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Radioactivity of long lived gamma emitters in milk powder consumed in Kuwait and estimates of annual effective doses

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ABSTRACT

A study of natural and anthropogenic radionuclides in milk powder consumed in Kuwait was performed. The milk powder samples originated from 12 different countries, and were designated for three distinct age groups, namely adults, children, and infants. The study targeted four long-lived gamma emitting radionucides, namely ^{40}K, ^{137}Cs, ^{226}Ra, and ^{232}Th. Annual effective doses were estimated for the three age groups from consumption of milk powder.

Keywords: NORM; milk; foodstuff; Kuwait; Cs-137.

INTRODUCTION

Radioactivity in the environment originates from natural and anthropogenic (man-made) sources. Natural radionuclides include isotopes of potassium (^{40}K), uranium (^{238}U and its decay series), and thorium (^{232}Th and its decay series). These natural occurring radioactive materials (NORM) are long-lived (in the order of 10^{10} years) and are typically present in environmental samples.

Anthropogenic radionuclides are products of nuclear processes in industrial, medical, and military applications. Releases to the environment can be either controlled (regulated discharges) or uncontrolled (accidents). For example, it is estimated that 9×10^{16} Bq of the Cesium isotope ^{137}Cs were released to the environment from the Chernobyl accident (IAEA, 2006). The presence of anthropogenic radionuclides in environmental samples is an indicator of a previous contaminating event.

Natural and anthropogenic radionuclides are found in terrestrial and aquatic food chains, with subsequent transfer to humans through ingestion of food. Therefore, there is a global interest in human radiation exposure due to radionuclide intake from food (Al-Azmi *et al.*, 1999; Al-Masri *et al.*, 2004; Al-

Masri *et al.*, 2006; Baeza *et al.*, 2004; Desimoni *et al.*, 2009; Franic *et al.*, 2008; Hosseini *et al.*, 2006a; Hosseini *et al.*, 2006b; IAEA, 1989, 1994, 2009; ICRP, 1996; Jibiri & Okusanya, 2008; Kamenik *et al.*, 2009; Melquiades & Appoloni, 2000; Shiraishi *et al.*, 1997; Yu & Mao, 1994).

Among the types of food that are commonly consumed worldwide is milk powder. Hence, studies on the radioactivity of milk powder have been performed in various regions across the globe (Ababneh *et al.*, 2009; Altzitzoglou & Bohnstedt, 2008; Baeza *et al.*, 2004; Desimoni *et al.*, 2009; Hermanspahn, 2009; Hosseini *et al.*, 2006b; Jibiri & Okusanya, 2008; Melquiades & Appoloni, 2000). Results of these studies revealed interesting regional dependences of radionuclide concentration (Altzitzoglou & Bohnstedt, 2008; Eisenbud & Thomas, 1997; Hermanspahn, 2009). These dependences are not surprising since radionuclides may differ in their types and quantities from one region to another, depending on the regional environmental nature, and whether or not the region was exposed to fallout from nuclear contaminating events (Altzitzoglou & Bohnstedt, 2008; Hermanspahn, 2009). These studies also helped in establishing baselines of radiation exposure to people from consumption of milk powder (Ababneh *et al.*, 2009; Desimoni *et al.*, 2009).

A thorough literature search reveals only a small number of studies on radionuclide content of food consumed in Kuwait (Al-Azmi *et al.,* 1999). This was the main motive to conduct the current study, in order to meet the important national requirement of establishing a baseline of radioactivity exposure to the general public from food consumption. For a systematic approach, this study focused on one type of foodstuff that is widely consumed by various age groups in Kuwait, namely milk powder. Hence the aim of this study is to quantify the presence of long-lived gamma emitters in milk powder consumed in Kuwait, and to estimate annual effective doses to the general public due to this consumption.

MATERIALS AND METHODS

Milk powder samples were collected from the Kuwaiti local market. The collection took place between January and June of 2009. To ensure a comprehensive and a wide-spread representation, 66 different brands that originated from 12 different countries were selected (Table 1). The designated age groups, namely adult, child, and infant, varied from one sample to another. Since milk powder is not produced locally in Kuwait, all samples were imported. Because commercial milk powder comes dried, powdered, and ready to use, the samples did not undergo any special preparations or lab treatments.

