International Journal of Innovative Research and Scientific Studies, 8(2) 2025, pages: 4046-4053

IJIRSS
International Journal of Innovative Research & Scientific Studies

ISSN: 2617-6548

URL: www.ijirss.com

The annual effective dose for children resulting from the ingestion of radioactive nuclides found in basic diets

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Abstract

The concentrations of natural radionuclides uranium-238 (238U), thorium-232 (232Th), and potassium-40 (40K) were determined in sixteen basic baby meals that were randomly collected from the markets of Hilla, Iraq, using NaI(Tl). The activity concentration of 238U ranged from 0.075 ± 0.013 Bq.kg-1 in (MG1) to 18.21 ± 0.055 Bq.kg-1 in (SG2), with an average value of 4.00 ± 0.145 Bq.kg-1. The concentration of 232Th ranged from 0.067 ± 0.009 Bq.kg-1 in (MG4) to 15.60 ± 0.08 Bq.kg-1 in (FG1), with an average of 4.97 ± 0.149 Bq.kg-1, while the 40K concentration ranged from 7.210 ± 1.932 Bq.kg-1 in (FG4) to 321.75 ± 0.89 Bq.kg-1 in (MG2), with an average of 96.384 ± 0.895 Bq.kg-1. The annual effective dose resulting from radionuclide ingestion was calculated by analyzing the spectrum of radionuclides and using the annual rate of food consumption and age-dependent dose conversion parameters published in the report of the United Nations Scientific Committee on the Effects of Atomic Radiation. The total effective dose ranged from 0.930 μSv.y-1 in (MG1) to 0.197 μSv.y-1 in (SG2), with an average value of 55.188 μSv.y-1, all of these values being less than the global total dose value of 200 μSv.y-1 for all. This study could be helpful because updated data show a database of natural radionuclide activity in some children's staple diets and annual effective exposure dose values.

Keywords: Annual effective dose, cancer risks, gamma-ray spectroscopy, ingestion dose, radioactivity.

DOI: 10.53894/ijirss.v8i2.6229
Funding: This study received no specific financial support.
History: Received: 21 February 2025 / **Revised:** 25 March 2025 / **Accepted:** 27 March 2025 / **Published:** 16 April 2025

Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.
Transparency: The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.
Acknowledgments: The authors extend our sincere thanks to the presidency of the University of Babylon and the laboratories of the College of Science for Advanced Studies in the Department of Physics.
Publisher: Innovative Research Publishing

1. Introduction

The goal of establishing radiological protection groups in the twentieth century was to ensure the safety of humans. Their objective is to limit the use of ionizing radiation by setting standards and making recommendations [1]. Reducing the risk of outdoor gamma radiation exposure has been the primary goal of ionizing radiation regulatory bodies such as CNEN (Comissão Nacional de Energia Nuclear) and the IAEA (International Atomic Energy Agency). Therefore, according to international organizations, it is obligatory to measure the natural radioactivity to which people are exposed, categorized by age groups [2].

Radionuclides in the air, food, and water can cause ionizing radiation exposure by inhalation and ingestion [3]. Natural sources of radionuclides include soil, water, and air; human-made sources include nuclear power plants and radiation therapy [4]. These radionuclides can enter the bloodstream in a variety of ways, including inhalation, ingestion, and other similar routes [5, 6]. Naturally occurring radioactive materials (NORM) refer to the natural sources of radioactivity in the environment. These materials can be classified into two categories: from cosmic sources and from the Earth [7].

NORMs are present in the environmental media, where certain radioactive elements have been passed to the food chain. These materials consist of naturally occurring radioactive elements, including radium, uranium, thorium, and potassium, which are present in minerals, ores, and the Earth's crust [8]. Radionuclides in plants originate from either the absorption of radionuclides through the root system or the deposition of radionuclides from the atmosphere onto the aboveground part of the plant [9-11]. The spatial allocation of radionuclides within various plant components is contingent upon their chemical characteristics and many plant and soil-specific variables [12]. Hence, radionuclides play a vital role in the ingestion dose and are found in the biological systems of plants, animals, soil, water, and air [13, 14].

