

Radiological Risks Due to Long-Lived Gamma Emitters in Breakfast Cereal Samples from Iraqi Markets

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ABSTRACT

The limits of radionuclides contained in foods should be minimal for safe human consumption. This study examined the radiological hazards of ^{238}U , ^{232}Th , and ^{40}K in cereal samples, for three age groups—infants, children, and adults—using a NaI(Tl) detector. The results ranged from 5.67 ± 0.61 to 11.82 ± 1.09 Bq/kg, 2.27 ± 0.29 to 9.76 ± 0.61 Bq/kg, and 152.37 ± 3.34 to 323.63 ± 7.56 Bq/kg, respectively, and showed that the levels were within the limits set by UNSCEAR: $^{238}\text{U} = 33$ Bq/kg, $^{232}\text{Th} = 45$ Bq/kg, and $^{40}\text{K} = 420$ Bq/kg.

Keywords-natural radioactivity; NaI(Tl) detector; breakfast cereals; radiological risk; Iraqi markets

I. INTRODUCTION

Naturally Occurring Radioactive Materials (NORM) are elements that can be found in the environment [1], including radioactive decay chains, such as those of Uranium-238 (^{238}U) and Thorium-232 (^{232}Th), as well as non-sequential isotopes, such as Potassium-40 (^{40}K), with half-lives exceeding hundreds of millions of years. NORMs are a significant source of radiation exposure for humans because they produce alpha or beta particles that can enter the body through ingestion or inhalation. Some radionuclides also emit gamma radiation, a primary source of the human exposure to the natural radiation [2]. A significant amount of radioactivity comes from the thorium and uranium series radionuclides emitted from rocks and soil. The plants absorb these decay products, which are then transferred to various foods, resulting in detectable levels of natural radioactivity [3]. Cereals and other grains tend to have higher radioactivity levels, while dairy products, fruits, and vegetables typically have lower levels [4]. The United Nations' Radiation Protection Agency is responsible for

promoting the safe use of atomic energy and preventing the radioactive pollution. National agencies worldwide also work to protect citizens, and authors in [5-9] examined the radioactivity in food. In Iraq, establishing a national database on food-related radioactivity exposure is a priority. This study focuses on investigating the natural radioactivity levels in breakfast cereals, which are widely consumed by people of all ages. These plant-based products, made from ingredients, such as flour, rice, corn, and oatmeal, may contain radioactive nuclides. Thus, the objective of this research is to determine the levels of gamma-ray emitters (^{238}U , ^{232}Th , and ^{40}K) and associated radiological risks, including the annual permissible doses and cancer risk, for infants, children, and adults.

II. MATERIALS AND METHODS

A. Breakfast Cereal Samples

A total of ten samples of commonly consumed breakfast cereals were collected from a local market in the Al-Najaf in June 2024, as presented in Table I.

TABLE I. BREAKFAST CEREAL SAMPLES

No.	Name	Code	Country
1	Corn flakes	B1	Turkey
2	Toons (honey crisps)	B2	Egypt
3	Corn flakes	B3	Germany
4	Magic mix	B4	Ukraine
5	Choco rings	B5	Turkey
6	Pop pins	B6	Lebanon
7	Honey rings	B7	Turkey
8	Toons (corn flakes)	B8	Egypt
9	Ozmo	B9	Turkey
10	Kellayys	B10	Spain

B. Preparation of Breakfast Cereal Samples

Prior to measurement, each sample was subjected to a pretreatment process that entailed powdering, drying at 100 °C for 1 h, sieving (200 mesh), and weighing (approximately 700 kg). These steps were essential to achieve a homogeneous state for the sample. The powdered samples were then transferred into Marinelli beakers, each with a capacity of 1 lt. Subsequent to the sealing process, the sample-filled containers were stored for a minimum of 30 days to ensure the formation of secular equilibrium between the radium and radon [10].

