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Research Note

Assessment of Annual Effective Dose for Natural Radioactivity of Gamma Emitters in Biscuit Samples in Iraq

ALI ABID ABOJASSIM,[1]* LUBNA A. AL-ALASADI,[1] AHMED R. SHITAKE,[2] FAEQ A. AL-TEMEMIE,[1] AND AFNAN A. HUSAIN[1]

[1]*Faculty of Science, Department of Physics, and* [2]*Faculty of Medicine Teeth, University of Kufa, Najaf 54001, Iraq*

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ABSTRACT

Biscuits are an important type of food, widely consumed by babies in Iraq and other countries. This work uses gamma spectroscopy to measure the natural radioactivity due to long-lived gamma emitters in children's biscuits; it also estimates radiation hazard indices, that is, the radium equivalent activity, the representative of gamma level index, the internal hazard index, and the annual effective dose in children. Ten samples were collected from the Iraqi market from different countries of origin. The average specific activities for ^{226}Ra, ^{232}Th, and ^{40}K were 9.390, 3.1213, and 214.969 Bq/kg, respectively, but the average of the radium equivalent activity and the internal hazard index were 33.101 Bq/kg and 0.107, respectively. The total average annual effective dose from consumption by adults, children, and infants is estimated to be 0.655, 1.009, and 0.875 mSv, respectively. The values found for specific activity, radiation hazard indices, and annual effective dose in all samples in this study were lower than worldwide median values for all groups; therefore, these values are found to be safe.

The primordial radionuclides have half-lives that are so long, that they have survived since their creation; they keep decaying to attain the stable state and produce ionizing radiation in various degrees *(18)*. Two primary types of radiation exposure are connected with work involving radioisotopes: external and internal. External hazards arise when radiation from a source external to the body penetrates the body and causes a dose of ionizing radiation. These exposures can be from gamma or X rays, neutrons, alpha particles, or beta particles; they are dependent upon both the type and energy of the radiation. Radioactive materials may be deposited in the body when an uptake occurs through inhalation, ingestion, or skin contact *(17, 19)*. Doses by ingestion (internal source) are due mainly to ^{40}K and to the ^{238}U and ^{232}Th series radionuclides that are present in food and drinking water. Biscuits are a popular food product and are consumed by a wide range of populations, due to their variety in taste, long shelf life, and relatively low cost *(20)*. They are made from a combination of flour, shortening, leavening, and milk or water. Studies worldwide have investigated natural radionuclides in food consumed in different parts of the world *(1, 2, 7, 8, 11, 16)*. The Fukushima nuclear accident has raised much concern about contaminated foods. It is important to compare the doses received from anthropogenic radionuclides *(5, 12, 13)* with doses that stem from natural radionuclides, as targeted in this study.

* Author for correspondence. Tel: (964) 780-1103720; E-mail: ali.alhameedawi@uokufa.edu.iq, www. http://sci.uokufa.edu.iq/ar/teaching/alia.

In this study, we examined the radioactive content of biscuits consumed by infants, children, and adults in Iraq. We aimed to determine natural radionuclide activity concentrations in biscuit samples available in the Iraqi markets and also aimed to estimate radiation hazard indices and annual effective doses from biscuit consumption among various age groups.

MATERIALS AND METHODS

Whole biscuit samples were purchased from different supermarkets in Iraq, and a representative variety were selected: 10 different biscuits from three countries of origin (Table 1). Because biscuit products are not locally produced in Iraq, all samples were imported. After collection, each biscuit sample was kept in a plastic bag and labeled with its name and country of origin. Then the samples were electronically crushed, using an electric mill. For homogeneity, the samples were sieved (0.8-mm-

TABLE 1. *Names and origins of biscuit samples in this study*

Sample ID	Biscuit name	Country of origin
B1	Petit Beurre var	Iran
B2	Baby Biscuit	Iran
B3	Rana Pet whole	Iran
B4	Minoo	Iran
B5	Popel	Iran
B6	Snakkers	Iran
B7	Taky Crack	Turkey
B8	Petit	Turkey
B9	Luna	Saudi Arabia
B10	Sesame Biscuit	Saudi Arabia

TABLE 2. *Dose conversion factors*[a]

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

[a] Values given as nSv/Bq.

pore-size sieve); they were kept moisture-free in an oven, in order to reach a constant weight. Samples were packed in 1-liter polyethylene plastic Marinelli beakers of constant volume, to achieve geometric homogeneity around the detector, and then the respective net weights were measured and recorded with a highly sensitive digital weighing balance (±0.01%). Next, the Marinelli beakers were sealed with PVC tape and were stored for about 1 month before counting, to allow secular equilibrium to be attained between ^{222}Rn and its parent ^{226}Ra in uranium chain *(14)*. The gamma spectrum from each sample was recorded using a NaI(Tl) detector (crystal volume 3 by 3 in. [7.6 by 7.6 cm]) and a PC-based multichannel analyzer (4096 channel) and was processed using Maestro-32 software (Ortec, Oak Ridge, TN). The samples were placed on the detector and measured for a period of 18,000 s. We obtained our results from the gamma rays emitted by the progenies of ^{226}Ra and ^{232}Th, which are in secular equilibrium with them, whereas ^{40}K was estimated directly by its gamma line of 1,460 keV. Hence, the specific activity of ^{226}Ra was determined using the gamma line 1,765 keV (^{214}Bi), and that of ^{232}Th was determined using the gamma-ray line 2,614 keV (^{208}Tl).

