e-Jurnal Sains Nuklear Malaysia, 2023, Vol. 35 (No.1) : 11 – 21
eISSN: 2232-0946

RADIOACTIVITY CONCENTRATION ASSOCIATED WITH CANCER RISK ARISING FROM THE CONSUMPTION OF PRE-MIX INSTANT PACKAGE BEVERAGE

Yii Mei-Wo, Dainee Nor Fardzila Ahmad Tugi, Maziah Mahmud, Nor Aza Hassan and Mohamad Asri Ramli

Radiochemistry and Environment Group
Waste and Environmental Technology Division
Malaysian Nuclear Agency, 43000 KAJANG, MALAYSIA
*Corresponding author: yii@nm.gov.my

ABSTRACT

Beverage consumption containing radionuclides may contribute to radiation dose and poses a higher cancer risk to human. Studies were conducted to determine the concentration of radionuclides present in the pre-mix instant beverage. Based on the consumption rate by Malaysian adults, the annual effective dose and the associated cancer risk were estimated. The activity concentration was found to range between 63 to 1360 Bq/kg for ^{40}K. For other natural radionuclides of ^{226}Ra, ^{228}Ra, ^{232}Th, and ^{238}U, it ranged between 0.88 – 6.43 Bq/kg, 0.83 – 8.48 Bq/kg, 0.62 – 5.73 Bq/kg and 2.64 –21.49 Bq/kg, respectively, whilst the artificial radionuclides were less than 2 Bq/kg. Calculated annual effective doses due to the intake of radionuclides by ingestion were between 44.6 – 170.0 µSv/y, with the potential of cancer risk incurrence between 16 to 59 cases in every 100,000 people.

Keywords: Radionuclides, pre-mix beverage, effective dose, cancer risk

INTRODUCTION

Modernization and technological advancement had changed the living style of humans in modern days. Nowadays, multi-flavour beverages can be easily found in the market. Among those, pre-mix instant beverages are also available where people just have to add hot water to it and can enjoy a cup of hot beverage instantly. According to the survey conducted by Institute for Public Health, (IPH, 2014), Malaysian adults consumed on average 51.8 g (2-3 packages) of pre-mix beverages per day. For the black coffee package, averaged 3 packs per day of 13.5 g.

The potential of radionuclide contamination in the diet requires assessment to ensure food safety. Radionuclides can originate from various sources; by human activities (^{134}Cs, ^{137}Cs), such as the release from nuclear weapons testing or accidents, or naturally occurring, such as primordial (^{40}K, ^{226}Ra, ^{228}Ra, ^{232}Th, ^{238}U) in the earth crust or through cosmogenic formation (UNSCEAR, 2000). These radionuclides can enter the human body either through inhalation of radon gas or ingestion of contaminated food (IAEA, 1989; UNSCEAR, 2000; Afshari et al., 2009; Alharshan et al., 2017; Jemii and Mazouz, 2020). Ingestion of radioactive contaminated foods contributes a large fraction of internal radiation exposure (Baeza et al., 2004; UNSCEAR, 2008; Afshari et al., 2009; Alamoudi, 2013; Godyn´ et al., 2014; Desideri et al., 2014; Uwatse et al., 2015; Sahar et al., 2016). Therefore, food radioactivity and its associated dose assessment are necessary for establishing rules and regulations related to radiation protection (Alharshan et al., 2017).

Depending on the radionuclide's chemical properties, they will act differently inside the human body. For instance, radiums, which behaves like calcium, will be absorbed into bone and teeth (VKM, 2017). Prolonged internal exposure of humans to high levels of radium may produce bone and sinus cancers. Whilst, uranium, and thorium can get accumulated in the bone up to an extent of 70%

(UNSCEAR, 2000). On the other hand, potassium-40 will behave the same as other potassium isotopes in the environment, being assimilated into the tissues of all plants and animals through normal biological processes and then distributed uniformly in the human body (Baeza et al., 2004). Caesium which is in the same chemical group as potassium will be expected to behave similarly (VKM, 2017).