C. Gamma-Ray Spectroscopy System

Measurements were conducted using a scintillation detector of the NaI(Tl) type, which is a sodium iodide detector, manufactured in the USA by the ORTEC company. In the present study, the Certified Reference Materials (CRMs) for standard gamma-ray sources that were supplied by the International Atomic Energy Agency (IAEA) in the Model RSS-8 source set were used. The energy resolution for the NaI(Tl) detector is 7.5% at the 0.662 MeV ^{137}Cs photopeak. Additionally, the energy calibration and efficiency for the detector were determined using a standard point source for gamma-rays, ^{137}Cs , ^{60}Co , ^{22}Na , ^{54}Mn , and ^{152}Eu . A five-hour counting period was conducted under identical conditions for each sample in a container and an empty container to ascertain the background. Subsequently, the gamma-ray spectra were analyzed using MASTRO-32 software, where the photopeaks at gamma-ray energy lines considered were 17659 keV (^{238}U), 2614 keV (^{232}Th), and 1460 keV (^{40}K) [11, 12]. The values of the Minimum Detection Limit (MDL) for three radionuclide isotope energies were 3.17 ± 0.08 Bq/kg, 1.2 ± 0.01 Bq/kg, and 11.54 ± 0.61 Bq/kg, respectively. In order to ensure the efficacy of the quality control procedures, a series of measurements were performed on the levels of radionuclides ^{238}U , ^{232}Th , and ^{40}K in breakfast cereal samples using a high-efficiency gamma-ray spectrometer. All spectra were acquired and analyzed using MAESTRO-32 software, which provided tools for energy calibration, peak adjustment, and background subtraction. The measurement uncertainty, which includes statistical counting errors, source activity calibration, and detector efficiency adjustment, typically ranged between $\pm 5\%$ and $\pm 10\%$, depending on the energy and sample activity.

III. CALCULATIONS

A. Specific Activity (A)

The specific Activity (A) of the gamma-emitting radionuclides in the sample can be calculated by [13, 14]:

$$A \left(\frac{\text{Bq}}{\text{kg}} \right) = \frac{N(\text{count})}{I_{\gamma} \epsilon M(\text{kg}) T(\text{s})} \quad (1)$$

where N is the net area under the photopeak, I_{γ} is the probability of gamma decay, ϵ is the efficiency of the gamma-ray detector, M is the weight of the measured sample in kg, and T is the live time for spectrum collection in sec.

B. Annual Effective Dose (AED)

The AED resulting from the ingestion of natural radionuclides in foods can be calculated by [5, 15]:

$$\text{AED} \left(\frac{\text{mSv}}{\text{y}} \right) = A \left(\frac{\text{Bq}}{\text{kg}} \right) \times I \left(\frac{\text{kg}}{\text{y}} \right) \times E \left(\frac{\text{Sv}}{\text{Bq}} \right) \quad (2)$$

where I is the annual intake of the studied samples (kg/y) [16, 17], and E is the ingested dose conversion factor for radionuclides (Sv/Bq) for infants, children, and adults of certain age groups. In this study, the values of I factor (in Bg/y) for different age groups are: the annual weight gain for children aged 1–10 years is 1.7 kg, for adolescents aged 11–17 years is 1.7 kg, and for adults aged 18 years and older is 5 kg. These values were adopted based on general dietary patterns reported in literature, particularly those that highlight the consumption of cereals in processed forms, such as breakfast cereals and other cereal-based products [16, 17]. Despite the absence of precise national dietary intake data for Iraq, the available figures offer reliable estimates, reflecting the conservative consumption patterns observed in the region. The selected values permit a realistic evaluation of the radiological risks associated with cereal consumption, particularly given that the cereals do not constitute the primary staple food in all Iraqi households.

C. Excess Lifetime Cancer Risk (ELCR)

The likelihood of developing cancer over a lifetime at a given exposure level, assuming a typical lifespan of 70 years can be expressed as [18]:

$$\text{ELCR} = \text{AED} \left(\frac{\text{mSv}}{\text{y}} \right) \times DL(\text{y}) \times RF \left(\frac{1}{\text{Sv}} \right) \quad (3)$$

where DL is the normal life duration (evaluated to be 70 years) and RF is the risk factor (Sv).

