Chapter

Economic Approach to Risk Analysis of Naturally Occurring Radioactive Materials (NORMs) in Dairy Milk Products Consumed in Nigeria

Ezekiel O. Agbalagba and Hannah O. Agbalagba

Abstract

One of the UN SDGs is for sustainable food for all; thus the need for safety in milk consumption in Nigeria which is also consonant with *the NAFDAC* regulatory plan of safety of food in Nigeria. This research work examined the radioactivity content in milks (powdered and liquid) consumed in Nigeria using sodium iodide (7.6 cm × 7.6 cm NaI(Tl)) detector. The estimated total cost of health detriment of consumption of the investigated milk products shows that the children age group has the highest cost health detriment per-caput dose with an estimated total cost of health detriment of US $17.26 million, followed by the adult age group with an estimated cost implication of US $11.86 million, and infants with the least computed cost implication of US $10.192 million. The overall results show that the milks consumed in Nigeria are radiologically safe and may not constitute any direct radiological health burden to consumers of these milk brands. Optimization of radiation protection mechanism for cost-benefit analysis is recommended.

Keywords: gamma spectroscopy, milk samples, natural radioactivity, economic-benefit analysis

1. Introduction

Radionuclide consequence recognizes no boundaries and therefore it is trans-border in nature. It can migrate through food, air, and soil and be transported to faraway countries from where its pollution or contamination occurs. An assessment of any release of radioactivity to the environment is important for the protection of public health, especially if the released radionuclides can enter the food chain. Milk as a staple food may naturally represent a comprehensive radioactive food chain because cows consume grass and are exposed to the same radioactive elements as food crops and water supply.

Contamination pathway: emitted radionuclides go into the human body through multifaceted mechanisms which include the intake of foodstuffs via food chain from natural sources. Vegetables and green leafy are susceptible to exterior contamination during the growing season, whereas roots and tubers get contaminated through the ingestion of nutrient from the soil [1, 2]. Grains are subjected to contamination mostly during storage or fallout may occur during the growing season as in the case of Fukushima Daiichi nuclear fallout. These liberated radionuclides may be transported into the grains and grasses through the plant growth process and find their way into the food chain when grazed by a cow [3]. Pollution of dairy products like milk is largely due to animal grazing and consumption of contaminated grass and drinking waters. Thus grass is essentially a direct source or pathway of radionuclides to animals and to man through meat and milk consumption. If dairy milk starts testing positive for high level of radioactive elements, this is indicative of radioactive contamination of the total food supply [4]. Milk samples that contain high levels of radioactivity when ingested by man could accumulate in certain parts of the body, for example, uranium-238 and radium-226 accumulates in human kidney and lungs, and thorium-232 accumulates in human liver, skeleton, tissue, and lungs, while potassium-40 accumulates in the muscles [5]. The accumulation of these radionuclides in any vital organs of the human body will affect the health condition that may cause various forms of diseases and weakening of the immune system and contribute to the increase in mortality rate [6].

1.1 Statement of the problem

Since the end of Second World War in 1948, research works on radionuclide contamination of food in the environment, and its transfer mechanism and pathway to animals and human population have been reported with vigor (ICPR, 1993 & 2000, [2, 7–11]); milk has been one of the staple foodstuff products that was featured prominently in the food items studied [9]. This may be due to its vital position in a family's daily food consumption plan, thus a reliable indicator of natural radionuclides to man for its high consumption rate globally. It is one of the essential food for human nutrition and contains most of the macronutrients, namely, protein, carbohydrates, fat, vitamins (A, B, and D groups), and trace elements such as calcium, phosphate, magnesium, zinc, and selenium [7, 12]. Milk is a rudimentary foodstuff for the infants compared to adults, on apparent body weight basis. Thus, milk consumed in Nigeria need to be assessed for radiological risk level for proper economic benefit analysis. It is therefore pertinent to set a radionuclide regulatory framework necessary in establishing guidelines relating to radiation protection in milk as a staple foodstuff. To the best of our knowledge, comprehensive data base on levels of radionuclides in staple foodstuffs and standard radionuclide regulatory framework for food imported and consumed in the country are inadequate, these lay credence to this research work.

1.2 Aim and objectives of the study

This research work was designed to examine the level of natural radionuclides present in liquid and powdered milk products consumed in Nigeria with a view to establishing their specific activities and compare same with values reported in other parts of the world. Assessment of the annual internal dose from the intake of the milk product will be determined, while the doses to the different sensitive human organs were estimated to establish their radiological risk to man. The result would be a contribution to the creation of a standard catalogue of natural radioactivity in foodstuff (milk) in Nigeria. This can serve as a baseline data for possible evaluation of future change in activity levels of these milk products due to environmental factors, ingredient composition, etc. The result obtained in this study will also be useful to the country food and drug regulatory body which has the obligation to protect the public health by ensuring that only the right quality of food and drugs are imported and consumed in the country.

2. Materials and methods

2.1 Sample collection

To collect milk samples that represent a fair proportion of milk products consumed in Nigeria, a survey was carried out, which involves visiting homes, major supermarkets, fast food outlets, hotels, and major milk distributors throughout the six geopolitical zones in Nigeria. The survey revealed that the acceptability of brands of the milk (powdered or liquid) is dictated by its availability, cost, and social class of consumers. The availability of specific products in a region is closely related to the proximity to the manufacturer or key distributor and the awareness due to advertisement of the products in the area. This in situ assessment has shown that 10 leading powdered milk and 11 liquid milk brands were consumed by a large sector of the populace in the six geopolitical zones of the country in the following order: Peak > Cowbell > Coast > Loya > Nunu > Miksi > Dano > real milk for powdered milks and peak > Three Crown > Coast > Hollandia > Olympic > Nunu > Nutri milk > vital milk > Lady liberty > Bridel in liquid milks, of these Dano milk (Demark), Bridel milk (France), and Lady liberty (USA) are imported milk brands. These 10 powdered milk brands and 11 liquid milk brands were then sourced from various shopping malls and local markets. Two hundred (200) grams of the powdered milk collected was put in a cylindrical polystyrene container and sealed with tapes to prevent radon permeability, while for liquid milk, 200 cl of the homogenous samples was filled into a Marinelli beaker which was hitherto washed, rinsed with diluted H_2SO_4 acid to prevent the samples from being contaminated, and sealed and weighed as samples for gamma spectroscopy analysis.