Prior to measurement, each sample was placed in a cylindrical container with dimensions 9 cm in diameter and 10 cm in height. After being sealed, the sample-filled containers were left for a period of at least 4 weeks to reach secular equilibrium between parent radionuclides and their daughters. Measurements were performed using a high purity germanium (HPGe) p-type detector. The low background Ortec system had an energy resolution of 1.75 keV FWHM at the 1.33 MeV of ^{60}Co photopeak. The counting system of 80% relative efficiency was connected to a multi-channel analyzer. Energy calibration for the detector was performed using a set of point sources in addition to a cylindrical standard reference material (IAEA-152 milk powder).

Table 1. Brand names, designated age groups, and origins of milk powder samples investigated in the current study

Brand name / description	**Country of Origin**	**Age group**	**Sample weight (g)**
Regilate- low fat instant semi skimmed milk powder.	France	Adult	214.26
France Lait instant full cream milk powder.	France	Adult	221.93
Regilate- 0% fat instant skimmed milk powder.	France	Adult	172.71
Regilate- Vitamilk instant skimmed milk powder- 0 fat 10 vitamins.	France	Adult	167.41
Full cream spray milk powder (Ration)	Holland	Adult	249.78
Cost full cream milk powder.	Holland	Adult	200.82
Klim- Calcium milk powder - full cream.	Holland	Adult	224.95
Rainbow Quality milk- full cream milk powder	Holland	Adult	221.46
Amul- full cream milk powder.	India	Adult	232.2
Anchor full cream milk powder.	New Zealand	Adult	236.14
Anlene Full cream high calcium milk powder for adults.	New Zealand	Adult	253.92
Anlene Low fat high calcium milk powder for adults.	New Zealand	Adult	225.58
Luna milk- full cream milk powder.	New Zealand	Adult	230.12
NesVita-probones.Fat free Vanilla flavored non fat milk	Philippines	Adult	231.11
Melody Full cream milk powder.	UAE	Adult	244.85
Nido milk powder 3 plus.	Malaysia	Child	232.54
Nido milk powder 5 plus.	Malaysia	Child	222.38
Anchor growing up milk powder 1plus with honey.	New Zealand	Child	264.52

Cont. Table 1. Brand names, designated age groups, and origins of milk powder samples investigated in the current study

Brand name / description	Country of Origin	Age group	Sample weight (g)
Anchor growing up milk powder 3 plus with honey	New Zealand	Child	270.78
Guigoz 1 starter infant formula with iron suitable from birth.	France	Infant	230.44
Guigoz 2 follow up infant formula with iron suitable from 6th month.	France	Infant	234.11
Novalac IT1 infant formula from 0 to 6 months.	France	Infant	253.85
Novalac AC1 infant formula from 0 to 6 months.	France	Infant	240.99
Novalac AC2 follow up formula from 6 month onward.	France	Infant	237.82
Novalac AR1 infant formula from 0 to 6 months.	France	Infant	230.47
Novalac AC2 follow up formula from 6 month onward.	France	Infant	219.41
Novalac 1 infant formula from 0 to 6 months.	France	Infant	245.84
Novalac 2 follow up formula from 6 -12 month.	France	Infant	230.63
Novalac 3 growth formula for children from 1-3 years.	France	Infant	252.23
France Lait LF lactose free infant formula- from birth -enriched with iron.	France	Infant	244.55
France Lait 1 lactose from 0-6 months - enriched with iron.	France	Infant	269.17
France Lait 2 follow on formula from 6 months - enriched with iron.	France	Infant	273.9
France Lait growing up milk formula from 1-3 years	France	Infant	259.76
France Lait growing up milk formula from 1-3 years	France	Infant	249.35
Milopa HN25 Special formula -	Germany	Infant	169.47
Milopa 3. baby milk powder from 1-3 yrs.	Holland	Infant	250.98
Bebelac 3. baby milk powder from 1-4 yrs fortified with iron	Holland	Infant	249.4
Milopa Aptamil 1 infant milk from birth to 6 months.	Holland	Infant	240.05
Milopa Aptamil 2 follow on milk from 6 months to 12 months.	Holland	Infant	263.82

Cont. Table 1. Brand names, designated age groups, and origins of milk powder samples investigated in the current study