IV. STATISTICAL ANALYSIS

The statistical analyses were conducted using SPSS software, version 27. The analyses included the mean and standard deviation (Mean \pm S.D.). The confidence level or significance level for this investigation was set at p-value < 0.05.

V. RESULTS AND DISCUSSION

As shown in Table II, the range values of the specific activity for ^{238}U , ^{232}Th , and ^{40}K were found to vary from 5.67 ± 0.61 Bq/kg to 11.82 ± 1.09 Bq/kg, from 2.2 ± 0.29 Bq/kg to 9.76 ± 0.61 Bq/kg, and from 152.37 ± 3.34 Bq/kg to $323.63 \pm$

7.56 Bq/kg, respectively, while the key values of ²³⁸U, ²³²Th, and ⁴⁰K were 8.54 ± 1.06 Bq/kg, 7.05 ± 0.49 Bq/kg, and 216.58 ± 4.79 Bq/kg, respectively. Figure 1 presents a comparison of the specific activities of the three studied isotopes (in unit Bq/kg) for all samples. The maximum values were observed in samples B7 (Honey rings from Turkey), B8 (Toons from Egypt), and B4 (Magic mix from Ukraine), respectively, while the minimum were B3 (Corn flakes from Germany), B1 (Corn flakes from Turkey), and B3 (Corn flakes from Germany), respectively.

TABLE II. RESULTS OF SPECIFIC ACTIVITY OF ²³⁸U, ²³²Th, AND ⁴⁰K IN BREAKFAST CEREAL SAMPLES

No.	Code	Specific activity (Bq/kg)		
		²³⁸ U	²³² Th	⁴⁰ K
1	B1	9.86 ± 0.99	2.27 ± 0.29	236.05 ± 5.08
2	B2	9.24 ± 0.97	9.56 ± 0.60	188.98 ± 4.59
3	B3	5.67 ± 0.61	4.49 ± 0.33	152.37 ± 3.34
4	B4	9.08 ± 1.21	9.11 ± 0.73	323.63 ± 7.56
5	B5	9.12 ± 0.95	9.37 ± 0.58	246.17 ± 5.18
6	B6	9.65 ± 0.98	6.17 ± 0.47	223.31 ± 4.92
7	B7	11.82 ± 1.09	7.84 ± 0.54	194.57 ± 4.63
8	B8	9.98 ± 1.01	9.76 ± 0.61	181.43 ± 4.53
9	B9	7.07 ± 0.79	5.70 ± 0.40	248.12 ± 4.56
10	B10	7.92 ± 0.72	6.22 ± 0.38	171.19 ± 3.50
Mean ± S.D.		8.54 ± 1.06	7.05 ± 0.49	216.58 ± 4.79

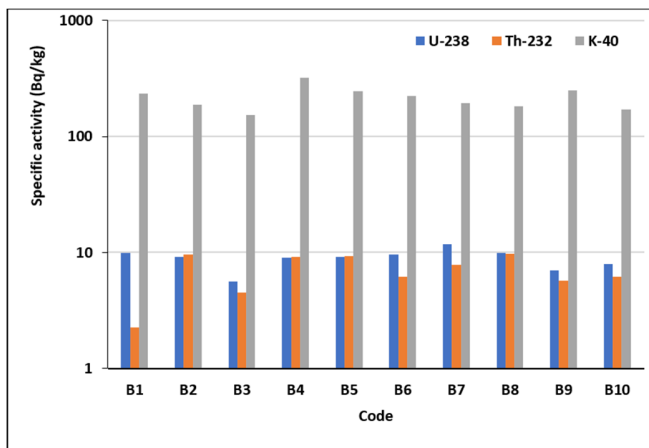


Fig. 1. Relation between specific activity with sample code.