The work done by the IAEA in this field is of utmost importance since harmful effects on the organism can be caused by the annual effective dose rate, which depends on the analysis of natural radionuclide activity and the annual food consumption rate. As part of the Joint FAO/WHO Codex Alimentarius Commission, the IAEA has set worldwide standards for irradiated foods and assists nations in developing and implementing nuclear and associated procedures to guarantee food safety and quality [15, 16]. A person's internal dose can be effectively increased after consuming food that contains radionuclides, both naturally occurring and artificial. Food consumption is responsible for a significant amount, around one-eighth of the average yearly dosage from natural sources [17, 18].

The average radiation exposure to different organs is also a significant factor when considering long-term health. Long half-lifetimes and chemical behavior are the foundations of radionuclides' potential toxicity. Aside from being radioactive, uranium-238 is chemically poisonous and has radioactive properties; potassium-40, strontium-90, and cesium-137 are radioactive, and also minerals and elements that are vital to human nutrition [19, 20]. Given the significant increase in the number of people with cancer in the city of Hilla, especially young age groups, according to statistics from the Babylon Health Department, it was necessary to stand up and know most or some of these reasons [21]. Because 80% of cancer cases result from the ingestion of nuclei or substances containing natural radionuclides, according to a report by the International Commission on Radiological Protection (ICRP) [22, 23], it is necessary to determine the reasons for this increase. The first of these strategies was to study the diet of children between the ages of two and seven years, which we discussed in this article.

This study aimed to clarify the effect of exposure to radionuclides by surveying 40K, 238U, and 232Th concentrations in foods consumed by children and estimating the concentration of radionuclides present using gamma spectroscopy. The annual effective dose is calculated based on ingestion and the cancer risk associated with the activity of these radionuclides. A database has been created to assist government agencies and the general public with statistical information. Conversion factor data were compared with values in existing literature because these foods constitute a percentage of children's main diet.

2. Materials and Methods

2.1. Collection And Preparation of Samples

Sixteen food samples that were the focus of this study were analyzed in the Advanced Physics Laboratory of the Department of Physics at the University of Babylon in June 2023. According to Table 1, the samples analyzed were given the following capital letters, and the groups were also given the following initials: M for meat group, V for vegetable group, F for fruit group, and S for starch and bread group. These samples were extracted from the standard diet of children aged between two and seven years and collected from Hilla markets.

All samples were examined in their raw food state. Before the detection of radioactivity, raw food components were dried in a humidity-free oven at 65°C for 1–5 days to achieve constant weight and remove any moisture absorption. After the samples are electronically crushed using an electrical device, they are placed in a nylon bag bearing their names and weights to be stored for a long period before being examined.

A digital balance with a hundredth scale was used to measure the masses of the samples. This equation was used to measure the mass of the samples under study ($ms = mt - mf$): where ms is the mass of the model, mt is the mass of the model plus the mass of the model holder, and mf is the mass of the container. Gram precision was used for this purpose. To reach a state of secular equilibrium, the samples were closed and left for a period of no less than 45 days in climatic conditions characterized by minimal temperature fluctuations. According to Table 1, the sample groups analyzed were given the following capital letters.

Table 1.
Basic meal groups and scientific symbols used to denote some food items for children in this study.

No.	Basic food meal groups	Symbol groups	Trade Name	Scientific Name	Code of Samples
1	Meats Group	M	Fish	Pisces	MG1
			Chicken	Gallus gallus	MG2
			Red meat	-----	MG3
			1.1. *eggs*	-----	GM4
2	Vegetables Group	V	spinach	Spinacia oleracea	VG1
			Broccoli	Brassica oleracea var. italica	VG2
			parsley	Petroselinum crispum	VG3
			carrot	Daucus carota	VG4
3	Fruits Group	F	banana	Musa	FG1
			apples	Malus	FG2
			orange	Citrus ×sinensis	FG3
			Strawberry	Fragaria x ananassa	FG4
4	Starch and Bread Group	S	Bread	-----	SG1
			the rice	Oryza sativa	SG2
			Potato	Solanum tuberosum	SG3
			Pasta	----	SG4

2.2. Operating System for Gamma Spectrometry Data Acquisition

Basic rations of baby foods that were part of this study were measured using a NaI (Tl) detector (3x3). The ORTEC cylindrical chamber is divided into two halves and consists of a lead and stainless-steel outer part. The widths of these parts were 20 cm and 5 cm, respectively. The chamber design facilitated the assessment of the entire radiation environment. Among its many benefits, this detector excels at capturing gamma rays. Easy sampling. Its accuracy in storing sample results and spectra is its hallmark. It comes with containers for testing samples, and it is easy to calibrate the power [24].

