).

An apparently weak risk for lung cancer has been early noticed (BMJ, 1955). According to a prestigious Syrian lung specialist, this would be due to the low temperatures and filtration of part of the tar (Mohammad, 2000). A recent study on carinoembryonic antigen (CEA) levels in Pakistani hookah smokers using several times a day huge amounts of a tobacco–molasles mixture (the weight equivalent of up to 60 cigarettes) tends to support such a hypothesis to a certain extent (Sajid et al., 2008). The only consensus is on CO levels though the diverse types of charcoal, tobacco-based mixtures and degrees of ventilation (indoors, outdoors), etc, should be taken into account (Chaouachi, 2007a). Mean expired CO (expired tidal CO, i.e. CO in the lungs) may thus reach values as high as 48 mg/m³ at the end of a session (with quick-lighting charcoal) (Bacha et al., 2007).

Concerning nicotine, the already existing confusion, particularly due to the use of smoking machines (Chaouachi, 2007b), has been amplified by a meta-analysis of the available data and the current evidence (Neergaard et al., 2007). In fact, a team in Kuwait has established, with a rigorous methodology, that the intake is not as high as in cigarettes (Al-Mutairi et al., 2006).

As for narghile tar, it is qualitatively different from that produced by cigarettes; notably, glycerol is expected, as in the harm reduction Eclipse cigarette, to form a great part of the tar. Cigarettes containing more nitrosamines are not those with a higher tar content (Gray et al., 1998), so that the rating of tar with smoking machines makes no sense.

Tobacco smoke contains more than 4000 different chemicals, most of which are generated during the combustion process. More than 40 compounds are carcinogenic substances, which include some radionuclides such as radioactive polonium (210Po) (Kuper et al., 2001).

The work presented here aims at shedding more light on the radiological health hazards due to narghile smoking, by measuring the activity concentration of some natural radionuclides and estimating the internal radiation dose due to narghile tobacco (moassel) smoking.

2. Health effects

An overview of what sound research says today about narghile smoking and health is necessary. Caution is needed and quick statements should be avoided. Further to finding that when passed through water (50 cm³), the combustion gases of cigarette smoke had no inhibitory effect on the respiratory epithelium cilia, French researchers concluded, 47 years ago, that narghile users could therefore “without apparent disorders, smoke dramatically greater quantities of tobacco than ours [i.e. in Europe] in our countries” (Guillerm et al., 1961).

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3. Experimental work

3.1. Sampling and samples preparation

Thirty eight moassel tobacco samples of three different moassel tobacco brands from Egypt and Saudi Arabia were randomly collected from the local markets of Cairo City and Riyadh City. Four moassel tobacco packs from each source, 50 g weight each, were mixed to form composite sample of 200–250 g weight. Samples were dried at about 80 °C, then pulverized and homogenized. For total uranium analysis, a few grams of some dried samples were ashed at 550 °C for about 12 h.

3.2. Analytical techniques

3.2.1. Gamma spectrometric analysis

The dried samples were transferred to polyethylene containers of 100 cm³ capacity and sealed at least for 4 weeks to reach secular equilibrium between radium and thorium, and their progenies. The 226Ra (238U) series, 232Th series, 40K, 137Cs and 210Pb activity concentrations were measured using well calibred gamma spectrometry based on hyper-pure germanium (HPGe) detectors. The HpGe detector had a relative efficiency of 40% and full width at half maximum (FWHM) of 1.95 keV for 60Co gamma energy line at 1332 keV. The gamma transmissions used for activity calculations are 352.9 (214Pb), 609.3, 1120.3 and 1764.5 keV (214Bi) for 226Ra (238U) series, 338.4, 911.1 and 968.9 keV (228Ac) for 232Th series, 1460.7 keV for 40K, 661.6 keV for 137Cs, 63 keV for 226Ra and 46.5 keV for 210Pb. The gamma spectrometers were calibrated for high energy range (186–2500 keV) using both 226Ra point source and potassium chloride standard solutions and for low energy range (30–180 keV) using reference samples in the same geometry as the samples (El-Tahawy et al., 1992). The lower limit of detection, with 95% confidence, for 226Ra, 232Th and 40K is 0.28, 0.16 and 1.0 Bq/kg, respectively, for 20 h counting time and 1 L sample volume (Currie, 1968).