Sahar et al. (2016) reported that the concentration of natural radioactivity in food is often in the range of 40 to 600 Bq/kg of food while the artificial level varies depending on the incident and the level of exposure. The concentrations of ^{226}Ra, ^{228}Ra, ^{232}Th and ^{238}U radioactivity in different foods varies from <0.0004 – 9.4 Bq/kg, 0.038 – 0.32 Bq/kg, 0.0002 – 0.33 Bq/kg and 0.0001 – 2.9 Bq/kg, respectively (UNSCEAR, 2000). Priharti and Samat (2017) reported that natural radionuclide activity concentration (^{226}Ra, ^{232}Th dan ^{40}K) in staple food, vegetables, fruits and dishes in the central area of Malaysia varies from 0.45 – 5.64 Bq/kg, 0.39 – 4.40 Bq/kg, 75.39 – 1072.59 Bq/kg, respectively.

The total annual effective dose from natural radionuclides present within our human body works out to be approximately 0.3 mSv annually (Rao, 2012). Priharti and Samat (2017) also reported that annual dose exposure due to food intake from natural radionuclides of ^{232}Th and ^{238}U series, and ^{40}K is 0.12 mSv and 0.17 mSv, respectively. A typical annual effective dose ranges from the ingestion of foods ranging between 0.2 – 1 mSv (UNSCEAR 2008). International Commission on Radiological Protection (ICRP) recommended 1 mSv as the annual effective dose for a member of the public due to the operation of nuclear facilities and the applications of radiation and radionuclides. Dose from medical exposure and background exposure to naturally occurring radionuclides is not included in the dose limit for the members of the public (Rao, 2012).

Cancer and heritable effects are the most important health effects of ionizing radiation at relatively low doses and dose rates. Based on both animal studies and epidemiological research, the International Agency for Research on Cancer (IARC) has categorized all types of ionising radiation as carcinogenic for humans (IARC, 2012). There is no doubt that these health effects are indeed occurring (at least found in mice study, for heritable effects); but the magnitude of the risk at low doses and low dose rates is debatable. Cancer is well documented in the range of doses defined as moderate, 100 mSv – 1 Sv. This documentation is based on epidemiological cancer studies of cohorts irradiated in association with the use and testing of nuclear weapons, and from radiation accidents, workers exposed to radiation, and groups subject to medical exposures (UNSCEAR, 2013).

Potential cancer risk at very low doses, including those resulting from natural background radiation, is, in general, too low to be determined in observational (epidemiological) studies. However, experimental studies have shown that DNA damage can also be induced at very low doses. Depending on the type of cancer, the latency period can range from 2 to 30 years. Thyroid and bone cancer, and leukemia can appear within a few years of radiation exposure, whereas most types of cancer are not expressed until at least 10 years after exposure (VKM, 2017).The study aims to determine the concentration of some natural and artificial radionuclides in the pre-mix package beverage, estimate the annual effective dose and associated cancer risk that arise from the consumption of pre-mix beverages among Malaysian adults (> 17 y), based on Malaysian consumption study and the concentration of radionuclides found in the beverages.

EXPERIMENTAL DETAILS

Activity concentration of radionuclides

Activity concentration of natural (^{40}K, ^{226}Ra, ^{228}Ra, ^{232}Th, ^{238}U) and artificial (^{134}Cs, ^{137}Cs) radionuclides reported in this article was based on measurement from a total of twenty-two different beverage samples using the same unit of HPGe gamma spectrometry for 15 hours each. The sample was prepared in a 350 ml cylindrical container, sealed with PVC tape and stored for a month to achieve secular equilibrium. Equipment set-up and radionuclides identification are the same as reported earlier in Yii (2019). The reference material IAEA-Soil-6 was used as quality control evaluation. If measurement values for the reference material were within the 95% confidence level (as stated in the certificate), the results of samples will be accepted. The minimum detectable activities (MDA) following the Currie Limit method set for ^{40}K was 5 Bq/kg, for ^{226}Ra, ^{228}Ra, ^{232}Th and ^{238}U was 0.5 Bq/kg, and for ^{134}Cs and ^{137}Cs was 1.0 Bq/kg, respectively, after considering the sample size and counting time (Wan-Mahmood et al., 2016). However, some samples having lighter density will expected to give higher detection limit. Measured samples were 3-in-1coffee (including white coffee), chocolate drinks and black coffee available from local markets.

