Radioactivity of long lived gamma emitters in breakfast cereal consumed in Kuwait and estimates of annual effective doses

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Background: Breakfast cereal is a nutritious type of food that is widely consumed by various age groups in Kuwait. This study investigates the presence of long-lived gamma emitters in breakfast cereal, and estimates annual effective doses to various age groups. ***Materials and Methods:*** Breakfast cereal samples were collected from the Kuwaiti local market. The samples originated from different countries. After proper lab treatment, the samples underwent gamma spectroscopy, where the targeted radionuclides were ^{226}Ra, ^{232}Th, and ^{40}K. ***Results:*** While ^{40}K was detected in all samples, ^{226}Ra and ^{232}Th were detected in most samples. The activity concentration of each targeted radionuclide varied from one sample to another. The annual effective dose from consumption of breakfast cereal is estimated to be 129, 185, and 351 μSv for the adult, child, and infant age groups respectively. ***Conclusion:*** The obtained activity concentrations are found to agree with those reported in the literature. Moreover, the estimated annual effective doses are found to be safe. **Iran. J. Radiat. Res., 2012; 10(3-4): 117-122**

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INTRODUCTION

Natural radioactivity is caused by the presence of natural occurring radioactive matter (NORM) in the environment. Examples of natural radionuclides include isotopes of potassium (^{40}K), uranium (^{238}U and its decay series), and thorium (^{232}Th and its decay series). In addition to being long-lived (in the order of 10^{10} years), these radionuclides are typically present in air, soil, and water in different amounts and levels of activity.

Natural radionuclides are found in terrestrial and aquatic food chains, with subsequent transfer to humans through ingestion of food. As such, international efforts were brought together collaboratively to apply adequate procedures in investigating radionuclides in food (1), and to set essential guidelines to protect against high levels of internal exposure that may be caused by food consumption (2, 3). Moreover, numerous studies were conducted worldwide to investigate natural radionuclides in food consumed in different parts of the world (4-11).

The importance of this issue is realized in Kuwait, accompanied by a desire to establish a national baseline of radioactivity exposure from food consumption. For a systematic treatment, a methodical approach is undertaken that focuses on a certain type of food per study. Because breakfast cereal is popular among all ages, the current study focuses on investigating the natural radioactive content in breakfast cereal. The present study also aims to estimate annual effective doses from consumption of breakfast cereal among various age groups.

MATERIALS AND METHODS

Breakfast cereal samples were collected from the Kuwaiti local market. The collection took place between January and June of 2010. To ensure a comprehensive and a wide-spread representation, 27 different brands that originated from 9 different countries were selected (table 1).

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The designated age groups, namely adult, child, and infant, varied from one sample to another. Since breakfast cereal is not locally produced in Kuwait, all samples were imported.

Prior to measurement, each sample underwent a pre-treatment that consisted of powdering. This step was crucial for achieving a homogeneous state for the sample. Because breakfast cereal comes dried, the samples did not undergo any drying process. Each sample was then placed in a cylindrical container with dimensions 6 cm in diameter and 10 cm in height. After being sealed, the sample-filled containers were left for a period of at least 4 weeks to reach secular equilibrium between parent radionuclides and their daughters.

Measurements were performed using a high purity germanium (HPGe) detector (Ortec, USA). The low background system, has an energy resolution of 1.75 keV FWHM at the 1.33 MeV ^{60}Co photopeak. This counting system of 80% relative efficiency is connected to a multi-channel analyzer (MCA) (Ortec, USA) and a computerized arrangement. Energy calibration for the detector was performed using a set of point sources. Efficiency calibration was done using a standard source with a cylindrical geometry. To reduce statistical counting error, each sample was counted for a period of 24 hours. An empty container was also counted under the same conditions to determine the background counts.

For spectrum analysis, Gamma Vision software (Ortec, USA) was used, where the photopeaks considered were 609 keV (^{226}Ra),

Table 1. Samples investigated in this study.

