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Measurement of Radioactivity in Carbonated Soft Drinks and Annual Dose Assessment

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Abstract

A set of measurements have been conducted, using gamma spectrometry technique, in order to determine the activity-level in some carbonated soft drinks. The obtained activity is about 0.18 ± 0.07 Bq/l for ^{137}Cs, whereas it is less than 0.13, 0.18 and 4.51 Bq/l respectively for ^{212}Pb, ^{214}Pb and ^{40}K. The total average annual dose is about 3.49, 1.69 and 1.68 μSv/y respectively for 7 - 12, 12 - 17 and >17 years old person leading to a radiological risk about 0.142 for adolescent and adults. The obtained results show no significant radiation dose and radiation hazard on human health due to the consumption of these carbonated soft drinks.

Keywords

Gamma-Ray Spectrometry, HPGe Detector, Carbonated Soft Drinks, Effective Dose, Risk Assessment

1. Introduction

The main sources of natural radioactivity in the environment are the earth and the atmosphere. ^{232}Th and ^{238}U and their associated progeny (such as ^{214}Pb, ^{212}Pb, ^{214}Bi, ^{228}Ac, …) as well as ^{40}K are usually the most found natural radionuclides in earth samples. Some artificial radionuclides, such as ^{134}Cs, ^{137}Cs, ^{90}Sr and ^{131}I [1] [2] could be present with a small activity in food, water or beverages (juices, soft drinks). These artificial radionuclides are a consequence of human nuclear activities. Over the end years, humans are more susceptible to be exposed to these radiations either by inhalation of radioactive gas or by ingestion of food, water and other beverages. When these radionuclides enter into the body, their subsequent decay may damage the cells and affect the human health [3]. Beverages such as fruit juices and carbonated soft drinks are widely consumed nowadays and may contain both natural and artificial radionuclides. However, they represent one of the important sources of radioactivity for the consumed. It is then important to know the amount of radionuclides in these products and estimate their potential radiological risk to the human health. Carbonated soft drinks represent one of the important consumed beverages. They contain essentially water (most crucial ingredient), sugar, carbon dioxide and some flavorings and preservatives with different concentrations. Since each person should consume around 2 liters of fluid each day especially in hot weather. The consumption of carbonated soft drinks can help to reach this target and then they represent a positive role in a balanced diet.

Over the end years, the consumption of carbonated soft drinks in the world has been increased [4] especially for adolescents and adults. For example, young adolescents in the low and middle-income countriess reported having consumed soft drinks 1.39 times per day [4]. The consumption rate of the carbonated soft drinks varies from a country to another and the high-income countries, such as USA have the highest consumption rate in the world compared to the other countries [5]. A recent report states that the average annual consumption worldwide of soft drinks is about 11.4 US gallons per person [6], which is quite important to justify, in our opinion, the radiological survey of these products. In this paper, we report the activity-level of gamma emitters radionuclides in some carbonated soft drinks commercialized in Tunisia markets using gamma-ray spectrometry technique. The measurements are then exploited to determine the annual effective dose due to the consumption of these beverages as well as the radiological risk for different age groups.

2. Materials and Methods

2.1. Experimental Setup

The measurements were performed with the gamma spectrometry technique using a high-purity germanium gamma detector (HPGe). The type of the detector is GMX80P4-95 with a cryostat configuration CFG-PV4. Its relative efficiency is equal to 3% at 186 keV and its energy resolution (FWHM) is 2 keV at 1.33 MeV. In order to reduce the background radiations, the detector is shielded by 10 cm of lead with a copper of 3 mm [7] and it is cooled by liquid nitrogen. The detection chain contains a high voltage power supply powered at 3500 V, a preamplifier and an amplifier (model 2002 Canberra) having a positive polarity, a gain of 1000 and a 2 μs shaping time. The identification of the obtained peaks and the data analysis was carried out using the Genie 2000 software (Canberra) and ROOT scientific software toolkit [8]. The calibration of both energy and efficiency is carried out using a multi-nuclides standard source [7].

In this work, five samples of carbonate soft drinks (Coca Cola, Fanta, Boga Mint, Viva and Apla) commercialized in Tunisia markets, have been studied. Each sample of 500 ml volume is stored in Marinelli backer. All Marinelli backers were tightly closed and left away about 4 weeks in order to reach a secular equilibrium between the parent radionuclides and their progenies, which are used to determine the activity concentration of their parents. The measurement time was set to t = 72 h (259200 s) for each sample as well as a distilled water sample in order to ensure a good counting statistic.