Calculation of annual effective dose

The annual effective dose due to the intake of radionuclides in foods can be calculated using the Formula given by (Till and Moore, 1988; Alam et al.,1999; UNSCEAR, 2000) as follows:

$$\mathbf{A_D = A_C * C_F * A_I} \quad \ldots \text{Eq (1)}$$

Where:
A_D is the annual effective dose (Sv/y) to an individual due to the ingestion of radionuclides,
A_C is the activity concentration of radionuclides in the ingested beverages (Bq/kg),
C_F is the dose conversion factor for ingested radionuclides (Sv/Bq) (ICRP, 1995), and
A_I is the annual intake of pre-mix beverages (kg/y) for Malaysians (IPH, 2014).

The conversion factor 'CF' varies depending on both radionuclides and the age of the individual based on the publication by ICRP (ICRP, 1995; ICRP, 2012). For the dose calculation, the total dose was obtained by using the sum of contributions for the radionuclides in the samples with the recommended conversion factors given by ICRP (ICRP, 1995; ICRP, 2012) as in Table 1.

Table 1: Dose conversion factors for radionuclides (^{40}K, ^{226}Ra, ^{228}Ra, ^{232}Th, ^{238}U, ^{134}Cs, ^{137}Cs) in adults

Radionuclides	Dose conversion factors (Sv/Bq)
^{40}K	6.2×10^{-9}
^{226}Ra	2.8×10^{-7}
^{228}Ra	6.9×10^{-7}
^{232}Th	2.3×10^{-7}
^{238}U	4.5×10^{-8}
^{134}Cs	1.9×10^{-8}
^{137}Cs	1.3×10^{-8}

Annual effective dose arises from food consumption strongly dependent on the amount of food consumed (Alzahrani, 2012; Kolapo, 2014). In this study, the amount of beverage powder consumed by adults in Malaysia was estimated to be 18.9 kg/y (for samples 1 – 15) based on a survey conducted by the Institute for Public Health of Malaysia (IPH) (IPH, 2014). Black coffee consumed was estimated to be three packs per day of 4.9 kg/y (for samples 16 – 22).

Calculation of relative cancer risk

Since the results of radiation effects on cell cultures, animal studies, and human epidemiology studies may be interpreted differently, variations are found in the published relative risk values, but they are within a few percentage points of each other (Peck and Samei, 2017). According to Lin (2010), one Sievert carries a 5% excess death risk from cancer and this is extrapolated linearly for lower doses. In this article, the effective dose from consumption of each sample and the 5% chance of cancer risk was used for the calculation of cumulative dose and risk up to the age of 70 years for the public. The calculation was performed using an online calculation spreadsheet provided under the Wise Uranium project. The cancer risk for 1 mSv/y exposure is equivalent to 350 cases per 100,000 people (Wise, 2018).

RESULTS AND DISCUSSION

Activity concentration of radionuclides

The measured activity concentrations of ^{40}K, ^{226}Ra, ^{228}Ra, ^{232}Th, ^{238}U, ^{134}Cs, and ^{137}Cs in the twenty-two beverage samples under the present study were summarized in Table 2. It can be noticed that ^{40}K was detected in all samples and was one to three orders of magnitudes higher when compared to the other radionuclides in the sample. It varied between 63 – 1360 Bq/kg (mean 601 Bq/kg). Meanwhile, the activity concentration for other natural radionuclides of ^{226}Ra, ^{228}Ra, ^{232}Th, and ^{238}U, was ranged between 0.88 – 6.43 Bq/kg (mean 2.46 Bq/kg), 0.83 – 8.48 Bq/kg (mean 3.11 Bq/kg), 0.62 – 5.73 Bq/kg (mean 2.29 Bq/kg) and 2.64 – 21.49 Bq/kg (mean 7.62 Bq/kg), respectively.

Table 2 : Concentration of radionuclides (^{40}K, ^{226}Ra, ^{228}Ra, ^{232}Th, ^{238}U, ^{134}Cs, ^{137}Cs) in individual pre-mix beverage