The procedure started with an energy efficiency calibration utilizing 60C0, 133Ba, 57Co, 137Cs, and 22Na, as indicated in Table 2. Precise energy readings were made possible thanks to this calibration technique. The energy efficiency of the NaI(Tl) detector was measured accurately using the calibration sources mentioned above. The source energies used for calibration range from 511.006 keV to 2500 keV.

The next step was to arrange the calibration source so that it was in perfect geometric alignment with the detector. A Marinelli beaker was used at this stage, with the calibration sources placed inside it. Optimal alignment of the sample under examination with the detector can be achieved through a consistent geometric arrangement in making the measurements [25].

The efficiency, defined as the ratio of incoming gamma ray photons to the pulses emitted by the detector, is always less than 100%. The efficiency of the gamma-ray spectrometer is calculated using the following formula:

$$\varepsilon = \frac{\mathrm{N_{net}}}{A \times \mathrm{I\gamma} \times \mathrm{t}} 100\% \qquad (1)$$

where N_{net} is the area under the photo peak, t is time per second, $I\gamma$ is the percentage of energy intensity emitted by the radioactive source, and A is the activity of samples of measured time, which is measured from the following equation:

$$A = A_o\, e^{-\lambda t} \qquad (2)$$

where A_o: The effectiveness of the nuclide upon manufacturing, λ: decay constant.

Using reference sources with known energies in Table 2, the efficiency of the thallium-doped sodium iodide NaI(Tl) detector is calibrated. You can calculate the total radioactivity and find out the source of the radiation using the decay equation (2). In addition, radioactivity is also recorded by the detector. After this calculation, the efficiency (Ɛ%) is determined using equation (1) for each energy emitted by the radiant sources within 500 seconds [13].

Table 2.
Standard sources and their energies used in NaI (Tl) detector calibration.

Number	Source	E(keV)	Efficiency×10^{-6}
1	Barium-133	383.7	186152
2	Sodium - 22	511	144310
		1274.5	31342
3	Caesium-137	661.6	106779
4	*Manganese-54*	834.8	75517
5	Cobalt-60	1173.24	38378
		1332.5	27909

3. Theoretical Calculations and Radiological Health Risk Parameters

The scenarios that were considered included the possibility of analyzing internal exposure to gamma radiation related to the activity levels of natural radionuclide series in the basic meals of children aged from two to seven years. Software models were applied to the activity concentration data to evaluate effective radiation dose and cancer risk.

3.1. Specific Activity

To calculate the concentration of natural radionuclides and their risk factors in the study samples, note that the time used to measure each sample is 86400 seconds. This was done after calibrating the efficiency of the nuclear detector and detecting background radiation. After completing the energy calibration of the NaI (Tl) detector, it is possible to identify the radionuclides emitted from a particular substance by analyzing their gamma spectra. Once the radionuclide emitted from the sample has been placed, the next critical step in radiological analysis is to measure the specific activity of the radionuclide. Equation 3 specifies the parameters that are used for this purpose [14].

$$A(\mathrm{Bq/kg}) = \frac{N}{t \times \varepsilon \times I_{\gamma} \times m} \quad (3)$$

In this context, N represents the net area under peak, t denotes the counting time in seconds, Iγ denotes the gamma emission potential, m represents the weight of the pattern in kg, and ε denotes the detector efficiency at a specific gamma energy.

Radium equivalent (RaEq) is a standard radioactive index that measures the actual activity level of natural radionuclides in the main meals of the food samples in this study. It is used to calculate the non-uniform distribution of natural radionuclides in samples by the expression [26]:

$$Ra_{eq}=1.0C_U+1.430C_{Th}+0.0770C_K \quad (4)$$

The maximum allowable value of $Raec$ should be 370 Bq.kg-1, and the effective exposure to the public should be limited to 1 mSv.y-1, according to UNSCEAR [1].