The distilled water sample is used as a background sample and its activity-level will be subtracted from the carbonated soft drinks one in order to account for the activity coming from the environment and the gamma absorption effect in the samples.

2.2. Activity and Annual Dose Calculation

The specific activity concentration (A) of a given radionuclide present in samples was calculated using the Equation (1) [3] [7]:

$$A(\mathrm{Bq/l}) = \frac{N_s - N_{BG}}{VtP_\gamma \varepsilon_\gamma} \quad (1)$$

where: N_s and N_{BG} are the number of counts in the radionuclide photo peak of the carbonated soft drinks and the background respectively, ε_γ is the total absorption efficiency, P_γ is the gamma-ray emission probability of the corresponding gamma-ray energy and V is the volume (500 ml) of each sample. The activity concentration of the present radionuclides was determined using the following gamma lines: (351.9 keV, P_γ = 35.6%) for ^{214}Pb, (238.63 keV, P_γ = 43.6%) for ^{212}Pb, (1460.8 keV, P_γ = 10.66%) for ^{40}K and (661.7 keV, P_γ = 85.1%) for ^{137}Cs.

A check of the presence of many other natural and artificial radionuclides was systematically performed but their specific activities were not reported herein when they are below the minimum detectable activity (MDA) defined by [7]:

$$\mathrm{MDA}(\mathrm{Bq/l}) = \frac{2.71 + 4.65\sqrt{\mathrm{NBG}}}{VtP_\gamma \varepsilon_\gamma} \quad (2)$$

The annual effective dose D (Sv/y) due to the ingestion of radionuclides present in carbonated soft drinks was calculated using the following equation [7] [9]:

$$D = AIf \quad (3)$$

where: A (Bq/l) is the specific activity, I is the average annual consumption of carbonated soft drinks (11 gallons per year which is about 44 l/y) [6] and f (Sv/Bq) is the dose conversion coefficient via ingestion whose values, for different age groups, are presented in **Table 1** [10].

2.3. Radiological Risk Assessment

The radiological hazard due to an internal exposure to a radioactive source is a term used to identify the risk factors that have the potential to cause harm to the human health.

The radiological risk, due to carbonated soft drinks consumption, is calculated using the following equation [3] [7] [11]:

Table 1. Dose conversion coefficient via ingestion (Sv/Bq) [10].

Age group (y)	^{212}Pb	^{214}Pb	^{40}K	^{137}Cs
7 - 12	2.0×10^{-8}	3.1×10^{-10}	1.3×10^{-8}	1.0×10^{-8}
12 - 17	1.3×10^{-8}	2.0×10^{-10}	7.6×10^{-9}	1.3×10^{-8}
>17	6.0×10^{-8}	1.4×10^{-10}	6.2×10^{-9}	1.3×10^{-8}

$$\text{Risk} = D_{\text{int}} \times SF \times t \quad (4)$$

where: $D_{\text{int}} = A \times I$ represents the average daily intake of soft drinks expressed in pico-Curie, SF (risk/pCi) is the cancer slope factor (morbidity) and presented in Table 4 and t (365 days) is the exposure duration.

3. Results and Discussion

The specific activity concentrations of the different radionuclides found in the studied carbonated soft drinks samples are presented in Table 2. The upper limits of the activities are given within 68% confidence level. The obtained values indicate that ^{40}K, one of the important elements for the body metabolism, is the major contributor of radioactivity in carbonated soft drinks as it is the case for many other beverages and foods.

The average maximum activity of ^{40}K, detected in three samples, is less than 4.51 Bq/l. The existence of this natural radionuclide in our samples is essentially due to the mineral water used to prepare these beverages and to the presence of low concentrations of potassium benzoate.

This acid is used to preserve beverages by inhibiting the growth of mold, yeast and some bacteria. The obtained activity concentrations of ^{40}K is relatively low to other beverages such as coffee, tea or fruit juices [12] [13] [14], which contain a higher amount of rough vegetal products, furthermore it is lower than that reported in Mexico soft drinks [15].

For ^{212}Pb (progeny of ^{232}Th) and ^{214}Pb (progeny of ^{226}Ra), the specific activity is respectively less than 0.13 and 0.18 Bq/l. These radionuclides exist in the environment and the soil, where their average activity concentrations are about 32 Bq/kg for ^{226}Ra and 45 Bq/kg for ^{232}Th according to UNSCEAR [16].