No	Type	Activity concentration (Bq/kg)						
		^{40}K	^{226}Ra	^{228}Ra	^{232}Th	^{238}U	^{134}Cs	^{137}Cs
1	3 in 1 coffee	384 ± 32	<1.38	<1.28	<0.96	5.56 ± 0.57	<1.00	<1.00
2	3 in 1 coffee	517 ± 43	3.35 ± 0.28	2.36 ± 0.21	1.71 ± 0.15	5.47 ± 0.42	<1.00	<1.00
3	3 in 1 coffee	276 ± 23	<1.00	<0.93	<0.70	2.75 ± 0.29	<1.00	<1.00
4	3 in 1 coffee	263 ± 22	1.54 ± 0.13	2.82 ± 0.24	1.94 ± 0.17	3.61 ± 0.36	<1.00	<1.00
5	3 in 1 coffee	258 ± 21	0.94 ± 0.08	<0.84	<0.63	3.96 ± 0.38	<1.00	<1.00
6	3 in 1 coffee	275 ± 23	<0.88	<0.83	<0.62	3.26 ± 0.30	<1.00	<1.00
7	3 in 1 coffee	322 ± 27	<0.99	1.50 ± 0.13	1.34 ± 0.11	5.31 ± 0.49	<1.00	<1.00
8	3 in 1 coffee	292 ± 24	1.74 ± 0.15	2.35 ± 0.21	1.74 ± 0.15	4.51 ± 0.51	<1.00	<1.00
9	3 in 1 white coffee	63 ± 5	4.30 ± 0.36	3.60 ± 0.31	2.67 ± 0.23	8.14 ± 0.90	<1.00	<1.00
10	3 in 1 white coffee	392 ± 33	<1.71	3.75 ± 0.32	2.82 ± 0.24	5.94 ± 0.71	<1.00	<1.00
11	3 in 1 Espresso	463 ± 38	4.53 ± 0.37	5.10 ± 0.44	3.41 ± 0.29	11.31 ± 1.19	<1.00	<1.00
12	Choc drink	392 ± 32	<0.93	1.54 ± 0.14	1.27 ± 0.11	2.64 ± 0.27	<1.00	<1.00
13	Choc drink	360 ± 30	1.10 ± 0.09	1.00 ± 0.08	0.96 ± 0.08	3.46 ± 0.38	<1.00	<1.00
14	Choc drink	376 ± 31	<0.91	1.29 ± 0.12	1.08 ± 0.09	4.56 ± 0.46	<1.00	<1.00
15	Choc drink	386 ± 32	0.98 ± 0.08	2.67 ± 0.23	1.92 ± 0.16	4.91 ± 0.56	<1.00	<1.00

16*	Black coffee	1327 ± 108	3.72 ± 0.31	8.48 ± 0.73	5.73 ± 0.49	14.66 ± 1.42	<1.00	1.46 ± 0.27
17*	Black coffee	958 ± 79	<2.08	3.18 ± 0.28	1.96 ± 0.18	9.50 ± 1.05	<1.00	<1.00
18*	Black coffee	1360 ± 111	4.09 ± 0.34	7.51 ± 0.65	5.48 ± 0.47	15.71 ± 1.68	<1.00	1.17 ± 0.22
19*	Black coffee	1258 ± 102	2.87 ± 0.24	4.80 ± 0.41	3.41 ± 0.29	11.92 ± 1.09	<1.00	1.04 ± 0.19
20*	Black coffee	1345 ± 110	6.43 ± 0.53	3.19 ± 0.27	2.47 ± 0.21	21.49 ± 2.33	<1.00	1.75 ± 0.32
21*	Black coffee	895 ± 74	<2.80	<2.84	<2.16	<5.12	<1.00	<1.00
22*	Black coffee	1053 ± 86	5.89 ± 0.48	6.67 ± 0.56	5.49 ± 0.45	13.91 ± 1.17	<1.00	<1.00
	Range	63 – 1360	0.88 – 6.43	0.83 – 8.48	0.62 – 5.73	2.64 – 21.49	< 1.00	1.00 – 1.75

Remarks: Samples marked with '*' are sugar free black coffees where quantity consumed was different.

Most of these radioactivities values are significantly lower than the mean levels reported by UNSCEAR (2000) in soil (33 and 45 Bq/kg for ^{226}Ra and ^{232}Th, respectively). Meanwhile, the activity concentration for the artificial radionuclides of ^{134}Cs and ^{137}Cs was <1.00 Bq/kg and 1.00 – 1.75 Bq/kg (mean 1.06 Bq/kg), respectively. The obtained results are compared with the reported data in the literature as presented in Table 3. Generally, radioactivities found in the present study are higher than the values reported by Al-Alawy et al. (2020) but comparable to the study carried out by Kamal et al. (2015) and lower than those reported by Alharbi and Alamoudi (2017).