3.2. Calculate the effective Dose due to Eating Foods Containing Radionuclides

The committed dose is measured for fear of the possibility of random health risks resulting from the consumption of radionuclides present in basic meals. The estimate of the committed dose due to ingestion $Deff\ (mSv.y-1)$ was calculated as the product of the estimated activity concentration of the 238U, 232Th, and 40K decay cascade in the basic diets, taking into account the estimated annual consumption of the food types and the effective dose coefficients (C). [1] using equation (5) [25, 26].

$$Deff\ (Sv/y) = R \times C \times A \quad (5)$$

where: R is the dose factor shown in Table 3 published by ICRP 2012; C is the Quantities of food consumed during the year; A is the specific concentration of ^{238}U, ^{232}Th and ^{40}K in the study samples.

In order to determine the effective dose, consumption rates published by the United Nations Scientific Committee on the Effects of Atomic Radiation [1] were used based on age, as no documented official data on diet consumption rates were found. Factors such as radionuclide distribution, tissue retention, and secretion rate are taken into account when deriving effective dose factors [27, 28].

Table 3.
Determination of dose coefficients published by UNSCEAR [1].

Radionuclide	Effective dose coefficients (SvBq^{-1})		
	2-7 years	**12-17year**	**>17 year**
Uranium-238	8.0 x 10^{-8}	6.7 x 10^{-8}	4.50 x 10^{-8}
Thorium-232	3.5 x 10^{-7}	2.5 x 10^{-7}	2.30 x 10^{-7}
Potassium-40	2.1 x 10^{-8}	7.6 x 10^{-9}	6.20x10^{-9}

3.3. Lifetime Cancer Risk Calculation

To determine the potential long-term health effects of exposure to ionizing radiation, it is necessary to estimate the lifetime cancer risk (ELCR), part of the radiation health risk assessment. Based on the ICRP report, the standard practice is to assess radiation risks based on a linear dose-effect relationship. ICRP,1990 sets the fatal cancer risk factor at 0.05 Sv-1 for low doses [10, 29, 30]. In general, exposure to a total dose of 1 Sv-1 throughout a person's life increases the chance of dying from cancer by 5% [31-33]. This is the formula for calculating ELCR:

$$ELCR=LE \times D \times RF \quad (6)$$

where LE is the life expectancy (60 y), the risk factor per sievert (RF) is quantified with a specific value of 0.05, and D is the total effective dose to an individual.

4. Results and Discussions

4.1. Activity and Concentrations of Uranium, Thorium, and Potassium in Basic Meals of Baby Food

Four groups of basic baby foods were collected, and each group contained four basic types of foods consumed in Iraq in Hilla city, which were sweetened by spectrophotometry to calculate the concentration of natural radionuclide series, as shown in Table 4. The Radioactivity of U-238 in the food samples under study ranged from 0.075±0.013 Bq/kg (MG1) to 18.21±0.055 Bq/kg in (SG2) with an average value of 4.00±0.145 Bq/kg, for concentration 232Th from 0.067±0.009 Bq/kg in (MG4) to 15.60±0.08 Bq/kg in (FG1) with an average of 4.97±0.149 Bq/kg.

Finally, for the concentration of 40K, it ranged from 7.210±1.932 Bq/kg in (FG4) to 321.75±0.89 Bq/kg in (MG2), with an average of 96.384±0.895 Bq/kg, respectively. In all study samples, considered one of the basic meals in children's diets, 40K activity was within the permissible activity levels. It was found that the concentration of potassium is very high compared to other radionuclides represented by uranium and thorium, perhaps due to the 40K concentrations present in the soil that are transferred to plants or transferred to animal food, as potassium is a micronutrient.

However, 40K is a biological element and nutrient for the body, and its concentration in the human body is under precise metabolic control. Figure 1 represents the activity concentrations of the three radionuclides uranium-238, thorium-232, and potassium-40in four groups of basic food samples for baby food.

Table 4.
Concentration of natural radionuclides in some samples of consumer foods for children.