4.1.2. Polonium-210 analysis

Samples of known weights (3.3–6.4 g) were spiked with 209Po (Eγ = 4.9 MeV) as a tracer in order to calculate the chemical recovery of polonium from the analyzed samples after chemical treatment. The samples were dissolved in a rounded flask using three portions of a 50 mL HNO₃ (65%) and evaporated to near dryness on a sand bath at a temperature of about 90 °C. The sample residues were treated with three portions of 10 mL HCl (32%), and evaporated to near dryness. Finally, the samples were transferred into 50 mL glass beaker and dissolved in 35 mL 0.5 M HCl. Polonium was spontaneously plated from the solution at temperatures between 80 and 90 °C onto rotating stainless steel disks fixed in a Teflon disk holder (Flynn, 1968; Hamilton and Smith, 1986). The plated disks were measured using alpha spectrometers (Alpha Analyst CANBERRA), employing PIPS detectors with efficiencies of about 17% and an average resolution of 17 keV. The plated disks were measured using alpha spectrometers (Alpha Analyst CANBERRA), employing PIPS detectors with efficiencies of about 17% and an average resolution of 17 keV. The plated disks were measured using alpha spectrometers (Alpha Analyst CANBERRA), employing PIPS detectors with efficiencies of about 17% and an average resolution of 17 keV. The plated disks were measured using alpha spectrometers (Alpha Analyst CANBERRA), employing PIPS detectors with efficiencies of about 17% and an average resolution of 17 keV. The plated disks were measured using alpha spectrometers (Alpha Analyst CANBERRA), employing PIPS detectors with efficiencies of about 17% and an average resolution of 17 keV. The plated disks were measured using alpha spectrometers (Alpha Analyst CANBERRA), employing PIPS detectors with efficiencies of about 17% and an average resolution of 17 keV.
3.2.3. Total uranium analysis

Aliquots of 100 mg of the sample ash were dissolved using mineral acid (HNO₃ and HCl acids) and finally dissolved in 2 M HNO₃ solution. After uranium extraction using methyl isobutyl ketone (MIBK) and back-extracted into 0.5 M HNO₃ solution, 5 ml of samples extraction solution and 2 ml FLURAN reagent (sodium pyro-phosphate, sodium di-hydrogen phosphate) were measured for total uranium determination using a uranium analyzer of model Sintrex UA-3. Its work based on the fluorescence of uranium complex formed with FLURAN reagent to convert the uranyl species into a single form that has a high luminescent yield. In the UA-3, a nitrogen laser tube provides UV pulse excitation fluorescence. The uranium concentration in µg/g was calculated from the formula:

\[ U (\mu g/g) = \frac{D_1}{(D_2 - D_1)} V C_f \]

Table 2
Activity concentrations of 238U and 234Th (Bq/kg dry weight), and 238U/234Th activity ratio in moassel tobacco samples