In this study, it was found that in most of the beverages, the concentration of ^{40}K accounted for more than 95% of the total gamma activity. However, in sample no. 9, it was found that ^{40}K only accounted for 75% of the total gamma activity. Radionuclides are believed to be transferred from the soil to plants, then to the final products (UNSCEAR, 2008; Al-Alawy et al., 2020).

Meanwhile, higher radioactivities were found in black coffee samples no. 16, 18, 19, and 20. These coffees are pre-mixed coffee with Ganoderma extract. Ganoderma, as a fungus is believed to absorb nutrients and minerals from its host and the environment. They accomplish this by growing through and within the substrate on which they are fed. Numerous hyphae network through the wood, cheese, soil, or flesh from which they are growing (UCMP, 2022).

Table 3: Comparison of the radionuclides activity concentrations (Bq/kg) of the present study with other literatures in coffee

Region	^{40}K	^{226}Ra	^{228}Ra	^{232}Th	^{238}U	^{134}Cs	^{137}Cs	Reference
Malaysia	63 – 1360	0.88 – 6.43	0.83 – 8.48	0.62 – 5.73	2.75 – 21.49	< 1.00	1.00 – 1.75	Present study
Malaysia	(429.4 ± 305.5)	(2.1 ± 0.7)		(2.2 ± 0.3)	(1.8 ± 0.2)			Kamal et al. (2015)
Iraq	93.8 – 183.2			0.36 – 3.21	1.63 – 8.34		0.27 – 0.48	Al-Alawy et al. (2020)
Arabian coffee	840 – 1197	2.57 – 10.63		ND – 8.01	ND – 135.11		ND	Alharbi and Alamoudi (2017)
Turkish coffee	161 – 2411	ND – 10.09		ND – 9.75	ND – 57.16		ND	Alharbi and Alamoudi (2017)

Remarks: ND – Non-Detectable; Value in bracket is average value.

Annual effective dose

The total annual effective dose (sum of total radioactivity dose) for adults who consumed the pre-mix beverages was presented in Table 4. The calculation was performed with Eq. 1 above by using the quantity of beverage powder consumed in a year (18.9 kg/y for samples 1 – 15, and 4.9 kg/y for samples 16 – 22) multiplied by the sum of the total dose per year obtained for each radionuclide concentration (Table 2) and the dose conversion factor (Table 1). From the results presented in Table 4, we could find that the annual effective dose ranged between 44.6 – 170.0 µSv/y. All samples except samples no. 2, 10 and 11 are having an effective dose of less than 100 µSv/y. Therefore, consumption of these pre-mix beverages would be considered to present an insignificant health hazard to human.

As mentioned above, ^{40}K accounted for most of the total gamma activity in the sample. Since potassium is an essential element for humans and it is absorbed mainly from the ingested food. There is no legislation governing ^{40}K since it cannot be eliminated, and consumption of foods also does not significantly alter the potassium content, hence the potassium radioactivity inside the body (Stansfield, 2003; WHO, 2017). Under such consideration, the contribution of ^{40}K to the total effective dose can then be ignored and subtracted. From the current study, ^{40}K concentration in all samples, was found to contribute about 30 – 60% of the total dose except for sample no. 9, which is only having an 8% dose contribution from the ^{40}K. Figure 1 presented the total dose with and without considering the contribution from ^{40}K. After subtracting the contribution of ^{40}K, most samples will have an effective dose of less than 100 µSv/y except sample no. 11. Overall, it appears that the estimated annual dose from the consumption of pre-mix beverages is below the reference value of 1.0 mSv as recommended by ICRP (ICRP, 1995).