Number	Samples	Specific Activity (Bq/kg)			Ra_{eq} (Bqkg^{-1})
		^{40}K	^{238}U	^{232}Th	
1	MG1	9.890±0.824	0.075±0.013	0.846±0.011	2.046
2	MG2	321.75±0.89	0.571±0.131	0.921±0.013	26.66
3	MG3	92.04±0.703	1.02±0.145	2.71±0.072	11.98
4	GM4	43.14±0.366	0.021±0.011	0.067±0.009	3.439
5	VG1	58.91±0.858	3.74±0.062	2.69±0.008	12.12
6	VG2	187.12±1.24	2.43±0.074	3.27±0.049	21.51
7	VG3	67.21±0.833	3.01±0.070	2.74±0.060	12.10
8	VG4	21.71±0.441	3.68±0.034	4.10±0.064	11.21
9	FG1	84.270±1.36	4.95±0.176	15.60±0.08	33.75
10	FG2	9.210±0.741	1.21±0.026	2.33±0.005	5.251
11	FG3	48.91±1.416	1.410±0.20	0.921±0.164	6.493
12	FG4	7.210±1.932	0.92±0.006	1.22±0.007	3.220
13	SG1	27.410±0.36	10.23±0.05	13.33±0.057	31.40
14	SG2	296.97±1.001	18.21±0.055	12.21±0.107	58.54
15	SG3	124.21±0.773	2.29±0.030	3.21±0.006	16.44
16	SG4	142.19±0.210	11.31±0.158	13.28±0.037	41.25
Average		96.384±0.895	4.00±0.145	4.97±0.149	18.59

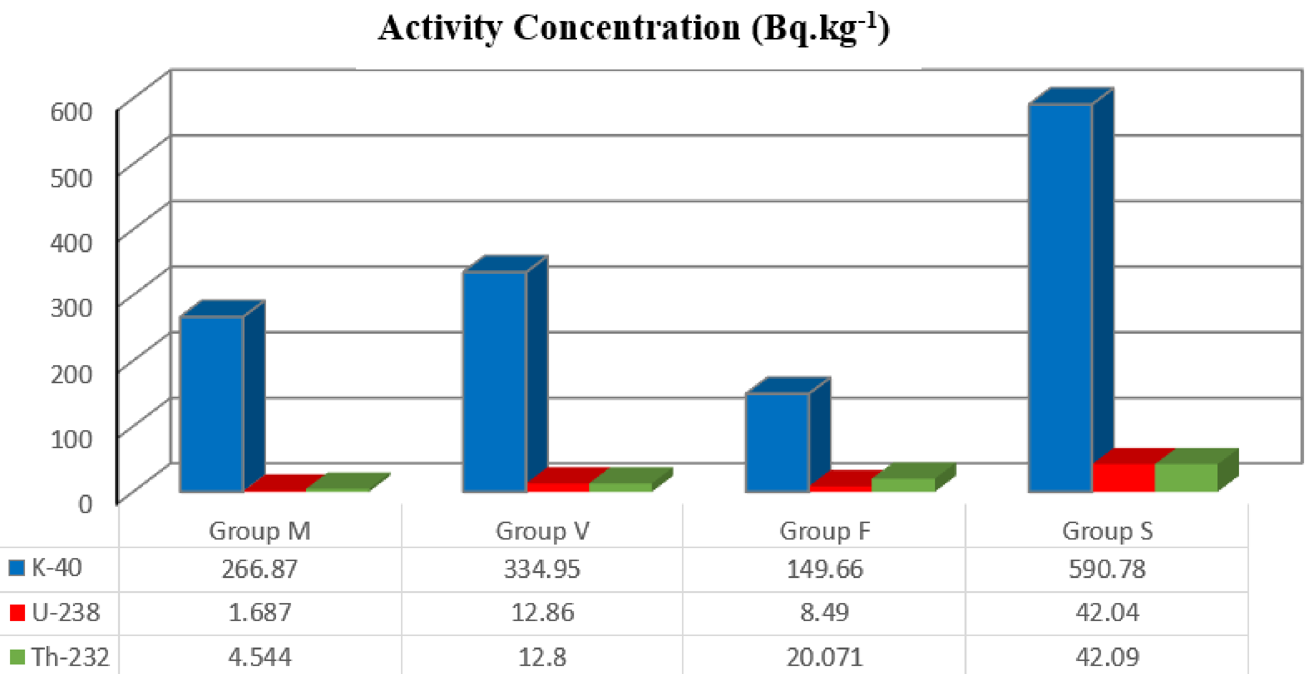

Figure 1.
Concentration of radioactivity for groups M, Y, F, and S.