Sample ID	Brand name	Age group	Country of Origin	Basic ingredient
1	Kellog's Special 98% fat free	Adult	UK	Flour
2	Milupa baby Cereal	Infant	Poland	Rice
3	Heinz Baby Cereal	Infant	South Africa	Flour
4	Fance Lait _Baby Cereal	Infant	France	Rice
5	Hero Biscuits	Infant	Italy	Flour
6	Farleys Rusk	Adult	Oman	Flour
7	Mr Kanny Slim Flakes	Adult	Italy	Rice
8	Nestle Cookie Crisps	Child	France	Flour
9	Poppins- Frosated Flakes	Adult	Lebanon	Corn
10	Poppins-Choco pops	Child	Lebanon	Rice
11	Poppins-Corn Flakes	Adult	Lebanon	Corn
12	Kellog's Froot Loops	Child	Germany	Flour
13	Kellogs All Bran -Plus.	Adult	UK	Flour
14	Dieterba First Biscuit	Infant	Italy	Flour
15	Kellog's all bran flakes	Adult	UK	Flour
16	Kellog's all bran raisin	Adult	UK	Flour
17	Nestle fitness fruits	Adult	France	Flour
18	Kellog's corn flakes honey n nuts	Adult	UK	Corn
19	Nestle nesquick	Child	Poland	Flour
20	Kellog's rice crispies	Child	Spain	Rice
21	Poppind choco bumps	Child	Lebanon	Flour
22	Kellog's just right	Adult	UK	Flour
23	Kellog's cocopops-chacos	Child	Germany	Flour
24	Kellog's cocopops-jumbos	Child	Germany	Corn
25	Alpen swiss muesli	Adult	UK	Flour
26	Kellog's frosties corn flakes	Adult	Germany	Corn
27	Kellog's corn flakes	Adult	Germany	Corn

911 keV (^{232}Th), and 1460 keV (^{40}K). The minimum detectable activities (MDA) for ^{226}Ra, ^{232}Th, and ^{40}K are (in Bq kg^{-1}) 0.32, 0.29, and 3.67 respectively.

To investigate the statistical significance of the obtained results, an analysis of variance was performed, using the ANOVA function in Matlab (Mathworks, USA). Each targeted radionuclide was tested for regional, age-group, and basic-ingredient dependence. Regional dependence tests included 9 statistical groups corresponding to the 9 countries from which the samples originated. Age-group dependence tests included only 3 statistical groups, namely adult, child, and infant. Similarly, basic-ingredient dependence tests included 3 statistical groups, namely flour, rice, and corn. All activity concentrations were considered in the statistical analysis. Activity concentrations that were below the MDA, and those that were undetected were entered as zeros.

RESULTS AND DISCUSSION

Table 2 presents the activity concentrations for ^{226}Ra, ^{232}Th, and ^{40}K, in the breakfast cereal samples. Activity concentrations above the MDA for ^{226}Ra are found in 19 samples. The maximum value is 2.43 ± 0.15 Bq kg^{-1} (adult breakfast cereal

Table 2. Activity concentrations of the measured samples.

Sample ID	^{226}Ra (Bq kg^{-1})	^{232}Th (Bq kg^{-1})	^{40}K (Bq kg^{-1})
1	0.58 ± 0.17	BDL	67.74 ± 1.75
2	0.93 ± 0.21	0.36 ± 0.06	227.16 ± 3.94
3	1.2 ± 0.16	1.52 ± 0.16	221.73 ± 3.75
4	0.34 ± 0.05	0.54 ± 0.07	218.70 ± 3.75
5	0.32 ± 0.08	0.84 ± 0.11	92.26 ± 2.12
6	BDL	0.77 ± 0.09	37.97 ± 1.35
7	ND	BDL	103.15 ± 2.09
8	BDL	0.86 ± 0.06	74.77 ± 1.87
9	0.45 ± 0.06	BDL	19.86 ± 0.96
10	0.39 ± 0.041	0.39 ± 0.06	91.62 ± 1.99
11	BDL	BDL	31.69 ± 1.12
12	0.63 ± 0.07	1.12 ± 0.035	62.88 ± 1.71
13	2.43 ± 0.15	BDL	300.10 ± 3.87
14	BDL	0.77 ± 0.09	49.92 ± 1.61
15	0.49 ± 0.10	0.64 ± 0.10	161.74 ± 2.71
16	BDL	0.47 ± 0.10	216.24 ± 3.07
17	0.47 ± 0.08	BDL	116.01 ± 2.22
18	0.89 ± 0.15	0.49 ± 0.08	38.12 ± 1.31
19	1.44 ± 0.14	0.34 ± 0.05	120.17 ± 2.38
20	0.67 ± 0.13	0.29 ± 0.05	46.62 ± 1.5
21	BDL	0.55 ± 0.10	143.62 ± 2.63
22	BDL	0.60 ± 0.06	94.93 ± 2.01
23	1.26 ± 0.05	0.51 ± 0.10	141.66 ± 2.50
24	0.32 ± 0.06	0.31 ± 0.04	96.22 ± 2.18
25	0.53 ± 0.06	BDL	159.20 ± 2.75
26	0.34 ± 0.06	BDL	13.89 ± 0.76
27	0.57 ± 0.09	0.40 ± 0.04	22.93 ± 0.98