2.2 Gamma spectroscopy analysis

The collected sealed samples were left for a minimum of 4 weeks to allow secular equilibrium prior to the counting of the samples for radioactivity concentration. The counting for radioactivity was carried out using a $7.6cm \times 7.6cm$ NaI(Tl) detector for 10 h (Model Bircom, USA) housed in a 10-cm-thick lead shield to reduce background gamma radiation. The detector with energy resolution (FWHM) of 7.5% at 662 keV was coupled to a set of electronics which consist of pre-amplifier, main amplifier, analog-to-digital converter (ADC), and a Canberra Multichannel Analyzing (MCA) computer system. The integrated spectroscopy system was used for the power supply and the data acquisition of the energy spectra and utilized SAMPO S100 software package from Canberra (MAESTRO window USA). The energy calibration of the detector was performed between the gamma energy range of 83 keV and 1875 keV using International Atomic Energy Agency standard point sources (^{109}Cd, ^{57}Co, ^{137}Cs, ^{54}Mn, and ^{22}Na), the energy range of the radionuclide to be identified. To simulate the milk samples, 100 g of IAEA-375 reference sample was used. The radioactivity concentrations of ^{226}Ra/^{238}U were determined from the photopeaks of 609.32 keV (^{214}Bi), 1120.20 keV (^{214}Bi), and 352.6 keV (^{214}Pb) and that of ^{232}Th from 969.3 keV (^{228}Ac) and 583.78 keV (^{208}Tl), while the radioactivity of ^{40}K was evaluated from 1460.3 keV photopeak following the decay of ^{40}K. The background spectrum measured under the same settings for both the standard and sample measurement was used to correct the computed sample activity concentration in agreement with Arogunjo et al. [13].

3. Results and discussion

3.1 Results

The measured radioactivity levels of the three naturally occurring radionuclides, ^{226}Ra, ^{232}Th, and ^{40}K, identified in the sampled milk under investigation including their uncertainty are presented in **Table 1**.

The obtained results of the radioactivity concentration indicate that ^{226}Ra activity in powdered milk varied from 14.2 ± 5.9 Bq kg^{-1} to 26.8 ± 8.3 Bq kg^{-1} with a mean activity concentration of 19.3 ± 7.2 Bq kg^{-1}, and ^{232}Th activity varied from 8.8 ± 3.6 Bq kg^{-1} to 15.0 ± 5.9 Bq kg^{-1} with a mean activity concentration of 12.1 ± 4.8 Bq kg^{-1}, while ^{40}K varied from 317.5 ± 77.6 Bq kg^{-1} to 589.8 ± 94.6 Bq kg^{-1} with a mean activity level of 468.0 ± 72.7 Bq kg^{-1}. The ^{226}Ra radioactivity concentration in liquid milk varied from 12.2 ± 4.7 Bq kg^{-1} to 21.2 ± 8.3 Bq kg^{-1} with a mean activity concentration of 16.6 ± 6.3 Bq kg^{-1}, and ^{232}Th activity concentration varied from 6.8 ± 3.0 Bq kg^{-1} to 13.2 ± 6.1 Bq kg^{-1} with a mean activity concentration of 10.6 ± 4.3 Bq kg^{-1}, while ^{40}K varied from 218.6 ± 39.4 Bq kg^{-1} to 484.2 ± 67.9 Bq kg^{-1} with a mean activity level of 317.6 ± 58.5 Bq kg^{-1}. It was observed that ^{40}K samples have the highest activity concentration trailed by ^{226}Ra samples, while ^{232}Th samples had the least activity level. Evaluation of the three naturally occurring radionuclide concentrations in the milk samples with the UNSEAR 2000 permissible limit for powdered milks and liquid milk samples shows that all ^{226}Ra and ^{232}Th activity levels in both samples are well below the permissible limits, while ^{40}K exceeded the permissible limit in Peak milk, Peak Chocolate, Cowbell Chocolate, Loya, Miksi, Coast, Real, and Nunu milk for powdered milk and exceeded the permissible limit for liquid milk in Vital and Nutric milk. It is pertinent to note that the activity levels determined in the current study are above the values gotten for milk consumed in some countries like Saudi Arabia [7]; Iran/France [14]; Jordan [15]; Egypt [16]; and Syria [17], while the values are comparable to those milk consumed in other countries like New Zealand [14] and Brazil [18]. Conversely, this result shows that the mean activity concentrations in the various milk brands sampled are well within their international permissible limits. The difference in the radioactivity levels in the various brands of milk sampled suggests that the source of raw materials used for the production of the milks is a contributory factor.

The estimated Radium equivalent (Ra_{eq}), annual gonadal dose equivalent (AGED), internal hazard (H_{in}) indices, annual effective dose equivalent (AEDE) received, and excess lifetime cancer risk (ELCR) for the various milk products sampled are presented in **Table 2**.

3.2 Radium equivalent activity (Ra_{eq})

The model of the radium equivalent activity establishes the use of a single index to define the gamma output or compare the specific activities of materials containing ^{226}Ra, ^{232}Th, and ^{40}K by a single quantity, which takes into consideration the radiation risk associated with these NORMs [19–22]. The radium equivalent activity represents a weighted factor of activities of the three natural radionuclides

S/N	Powdered milk sample	Radioactivity concentration (Bq kg^{-1})		
		^{226}Ra	^{232}Th	^{40}K
1	Peak milk	26.8 ± 8.3	9.5 ± 2.2	536.1 ± 84.3
2	Peak Chocó milk	17.6 ± 6.9	12.3 ± 4.1	424.7 ± 67.9
3	Cowbell milk	17.4 ± 7.1	13.1 ± 5.4	317.5 ± 77.6
4	Cowbell Chocó milk	16.4 ± 6.7	8.8 ± 3.6	544.2 ± 83.4
5	Nunu milk	26.5 ± 6.5	10.1 ± 4.9	513.5 ± 74.3
6	Loya milk	14.2 ± 5.9	14.7 ± 6.1	413.3 ± 83.3
7	Miksi milk	15.1 ± 7.2	12.8 ± 5.5	589.8 ± 94.6
8	Coast	18.6 ± 6.0	13.3 ± 6.3	422.4 ± 64.4
9	Real milk	21.0 ± 8.5	15.0 ± 5.9	519.9 ± 95.6
10	Dano milk (Demark)	19.5 ± 8.4	10.9 ± 4.2	398.4 ± 66.3
	Mean activity conc.	**19.3** ± **7.2**	**12.1** ± **4.8**	**468.0** ± **72.7**
S/N	**Liquid milk sample**	**Radioactivity concentration (Bq l^{-1})**		
		^{226}Ra	^{232}Th	^{40}K
1	Hollandia milk	12.2 ± 4.7	12.6 ± 5.8	321.4 ± 66.3
2	Vital milk	21.2 ± 8.4	9.9 ± 3.8	476.1 ± 84.1
3	Nutric milk	15.0 ± 5.9	8.9 ± 3.2	484.2 ± 67.9
4	Peak milk	13.2 ± 4.6	8.0 ± 3.1	218.7 ± 49.0
5	Three Crown milk	17.2 ± 8.3	13.2 ± 5.7	324.2 ± 51.9
6	Olympic milk	16.3 ± 4.5	12.5 ± 4.6	268.9 ± 58.6
7	Coast milk	18.1 ± 5.5	13.2 ± 6.1	312.8 ± 49.3
8	Nunu milk	17.5 ± 6.3	9.9 ± 3.6	218.6 ± 39.4
9	Condensed Peak milk	19.2 ± 8.4	10.6 ± 4.2	272.9 ± 50.1
10	Bridel milk (France)	15.8 ± 6.5	11.3 ± 4.6	282.2 ± 73.3
11	Lady Liberty (USA)	14.2 ± 6.1	6.8 ± 3.0	313.3 ± 53.3
	Mean activity conc.	**16.6** ± **6.3**	**10.6** ± **4.3**	**317.6** ± **58.5**

Table 1.
Specific activity concentration of the powdered and liquid milk products commonly consumed in Nigeria.

measured and is based on the estimation that 1.0 Bqkg^{-1} of ^{226}Ra, 0.7 Bq kg^{-1} of ^{232}Th, and 13.0 Bq kg^{-1} of ^{40}K produce equal radiation dose rates [23, 24].