The results of the annual permissible dose from each gamma emitter (²³⁸U, ²³²Th, and ⁴⁰K) in breakfast cereal samples consumed by three age groups, infants, children, and adults, are displayed in Tables III-V, respectively. Table III shows that the mean values of AED in infants for ²³⁸U, ²³²Th, and ⁴⁰K were 0.015 ± 0.0008 mSv/y, 0.005 ± 0.0005 mSv/y, and 0.015 ± 0.001 mSv/y, respectively. Table IV demonstrates that the mean values of AED in children for ²³⁸U, ²³²Th, and ⁴⁰K were 0.012 ± 0.0006 mSv/y, 0.004 ± 0.0004 mSv/y, and 0.005 ± 0.0003 mSv/y, respectively, and Table V shows that the mean values of AED in adult age groups for ²³⁸U, ²³²Th, and ⁴⁰K were 0.013 ± 0.0007 mSv/y, 0.008 ± 0.0008 mSv/y, and 0.007 ± 0.00046 mSv/y, respectively. Furthermore, the range values of the total AED in three age groups (infants, children, and adults) were 0.024–0.045 mSv/y, 0.013–0.024 mSv/y, and 0.018–0.033 mSv/y, respectively. The mean values

of the total AED in three age groups (infants, children, and adults) were 0.035 ± 0.001 mSv/y, 0.021 ± 0.0009 mSv/y, and 0.028 ± 0.0014 mSv/y, respectively. Figure 2 presents a comparison of the results of the annual permissible dose (in unit mSv/y) due to ²³⁸U, ²³²Th, and ⁴⁰K for the three age groups under study. The minimum and maximum values of AED for ²³⁸U, ²³²Th, and ⁴⁰K, as well as the total AED, were identified in samples B3 (Corn flakes from Germany) and B4 (Magic mix from Ukraine), respectively.

TABLE III. RESULTS OF ANNUAL PERMISSIBLE DOSES FOR INFANTS

No.	Code	Annual permissible doses (mSv/y)			
		²³⁸ U	²³² Th	⁴⁰ K	Total
1	B1	0.016	0.002	0.017	0.035
2	B2	0.015	0.007	0.013	0.036
3	B3	0.009	0.003	0.011	0.024
4	B4	0.015	0.007	0.023	0.045
5	B5	0.015	0.007	0.018	0.040
6	B6	0.016	0.005	0.016	0.036
7	B7	0.019	0.006	0.014	0.039
8	B8	0.016	0.007	0.013	0.037
9	B9	0.012	0.004	0.018	0.034
10	B10	0.013	0.005	0.012	0.030
Mean±S.D.		0.015 ± 0.0008	0.005 ± 0.0005	0.015 ± 0.001	0.035 ± 0.001

TABLE IV. RESULTS OF ANNUAL PERMISSIBLE DOSES FOR CHILDREN

No.	Code	Annual permissible doses (mSv/y)			
		²³⁸ U	²³² Th	⁴⁰ K	Total
1	B1	0.013	0.001	0.005	0.020
2	B2	0.013	0.005	0.004	0.021
3	B3	0.008	0.002	0.003	0.013
4	B4	0.012	0.004	0.007	0.024
5	B5	0.012	0.005	0.005	0.022
6	B6	0.013	0.003	0.005	0.021
7	B7	0.016	0.004	0.004	0.023
8	B8	0.014	0.005	0.004	0.022
9	B9	0.010	0.003	0.005	0.018
10	B10	0.011	0.003	0.004	0.018
Mean ± S.D.		0.012 ± 0.0006	0.004 ± 0.0004	0.005 ± 0.0003	0.021 ± 0.0009

TABLE V. RESULTS OF ANNUAL PERMISSIBLE DOSES FOR ADULTS

No.	Code	Annual permissible doses (mSv/y)			
		²³⁸ U	²³² Th	⁴⁰ K	Total
1	B1	0.014	0.003	0.007	0.024
2	B2	0.013	0.011	0.006	0.030
3	B3	0.008	0.005	0.005	0.018
4	B4	0.013	0.010	0.010	0.033
5	B5	0.013	0.011	0.008	0.031
6	B6	0.014	0.007	0.007	0.028
7	B7	0.017	0.009	0.006	0.032
8	B8	0.014	0.011	0.006	0.031
9	B9	0.010	0.007	0.008	0.024
10	B10	0.011	0.007	0.005	0.024
Mean ± S.D.		0.013 ± 0.0007	0.008 ± 0.0008	0.007 ± 0.00046	0.028 ± 0.0014