BDL : Below detection limit
ND : Not detected

sample from UK), the minimum detected value is 0.32 ± 0.08 Bq kg^{-1} (infant breakfast sample from Italy). The average activity concentration for the adult age group is (± SD) 0.75 ± 0.65 Bq kg^{-1}, for the child age group 0.79 ± 0.46 Bq kg^{-1}, and for the infant age group 0.70 ± 0.44 Bq kg^{-1}.

^{232}Th activity concentrations are above the MDA in 19 samples. The maximum value is 1.52 ± 0.16 Bq kg^{-1} (infant breakfast cereal sample from South Africa), and the minimum value is 0.29 ± 0.05 Bq kg^{-1} (child breakfast cereal sample from Spain). The average activity concentration for the adult age group is (± SD) 0.52 ± 0.10 Bq kg^{-1}, for the child age group 0.57 ± 0.31 Bq kg^{-1}, and for the infant age group 0.81 ± 0.44 Bq kg^{-1}.

^{40}K was detected in all samples, with a maximum value of 300.10 ± 3.87 Bq kg^{-1} (adult breakfast cereal sample from UK), and a minimum value of 13.89 ± 0.76 Bq kg^{-1} (adult breakfast cereal sample from Germany). The average activity concentration for the adult age group is (± SD) 99.01 ± 85.10 Bq kg^{-1}, for the child age group 96.75 ± 36.36 Bq kg^{-1} , and for the infant age group 161.40 ± 84.42 Bq kg^{-1}.

The presence of the natural radionuclides in breakfast cereal is expected. Specifically, detection of ^{40}K in all samples is anticipated due to its natural abundance. As for ^{226}Ra and ^{232}Th, their detection in some samples (in about 70% of the total samples) does not necessarily simply their absence in others. It is well understood that background levels and system MDA could conceal minor photopeaks [12]. In fact, the infrequency of ^{226}Ra and ^{232}Th detection in food samples is reported by various authors [4, 8, 9].

Statistical significance is observed in the amount of ^{40}K in samples with corn as its basic ingredient. Interestingly, the activity concentration of ^{40}K in corn-based samples are significantly lower ($P < 0.05$) than the flour-based and rice-based samples (figure 1). This basic-ingredient dependence may be related to the botanical uptake of nutrients that differs from one type of cereal to another. No other statistically significant dependence, regional, age-group, or basic-ingredient are observed for any of the targeted radionuclides.

The results from the present study have been compared to those reported in the literature (table 3). The overlap of the results of the present work with those reported in the literature suggests agreement. In addition, results of the present work and those reported in the literature exceed the reference values given by UNSCEAR. Such difference is not uncommon as it is reported in the literature [8].

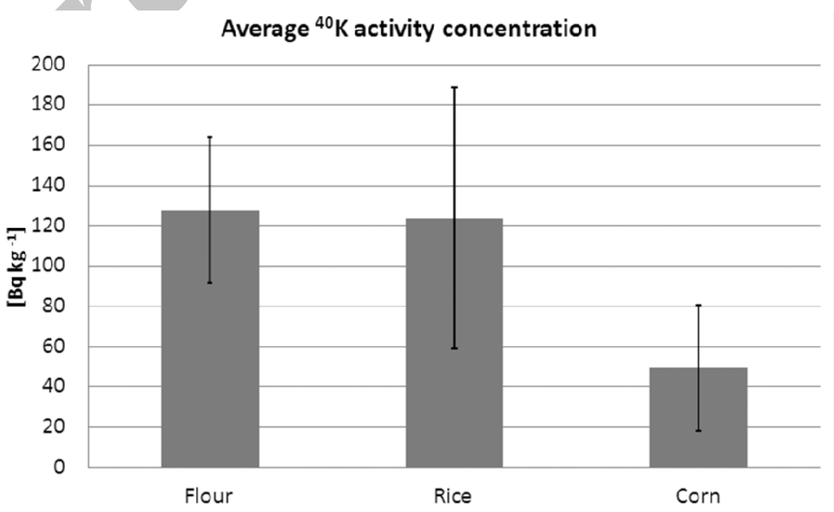

Figure 1. The average activity concentration of corn-based breakfast cereals is statistically different (P < 0.05) than the flour-based and the rice-based.