The radium equivalent activity concentration is given as [23]:

$$Ra_{eq} = C_{Ra} + 1.43\ C_{Th} + 0.0770\ C_K \qquad (1)$$

where C_{Ra}, C_{Th}, and C_K are the radioactivity concentrations in Bq kg^{-1} of ^{226}Ra, ^{232}Th, and ^{40}K, respectively.

The consumption of any foodstuff whose Ra_{eq} concentration exceeds 370 Bq kg^{-1} should be discouraged to avoid radiation hazards. The result of the estimated radium equivalent dose rates in **Table 2** shows a value range of 60.6 ± 20.8 Bq kg^{-1} in Cowbell milk to 82.5 ± 24.3 Bq kg^{-1} in real milk with a mean value of 72.6 ± 19.7 Bq kg^{-1} in powdered milk brands, while in liquid milk brand, the range of value is 41.5 ± 12.9 Bq l^{-1} in Peak milk to 72.0 ± 20.3 Bq l^{-1} in Nutric milk with a

Milk samples	Ra_{eq} ($Bqkg^{-1}/Bq\ l^{-1}$)	AGED (μSvy^{-1})	H_{in}	AEDE (μSvy^{-1})	ELCR $\times 10^{-3}$ ($mS\ vy^{-1}$)
Powder milk ($Bq\ kg^{-1}$)					
Peak milk	81.7 ± 17.9	290.6	0.3	200.2	0.7
Peak Chocó milk	67.9 ± 18.0	239.1	0.2	166.3	0.6
Cowbell milk	60.6 ± 20.8	208.3	0.2	146.2	0.5
Cowbell Chocó milk	70.8 ± 18.3	258.2	0.2	177.2	0.2
Nunu milk	65.7 ± 19.4	230.8	0.2	196.7	0.6
Loya milk	67.0 ± 21.1	235.0	0.2	164.8	0.6
Miksi milk	78.8 ± 22.3	285.3	0.3	197.7	0.2
Coast milk	70.2 ± 19.9	245.8	0.2	171.2	0.7
Real milk	82.4 ± 24.3	290.7	0.3	202.6	0.7
Dano milk (foreign)	80.4 ± 19.2	285.0	0.3	160.4	0.6
Mean value	72.6 ± 20.1	256.9	0.25	178.4	0.6
Global standard	370	300	≤1.0	450	0.29 ($mS\ vy^{-1}$)
Liquid milk ($Bq\ L^{-1}$) $\times 10^{-3}$					
Hollandia milk	54.9 ± 18.1	191.0	0.2	134.4	0.5
Vital milk	53.7 ± 18.8	184.8	0.2	177.1	0.6
Nutric milk	72.0 ± 20.3	256.4	0.3	163.8	0.6
Peak milk	65.0 ± 15.8	235.6	0.2	99.6	0.3
Three Crown milk	48.0 ± 14.5	170.6	0.2	147.2	0.5
Olympic milk	41.5 ± 12.7	142.9	0.2	131.5	0.5
Coast milk	61.1 ± 20.5	210.2	0.2	146.7	0.5
Nunu milk	54.9 ± 15.6	187.1	0.2	114.8	0.4
Condensed Peak milk	61.1 ± 18.0	209.3	0.2	132.5	0.5
Bridel milk (foreign)	48.4 ± 14.6	163.9	0.2	129.5	0.5
Lady Liberty (foreign)	55.3 ± 18.3	189.1	0.2	117.7	0.4
Mean value		173.2	0.20	135.9	0.5
World standard	370	300	≤1.0	450	0.29 ($mS\ vy^{-1}$)

Table 2.
Mean radium equivalent and summary of computed radiological risk parameter of milk samples.

mean value of 56.2 ± 17.0 $Bq\ l^{-1}$. All the values obtained are within the international acceptable limit for Ra_{eq} and therefore comply with the radium equivalent standard for radioactivity concentration. The percentage contributions of the three naturally occurring radionuclides in the powdered and liquid milk samples are shown in **Figures 1** and **2**, respectively. These percentages were calculated based on the estimation that 1 $Bq\ kg^{-1}$ of ^{226}Ra, 0.7 $Bq\ kg^{-1}$ of ^{232}Th, and 13 $Bq\ kg^{-1}$ of ^{40}K produce the same radiation dose rates in the radium equivalent [24]; the average percentage contribution of ^{40}K is 42%, and for ^{226}Ra the percentage contribution to the entire milk content is 20%, while ^{232}Th percentage contribution to the powdered milk samples is 38%. The percentage contribution of the three natural radionuclides (^{226}Ra, ^{232}Th, and ^{40}K) to the liquid milk samples were computed to be 24, 36, and 40%, respectively, which shows that ^{232}Th contributes the highest radioactivity dosage to both the powdered and liquid milk activity concentration.

3.3 Annual gonad equivalent dose (AGED)

The gonads, the active bone marrow, and the bone surface cells are classified as organs of interest by UNSCEAR (2003). The annual gonadal dose equivalent (AGED, mS vy^{-1}) owing to the specific activities of ^{226}Ra, ^{232}Th, and ^{40}K was computed using [25]:

$$\mathrm{AGED}\ (\mu\mathrm{S\ vy}^{-1}) = 3.09C_{Ra} + 4.18C_{Th} + 0.314C_{K} \quad (2)$$

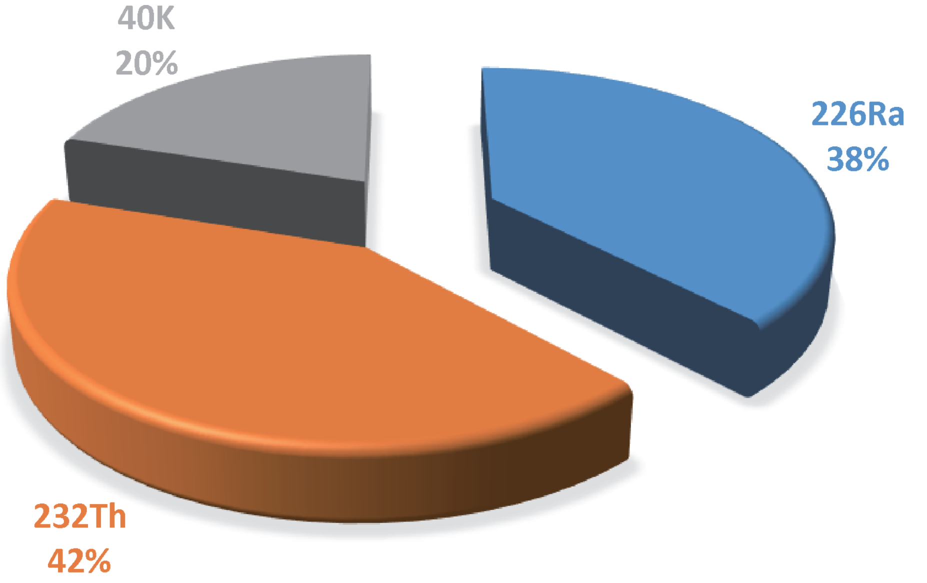

Figure 1.
Percentage contribution of the three natural radionuclides measured in powdered milk.