<table>
<thead>
<tr>
<th>Samples</th>
<th>Code</th>
<th>238U ± E</th>
<th>234Th ± E</th>
<th>238U/234Th ± E</th>
<th>238U ± E</th>
<th>234Th ± E</th>
<th>238U/234Th ± E</th>
<th>238U ± E</th>
<th>234Th ± E</th>
<th>238U/234Th ± E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ser. no.</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>EK 1</td>
<td>23 ± 2</td>
<td>1.5 ± 0.6</td>
<td>21 ± 4</td>
<td>&lt;0.9</td>
<td>666 ± 17</td>
<td>15</td>
<td>0.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>EK 2</td>
<td>6 ± 0.3</td>
<td>3 ± 0.4</td>
<td>11 ± 3</td>
<td>&lt;0.9</td>
<td>663 ± 13</td>
<td>2</td>
<td>0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>EK 3</td>
<td>1 ± 1.3</td>
<td>&lt;0.9</td>
<td>6 ± 0.5</td>
<td>&lt;0.9</td>
<td>735 ± 22</td>
<td>3</td>
<td>0.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>EK 4</td>
<td>6 ± 0.6</td>
<td>3 ± 0.1</td>
<td>13 ± 10</td>
<td>&lt;0.9</td>
<td>450 ± 23</td>
<td>2</td>
<td>0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>EK 5</td>
<td>&lt;0.7</td>
<td>6 ± 1.8</td>
<td>17 ± 10</td>
<td>&lt;0.9</td>
<td>28 ± 12</td>
<td>&lt;</td>
<td>0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>EK 6</td>
<td>3 ± 0.4</td>
<td>3 ± 0.1</td>
<td>17 ± 16</td>
<td>&lt;0.9</td>
<td>604 ± 32</td>
<td>10</td>
<td>0.1</td>
<td></td>
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<tr>
<td>7</td>
<td>EK 7</td>
<td>&lt;0.7</td>
<td>&lt;0.9</td>
<td>10 ± 0.5</td>
<td>&lt;0.9</td>
<td>532 ± 6</td>
<td>&lt;</td>
<td>0.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>EK 8</td>
<td>&lt;0.7</td>
<td>4 ± 0.4</td>
<td>14 ± 1.3</td>
<td>4 ± 0.6</td>
<td>544 ± 25</td>
<td>&lt;</td>
<td>0.3</td>
<td></td>
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<tr>
<td>9</td>
<td>EK 9</td>
<td>&lt;0.7</td>
<td>6 ± 1.5</td>
<td>17 ± 2</td>
<td>&lt;0.9</td>
<td>437 ± 9</td>
<td>4</td>
<td>0.1</td>
<td></td>
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</tr>
<tr>
<td>10</td>
<td>EK 10</td>
<td>6 ± 0.5</td>
<td>1.8 ± 0.5</td>
<td>17 ± 2</td>
<td>&lt;0.9</td>
<td>583 ± 12</td>
<td>4</td>
<td>0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>SK 1</td>
<td>11 ± 0.6</td>
<td>4 ± 0.5</td>
<td>19 ± 2</td>
<td>8 ± 1.5</td>
<td>624 ± 11</td>
<td>3</td>
<td>0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>SK 2</td>
<td>11 ± 0.8</td>
<td>7 ± 0.9</td>
<td>15 ± 1.5</td>
<td>&lt;0.9</td>
<td>633 ± 13</td>
<td>16</td>
<td>0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>SK 3</td>
<td>4 ± 1.0</td>
<td>&lt;0.9</td>
<td>18 ± 1.8</td>
<td>&lt;0.9</td>
<td>562 ± 28</td>
<td>17</td>
<td>0.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>SK 4</td>
<td>12 ± 0.5</td>
<td>1.9 ± 0.3</td>
<td>10 ± 1.0</td>
<td>&lt;0.9</td>
<td>493 ± 9</td>
<td>6</td>
<td>0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>SK 5</td>
<td>20 ± 1.2</td>
<td>6 ± 1.1</td>
<td>16 ± 1.7</td>
<td>&lt;0.9</td>
<td>583 ± 12</td>
<td>4</td>
<td>0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>SK 6</td>
<td>17 ± 4</td>
<td>5 ± 1.8</td>
<td>8 ± 0.9</td>
<td>&lt;0.9</td>
<td>759 ± 0</td>
<td>3</td>
<td>0.6</td>
<td></td>
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</tr>
<tr>
<td>17</td>
<td>SK 7</td>
<td>&lt;0.7</td>
<td>4 ± 0.3</td>
<td>19 ± 1.5</td>
<td>5 ± 0.7</td>
<td>964 ± 20</td>
<td>&lt;</td>
<td>0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>SK 8</td>
<td>&lt;0.7</td>
<td>8 ± 1.2</td>
<td>22 ± 2.0</td>
<td>4 ± 0.2</td>
<td>879 ± 15</td>
<td>&lt;</td>
<td>0.3</td>
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</tbody>
</table>

Table 3
Activity concentrations of 239/240Pu and 226Ra, Bq/kg dry weight, and 239/240Pu 226Ra activity ratio in moassel tobacco samples