Brand name / description	Country of Origin	Age group	Sample weight (g)
Milopa Aptamil 1 Comfort infant milk for cases of colic and constipation from birth to 6months	Holland	Infant	255.92
Milopa Aptamil 2 Comfort follow on milk for cases of colic and constipation from 6 month	Holland	Infant	279.33
Milopa Aptamil Premature infant milk from birth on wards.	Holland	Infant	233.99
Milopa Aptamil Hypo-Allergenic Infant Milk for infants at risk of allergies- from birth onwards	Holland	Infant	274.45
Bebelac HA Hypoallergenic formula- from birth onwards.	Holland	Infant	250.95
Milopa Aptamil AR for infant with regurgitation in infant milk formula from birth onwards.	Holland	Infant	238.15
Bebelac AR infant milk formed for regurgitation, from birth onwards formula.	Holland	Infant	235.22
Bebelac EC infant milk formula for extra care- from birth onwards.	Holland	Infant	267.25
Bebelac FL infant milk formula for free of lactose- from birth onwards.	Holland	Infant	244.03
Bebelac 1 infant milk formula from birth onwards.	Holland	Infant	243.98
Bebelac 2 infant milk formula from 6 months.	Holland	Infant	246.65
al110 Lactose free infant formula.	Holland	Infant	245.09
Nan1 starter infant formula fortified with iron.	Iran	Infant	274.31
Nan2 follow up infant formula fortified with iron. Suitable from 6th month	Iran	Infant	261.87
S-26 LF milk based lactose free infant formula from birthonward.	Ireland	Infant	249.34
S-26 Gold- stage 1 infant formula from birth to 6 month.	Ireland	Infant	253.20
Promil Gold- stage 2 follow-on formula from 6-12 months.	Ireland	Infant	233.91
Progress Gold- stage 3 growing up milk formula from 1-3years.	Ireland	Infant	249.88

Cont. Table 1. Brand names, designated age groups, and origins of milk powder samples investigated in the current study

Brand name / description	Country of Origin	Age group	Sample weight (g)
Similac Advance Infant Formula 1- from birth	Ireland	Infant	244.72
Similac Gain Advance follow on Formula 2- from 6 month onward	Ireland	Infant	248.89
Gain Plus Advance growing up milk Formula for children from 12 months onwards	Ireland	Infant	253.93
Nido milk powder 1 plus.	Malaysia	Infant	233.68
Similac Advance Lactose free- Iron Fortified,	Spain	Infant	243.75
Similac Advance HA	Spain	Infant	250.35
Nan3 follow up infant formula fortified with iron.	Switzerland	Infant	256.17
NanHA1 starter infant formula fortified with iron (hypoallergenic).	Switzerland	Infant	280.81
NanHA2 follow up infant formula fortified with iron (hypoallergenic).	Switzerland	Infant	279.34

Efficiency calibration was done using a standard source with the same geometry of the standard IAEA milk powder. To reduce statistical counting error, the samples were counted for a period of 86400 seconds (one full day). An empty container was also counted under the same conditions to determine the background counts. For spectrum analysis, Gamma Vision software was used, where the photopeaks considered were 609 keV (^{226}Ra), 662 keV (^{137}Cs), 911 keV (^{232}Th), and 1460 keV (^{40}K). The activity concentration A (in Bq kg^{-1}) of each radionuclide in each sample was calculated from the formula (IAEA, 1989)

$$A = \frac{N}{\in P_{\gamma} tm} \tag{1}$$

where N is the net counts of the corresponding photopeak. P_{γ} and ε are the emission probability per disintegration and the detector efficiency respectively at the specific gamma line. t is the counting time in seconds, and m is the mass of the sample in kg.

The minimum detectable activity (MDA) was calculated using the formula (Currie, 1968)

$$MDA = \frac{2.71 + 4.66 S_b}{\in P_{\gamma} tm} \tag{2}$$

where S_b is the standard error in the net background count for the photo-peak. The MDA values for the counting system were calculated to be 0.32, 0.34, 0.29, and 3.67 Bq kg^{-1} for ^{226}Ra, ^{137}Cs, ^{232}Th, and ^{40}K, respectively.

To investigate the statistical significance of the results, an analysis of variance (ANOVA) was performed. Each targeted radionuclide was tested for regional and age-group dependence. Regional dependence tests included 12 statistical groups corresponding to the 12 countries from which the samples originated. Age-group dependence tests, on the other hand, included only 3 statistical groups, namely adult, child, and infant. Concentrations that were below the MDA, and those that were undetected were entered as zeros.