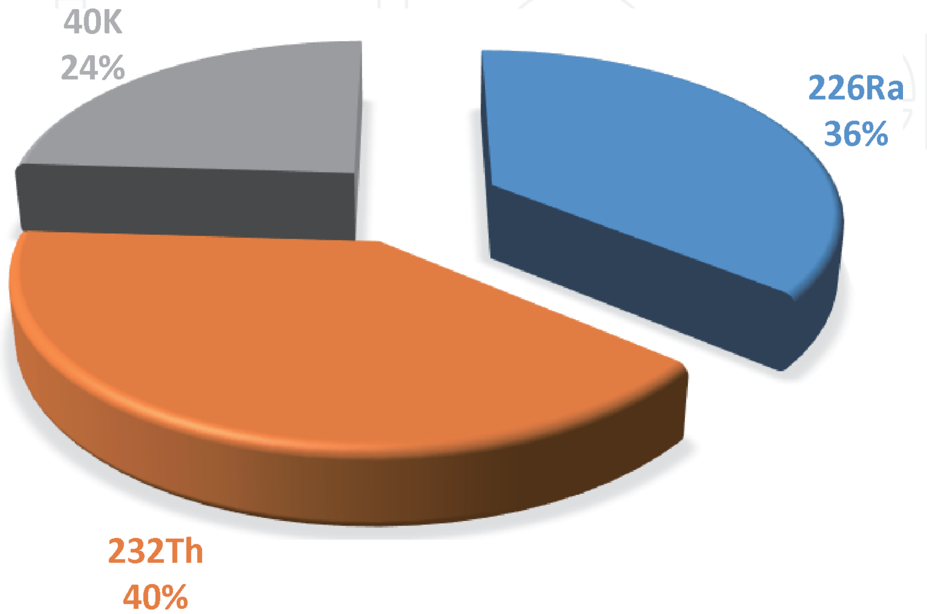

Figure 2.
Percentage contribution of the three natural radionuclides measured in liquid milk.

where C_{Ra}, C_{Th}, and C_K represent the radioactivity levels of ^{226}Ra, ^{232}Th, and ^{40}K, respectively.

If the radioactivity of the food source is higher than the world permissible value of 0.30 $mSvy^{-1}$, the model suggests that the food product is a potential source of radiological health risk to the consumer. In the studied powdered milk samples, AGED activity concentration varied from 208.3 $\mu S\ vy^{-1}$ to 290.7 $\mu S\ vy^{-1}$, whereas in liquid milk samples analyzed, the estimated activity levels varied from 170.6 $\mu S\ vy^{-1}$ to 256.4 μSvy^{-1}. Although the obtained 290.7 $\mu S\ vy^{-1}$ activity concentration value in *Real* powdered milk is approximately the maximum permissible limit value, all other obtained estimated values in both liquid and powdered brands of milk sampled are well within the global maximum permissible values of 300 $\mu S\ vy^{-1}$ [26]; thus the different milk samples examined may not cause any immediate radiological health side effects in terms of AGED index.

3.4 Internal gamma indices

The internal hazard (H_{in}) index is defined according to Zarie and Al-Mugren [27] as:

$$H_{in} = C_{Ra}/185 + C_{Th}/259 + C_K/4810 \quad (3)$$

where C_{Ra}, C_{Th}, and C_K represent the radioactivity levels of ^{226}Ra, ^{232}Th, and ^{40}K correspondingly. H_{in} should be less than the unity for the radiation risk to be insignificant.

The internal hazard index (H_{in}) estimates the internal exposure rate to oncogenic radon nuclides and its short-lived progeny. The mean radioactivity values of the computed H_{in} for powdered and liquid milk products are 0.3 and 0.2, respectively, which are well below the unity value recommended as the permissible limit. It is observed from the values obtained that powdered milks contain more of the natural radionuclides than liquid milk samples, which may be a result of the activity concentration through evaporation to dryness of the raw liquid milk. But all the milk samples analyzed met the minimum internal gamma index requirement for consumption.

3.5 Annual effective dose equivalent (AEDE)

The annual effective dose equivalent received was computed from absorbed dose rate by applying a dose conversion factor of 0.7 $Sv\ Gy^{-1}$ and the occupancy of 0.8 (19/24) recommended by UNSCEAR [26] and Veiga et al. [28]. Therefore, the annual effective dose equivalent ($\mu S\ vy^{-1}$) was calculated using the formula [26]:

$$\text{AEDE}\ (\mu S\ vy^{-1}) = \text{absorbed dose}\ (nG\ yh^{-1}) \times 8760\ h \times 0.7\ SvGy^{-1} \times 0.8 \times 10^{-3} \quad (4)$$

The estimated annual effective dose equivalent obtained for the powdered and liquid milk brands analyzed is shown in **Table 2**. The values obtained for the powdered milk varied from 146.2 $\mu S\ vy^{-1}$ to 202.6 $\mu S\ vy^{-1}$ with a mean activity dose level of 178.4 $\mu S\ vy^{-1}$, while in the liquid milk, the activity dose levels ranged from 99.6 $\mu S\ vy^{-1}$ to 177.1 $\mu S\ vy^{-1}$ with a mean activity concentration of 135.9 $\mu S\ vy^{-1}$. The obtained result shows that the milk samples surveyed have their annual effective dose equivalent values lower than the world average values of 450 $\mu S\ vy^{-1}$ [26, 29–31]. This result shows that the various sampled milk brands are radiologically safe going by the global recommended permissible limit of annual effective dose rate.

3.6 Excess lifetime cancer risk

Excess life cancer risk predicts the likelihood of developing cancer over a lifetime at a certain exposure rate. It is a value representing the number of extra cancers expected in a given number of people on exposure to a carcinogen at a given dose.