<table>
<thead>
<tr>
<th>Sample</th>
<th>239/240Pu ± E</th>
<th>226Ra ± E</th>
<th>226Ra/239/240Pu ± E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ser. no.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>SK 1</td>
<td>7 ± 0.5</td>
<td>19 ± 2</td>
</tr>
<tr>
<td>2</td>
<td>SK 2</td>
<td>11 ± 0.7</td>
<td>16 ± 1.5</td>
</tr>
<tr>
<td>3</td>
<td>SK 3</td>
<td>14 ± 0.69</td>
<td>8 ± 0.9</td>
</tr>
<tr>
<td>4</td>
<td>SK 4</td>
<td>32 ± 2</td>
<td>11 ± 0.2</td>
</tr>
<tr>
<td>5</td>
<td>SS 1</td>
<td>7 ± 0.45</td>
<td>9 ± 1.3</td>
</tr>
<tr>
<td>6</td>
<td>SS 2</td>
<td>11 ± 0.68</td>
<td>3 ± 0.7</td>
</tr>
<tr>
<td>7</td>
<td>SS 3</td>
<td>10 ± 0.72</td>
<td>15 ± 1.8</td>
</tr>
</tbody>
</table>

\[ a \] Using alpha spectrometry.
\[ b \] Using gamma spectrometry.
\[ c \] Error due to photo-peak area calculation.
where $D_1$ is the fluorescence due to the uranium in the sample, $D_2$ is the fluorescence due to the uranium in the spiked sample (sample + standard), $V_1$ is the volume of the sample (mL), $V_2$ is the volume of the standard (mL), $C$ is the concentration of uranium standard solution ($\mu$g/mL), and $f$ is the conversion factor (weight of dissolved sample in gram/volume of the measured sample in mL).

The minimum detection limit of the system is 0.05 ng/mL (0.63 mBq $^{238}$U/L, and the precision is about 15% at the 0.05 ng/mL levels. The quenching effect, caused by interfering elements such as Fe, Mn, Cu, Ni, and organic matter, was eliminated by using an internal standard spike (Diab et al., 2001).

### 4. Results and discussion

The activity concentration of $^{234}$Th, $^{226}$Ra, $^{210}$Pb, $^{232}$Th and $^{40}$K, Bq/kg dry weight, in moassel tobacco samples of three different brands (K, S and Z type) is given in Table 1. The average ± standard deviation and the range of the activity concentration (Bq/kg dry weight) of $^{234}$Th, $^{226}$Ra, $^{210}$Pb, $^{232}$Th and $^{40}$K in different brands of moassel samples are given in Table 4. It is obvious that the average activity concentrations of $^{234}$Th, $^{226}$Ra, $^{210}$Pb, $^{232}$Th and $^{40}$K in the different brands and their average value are very close while the ranges of $^{234}$Th, $^{226}$Ra and $^{210}$Pb (from 8- to 10-fold) are wider than that of $^{232}$Th and $^{40}$K (from 2- to 3-fold). This could be explained by the physico-chemical behavior of each element, their radioactivity concentrations in soils where tobacco was planted and the atmospheric fallout rate especially for $^{210}$Pb.

Activity concentration of $^{238}$U and $^{234}$Th in Bq/kg and $^{238}$U/$^{234}$Th activity ratio in selected samples are given in Table 2. The average ± standard deviation and the range of the activity concentration (Bq/kg dry weight) of $^{238}$U are given in Table 4.

The activity concentration of $^{210}$Po in cigarette, moassel and jurak, Table 5 (Abdul-Majid et al., 1995; Al-Arifi, 2005).

#### 4.1. Natural Radionuclides

For radiological dose assessment, it is essential to have experimental and/or theoretical data of each radionuclide, fractions, percentages that are released into or remained in smoke, smoke, ash, and filter. Based on these data, the percentages that are internally inhaled into the smoker’s lung are calculated. After searching the literature, we conclude that this data is only available for $^{210}$Po in cigarette, about three studies (Skwarcz et al., 2001; Khater, 2004; Desideri et al., 2007), and for $^{210}$Po and $^{210}$Pb in tobacco products (moassel and jurak), only one study (Al-Arifi, 2005). There is an urgent need to estimate the intake of different natural radionuclides in moassel and jurak due to their smoking. This study Abdul-Majid et al. (1995) estimated the radiation doses due to inhalation of only $^{210}$Po and $^{210}$Pb (IAEA-safety series 115, 1994). There is a great lack of information about natural radionuclides, such as $^{226}$Ra, $^{238}$U and $^{232}$Th, intake via smoking.