The results of ELCR from each gamma emitter (²³⁸U, ²³²Th, and ⁴⁰K) in breakfast cereal samples consumed by three age groups (infants, children, and adults) are depicted in Table VI. The range values of ELCR × 10⁻³ for infants, children, and adults were 0.082-0.157, 0.047-0.085, and 0.062-0.116, respectively, and the mean values of ELCR × 10⁻³ in infants,

children, and adults were 0.124 ± 0.006 , 0.072 ± 0.003 , and 0.096 ± 0.005 , respectively. Figure 3 portrays a comparative analysis of the ELCR outcomes for ^{238}U , ^{232}Th , and ^{40}K in three distinct age groups: infancy, childhood, and adulthood, showing that the minimum and maximum values of ELCR were in samples B3 (Corn flakes from Germany) and B4 (Magic mix from Ukraine).

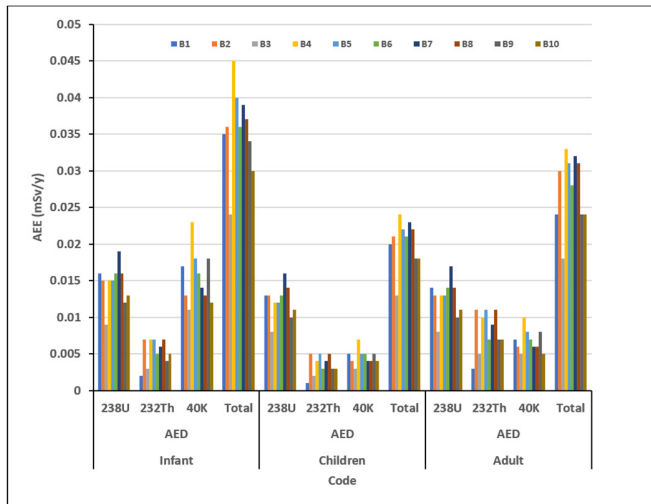


Fig. 2. Relation between AED with sample code and age groups.

TABLE VI. RESULTS OF ELCR FOR INFANT, CHILD, AND ADULT

No.	Code	ELCR $\times 10^{-3}$		
		Infant	Child	Adult
1	B1	0.121	0.069	0.083
2	B2	0.126	0.075	0.104
3	B3	0.082	0.047	0.062
4	B4	0.157	0.085	0.116
5	B5	0.139	0.079	0.109
6	B6	0.127	0.074	0.096
7	B7	0.137	0.084	0.111
8	B8	0.128	0.078	0.108
9	B9	0.118	0.063	0.085
10	B10	0.105	0.062	0.082
Mean \pm S.D.		0.124 ± 0.006	0.072 ± 0.003	0.096 ± 0.005

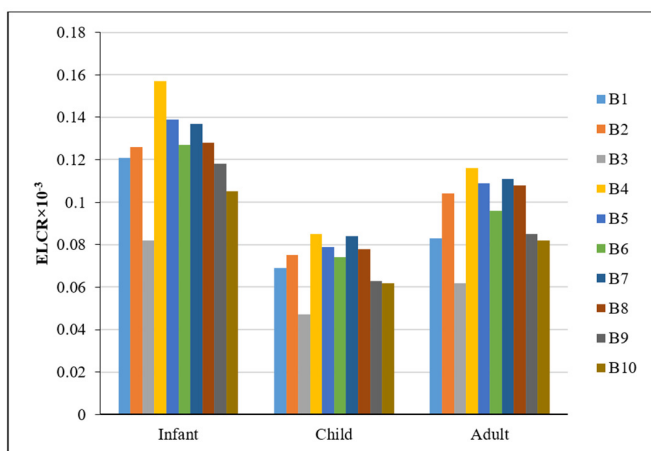


Fig. 3. Relation between ELCR with sample code and age groups.