Excess lifetime cancer risk is given as Taskin et al. [32]:

$$\text{ELCR} = \text{AEDE} \times \text{DL} \times \text{RF} \tag{5}$$

The parameters used are defined; thus AEDE is the annual effective dose equivalent, DL is average duration of life (estimated to be 70 years), and RF is the risk factor (S/v), i.e., fatal cancer risk per Sievert. ICRP uses a RF of 0.05 for the public for stochastic effects [32]. The intake of milk containing an elevated level of radionuclide may increase the chance of cancer risk. If the radioactivity in the milk is higher than the world average, it could be a source of radiation to the human body and some specific organs, in that their ELCR would be greater than the world average of 0.29 mS vy^{-1} in such body. The estimated ELCR obtained in all the measured samples is lower than the international standard limit.

Table 3 presents the estimated values of the annual effective dose of the three age groups of infants, children, and adult represented in this evaluation.

Table 4 shows the dose conversion factor for the three different age groups used in estimating the annual effective dose rate to individual consumption of the various milk samples in Nigeria.

3.7 Annual effective dose for different age groups

"The annual effective dose E_D to individuals due to the ingestion of the radionuclides in powder and liquid milk is estimated using the equation.

$$E_D = A_c \times I_{in} \times E \tag{6}$$

where the parameters; E_D is the annual effective dose in (Svy^{-1}), A_c is the activity concentration of the radionuclides in milk; E is the dose conversion factor and I_{in} is the annual intake of milk with respect to the age group" [15].

Table 3 presents the result of the computed annual ingestion dose to the three age groups (infants, children, and adults), with an estimated annual milk intake of 15 kg, 14 kg, and 10 kg, respectively, and using the conversion factor values in **Table 4**. The results obtained indicate that the infants' accumulated maximum and minimum effective dose values are 1743.0 μS vy^{-1} and 892.7 μS vy^{-1}, respectively, with an average dose rate of 1345.4 μS vy^{-1}. For the children, the obtained values for the annual accumulated maximum and minimum effective ingestion doses are 1048.9 μS vy^{-1} and 546.8 μS vy^{-1}, respectively, with an average dose rate of 822.5 μS vy^{-1}. The accumulated maximum and minimum annual effective ingestion doses obtained for adults are 235.1 μS vy^{-1} and 122.3 μS vy^{-1}, respectively, with an average annual dose rate of 181.1μSvy^{-1}. The obtained dose rates in the three different age groups show that the annual ingestion dose exceeded the UNSCEAR [26], maximum permissible limit by 68% for the infants, and 2.8% for the children; however, the adult value is 22.6% below the recommended maximum permissible limit. This obtained result indicates that the ingestion rate of milk by infants and

Radionuclides	Powdered milk	Annual effective dose(μSv)		
		Infants	Children	Adult
^{40}K	Maximum	371.6	107.4	47.5
	Minimum	200.0	57.8	25.6
	Average	294.8	85.2	37.7
^{226}Ra	Maximum	386.4	300.5	97.7
	Minimum	204.3	158.9	51.7
	Average	277.9	216.2	70.3
^{232}Th	Maximum	1279.9	817.4	134.3
	Minimum	748.1	477.8	78.5
	Average	1034.6	660.7	108.5
	Accumulated mean	1607.3	962	186.5
Radionuclides	**Liquid milk**	**Annual effective dose(μSv)**		
		Infants	**Children**	**Adult**
^{40}K	Maximum	305.1	88.1	39.0
	Minimum	137.7	39.8	17.6
	Average	200.1	57.8	25.6
^{226}Ra	Maximum	305.9	237.9	77.3
	Minimum	175.4	136.4	44.3
	Average	239.0	185.9	60.4
^{232}Th	Maximum	1132.0	722.9	118.8
	Minimum	579.7	370.2	60.8
	Average	906.3	578.8	95.1
	Accumulated maximum	1743.0	1048.9	235.1
	Accumulate minimum	892.8	546.4	122.8
	Accumulated mean	1345.4	822.5	181.1
	UNSCEAR 2000 standard	200–800	200–800	200–800

Table 3.
Annual effective dose to infant, children, and adult age groups due to intake of natural radionuclides in powdered and liquid milk samples of quantities 15 kg y^{-1}, 14 kg y^{-1}, and 8 kg y^{-1}, respectively.

	Dose conversion factors (nSv/Bq)		
	^{40}K	^{226}Ra	^{232}Th
Infant (1–2 y)	42	4700	4600
Children (7–12 y)	13	800	290
Adult (>17 y)	6.2	280	230

Table 4.
The dose conversion factors of ^{40}K, ^{226}Ra, and ^{232}Th for the infant, children, and adult age groups [33].

children should be reduced to avoid any future amassed radiological health side effect [34]; accordingly an optimized amount of milk is required to be recommended as a yearly permissible limit for consumption.

Table 5 shows the optimized annual consumption rate to stay within the international recommended range.

Following the exceeding of the UNSCEAR [26] μSvy^{-1} permissible limit from the recommended quantity of milk to be consumed by the three age groups, **Table 5**

		Annual effective dose (μSv)	
		Infants	**Children**
Radionuclides in powdered milk			
^{40}K	Average	137.59	66.92
^{238}U	Average	129.70	169.84
^{232}Th	Average	482.79	519.09
	Accumulated average	750.1	755.9
Radionuclides in liquid milk			
^{40}K	Average	106.71	53.67
^{238}U	Average	127.49	172.64
^{232}Th	Average	483.36	537.42
	Accumulated average	717.6	763.7
	UNSCEAR 2000 standard	800	800

Table 5.
Annual effective dose to infants and children with a proposed annual consumption of 7 and 11 kg, respectively, of powder milk samples and 8 and 13 kg, respectively, for liquid milk.

Organs	**Effective dose rate to organs ($mS\ vy^{-1}$): powdered milk**		
	Infants	**Children**	**Adult**
Lungs	0.8	0.5	0.1
Ovaries	0.8	0.5	0.1
Bone marrow	0.9	0.5	0.1
Testes	1.1	0.6	0.1
Kidneys	0.8	0.5	0.1
Liver	0.6	0.4	0.1
Whole body	0.9	0.5	0.1

Organs	**Effective dose rate to organs ($mSvy^{-1}$): liquid milk**		
	Infants	**Children**	**Adult**
Lungs	0.7	0.4	0.1
Ovaries	0.6	0.4	0.1
Bone marrow	0.7	0.5	0.1
Testes	0.9	0.5	0.1
Kidneys	0.7	0.4	0.1
Liver	0.5	0.3	0.1
Whole body	0.7	0.5	0.1

Table 6.
Dose rate to different organs of the body due to radionuclides in powder and liquid milk.

Organ or tissue	Conversion factor (F)
Lungs	0.64
Ovaries	0.58
Bone marrow	0.69
Testes	0.82
Whole body	0.68
Kidney	0.62
Liver	0.46

Table 7.
Average values of F for different organs or tissues [33].

presents an optimized annual quantity of powdered milk to be consumed as 7 kg and 11 kg for children and infants, respectively, and 8 kg and 13 kg were recommended for children and infants, respectively, for liquid milk, while adult was not optimized because the value obtained was within the international permissible limit. Using the optimized quantity, the annual accrued values obtained for infants and children for powdered milk were 750.1 μSv and 755.9 μSv, respectively, while the accumulated values recorded for liquid milk were 717.6 μSv and 763.7 μSv for infants and children, respectively. The values recorded are well below the 800 μSv [26] yearly recommended permissible limit.