Count rates for each detected photopeak and activity for each of the detected nuclides were calculated. The specific activity (in Bq/kg), A_{Ei} of a nuclide *i* with a peak at energy *E,* is given by equation 1 *(6)*:

$$A_{Ei} = \frac{N_P}{t_c \times I_\gamma(E_\gamma) \times \varepsilon(E_\gamma) \times M} \quad (1)$$

where N_P is the number counted in a given peak area corrected for background peaks of a peak at energy E_i, $\varepsilon(E_\gamma)$ is the detection efficiency at energy *E,* t_c is the counting lifetime, $I_\gamma(E_\gamma)$ is the number of gammas per disintegration of this nuclide for a transition at energy *E,* and *M* is the mass in kilograms of the measured sample.

Two radiation indices were calculated: the radium equivalent activity (Ra_{eq}) and the internal hazard index (H_{in}). In addition, the annual effective dose, *D,* was estimated for the different age groups.

Distribution of ^{226}Ra, ^{232}Th, and ^{40}K in the environment is not uniform; thus, with respect to radiation exposure, radioactivity has been defined in terms of Ra_{eq} (Bq/kg) to compare the specific activities of materials containing different amounts of ^{226}Ra, ^{232}Th, and ^{40}K *(3, 15)*.

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad (2)$$

where A_{Ra}, A_{Th}, and A_K are the specific activity concentrations (Bq/kg) of ^{226}Ra, ^{232}Th, and ^{40}K, respectively. The index is useful to compare the specific activities of materials containing different concentrations of ^{226}Ra, ^{232}Th, and ^{40}K. Internal exposure to ^{222}Rn and its radioactive progeny is controlled by the H_{in}, given by equation 3 *(4, 16)*:

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4,810} \quad (3)$$

For the safe use of a material in the construction of dwellings, the maximum value of H_{in} should be less than unity *(10)*.

The annual effective dose from consumption of the biscuit samples is calculated using equation 4 *(19)*.

$$D\left(\frac{Sv}{year}\right) = A \times E \times I \quad (4)$$

where *A* is the activity concentration for the radionuclide (Bq/kg), *E* is the dose conversion factor for the radionuclide (Sv/Bq), and *I* is the annual intake of sample (kg/year).

The values of *E* (Table 2) are in accordance with International Commission on Radiological Protection classifications *(9),* namely, adult, child (10 years old), and infant (1 year old); but values of *I* are taken to be 140, 90, and 45 kg/year for the age groups of adult, child, and infant, respectively, in accordance with the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) *(19)*.

RESULTS

Table 3 shows the measured ranges and arithmetic mean specific activity concentrations ± standard deviation in Bq/

TABLE 3. *Specific activities of the biscuit samples*[a]

Sample ID	Specific activity (Bq/kg)		
	^{226}Ra	^{232}Th	^{40}K
B1	10.528 ± 1.043	4.205 ± 0.350	164.058 ± 4.355
B2	25.591 ± 1.529	1.887 ± 0.221	201.460 ± 4.541
B3	8.589 ± 0.891	4.024 ± 0.324	222.822 ± 4.801
B4	0.986 ± 0.312	16.651 ± 0.681	156.243 ± 4.154
B5	11.252 ± 1.131	BDL[a]	256.122 ± 5.709
B6	7.297 ± 0.787	BDL	200.823 ± 4.369
B7	7.160 ± 0.849	1.084 ± 0.176	169.662 ± 4.378
B8	2.734 ± 0.558	1.869 ± 0.246	207.522 ± 5.146
B9	BDL	1.489 ± 0.197	220.7529 ± 4.779
B10	19.764 ± 1.503	BDL	350.226 ± 6.694
Avg	10.433	4.458	214.969
Worldwide median value[b]	35	30	400

[a] BDL, below detection limit.
[b] Data from UNSCEAR (2000) *(19)*.

TABLE 4. *Radiation hazard indices from consumption of biscuit samples*

Sample ID	Radium equivalent	Internal hazard
B1	31.893	0.107
B2	53.995	0.187
B3	33.464	0.108
B4	30.092	0.102
B5	35.812	0.114
B6	25.898	0.081
B7	24.387	0.078
B8	21.758	0.065
B9	18.487	0.051
B10	55.229	0.179
Avg	33.097	0.107
Worldwide median value[a]	<370	≤1

[a] Data from UNSCEAR (2000) *(19)*.

kg for ^{226}Ra, ^{232}Th, and ^{40}K in biscuit samples collected from various Iraqi markets compared with the worldwide median values reported by UNSCEAR in 2000 *(19)*. The specific activities of ^{226}Ra and ^{232}Th ranged from 0.986 ± 0.311 to 25.591 ± 1.529 Bq/kg (average, 10.433 Bq/kg) and from 1.084 ± 0.175 to 16.651 ± 0.681 Bq/kg (average, 4.584 Bq/kg), respectively, whereas the specific activity of ^{40}K ranged from 156.243 ± 4.153 to 350.226 ± 6.694 Bq/kg (average, 214.969 Bq/kg).