#### 4.2. Comparison with Other Studies

Two previous studies have measured natural radionuclides in similar tobacco samples and their products (tobacco leaf, cigarette, moassel, and jurak). Abdul-Majid et al. (1995) measured the activity concentration of $^{226}$Ra, $^{232}$Th and $^{40}$K in a limited number of samples (4–5) of tobacco leaf, moassel, jurak and charcoal samples from Saudi Arabia and their mean activity concentration (range) was 1.8 (0.7–2.7), 2.6 (1.7–3.1) and 445 (305–816) Bq/kg, respectively. These values are lower than our results, 3.2 (1.2–7.8), 6.51 (3.7–10.3) and 719 (437–1004) Bq/kg, respectively, that could be due to the non-standard method of moassel preparation and the possible variation in the radioactivity contents of the raw materials, especially tobacco. Al-Arifi (2005) has measured the activity concentration of $^{210}$Po in cigarette, moassel and jurak, Table 5 (Abdul-Majid et al., 1995; Al-Arifi, 2005).

Most published studies on radioactivity in tobacco and its percentage intake via smoking were measured for $^{210}$Po and $^{210}$Pb in cigarette, and only a few studies (Godoy et al., 1992; Katsanevakis et al., 1996; Papastefanou, 2006; Abdul-Majid et al., 1995; Al-Arifi, 2005) measured other natural radionuclides in cigarette or other tobacco products (e.g. moassel and jurak). Although there are very clear differences between the dose equivalent conversion factors (mSv/Bq) of $^{226}$Ra, $^{232}$Th and $^{210}$Pb (8.0, 7.8, 5.0 mSv/Bq, respectively) and that of $^{210}$Po and $^{210}$Pb (1.1 and 3.3 mSv/Bq, respectively) almost all studies estimated the radiation doses due to inhalation of only $^{210}$Po and $^{210}$Pb (IAEA-safety series 115, 1994). There is a great lack of information about natural radionuclides, such as $^{226}$Ra, $^{238}$U and $^{232}$Th, intake via smoking.

### 4.3. Intake via Smoking

The individual values of $^{210}$Po/$^{210}$Pb activity ratio have a wide range of variation, between 0.27 and 2.82.

Two previous studies have measured natural radionuclides in similar tobacco samples and their products (tobacco leaf, cigarette, moassel, and jurak). Abdul-Majid et al. (1995) measured the activity concentration of $^{226}$Ra, $^{232}$Th and $^{40}$K in a limited number of samples (4–5) of tobacco leaf, moassel, jurak and charcoal samples from Saudi Arabia and their mean activity concentration (range) was 1.8 (0.7–2.7), 2.6 (1.7–3.1) and 445 (305–816) Bq/kg, respectively. These values are lower than our results, 3.2 (1.2–7.8), 6.51 (3.7–10.3) and 719 (437–1004) Bq/kg, respectively, that could be due to the non-standard method of moassel preparation and the possible variation in the radioactivity contents of the raw materials, especially tobacco. Al-Arifi (2005) has measured the activity concentration of $^{210}$Po in cigarette, moassel and jurak, Table 5 (Abdul-Majid et al., 1995; Al-Arifi, 2005).