Table 4: Estimated effective dose and excess lifetime cancer risk after consumption of various beverages

Sample No	**Effective dose (µSv/y)**	**Excess lifetime cancer risk (case per 100,000)**
1	78.6	28 @ (1:3635)
2	121.9	43 @ (1:2344)
3	55.9	20 @ (1:5111)
4	87.9	31 @ (1:3250)
5	52.9	19 @ (1:5401)
6	53.7	19 @ (1:5321)
7	73.4	26 @ (1:3893)
8	86.2	30 @ (1:3315)
9	96.3	34 @ (1:2967)
10	121.9	43 @ (1:2344)
11	170.0	59 @ (1:1681)
12	81.3	28 @ (1:3514)
13	68.8	24 @ (1:4153)
14	75.0	26 @ (1:3810)
15	98.5	34 @ (1:2901)
16*	84.5	30 @ (1:3381)
17*	47.5	17 @ (1:6015)
18*	82.7	29 @ (1:3455)
19*	65.4	23 @ (1:4369)
20*	68.6	24 @ (1:4165)
21*	44.6	16 @ (1:6406)
22*	72.5	25 @ (1:3941)
Range	44.6 – 170.0	16 – 59 cases per 100,000 people

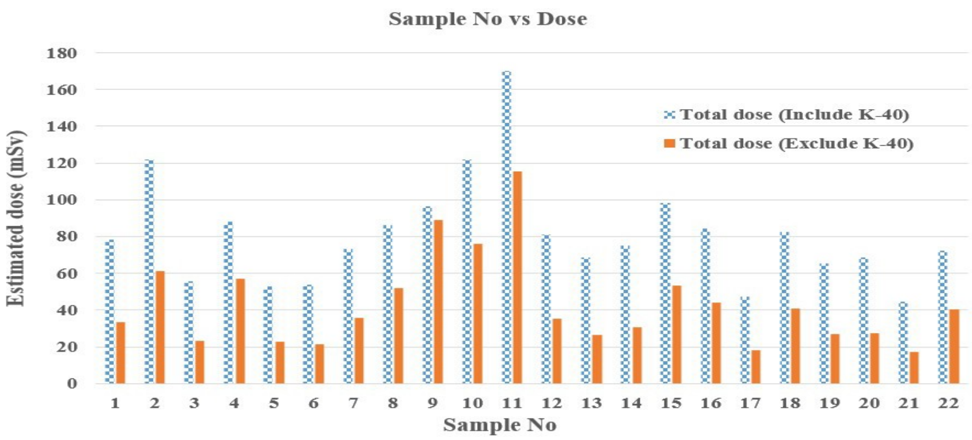

Figure 1: The estimated effective dose for individual samples, with and without the contribution from ^{40}K.

Excess lifetime cancer risk

From the estimated effective dose value, the cumulative lifetime cancer risk was calculated and presented in Table 4. Sample no. 11 shows the highest effective dose of 170.0 µSv/y with the potential risk of cancer occurrence is 59 cases in every 100,000 people. Radiation hazards associated with drinking this particular beverage may face greater health risks as compared to the others. Meanwhile, estimated doses ranged between 44.6 – 121.9 µSv/y if consuming other samples, which corresponds to the cancer risk occurrence of 16 – 43 case per 100,000 people. This cancer risk probability is comparable to the 14.4 – 18.1 cases per 100,000 as reported by Moon et al. (2016) for a study conducted in Korea but is lower when compared to cancer risk as reported by Priharti and Samat (2016) for Malaysian adults due to the intake of vegetables (81.3 case per 100,000) and fruits (68.3 case per 100,000).

CONCLUSIONS

In this study, the concentrations of some natural and artificial radionuclides in pre-mix beverages were measured. Based on the Malaysian adults' consumption rate of pre-mix beverages, the annual cumulative internal dose due to the beverage intake was calculated. In general, the largest contributor to the dose arising from the ingestion of beverages by people was due to the presence of natural radionuclides, particularly the ^{40}K, which is also an essential constituent of human cellular tissue. The total annual effective dose in an adult due to the ingestion of all radionuclides was estimated along with the excess lifetime cancer risk. From the calculation, the estimated doses ranged between 44.6 to 170.0 µSv/y which corresponds to the probability of cancer risk between 16 – 59 cases per 100,000 people. The highest cancer risk concern arises from the consumption of sample no. 11 with 59 cases in every 100,000 people. When the accumulated dose is higher, so do the cancer risk. Overall, the dose received by the population is still below the 1 mSv/y recommended limit by WHO and ICRP for radiological safety. Cooperation with the local authorities can be helpful for this study to collect more varieties of pre-mix beverage samples that should be tested in future to ensure that they are safe for consumption by Malaysian.