The annual effective dose from consumption of breakfast cereal is calculated using the formula [3].

$$D = AEI \qquad (1)$$

where D is the annual effective dose (Sv yr^{-1}), A is the activity concentration for the radionuclide (Bq kg^{-1}), E is the dose conversion factor for the radionuclide (Sv Bq^{-1}), and I is the annual intake of breakfast cereal (kg). Since both E and I are age-dependent, the calculation for the annual effective dose D is performed for all three age groups separately. Values for E (table 4) are selected based on the ICRP classifications [2], namely adult, child (10 years old), and infant (1 year old). On the other hand, values of I are taken to be 140, 90, and 45 kg yr^{-1} for the age groups of adult, child, and infant, respectively, in accordance to UNSCEAR [3].

The results of the annual effective dose D are presented in table 5. The activity concentration A used to calculate Table 5 are the averages for each radionuclide for each age group. Hence, the doses presented in table 5 are the average annual effective doses, the total of which are found to be 129, 185, and 351 µSv for the adult, child, and infant age groups respectively.

Table 4. Dose conversion factors (nSv Bq^{-1}).

	^{226}Ra	^{232}Th	^{40}K
Adults	280	230	6.2
Child (10 year old)	800	290	13
Infant (1 year old)	960	450	42

Table 5. Annual effective doses from consumption of breakfast cereal for adult, child, and infant age groups.

	^{226}Ra	^{232}Th	^{40}K	Total
Adults	29.4	16.744	83.16	129
Child	56.88	14.877	113.49	185
Infant	30.24	16.4025	304.29	351

It is clear from table 5 that ^{40}K is the largest contributor to the total annual effective dose from consumption of breakfast cereal. The contribution of this natural radionuclide is about 64%, 61%, and 87% for the adult, child, and infant age groups respectively. While these percentages may seem relatively large, it is important to know that the quantity of ^{40}K inside the human body is fairly constant due to its controlled homeostasis regardless of the intake amount [9, 13]. This physiological regulation diminishes any health concerns with regard to the relatively high effective doses of ^{40}K.

Table 3. Activity concentrations of ^{226}Ra , ^{232}Th, and ^{40}K for breakfast cereal reported in the literature, compared with values found in the present study.

Origin	^{226}Ra (Bq kg^{-1})	^{232}Th (Bq kg^{-1})	^{40}K (Bq kg^{-1})	Reference
France	0.0 - 0.47	0.0 - 0.86	74 - 218	(Present study)
Germany	0.32 - 1.26	0.0 - 1.12	14 - 144	(Present study)
Italy	0.0 - 0.32	0.0 - 0.84	50 - 103	(Present study)
Lebanon	0.0 - 0.45	0.0 - 0.55	20 - 92	(Present study)
Nigeria	0.0 - 30.0	-	20 - 233	9
Oman	0	0.77	38	(Present study)
Poland	0.93 - 1.44	0.34 - 0.36	120 - 227	(Present study)
South Africa	1.2	1.5	221	(Present study)
Switzerland	< 4.2	-	72	9
Syria*	-	-	176 - 216	5
UK	0.0 - 0.9	0.0 - 0.6	38 - 300	(Present study)
Reference value	0.08	0.003	-	3

* Country where study was performed, rather than country of origin.

Hence, the estimated annual effective doses from all targeted radionuclides for all age groups are not alarming.

It is noteworthy that the intake values *I* [(3)], used in the dose calculations for this study, include all kinds of cereals consumed by the average person, such as bread, pastries, pasta, etc. where breakfast cereal is only one kind. Hence, using these all-kind intake values to estimate doses from consumption of a single kind only, namely breakfast cereal, may exaggerate the output numbers. Such exaggeration serve as a conservative approach in performing effective dose calculations.

CONCLUSION

The present study is the first at the national level to investigate radioactivity of breakfast cereal. It is found that consumption of this type of foodstuff is safe for all studied age groups. The findings of this work will help in establishing a baseline of radioactivity exposure to the general public from ingestion of foodstuff.

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