Table 6 presents the result of calculated effective dose rate to the different human organs for consuming powdered and liquid milk.

Table 7 presents the average values of F, for different organ or tissue uses in the computation of the effective dose rate of these organs.

3.8 The effective dose rate (D_{organ}) in mS vyr^{-1} to different body organs or tissues

The annual effective dose to organ models evaluates the total amount of radionuclides consumed by man over a period of 1 year that goes to and accumulate in the different sensitive organs and tissues of the human body. The effective dose rate transported to a particular organ was calculated using the relation:

$$D_{organ}\left(mSvy^{-1}\right) = O \times E_D \times F \tag{7}$$

The parameter E_D represents the annual effective dose, O represents the occupancy factor with a value of 0.8, and F is the conversion factor of organ dose from consumption of the food.

Table 6 presents the obtained computed values of the effective dose rate assimilated by the various organs evaluated, while **Table 7** presents the conversion factors and F values for the seven organs/ tissues. The computed dose values obtained in powdered milks revealed that the human testes (organ) received the greatest dose of average values of 1.1 mS vy^{-1}, 0.6 mS vy^{-1}, and 0.1 mS vy^{-1} for infants, children, and adults, respectively; meanwhile, the dose received by the liver was established to be the least with average dose values of 0.6 mS vy^{-1}, 0.4 mS vy^{-1}, and 0.1 mS vy^{-1}, respectively. The computed results obtained from liquid milk follow the same trend with testes recording the highest radionuclide dose ingestion with average estimated dose levels of 0.9 mS vy^{-1}, 0.5 mS vy^{-1}, and 0.1 mS vy^{-1} for infants, children, and adults, respectively, and the least dose intake values of 0.5 mS vy^{-1}, 0.3 mS vy^{-1}, and 0.1 mS vy^{-1} were detected in liver for infants, children, and adults, respectively. It was observed from the results that the dose ingestion to infants' testes exceeded the world acceptable limit of 1.0 mSv annually to the human-sensitive organs/tissues. The relatively higher dose to the testes and low-dose intake to the liver are justifiable from food nutrient absorption rate [15, 31]. The high radiological dose to the testes may justify the rampant rate of prostate cancer among young men which may be linked to accumulated effects of the dose intake over time, which need further clinical investigation [34].

4. Risk factors and cost-benefit analysis

Cost-benefit analysis in radiation protection is the projection of radionuclide injection effects of consumption of food product versus the nutritional benefits derived from the intake of the food at low individual doses, below the dose limits. Applying the direct relationship between dose and effect, the health impairment is directly proportional to the effective dose-equivalent occasioned by the consumption of milk product. The proportionality element is termed the risk factors [35, 36].

4.1 Committed effective dose (C_D)

The committed effective dose to an individual assessed for three age groups (0–1 yr infant, 1–7 yrs children, and >17 yrs age group for adults) over a typical lifetime of 50 years was computed using the formula:

$$C_D = 50 \times E_D \tag{8}$$

The calculated committed effective doses to the various age groups are presented in **Table 8**. The obtained doses to infants and children were futuristic and a forecast of the probable dose to be committed to the individuals in the period of 50 years. The obtained dose values for adult over an average lifetime of 50 years for powdered milk and liquid milk were 9.3 mS vy^{-1} and 9.1 mS vy^{-1} doses, respectively. The committed doses obtained for children were 48.1 mS vy^{-1} and 41.1 mS vy^{-1} for powdered and liquid milk, respectively, while for infants it is 80.4 mS vy^{-1} and 67.3 mS vy^{-1}, respectively. The result obtained points to the fact that constant ingestion of the milk products may result to accumulation of radionuclides in some organs of the human, with more radionuclide dose intake in powdered milk than consuming liquid milk. Moreover, the values gotten are well within international standard.

Table 8 presents the summary of the result of the risk analysis and health detriment effect values that may arise from the consumption of milk product samples investigated in this study.

Table 9 presents the population of the three age groups under examination in this study, obtained from the National Population Commission report [37], and the computed two-thirds (2/3) of this population used for the evaluation of the collective effective dose equivalent.

4.2 Collective effective dose equivalent

It is insufficient that the risk to individuals is set at an adequately low level in radiation protection, but the total detriment to the public resulting from exposure to radiation should be kept as low as is reasonably achievable (ALARA) for health, economic, and social factors. The evaluation of the collective/total detriment to health for the public is the sum of detriments to the individuals making up the

Age group	Annual Effective dose E_D (μSv)		Committed effective dose C_D (mS vy^{-1})		Collective effective dose equivalent S_E (man-Sv)		Total health detriment (G) (man)		Mean THD (G) (man)	Total cost of detriment (man-Sv) $million
	Powdered milk	Liquid milk	Powdered milk	Liquid milk	Powdered milk	Liquid milk	Powdered milk	Liquid milk		
Infant (0–1 yr)	1607.3	1345.4	80.4	67.3	5,551.5	4,640.9	91.6	76.6	168	10.2
Children (7–12 yrs)	962.0	822.5	48.1	41.1	9,305.8	7,950.3	153.5	131.2	285	17.3
Adult (>17 yrs)	186.5	181.1	09.3	9.1	6,023.1	5,840.7	99.4	96.4	196	11.9

Table 8.
Summary of risk analysis of radiation dose from milk products.

Age	Population (P_i)	Two-thirds of the population ($\frac{2}{3}P_i$)
Infant (0–1 yr)	7,771,348	5,180,899
Children (7–12 yrs)	21,763,942	14,509,295
Adult (>17 yrs)	72.660,755	48,440,503

Table 9.
Nigeria population in different age groups [37].

public due to a level of radiation exposure. The statement of proportionality between stochastic biological effects and dose equivalent also applies to the collective detriment to health being directly proportional to the collective effective dose equivalent [38]. Hence the collective effective dose equivalent, S_E in a population comprising of N_i individuals, is evaluated as [39]:

$$S_E = \sum N_i H_{Ei} \quad (9)$$

where S_E represents the collective effective dose equivalent (person, Sv) and N_i is the number of persons in a population that are exposed to the radiation, while H_{Ei} represents the mean effective dose equivalent (μS vy^{-1}).

The Nigerian Population Commission [37] puts the population figure of people living in Nigeria as 140,431,790 with the age groups of 0–1 year, 7–12 years, and >17 years having population figures of 7,771,348; 21,763,942; and 72,660,755, respectively.

In Nigeria, approximately two-thirds of the population are expected or projected to make one brand of milk or the other as staple food; consequently two-thirds of the population of the different age ranges/groups are probable to have a radiation dose intake from milk products.