RESULTS

Table 2 presents the activity concentrations for ^{40}K, ^{137}Cs, ^{226}Ra, and ^{232}Th in the milk powder samples. ^{40}K was detected in all samples with a maximum value of 695.06 ± 6.9 Bq kg^{-1} (adult milk powder sample from France), a minimum value of 162.19 ± 3.14Bq kg^{-1} (infant milk powder sample from Holland), and an all-brand, all-age-group average of (± SD) 307.74 ± 127.37 Bq kg^{-1}. The average activity concentration for adult milk powder samples was 493.00 ± 109.50 Bq kg^{-1} (AVG± SD), for child milk powder samples it was 365.86 ± 63.19 Bq kg^{-1} (AVG± SD), and for infant milk powder samples it was 244.52 ± 55.78 Bq kg^{-1} (AVG± SD).

Table 2. Activity concentrations of ^{40}K, ^{137}Cs, ^{226}Ra, and ^{232}Th in milk powder in the current study

Country of Origin	Age group	^{40}K (Bq kg^{-1})	^{137}Cs (Bq kg^{-1})	^{226}Ra (Bq kg^{-1})	^{232}Th (Bq kg^{-1})
France	Adult	564.38 ± 5.43	0.43 ± 0.03	0.41 ± 0.02	ND
France	Adult	496.82 ± 5.04	BDL	ND	ND
France	Adult	695.06 ± 6.9	ND	BDL	ND
France	Adult	681.96 ± 6.8	ND	0.38 ± 0.02	0.69 ± 0.04
Holland	Adult	316.38 ± 3.88	ND	ND	ND
Holland	Adult	430.8 ± 5.02	ND	0.33 ± 0.02	ND
Holland	Adult	436.49 ± 4.79	BDL	ND	ND
Holland	Adult	481.14 ± 5.07	BDL	BDL	ND
India	Adult	390.77 ± 4.44	0.47 ± 0.05	0.55 ± 0.02	ND
New Zealand	Adult	510.81 ± 4.94	0.61 ± 0.04	ND	ND
New Zealand	Adult	345.91 ± 4.75	0.96 ± 0.03	BDL	ND

Table 2. Activity concentrations of ^{40}K, ^{137}Cs, ^{226}Ra, and ^{232}Th in milk powder in the current study

Country of Origin	Age group	^{40}K (Bq kg^{-1})	^{137}Cs (Bq kg^{-1})	^{226}Ra (Bq kg^{-1})	^{232}Th (Bq kg^{-1})
New Zealand	Adult	592.97 ± 5.43	0.39 ± 0.05	0.32 ± 0.02	ND
New Zealand	Adult	497.45 ± 4.96	0.81 ± 0.05	ND	0.64 ± 0.05
Philippines	Adult	526.53 ± 5.00	0.42 ± 0.04	BDL	0.31 ± 0.03
UAE	Adult	427.65 ± 4.55	BDL	BDL	ND
Malaysia	Child	301.29 ± 3.89	BDL	BDL	ND
Malaysia	Child	322.01 ± 4.21	ND	BDL	ND
New Zealand	Child	418.89 ± 4.26	0.85 ± 0.05	BDL	ND
New Zealand	Child	421.31 ± 4.19	1.03 ± 0.04	BDL	0.56 ± 0.03
France	Infant	189.02 ± 3.26	BDL	BDL	0.29 ± 0.03
France	Infant	259.05 ± 3.63	BDL	BDL	BDL
France	Infant	191.39 ± 3.08	BDL	0.47 ± 0.01	ND
France	Infant	174.24 ± 3.06	ND	ND	ND
France	Infant	217.24 ± 3.39	ND	BDL	ND
France	Infant	241.78 ± 3.62	ND	BDL	0.54 ± 0.03
France	Infant	242.42 ± 3.69	ND	BDL	ND
France	Infant	175.62 ± 3.12	ND	ND	BDL
France	Infant	232.37 ± 3.59	ND	ND	ND
France	Infant	293.38 ± 3.86	ND	ND	ND
France	Infant	220.36 ± 3.47	ND	BDL	ND
France	Infant	193.27 ± 3.04	ND	ND	ND
France	Infant	296.68 ± 3.74	ND	BDL	ND
France	Infant	358.17±4.14	ND	BDL	0.61 ± 0.02
France	Infant	366.74 ± 4.28	ND	ND	BDL
Germany	Infant	227.29 ± 4.4	ND	ND	BDL
Holland	Infant	279.07 ± 3.71	ND	ND	ND
Holland	Infant	267.46 ± 3.64	BDL	BDL	ND
Holland	Infant	188.1 ± 3.28	ND	ND	ND
Holland	Infant	276.7 ± 3.61	ND	ND	BDL
Holland	Infant	195.55 ± 3.19	ND	ND	ND
Holland	Infant	260.11 ± 3.41	ND	ND	BDL
Holland	Infant	162.19 ± 3.14	ND	BDL	BDL