4.2. Estimating the Annual Effective Dose of Basic Meals for Children

Table 5 represents annual effective dose calculations resulting from radionuclide activity concentration and lifetime cancer risk values resulting from ingestion of 238U, 232Th, and 40K radionuclides in the basal diet of children. This is compared to the global tolerable dose reported by UNSCEAR [1].

Annual effective dose values for a 40K intake ranged from 0.379 µSvy^{-1} in (MG1) to 102 µSvy^{-1} in (SG2), with an average value of 21.75 µSvy^{-1}. Therefore, the dose contribution from the intake of 40K to the basic child rations was not the result of higher radionuclide concentrations in these basic child rations but rather due to the increased consumption rate and the use of a low dose conversion factor of (2.1x10^{-8}) SvBq^{-1}, compared to other natural radionuclide conversion factors.

The annual effective ingestion doses resulting from 238U ranged from 0.011 μSvy^{-1} in (MG1) to 23.9 μSvy^{-1} in (SG2). Groups V, F, and S show significant increases in ingestion doses compared to values reported by the United Nations Scientific Committee on Atomic Radiation Research.

The effective dose received from 232Th as a result of main meals in infant food ranged from 0.540 μSvy^{-1} in (MG1) to 120 μSvy^{-1} in (FG1), which accounted for 0.12% (MG1) to 26.55% (FG1) of the total intake. Note that the permissible limit reported by UNSCEAR [1] for the effective dose is (0.26 μSvy^{-1}). From the results of this study, we note that the total annual effective dose for all four basic food groups is much less than the global permissible dose value (170 μSvy^{-1}) reported by UNSCEAR [1].

In Table 5, the average annual effective dose of natural radionuclides in samples of basic meals in children's food was estimated at 21.75μSvy^{-1} of 40K, 5.158 μSvy^{-1} of 238U, and 28.25 μSvy^{-1} of 232Th. The highest average annual internal dose was 232Th, and all of these average doses are less than the maximum annual dose of 1 million Sv for the general public [1].

The total effective dose ranged from 0.930 μSvy-1 in (MG1) to 197 μSvy^{-1} (SG2), with an average value of 55.188 μSvy^{-1}. From analyzing the results of the current study, it is clear that the average annual effective dose is 55.188 μSvy^{-1}, resulting from the intake of three radionuclides (uranium, thorium, and potassium) that are naturally present in children's diet meals. It won't be of great importance. All study model values for foods for children are well below the global tolerable value of 200 μC^{-1} reported by UNSCEAR [1]. The decrease in the total annual effective dose resulting from eating basic meals in children is the decrease in annual intake (1 kg/year). The relative contribution of radioactivity from naturally occurring 238U, 232Th, and 40K radionuclides to the total effective dose generated by 238U was 9.35%, followed by the contribution from 232Th and 40K of 51.19% and 39.45%, respectively, as in Figure 2.

4.3. Excess Lifetime Cancer Risk (ELCR)

When analyzing the results of the study samples, as shown in Table 5, the calculated lifetime cancer risk for the children's basic diet ranged from 0.02x10^{-4} to 4.93x10^{-4}, with an average of 1.32x10^{-4}. Current estimated values for cancer are below the global average (29x10^{-5}) according to UNSCEAR [1] based on the maximum annual dose for the general public of 1 mSv.

Table 5.
Annual effective dose, total effective ingestion dose and cancer risk due to ingestion of natural radionuclides.

Number	Samples	Annual radionuclide effective dose (μSv/y)			Total effective dose (μSv/y)	ELCR×10^{-4}
		^{40}K	^{238}U	^{232}Th		
1	MG1	0.379	0.011	0.540	0.930	0.023
2	MG2	12.3	0.083	0.588	13	0.325
3	MG3	3.53	0.149	1.73	5.41	0.135
4	GM4	1.65	0.003	0.043	1.70	0.043
5	VG1	9.03	2.18	6.87	18.1	0.453
6	VG2	28.7	1.42	8.35	38.5	0.963
7	VG3	10.3	1.76	7.00	19.1	0.478
8	VG4	9.98	6.45	31.4	47.9	1.20
9	FG1	38.8	8 .67	120	167	4.18
10	FG2	4.24	2.12	17.9	24.2	0.605
11	FG3	22.5	2.47	7.06	32	0.800
12	FG4	3.32	1.61	9.35	14.3	0.358
13	SG1	9.45	13.4	76.6	99.5	2.49
14	SG2	102	23.9	70.2	197	4.93
15	SG3	42.8	3.01	18.5	64.3	1.61
16	SG4	49	14.9	76.3	140	3.50
Average		21.75	5.158	28.25	55.188	1.381
Permissible limits [1]		170	0.32	0.26	200	2.9