Table 4 shows the Ra_{eq} and H_{in} values of ^{226}Ra, ^{232}Th, and ^{40}K in biscuit samples. The H_{in} was calculated for each sample using equation 3; it ranged from 0.051 in sample B9 to 0.1791 in sample B10, with an average value of 0.107. Table 5 shows the total annual effective dose (mSv) for adults, children, and infants, calculated using equation 4. The average values of the total annual effective dose equivalent due to the specific activity levels of ^{226}Ra, ^{232}Th, and ^{40}K for adults, children, and infants were found to be 0.655, 1.009, and 0.875 mSv, respectively (Fig. 1).

DISCUSSION

The maximum detectable specific activity values for ^{226}Ra were found in sample B2 (Baby Biscuit, made in Iran)

TABLE 5. *Total annual effective doses from consumption of biscuit samples by age groups*

Sample ID	Total annual effective dose (mSv)		
	Adult	Child	Infant
B1	0.691	1.059	0.850
B2	1.239	2.128	1.525
B3	0.659	0.984	0.874
B4	0.710	0.688	0.675
B5	0.663	1.109	0.970
B6	0.460	0.760	0.695
B7	0.463	0.742	0.652
B8	0.347	0.488	0.548
B9	0.239	0.297	0.447
B10	1.079	1.833	1.516
Avg	0.655	1.009	0.875

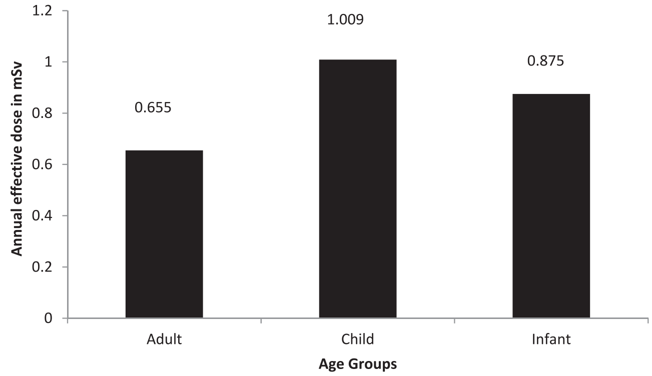

FIGURE 1. *The average annual effective doses from consumption of biscuit samples by age group.*

and the minimum detectable activities in sample B9 (Luna, made in Saudi Arabia). For ^{232}Th, the maximum detectable activities were found in sample B4 (Minoo, made in Iran), and the minimum detectable activities were found in samples B5 and B6 (Popel and Snakkers, made in Iran) and B10 (Sesame Biscuit, made in Saudi Arabia). For ^{40}K, the maximum detectable activities were found in sample B10 (Sesame Biscuit, made in Saudi Arabia) and the minimum in sample B4 (Minoo, made in Iran). These activity concentrations found for ^{226}Ra, ^{232}Th, and ^{40}K are lower than the world median values *(19)*. The estimated Ra_{eq} values, which varied from 18.486 Bq/kg in sample B9 to 55.229 Bq/kg in sample B10 (average, 33.097 Bq/kg), were lower than the maximum permissible level of 370 Bq/kg recommended by UNSCEAR in 2000 *(19)*. This indicates that the H_{in} in biscuit samples was lower than the permissible limit of 1 *(19)*. As seen in Table 5 and Figure 1, the total annual effective dose from biscuit consumption by children is larger than the dose from consumption by adults and infants. This larger value for children is due to the dose conversion factor for the radionuclide and the annual intake of sample. This indicates that the annual effective dose in all biscuit samples was lower than the permissible limit of 1 mSv recommended by the International Commission on Radiological Protection in 1996 *(9)*.

The study estimated the specific activity of radionuclides ^{226}Ra, ^{232}Th, and ^{40}K using gamma-ray spectroscopy on samples of different types of biscuit that are regularly consumed by all age groups in Iraq. Specific activity concentrations of these radionuclides in samples were lower than those reported by UNSCEAR. So, we can deduce that the levels of radionuclides in the studied biscuit samples are acceptable for normal consumption by adults, children, and infants. Also, the radiation hazard indices were found to be below the worldwide standard limits considered safe for radiological hazards. In total, the averages of annual effective doses due to the ingestion of all three natural radionuclides by adults, children, and infants were found to be within the average annual ingestion radiation dose due to natural sources. Therefore, the total average annual effective dose was far below the limit recommended by the World Health Organization and by the International Commission on Radiological Protection for radiological safety.

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