Table 2. Activity concentrations of ^{40}K, ^{137}Cs, ^{226}Ra, and ^{232}Th in milk powder in the current study

Country of Origin	Age group	^{40}K (Bq kg^{-1})	^{137}Cs (Bq kg^{-1})	^{226}Ra (Bq kg^{-1})	^{232}Th (Bq kg^{-1})
Holland	Infant	194.14 ± 3.13	ND	ND	ND
Holland	Infant	231.69 ± 3.55	ND	BDL	ND
Holland	Infant	204.31 ± 3.39	ND	ND	ND
Holland	Infant	205.97 ± 3.52	ND	ND	0.41 ± 0. 02
Holland	Infant	188.31 ± 3.1	ND	ND	ND
Holland	Infant	195.67 ± 3.22	ND	BDL	ND
Holland	Infant	197.57 ± 3.31	ND	ND	0.33 ± 0.02
Holland	Infant	275.42 ± 3.78	ND	ND	ND
Holland	Infant	228.28 ± 3.33	ND	BDL	BDL
Iran	Infant	254.78 ± 3.38	BDL	BDL	BDL
Iran	Infant	219.9 ± 3.21	ND	0.33 ± 0.01	0.35 ± 0.02
Ireland	Infant	215.59 ± 3.45	ND	ND	ND
Ireland	Infant	202.99 ± 3.27	ND	ND	BDL
Ireland	Infant	296.98 ± 3.94	ND	ND	BDL
Ireland	Infant	331.06 ± 4.02	ND	ND	BDL
Ireland	Infant	254.05 ± 3.68	ND	BDL	ND
Ireland	Infant	374.43 ± 4.28	ND	0.39 ± 0.01	BDL
Ireland	Infant	430.36 ± 4.48	ND	ND	BDL
Malaysia	Infant	266.18 ± 3.74	BDL	0.37 ± 0.02	ND
Spain	Infant	241.16 ± 3.95	ND	0.39 ± 0.02	BDL
Spain	Infant	210.44 ± 3.35	ND	0.35 ± 0.02	0.44 ± 0.02
Switzerland	Infant	232.56 ± 3.3	BDL	ND	ND
Switzerland	Infant	206.21 ± 3.24	BDL	0.43 ± 0.01	ND
Switzerland	Infant	286.22 ± 3.52	BDL	0.98 ± 0.02	ND

BDL: Below detection limit.

ND: No detected.

Activity concentrations above the MDA for ^{226}Ra were found in 13 samples only. The maximum value was 0.98 ± 0.02 Bq kg^{-1} for infant milk powder sample from Switzerland, the minimum value was 0.32 ± 0.02 Bq kg^{-1} for adult milk powder sample from New Zealand. The average activity concentration for adult milk powder samples was 0.4 ± 0.09 Bq kg^{-1} (± SD) and for infant milk powder samples was 0.45 ± 0.21 Bq kg^{-1} (± SD). All child milk powder samples had ^{226}Ra activity concentrations below the MDA.

^{232}Th activity concentrations were above the MDA in 11 samples only. The maximum value was 0.69 ± 0.04 Bq kg^{-1} for adult milk powder sample from France, and the minimum value was 0.29 ± 0.03 Bq kg^{-1} for infant milk powder sample from France. The average activity concentrations were 0.55 ± 0.21 Bq kg^{-1} for adult milk powder samples, and 0.42 ± 0.11 Bq kg^{-1} for infant milk powder samples. ^{232}Th was measureable in one sample of child milk powder only, with an activity concentration of 0.56 ± 0.03 Bq kg^{-1}.