Most published studies on radioactivity in tobacco and its percentage intake via smoking were measured for $^{210}$Po and $^{210}$Pb in cigarette, and only a few studies (Godoy et al., 1992; Katsanevakis et al., 1996; Papastefanou, 2006; Abdul-Majid et al., 1995; Al-Arifi, 2005) measured other natural radionuclides in cigarette or other tobacco products (e.g. moassel and jurak). Although there are very clear differences between the dose equivalent conversion factors (mSv/Bq) of $^{226}$Ra, $^{232}$Th and $^{210}$Pb (8.0, 7.8, 5.0 mSv/Bq, respectively) and that of $^{210}$Po and $^{210}$Pb (1.1 and 3.3 mSv/Bq, respectively) almost all studies estimated the radiation doses due to inhalation of only $^{210}$Po and $^{210}$Pb (IAEA-safety series 115, 1994). There is a great lack of information about natural radionuclides, such as $^{226}$Ra, $^{238}$U and $^{232}$Th, intake via smoking.

For radiological dose assessment, it is essential to have experimental and/or theoretical data of each radionuclide, fractions, percentages that are released into or remained in smoke, smoke, ash, and filter. Based on these data, the percentages that are internally inhaled into the smoker’s lung are calculated. After searching the literature, we conclude that this data is only available for $^{210}$Po in cigarette, about three studies (Skwarcz et al., 2001; Khater, 2004; Desideri et al., 2007), and for $^{210}$Po and $^{210}$Pb in tobacco products (moassel and jurak), only one study (Al-Arifi, 2005). There is an urgent need to estimate the intake of different natural radionuclides.
radionuclides to smoker lung and to estimate total internal radiation dose due to smoking, directly as a smoker or indirectly as second-hand smoke, i.e., by inhalation of environmental tobacco smoke. However, in striking contrast with cigarettes, narghile does generate almost no side-stream smoke because of its peculiarities (charcoal topping the bowl and less elevated temperatures). So, the only second-hand smoke that should be taken into account is the one rejected by the smoker, i.e., the one filtered by the hookah at the level of the bowl, inside the water, along the hose and then by the smoker’s lungs themselves. In this respect, experts have 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” (Baker and Dixon, 2006).

As for narghile, the model of its related social situations cannot be adequately expressed by smoking machines. The use of these should be discontinued as they are not adapted for the measurement of toxicants actually inhaled by the smoker (Chaouachi, 2007b). Prominent experts have shown that the chemical patterns and smoke components vary tremendously on a cigarette puff to puff basis (Adam et al., 2007). This is all the more true for narghile smoking where a smoking session is about 10 times longer. Consequently, a puff-by-puff analysis seems to be the most promising research avenue in this field.

Al-Arifi (2005) found that about 69% of 210Po concentration in moassel was inhaled by narghile smoker while 30% and only 1.7% were found in ash and water filter, respectively (Al-Arifi, 2005). Again, the partitioning percentages of other radionuclides between smoke, ash and water filter are unknown. The calculation of the inhalation radiation dose of narghile smokers due to inhalation of different radionuclides is practically impossible without other studies that should practically estimate these percentages. The average activity concentration of 210Po in cigarette, moassel and jurak (previous and present studies), the distribution percentage of 210Po between smoke, ash and water filter during smoking, calculated daily and annual 210Po concentration inhaled via smoking, and annual committed effective dose due to inhaled 210Po and 210Pb are given in Table 6 and shown in Fig. 1 (Khater, 2004; Al-Arifi, 2005). There is a clear correlation between the concentration of 210Po and 210Pb, because of the assumed secular equilibrium between them, and the tobacco concentrations, Fig. 1(a). The same trend is clear in moassel and jurak samples for other natural radionuclides such as 232Th and 40K, Table 5. It gives an indication that the radioactivity concentration in tobacco products depends basically on the tobacco content not on the other gradients such as molasses, glycerin and dry fruits.
The lower yield of $^{210}\text{Po}$ in jurák might be in relation with the Indian origin of this Saudi tobacco paste. The reason may be that $^{210}\text{Po}$ alpha-radioactivity of Indian tobacco would be several times lower than that of “Western” tobacco (Singh and Nilekani, 1976; cited by Zaga and Gattavecchia, 2006).