The formula for collective effective dose equivalent was accordingly modified to read:

$$S_E = \sum \frac{2}{3}(N_i H_{Ei}) \quad (10)$$

Table 9 presents the population of three age group brackets being studied in Nigeria. Since two-thirds of the estimated population of Nigerian projected to consume one brand of milk or the other, it is estimated that the 5,180,899 infants, 14,509,295 children, and 48,440,503 adults signifying 48.5% of the total population of Nigeria consume milk products. The estimated collective effective dose equivalent S_E obtained revealed that the value for infants is 5551.5man-Sv in powdered milk and 4640.9man-Sv in liquid milk. In the children age bracket, the values obtained are 9305.8man-Sv for powdered milk and 7950.3man-Sv for liquid milk. Similarly, in the adult age bracket, the collective effective dose equivalent values obtained are 6023.1man-Sv for powdered milk and 5840.7man-Sv for liquid milk. The values obtained revealed that the children population is probable to have the highest radionuclide dose from milk intake.

4.3 Total health detriment

The objective gross or total health detriment also known as collective health detriment "G" (man), resulting from exposure to gamma radiation in an environment or ingestion of irradiated products by man, is evaluated using the formula [38]:

$$G = R_T S_E \qquad (11)$$

From Eq. (11), R_T represents the total risk factor the body organs are exposed to, as recommended by the International Commission on Radiological Protection, ICRP [39], where these risk factors are used in assessing the fatal radiation-induced cancers and severe hereditary effects in the first two generations. It has a gross value of $1.65 \times 10^{-2}\ Sv^{-1}$, with $1.25 \times 10^{-2}\ Sv^{-1}$ representing the value for fatal radiation-induced cancers and $0.4 \times 10^{-2}\ Sv^{-1}$ representing the value for severe hereditary effects, for the first two generations, while S_E is the collective effective dose equivalent (man–Sv) [38].

The estimation of the total health detriment is vital and necessary because any health detriment on this populace will impact negatively on the entire population.

The total health detriment for the three age brackets computed in the different milk products examined is presented in **Table 8**. The total health detriment to man obtained for powdered milk are 91.6 for infants, 153.5 for children, and 99.4 for adults. In the liquid milks, the values obtained for the age groups are 76.6 for infants, 131.2 for children, and 96.4 for adults. This calculated total health detriment indicates that for every 5,180,899 Nigerian infants consuming milk products, 168 of them have the probability to have radiological health-related side effects from the intake of milk products. Similarly, the evaluation of the gross health detriment indicates that for every 14,509,295 Nigerian children consuming milk products, 285 are likely to have a radiological health risk from the intake of milk, while of the estimated 48,440,503 Nigerian adults that consume milk products, 196 are likely to have a radiological health hazard, with fatal radiation-induced cancers the most probable, going by the risk factor of $1.25 \times 10^{-2}\ Sv^{-1}$. The radiological index obtained shows a ratio of 1:30,839 for infants, 1:50,910 for children, and 1:247,145 for adults, with infants' radiological index ratio being the highest. This indicates that the infants are most vulnerable radiologically in milk intake.

4.4 Cost of detriment

The correlation between the cost of the health detriment and collective effective dose equivalent is a linear one. It is expressed as [38]:

$$Y_C = \alpha S_E \qquad (12)$$

where Y_C is the cost of health detriment, SE is the collective effective dose equivalent (man-Sv), and α is the collective dose equivalent constant. If it were possible to arrive at a common monetary value for the cost of radiation harmful stochastic health effects, then α would have a unique value. But it is not practically possible due to socioeconomic considerations that vary from country to country and from time to time. A review of literatures indicates a wide range of α values ranging from 1000 to 100,000 US dollars [38]. Considering the low per capita income of African countries including Nigeria which is below US $100 per day, the cost of detriment analysis value of US $1000 was assigned to human life. This value does not necessarily mean a real monetary value of life but rather is proposed to provide measures by which fair and consistent resources are allocated to radiation protection [21]. From the computed result of the total cost of health detriment from the collective effective dose equivalent to the different age group in **Table 8**, it was observed that children age group has the highest cost health detriment per-caput dose with an estimated total cost of health detriment of US $17.256 million, followed by adults with an estimated cost implication of US $11.864 million, while infants have the least with an estimated cost implication of US $10.192.

5. Conclusion

This investigation presents the gamma spectrometry evaluation of the natural radioactivity in powdered and liquid milk consumed in Nigeria. The radionuclide concentration of the milk samples was found to be dictated by the source the milks products were derived. Although the specific activity concentration of milk samples varied, their mean activities were less than the world permissible dose limit for the public. The radium equivalent activities obtained for all the milk samples (powdered or liquid) considered were all below the criterion limit of radiation dose (1.0 Sv y^{-1}). All the calculated radiological risk parameters show that none of the milk samples exceeded their recommended allowable level. It was however found from the annual effective dose calculation that the consumption of powder and liquid milk by infants and children at the rate of 14 kg y^{-1} and 15 kg y^{-1}, respectively, may lead to a radiation dose to vital organs of the body above normal recommended values, but optimized quantity was suggested for the group to stay within the recommended permissible limit. On the cost-benefit analysis, the estimated collective effective equivalent dose values obtained show that the children population receives the highest dose. The total health detriment values obtained revealed a low detrimental effect to consumers of these milk brands. The calculated values of the total cost of health detriment revealed that the children age group has the highest cost health detriment per-caput dose, followed by adults, while infants have the least; these values obtained are observed to be low. The overall result therefore shows that the powdered and liquid milks consumed in Nigeria are radiologically safe and may not cause immediate or significant radiation health hazard to consumers of the examined milk brands. However, optimizing radiation protection by means of this cost-benefit analysis is recommended.

Author details

Ezekiel O. Agbalagba* and Hannah O. Agbalagba
Federal University of Petroleum Resources, Nigeria

*Address all correspondence to: agbalagba.ezekiel@fupre.edu.ng; ezek64@yahoo.com

References

[1] Badran MM, Sharshar T, Elinimer T. Levels of ^{137}Cs and ^{40}K in edible parts of some vegetables consumed in Egypt. Journal of Environmental Radioactivity. 2003;**67**:181-190

[2] Tchokossa P, Olomo JB, Balogun FA, Adesanmi CA. Assessment of radioactivity contents of food in the oil and gas producing areas in Delta State, Nigeria. International Journal of Science and Technology. 2013;**3**(4):245-250

[3] Albrecht A, Schultze U, Liedgens M, Fluhler H, Frossard E. Incorporating soil structure and root distribution into plant uptake models for radionuclides: Toward a more physically based transfer model. Journal of Environmental Radioactivity. 2002;**59**:329-350

[4] Huff EA. Fukushima radiation treats US milk supplies at levels 2000 percent higher than EPA maximum. Update on Fukushima nuclear plant disaster 2011 online report. 2011

[5] Tawalbeh AA, Samat SB, Yasir MS, Omar M. Radiological impact of drinks intakes of naturally occurring radionuclides on adults of Central Zone of Malaysia. The Malaysian Journal of Analytical Sciences. 2012;**16**(2): 187-193