^{137}Cs was detected in 9 out of 66 samples. The maximum value was 1.03 ± 0.04 Bq kg^{-1} for child milk powder sample from New Zealand, and the minimum value was 0.39 ± 0.05 Bq kg^{-1} for adult milk powder sample from New Zealand. Interestingly, all samples originating from New Zealand contained ^{137}Cs above the MDA. The average activity concentration of ^{137}Cs for adult milk powder samples was 0.58 ± 0.22 Bq kg^{-1}, and for child milk powder samples was 0.94 ± 0.12 Bq kg^{-1}.

DISCUSSION

The presence of the natural radionuclides in milk powder was as expected. Specifically, detection of ^{40}K in all samples was anticipated due to its natural abundance. As for ^{226}Ra and ^{232}Th, their detection in some samples (in about 20% of the total samples) does not necessarily imply their absence in others. It is well understood that background levels and system MDA could conceal minor photo-peaks (Knoll, 2000). In fact, the infrequency of ^{226}Ra and ^{232}Th detection in food samples was reported by various authors (Ababneh *et al.*, 2009; Hosseini *et al.*, 2006b; Jibiri & Okusanya, 2008).

The presence of the anthropogenic radionuclide ^{137}Cs in some milk powder samples was not surprising. Nonetheless, the detection of this radionuclide in all samples originating from New Zealand was unexpected.

The difference in the presence of ^{137}Cs in samples originating from New Zealand was statistically significant ($P < 0.01$). This regional dependence could be explained by the nuclear weapon tests conducted in the South Pacific region in the 1950s (Eisenbud & Thomas, 1997). No other statistically significant regional or age-group dependence was observed for any of the targeted radionuclides.

Table 3. Activity concentrations of ^{40}K, ^{137}Cs, ^{226}Ra, and ^{232}Th of milk powder reported in the literature, compared with values found in the present study. Values in parentheses are averages ± standard deviations

Origin	^{40}K (Bq kg^{-1})	^{137}Cs (Bq kg^{-1})	^{226}Ra (Bq kg^{-1})	^{232}Th (Bq kg^{-1})	Reference
Argentina	400-608*	-	-	-	(Desimoni *et al*., 2009)
Brazil	475- 489	3.4 - 3.7	-	0.32-0.48	(Melquiades, 2000)
Chile	-	0.88*	-	-	(Desimoni *et al*., 2009)
Denmark	440-644	-	< 4.2	37	(Jibiri & Okusanya, 2008)
France	434	0.123	0.05 - 6	0.142 - 20	(Hosseini *et al*. 2006; Jibiri & Okusanya, 2008)
Adult	496-695	0.43	0.38 - 0.41	0.69	(Present study)
	609.6 ± 95	0.43 ± 0.03	0.4 ± 0.02	0.69 ± 0.04	(Present study)
Infant	174-366	-	-	0.29-0.61	(Present study)
	243.5 ± 61.4	-	-	(0.48 ± 0.17	(Present study)
Germany	610	3.2	0.064	0.094	(Hosseini et al., 2006)
Infant	227	-	-	-	(Present study)
	227.3 ± 4.4	-	-	-	(Present study)
Jordan	326*	-	-	-	(Ababneh et al., 2009)
Holland	845	-	30	42	(Jibiri & Okusanya, 2008)
Adult	316-481	-	0.33	-	(Present study)
	416.2 ± 70.25	-	0.33 ± 0.02	-	(Present study)
Infant	162-279	-	-	0.37	(Present study)
	223.0 ± 39	-	-	0.37 ± 0.06	(Present study)
New Zealand	549- 605	0.38 - 1.6	0.15 - 0.19	0.15- 0.17	(Hosseini *et al*.,2006; Hermanspahn, 2009)
Adult	345-592	0.39-0.96	0.32	0.64	(Present study)
	486.8 ± 103	0.69 ± 0.25	0.32 ± 0.02	0.64 ± 0.05	(Present study)
Child	418 - 421	0.85 - 1.0	-	0.56	(Present study)
	420.1 ± 1.7	0.94 ± 0.13	-	0.56 ± 0.03	(Present study)
Venezuela	402	1.55	-	-	(Hosseini *et al*.,2006)

*Equivalent to dry weight prepared from liquid milk

(1 kg of milk powder is approximately equal to 8 liters of liquid milk).