ACKNOWLEDGEMENTS

The authors would like to express special appreciation to the Malaysian Nuclear Agency. This study is part of the project "Malaysia's Foods – The Radioactivity Concentrations, Annual Effective Dose and Cancer Risk, NM- R&D-20-38." The authors are also thankful to the staff in the group for their kind cooperation and support during the implementation of this study.

REFERENCES

Afshari, N.S., Abbasisiar, F., Abdolmaleki, P. and Nejad, M.G. (2009). Determination of ^{40}K concentration in milk samples consumed in Tehran-Iran and estimation of its annual effective dose, Iran. *J. Radiat. Res.* 7:159–164.

Al-Alawy, I.T., Nasser, H.J. and Mzher, O.A. (2020). Natural Radionuclide Activity Concentrations and Radiological Hazard in Tea, Coffee, Wheat Fluor, and Powder Milk Consumed in Iraqi Markets, *AIP Conf. Proc.* 2213:020225.

Alam, M.N., Chowdhury, M.I., Kamal, M., Ghose, S., Islam, M.N. and Anwaruddin, M. (1999). Radiological assessment of drinking water of the Chittagong region of Bangladesh, *Radiat. Prot. Dosimetry* 82:207–214.

Alamoudi, Z.M. (2013). Assessment of Natural radionuclides in Powdered milk Consumed in Saudi Arabia and Estimates of the Corresponding annual Effective Dose, *J. Am. Sci.* 9:267–273.

Alharbi, W.R. and Alamoudi, Z.M. (2017). Radiological hazard of coffee to humans: a comparative study of Arabian and Turkish coffees, *Afr. J. Agric. Res.* 12(5):327–341.

Alharshan, G.A., Aloraini, D.A., Al-Ghamdi, H., Almuqrin, A.H., El-Azony, K.M. and Alsalamah, A.S. (2017). Measuring the Radioactivity Concentration of ^{40}K and ^{137}Cs and Calculating the Annual Internal Doses from Ingesting Liquid and Powdered Milk, *Radiochemistry* 59:98–103.

Alzahrani, J.H. (2012). Natural Radioactivity and Heavy Metals in Milk Consumed in Saudi Arabia and Population Dose Rate Estimates, *Life Sci.* 9:651–656.

Baeza, A., Corbacho, J.A. and Miro, C. (2004). Temporal evaluation of natural and man-made radioactivity levels in milk samples: dosimetry implications, *Bull. Environ. Contam. Toxicol.* 72:547–556.

Desideri, D., Meli, M.A., Roselli, C., Forini, N., Rongoni, A. and Feduzi, L. (2014). Natural radionuclides in Italian diet and their annual intake, *J. Radioanal. Nucl. Chem.* 299:1461–1467.

Godyn´, P., Dołhan´czuk-S´ro´dka, A., Ziembik, Z., Moliszewska, E. (2014). Estimation of the committed radiation dose resulting from gamma radionuclides ingested with food, *J. Radioanal. Nucl. Chem.* 299:1359–1364.

Institute for Public Health (2014). National Health and Morbidity Survey 2014: Malaysia Adult Nutrition Survey (MANS) T. Aris, A.A. Zainuddin, N.A. Ahmad and N. Yoep (eds.). Vol. III: Food Consumption Statistics of Malaysia, *Ministry of Health Malaysia*, Kuala Lumpur, 143.

IARC. (2012). Monographs on the Evaluation of Carcinogenic Risks to Humans Volume 100D, Radiation, *WHO*, Lyon, 363.

IAEA. (1989). Measurement of Radionuclides in Food and the Environment, Tech. Rep. Series No. 295, *IAEA*, Vienna, 169.

ICRP. (1995). Age - dependent Doses to Members of the Public from intake of Radionuclides - Part 5: Compilation of Ingestion and Inhalation Coefficients, ICRP Publication 72, Ann. ICRP 26 (1), *Pergamon*, Oxford.

ICRP. (2012). Compendium of Dose Coefficients based on ICRP Publication 60. ICRP Publication 119, Ann. ICRP 41(Suppl.) *Elsevier*, Essen.

Jemii, E. and Mazouz, M. (2020) Measurement of Radioactivity in Carbonated Soft Drinks and Annual Dose Assessment, *J. Environ. Prot. Sci.* 11:682–689.