[6] Adeniji AE, Alatise OO, Nwanya AC. Radionuclide concentrations in some fruit juices produced and consumed in Lagos, Nigeria. American Journal of Environmental Protection. 2013;**2**(2): 37-41

[7] Al-Zahrani JH. Natural radioactivity and heavy metals in milk consumed in Saudi Arabia and population dose rate estimate. Life Science Journal. 2012; **9**(2):651-656

[8] Emumejaye K. Determination of potassium-40 concentration in some powdered milk samples consumed in Delta State, Nigeria. Journal of Applied Physics. 2012;**2**:08-12

[9] Gaso MI, Segovia N, Cervantes ML, Herrera T, Perez-Silva E. Internal radiation dose from ^{137}Cs due to the consumption of mushrooms from a Mexican temperate mixed forest. Radiation Protection Dosimetry. 2000; **87**:213-216

[10] Jibiri NN, Ajao AO. Natural activities of 40K, 238U and 232Th in elephant grass (*Pennisetum purpureum*) in Ibadan metropolis, Nigeria. Journal of Environmental Radioactivity. 2005;**78**: 105-111

[11] Melquiades FL, Appoloni CR. Natural radiation levels in powered milk samples. Food Science and Technology. 2004;**24**(4):501-504

[12] Buldini PL, Cavalli S, Sharma JL. Matrix removal for the ion chromatographic determination of some trace elements in milk. Microchemical Journal. 2002;**72**:277-284

[13] Arogunjo AM, Ofuga EE, Afolabi MA. Levels of natural radionuclides in some Nigerian cereals and tubers. Journal of Environmental Radioactivity. 2005;**82**:1-6

[14] Hosseni T, Fathivan AA, Barati H, Karimi M. Assessment of radionuclides in imported foodstuffs in Iran. Journal of Radiation Research. 2006;**4**(3): 149-153

[15] Zaid QA, Khled MA, Anas MA, Abdalmajeid MA. Measurement of natural and artificial radioactivity in powder milk corresponding annual effective dose. Radiation Protection Dosimetry. 2010;**138**(3):278-283

[16] Ibrahim HS, Abdelfatah FH, Nadia HE, Hussen AM, Mohammed AN.

Radiolo-icalon solids, foodstuff and fertilizers in the Alexandria region Egypt. Turkish Journal of Engineering and Environmental Sciences. 2007;**31**: 9-17

[17] Al-Masri MS, Mukallati H, Al-Hamwi A, Khalili H, Hassan M, Assaf H, et al. Natural radionuclides in Syrian diet and their daily intake. Journal of Radioanalytical and Nuclear Chemistry. 2004;**260**(2):405-412

[18] Melquiades FL, Appoloni CR. ^{40}K, ^{137}Cs and ^{232}Th activities in Brazilian milk samples measured by gamma ray spectrometry. Indian Journal of Pure and Applied Physics. 2002;**40**:5-11

[19] Baratta EJ. Radium, Radon and Uranium in Drinking Water. Washington, DC: Lewis Publisher; 1990. pp. 203-213

[20] Frame P. Radium Equivalent Health Physics Society. 2006. Available from: http://hps.org/documents/background_radiation_fact_sheet.pdf

[21] Roy S, Alam MS, Miah FK, Alam B. Concentration of naturally occurring radionuclides and fission products in bricks samples fabricated and used in and around Great Dhaka City. Radiation Protection Dosimetry. 2000;**88**:255-260

[22] Sam AK, Abbas N. Assessment of radioactivity and the associated hazards in local and imported cement types used in Sudan. Radiation Protection Dosimetry. 2001;**93**:275-277

[23] Diab HM, Nouh SA, Hamdy A, El-Fiki SA. Evaluation of natural radioactivity in a cultivated area around a fertilizer factory. Journal of Nuclear and Radiation Physics. 2008;**3**(1):53-62

[24] Gang S, Diyun C, Zeping T, Zhiquang Z, Wenbiao X. Natural radioactivity levels in topsoil from the Pearl river delta zone, Guangdong, China. Journal of Environmental Radioactivity. 2012;**103**:48-53

[25] Al-Jundi J, Salah W, Bawa'aneh MS, Afaneh F. Exposure to radiation from the natural radioactivity in Jordanian building materials. Radiation Protection Dosimetry. 2006;**118**:93-96

[26] UNSCEAR (United Nation Scientific Committee on the Effects of Atomic Radiation). Sources and effect of ionizing radiation. In: Report to the General Assembly with Scientific Annaxes. New York: United Nations; 2000

[27] Zarie KA, Al Mugren KS. Measurement of natural radioactivity and assessment of radiation hazard in soil samples from Tayma area (KSA). Isotope and Radiation Research. 2010; **42**(1):1-9

[28] Veiga RG, Sanches N, Anjos RM, Macario K, Bastos J, Iguatemy M, et al. Measurement of natural radioactivity in Brazilian beach sands. Radiation Measurement. 2006;**41**:189-196

[29] IAEA. International Aomic Energy Agency. Measurement of radiation in food and the environment. In: Technical Reports Series 295. Vienna; 1989

[30] UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation). Sources and effects of ionizing radiation. In: Report to General Assembly. New York: United Nations; 1993

[31] World Health Organization, WHO. Guideline for drinking water quality; measurement of natural and artificial radioactivity in powder milk corresponding annual effective dose radiation protection. In: Recommendations. Vol. 1. Geneva: WHO; 1993

[32] Taskin HM, Karavus P, Ay A, Touzogh S, Hindiroglu S, Karaham G.

Radionuclide concentration in soil and lifetime cancer risk due to the gamma radioactivity in Kirklareli, Turkey. Journal of Environmental Radioactivity. 2009;**100**:49-53

[33] ICRP (International Commission on Radiological Protection). Age-dependent doses to members of the public from intake of radionuclides. Part 5: Compilation of ingestion and inhalation coefficients. In: ICR Publication 72. Oxford: Pergamon Press; 1996

[34] Marmuleva NI, Barinov EY, Petukhov VL. Radionuclides accumulation in milk and its products. Journal de Physique IV. 2003;**107**(2): 827-829

[35] ICRP, International Commission on Radiological Protection. Age-dependent dose to member of the public from intake of radionuclides. Part II. In: Publication-67. Oxford: Pergamon Press; 1993

[36] IAEA (International Atomic Energy Agency). International Basic Safety Standards for Protection against Ionizing Radiation and for Safety Radiation Sources. No. 115. Vienna: IAEA; 2003

[37] Nigeria Population Commission, NPC. Population distribution by age and sex. In: Priority Table. Volume IV. Population and Housing Census 2006. Federal Republic of Nigeria; 2010

[38] Ahmed JV, Daw HT. Cost-benefit analysis and radiation protection. A technical presentation on nuclear safety and environmental protection. IAEA Bulletin. 1991;**22**(5/6):13-22

[39] ICRP (International Commission on Radiological Protection). The 1990–91 recommendation of the International Commission on Radiological Protection. Publication 60. Annals of ICRP. 1991;**21**: 1-3