The results from the present study were compared to those reported in the literature (Table 3). The previous studies did not consider targeted age groups for the milk powder samples while reporting radionuclide activity concentration, thus making the present study unique. Table 3 shows the values of ^{40}K activity concentration of the present study agreeing in some cases with those reported in the literature for the same region. Such agreement is evident in the range overlap of the adult milk powder samples from New Zealand of the present study with the range of values reported in the literature for the same region. In other cases, however, the ^{40}K activity concentrations in the present study exhibit higher values than those reported in the literature for the same region (e.g. adult milk powder samples from France) or lower values (e.g. adult and infant milk powder samples from Holland). Similar variability is noticed for the activity concentrations of ^{137}Cs, ^{226}Ra, and ^{232}Th when comparing values of the present study with those reported in the literature for the same regions. Such variability has been previously reported by others (Ababneh *et al.*, 2009; Desimoni *et al.*, 2009; Hosseini *et al.*, 2006b).

Table 4. Dose conversion factors in nSv Bq^{-1} (ICRP, 1996)

Isotopes	K-40	Ra-226	Th-232	Cs-137
Adults	6.2	280	230	13
Children (10 year old)	13	800	290	10
Infants (1 year old)	42	960	450	12

The annual effective dose from consumption of milk powder was calculated using the following formula (UNSCEAR, 2000)

$$D = AEI \tag{3}$$

where D is the annual effective dose (Sv yr^{-1}), A is the activity concentration for the radionuclide (Bq kg^{-1}), E is the dose conversion factor for the radionuclide (Sv Bq^{-1}), and I is the annual intake of milk powder (in kg). Since both E and I are age-dependent, the calculation for the annual effective dose D was performed for all three age groups separately. Values for E (Table 4) were selected based on the International Commission on Radiological Protection (ICRP) classifications (ICRP, 1996), namely adults, children (10 years old), and infants (1 year old). Values of I were taken to be 14, 26, and 38 kg yr^{-1} for adults, children, and infants, respectively, in accordance with the official gazette data of ration distributed to Kuwaiti households (Government of Kuwait, 2009).

Table 5. Annual effective doses (μSv)from consumption of milk powder for adults, children, and infants

Isotopes	K-40	Ra-226	Th-232	Cs-137	Total
Adults	43	2	2	0.1	47.1
Children	123	0	4	0.2	127.2
Infants	390	16	7	0	413

The results of the annual effective dose D are presented in Table 5. The activity concentration A used in Table 5 are the averages for each radionuclide for each age group. Hence, the doses presented in Table 5 are the average annual effective doses, the total of which were found to be 47.1, 127.2, and 413 μSv for adults, children, and infants, respectively.

CONCLUSION

Long-lived gamma emitters in milk powder consumed in Kuwait have been investigated. The samples, which were collected from the local market, are designated for three different age groups, namely adults, children, and infants. The milk powder samples originated from 12 different countries. The study targeted four radionuclides, namely ^{40}K, ^{137}Cs, ^{226}Ra, and ^{232}Th. While ^{40}K was detected in all samples, the other radionuclides were detected in some samples with varying quantities, and undetected in others. Interestingly, ^{137}Cs was detected with statistical significance in all samples originating from New Zealand. This regional dependence can be explained by the nuclear explosion tests that were carried out some fifty years ago in the South Pacific. No other statistically significant regional or age group dependence was observed. In addition, the annual effective dose from consumption of milk powder was calculated for the three age groups.

The present study is the first one at the national level to investigate radioactivity of milk powder. The findings of this study will help in establishing a baseline of radioactivity exposure to the general public from ingestion of foodstuff. However, milk powder is only one dietary component and the focus of the present study was gamma emitters. To establish a more robust baseline, there is a need to investigate more types of foodstuffs, as well as targeting alpha and beta emitting radionuclides.

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دراسة المواد المشعة طويلة الأمد في الحليب المجفف المستهلك في الكويت

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خلاصة

تم دراسة مصادر الاشعاع الطبيعية والتى من صنع الأنسان في الحليب المجفف المستهلك في الكويت. عينات الحليب المجفف جاءت من 12 دولة مختلفة وكانت مخصصة لثلاث فئات عمرية مختلفة (البالغين، الأطفال، الرضع).

ركزت الدراسة على رصد 4 مواد اشعاعية طويلة الأمد مصدرة لأشعة جاما، ألا وهي ^{40}K، ^{137}Cs، ^{226}Ra، ^{232}Th وكذلك تم حساب الجرعات التأثيرية السنوية للفئات العمرية الثلاث من استهلاك الحليب المجفف.