The specific activity values for ^{40}K were found to exceed those of both ^{238}U and ^{232}Th and the specific activity values for ^{238}U were found to exceed those for ^{232}Th , as demonstrated in both Table II and Figure 1. The results for the gamma-ray emitters in the current breakfast cereal samples exhibited variability due to the geological characteristics of the soil in which the grains used for the cereal product were cultivated, as well as the number of chemical fertilizers used during the growing period. However, the results for ^{238}U , ^{232}Th , and ^{40}K in all breakfast cereal samples in this study were within the acceptable limits established by UNSCEAR 2008 [19], which are 33 Bq/kg for ^{238}U , 45 Bq/kg for ^{232}Th , and 420 Bq/kg for ^{40}K . The mean AED values for the breakfast cereal samples were the highest for infants, followed by adults and children. This variation can be attributed to the differences in the consumption rates and the conversion factor. However, the total AED results for all age groups in this study were within the UNSCEAR 2000 proposed limit of 0.32 mSv/y [5]. Additionally, the ELCR results for all breakfast cereal samples and age groups were below the global limit of 2.5×10^{-3} [20]. Table VII provides a comparative analysis of the specific activities of ^{238}U , ^{232}Th , and ^{40}K in breakfast cereals from this study with the results obtained from previous studies. The range values of ^{238}U in the present study were found to be higher than in Kuwait and lower than those in Nigeria and Iraq, and the range values of ^{232}Th and ^{40}K were found to be higher than in Kuwait, Nigeria, and Syria and lower than in Iraq.

TABLE VII. COMPARISON OF THE SPECIFIC ACTIVITY OF NATURAL RADIOACTIVITY FOR BREAKFAST CEREAL IN THE PRESENT STUDY WITH PREVIOUS STUDIES

No	Country	^{238}U (Bq/kg)	^{232}Th (Bq/kg)	^{40}K (Bq/kg)	Ref.
1	Kuwait	0.32 - 1.26	0.1 - 1.12	14 - 144	[5]
2	Syria	-	-	176 - 216	[5]
3	Nigeria	0.0-30.0	-	20 - 233	[6]
4	Iraq	2.383 - 29.818	13.682 - 5.838	345.857- 1117.815	[7]
5	Iraq	5.67-11.82	2.27 - 9.76	152.37 -323.63	Present study

The breakfast cereals contribute a smaller percentage of the total permissible dose because of their relatively low radionuclide concentrations and moderate consumption rates. However, the regular consumption over time, may pose a significant radiological risk. This highlights the necessity of ongoing monitoring and comprehensive dietary assessments that include all major food groups. The results of the present study indicate that the specific activity of gamma-ray emitters and radiological hazards, such as AED and ELCR, for the breakfast cereal samples consumed by all age groups (infants, children, and adults) are within limits.

VI. CONCLUSIONS

The natural radioactivity of gamma-ray emitters, including ^{238}U , ^{232}Th , and ^{40}K , as well as the annual permissible dose and cancer risk in the breakfast cereal samples available in Iraqi markets, were assessed. The findings revealed that the levels of three radionuclides were below the established safety threshold, as proposed by UNSCEAR 2008. Furthermore, the maximum and minimum values of the total AED were observed in B4 (Magic mix, Ukraine) and B3 (Corn flakes, Germany),

respectively. The findings suggest that the consumption of the breakfast cereal by individuals across all age groups (infants, children, and adults) is safe according to the established global permissible limits for food products. The data concerning the long-lived gamma emitters in breakfast cereal samples obtained from Iraqi markets may inform risk communication strategies targeting vulnerable groups, such as children, who are more sensitive to radiation exposure. Moreover, the methodology and results can be used as a model for broader food surveillance programs in Iraq and neighboring countries, especially those concerned with imported and processed foods.

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