These radionuclides can transfer from soil to fruit fruits or vegetables [17]. Their low transfer factor from the soil to soft drink rough components (fruits, plants and water) explains their low activity concentration in our samples. According IAEA, the mean value of the transfer factor for Pb from soil to fruit plants at temperate environment, derived from agricultural ecosystem is about 0.015 [18].

The artificial radionuclide ^{137}Cs is detected in the three samples of carbonated soft drinks brands which are all made in Tunisia (Boga mint, Viva and Apla). The obtained specific activities vary from 0.12 to 0.28 Bq/l with an average activity of 0.18 Bq/l. These Tunisian brands are made of local mint, lemon and apple among other components. The existence of this radionuclide is generally due to

Table 2. Specific activity of the different radionuclides present in the samples.

Samples	Specific Activity (Bq/l)			
	^{137}Cs	^{40}K	^{214}Pb	^{212}Pb
1	-	≤4.46	≤0.22	-
2	0.28 ± 0.07	≤5.51	≤0.19	≤0.2
3	-	-	≤0.14	-
4	0.15 ± 0.07	-	-	≤0.04
5	0.12 ± 0.07	≤3.58	-	≤0.15
Average	0.18 ± 0.07	≤4.51	≤0.18	≤0.13

-: Not detected.

the soil contamination [7] and can be transfer from soil to fruit trees and plants [19]. The mean value of the transfer factor from soil to fruit plants at temperate environment is about 0.021 for Cs [18].

It has to be noticed that the obtained low activities of ^{137}Cs present no potential health hazard to human because of the short biological half-life [20].

The annual effective dose due to the ingestion of the reported radionuclides, for different age groups, is presented in **Table 3**. The total average value is about 3.49, 1.69 and 1.68 µSv/y respectively for 7 - 12y, 12 - 17y and more than 17 years old. As stated previously, the major contribution of the total annual effective dose comes from ^{40}K. The maximum annual dose due to ^{40}K, obtained in our case for all age group, is very less than the recommended limit which is about 0.17 mSv/y [16]. All the obtained annual effective doses are very relatively low to the 1 mSv/y recommended limit given by the world organizations such as UNSCEAR [16] and ICRP [21].

The last part of the present work is the assessment of the radiological risk due to the consumption of carbonated soft drinks. The obtained values are presented in **Table 4**. Given that the daily intake of carbonated soft drinks is not exactly reported by any world organization, we have determined the radiological risk assuming that the daily intake is the same for adolescent and adults. The estimated value of 0.142×10^{-6} for the total risk is below the recommendation of the excess lifetime cancer risk which is between 10^{-6} and 10^{-4} [22]. This result indicates clearly that the radionuclides detected in the studied carbonated soft drinks do not present any radiological hazard on human health.

4. Conclusions

In this work, we have determined the activity concentrations of radionuclides present in the carbonated soft drinks commercialized in Tunisia markets using the gamma ray spectrometry technique. The results indicate low levels of radioactivity in all the consider samples, which is an expected result given that no any nuclear accident in the origin area of these materials. The annual effective dose, due to the ingestion of the soft drinks, and the radiological risk have been

Table 3. Annual effective dose (μSv/y).

Age group	^{212}Pb	^{214}Pb	^{40}K	^{137}Cs	Total
7 - 12y	0.114	0.002	2.579	0.792	3.488
12 - 17y	0.074	0.001	1.508	0.102	1.687
>17y	0.343	0.001	1.230	0.102	1.677

Table 4. Risk assessment due to the radionuclides present in the soft drinks.

	^{212}Pb	^{214}Pb	^{40}K	^{137}Cs	Total Risk (10^{-6})
Average daily intake (pCi)	0.423	0.585	14.679	0.585	
Slope factor (risk/pCi) [22]	2.50×10^{-11}	0.034×10^{-11}	2.47×10^{-11}	3.04×10^{-11}	
Risk (10^{-6})	0.386×10^{-2}	7.356×10^{-5}	0.132	0.650×10^{-2}	0.142

estimated and found below the recommended limits indicating no significant radiological hazard to the consumption of these beverages.

The present work can serve our community as well as the neighboring countries regarding radiological information on the studied carbonated soft drinks especially that is the first time where these products are studied in our country, furthermore, the recommended limit, concerning the carbonated soft drinks, has not been reported so much by the world organizations.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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