The calculated daily and annual intake of $^{210}\text{Po}$ via moassel smoking are based on assuming a certain smoking pattern: e.g. 20 cigarettes, 27 g moassel and 210 g jurak a day, which varies and depends on the smoker habits. Consequently, the intake rate and the calculated doses will be different, Fig. 1(b). Distribution patterns or percentages of $^{210}\text{Po}$ between smokers, ash and filter were estimated practically, Fig. 1(c) (Khatber, 2004; Al-Arifi, 2005). These values are variable and depend on smoker habits, i.e. puffing behavior (number of puffs, puff interval, puff duration, peak pressure, latency to peak pressure, average and total puff volume) (Battig et al., 1982). Al-Arifi (2005) mentioned that the increase in suction rate raises the ashing temperature of the tobacco, in addition to the intensity of hot air wind carrying the smoke steam. Both may elevate polonium in the smoke before trapping by the butt. Higher suction rate produces bigger smoke particulates, which are easily trapped by the butt and reduce the amount of polonium inhaled into lungs (Al-Arifi, 2005). The calculated annual committed effective dose, $\mu Sv/y$, due to inhalation of both $^{210}\text{Po}$ and $^{210}\text{Pb}$, Fig. 1(d), via cigarette, moassel and jurak smoking was $848, 876$ and $1154 \mu Sv/y$, respectively.

Although tobacco smoking is deadly, there are differences among tobacco products. For example, narghile tobacco pastes have no standard compositions with different ingredients and flavors. Water is assumed to filter the smoke but, because the smoke passes through water as bubbles, it only cools down the smoke. The cigarette’s filter removes a minimum of 96% of the particle phase of the smoke but just about 5% of $^{210}\text{Po}$. In practice, even if there is some filtration effect, a well packed narghile could be smoked for 30–45 min where different radionuclides associate with particles of different sizes, not only volatile $^{210}\text{Po}$, may enter the lungs with a significant dose. Finally, the evaluation of several parameters is essential for a proper dose assessment due to smoking, e.g. particulate size distribution, inhalation parameter, particle aerodynamic and electrical characteristics, deposition, removal and solubility in the lung and the fraction of the radionuclides in the tobacco that are transferred to the smoke and consequently to the smokers’ lungs (Abdul-Majid et al., 1995; Khatber, 2004).

5. Conclusions

Tobacco smoking is fatal in many ways and has severe health, economic and social consequences. Although natural radioactivity in tobacco could be one of the main reasons of the health impacts of tobacco smoking, there are very limited publications on natural radionuclides concentration in tobacco and tobacco products except for $^{210}\text{Po}$ in cigarettes. The aim of this study was to shed more light on the activity concentration of natural radionuclides in moassel tobacco that is used for narghile smoking. The results of our study indicate the existence of a wide range of variations in radioactivity contents that could be due to the non-standard manufacture procedure and/or their variation in tobacco. Unfortunately, there is an extreme dearth of research in this field. The distribution pattern of these radionuclides between smoke, ash and water filter is unknown, except for $^{210}\text{Po}$, which indicates the low related efficiency of water filter during narghile smoking.

We wish to emphasise on the urgent needs for more research on the activity concentration of natural radionuclides in tobacco and tobacco products (especially moassel and jurak), their behavior during smoking, the effect of different parameters, such as temperature, water filter, pH and others, and on their concentration in smoke and smokers’ intake. A public health priority should be essential to develop countermeasures for the banning of all forms of smoking (cigarettes, pipes, cigars and, of course, narghiles) whenever and wherever possible in public area. In parallel, ways must be identified for an efficient policy of harm reduction related to the internal intake of different radionuclides and chemical compounds.

Acknowledgment

The authors declare that they have no competing interests. The authors acknowledge the financial support of College of Science Research Center, King Saud University (Phy/2005/05). Dr. Kamal Chauouachi was involved from Spring to Autumn 2004 in the development of a no-carbon monoxide narghile prototype (harm reduction objective). He signed away all his past and future rights (total relinquishment, including rights related to a patent he was a co-author of) on June 15, 2005 (legally certified by State Attorney in Paris), before the potential commercial exploitation of the product. He has received only a lump sum for his participation in this project. Furthermore, he declares that, in the course of his 10-year research work on this issue, he has never received direct or indirect funding neither from pharmaceutical companies (nicotine “replacement” therapies products) nor from the tobacco industry.

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