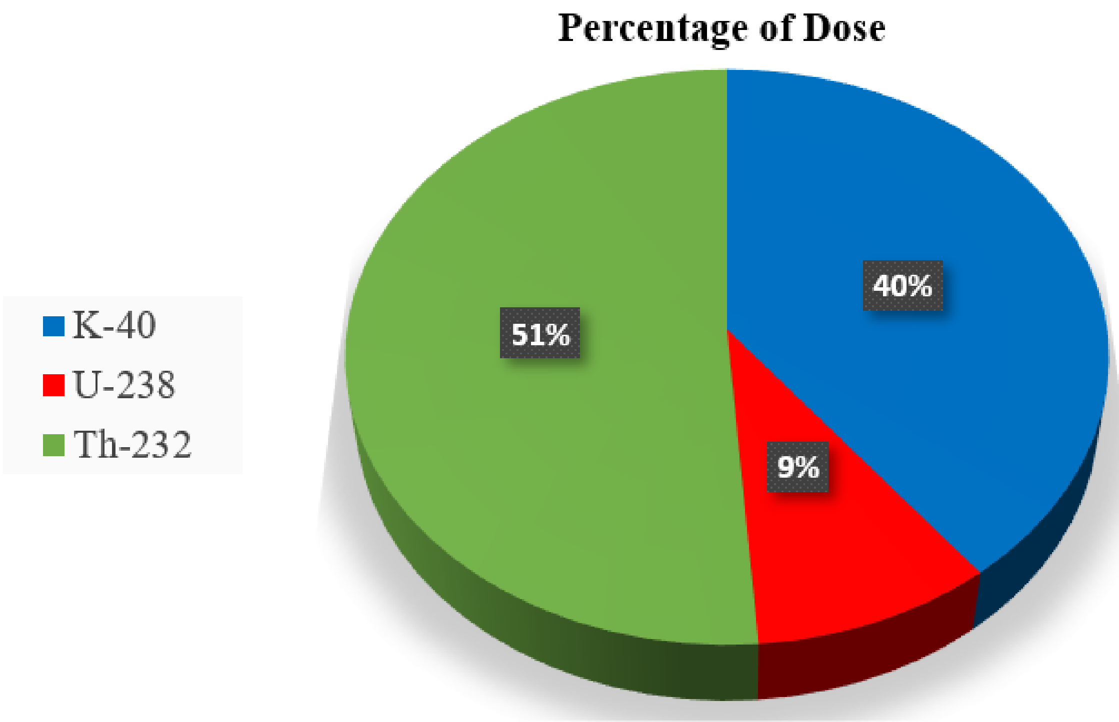

Figure 2.
Percentage contributions of natural radionuclides to the annual effective dose.

5. Conclusion

The study estimated the activity concentrations of radionuclides 238U, 232Th, and 40K using gamma-ray spectroscopy in some types of basic diets that Hilla children eat on a semi-regular basis and for ages ranging from two to seven years. This is because the gamma-ray spectrometer has high efficiency in detecting gamma rays and does not destroy samples during spectroscopic measurement. The detector also has the advantage of obtaining satisfactory results in determining gamma radiation emission lines in studying environmental contamination with radionuclides.

The concentration of radioactivity calculated in this study attracted the most attention, namely samples FG1, SG1, SG2, and SG4, which consequently increased the effective dose rate and lifetime cancer risk. Here, the specific activity of natural radionuclides, average annual food intake data, and dose factors from UNSCEAR [1] were used to calculate and evaluate effective annual dose values. According to UNSCEAR [1] the dose values of the samples in question were lower than the permissible values. One radionuclide that played a role in the effective dose was Th-232 due to its higher conversion factor than other radionuclides.

One of the innovations presented in this work is calculating the lifetime risk of cancer and thus understanding the risks associated with this type of staple meal in the diet of children in Hilla. This study may contribute to future scientific literature, as a database is available on the specific concentration of natural radionuclides present in some basic children's diets and effective dose values based on updated annual intake values.

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