Kamal, N.N.H.K., Khalid, N., Bahri, C.N.A.C.Z. and Majid, A.A. (2015). Determination of radionuclide activity and radiological impact from the intake of milk, wheat flour, tea and coffee, *Malaysian J. Anal. Sci.* 19(2):300–308. (In Malays).

Kolapo, A.A. (2014). Assessments of Natural Radioactivity and Heavy Metals in Commonly Consumed Milk in Oke-Ogun Area, Nigeria and Estimation of Health Risk Hazard to the Population, *J. Environment. Analytic. Toxicol.* 4:253–257.

Lin, E.C. (2010). Radiation Risk from Medical Imaging, *Mayo Clin. Proc*. 85(12):1142–1146.

Wan-Mahmood, Z., Yii, M.W., Khalid, M.A., Kontol, K.M., Ishak, A.K. and Yusof, M.A.W. (2017). Assessment of natural radioactivity level and radiological index in the vicinity of Lynas rare-earth processing plants, *ASEAN J. Sci. Technol. Dev.* 34:67–78.

Moon, E.K., Ha, W.H., Seo, S.W., Jin, Y.W., Jeong, K.H., Yoon, H.J., Kim, H.S., Hwang, M.S., Choi, H. and Lee, W.J. (2016). Estimates of Radiation Doses and Cancer Risk from Food Intake in Korea, *J. Korean Med. Sci.* 31:9– 12.

Peck, D.J. and Samei, E. (2017). How to Understand and Communicate Radiation Risk. Access online on 04th December 2018 at *The American College of Radiology*. Retrieved from https://www.imagewisely.org/Imaging- Modalities/Computed-Tomography/How-to-Understand-and-Communicate-Radiation-Risk.

Priharti, W. and Samat, S.B. (2016). Radiological risk assessment from the intake of vegetables and fruits in Malaysia, *Malays. J. Anal. Sci.* 20(6):1247–1253.

Priharti, W. and Samat, S.B. (2017). Evaluation of Natural Radionuclides ^{226}Ra, ^{232}Th and ^{40}K Activity Concentration in Food at the Central Area of Malaysia, *Sains Malays.* 46:945–951. (In Malays).

Rao, D.D. (2012). Radioactivity in human body and its detection, *Radiat. Prot. Environ.* 35:57–58.

Sahar, A.A., Al-kafaje, M.S.M. and Al-Ani, R.R. (2016). Assessment of Natural radionuclides in Powdered milk Consumed in Iraq, *J. Nat. Sci. Res.* 6:112–115.

Stansfield, C.M. (2003) Legislation - Contaminants and Adulterants. In: Encyclopedia of Food Sciences and Nutrition, B. Caballero, P. Finglas and F. Toldra (eds). 2nd edn, *Academic Press,* London, 3507–3513.

Till, J.E. and Moore, R.E. (1988). A pathway analysis approach for determining acceptable levels of contamination of radionuclide in soil, *Health Phys.* 55:541–548.

UNSCEAR. (2000). United Nations Scientific Committee on the Effects of Atomic Radiation, Sources, Effects and Risks of Ionizing Radiation. *United Nations*, New York.

UNSCEAR. (2008). United Nations Scientific Committee on the Effects of Atomic Radiation, Sources, Effects and Risks of Ionizing Radiation. *United Nations*, New York.

UNSCEAR. (2013). Levels and effects of radiation exposure due to the nuclear accident after the 2011 great east-Japan earthquake and tsunami, Annex A Sources, effects and risks of ionizing radiation, Report to the General Assembly with Scientific Annexes. *United Nations*, New York.

University of California Museum of Paleontology (2022). Fungi: Life History and Ecology. Access online on 05th April 2022. Retrieved from https://ucmp.berkeley.edu/fungi/fungilh.html#:~:text=Fungi%20are%20 heterotrophic.,on%20which%20 they%20are%20feeding.

Uwatse, O.B., Olatunji, M.A., Khandaker, M.U., Amin, Y.M., Bradley, D.A., Alkhorayef, M. and Alzimami, K. (2015). Measurement of Natural and Artificial Radioactivity in Infant Powdered Milk and Estimation of the Corresponding Annual Effective Dose, *Environ. Eng. Sci*. 32:1–9.

VKM, Alexander, J., Brantsæter A.L., Brunborg, G., Fæste, C.K., Jaworska, A., Komperød, M., Lillegaard, I.T.L., Rosseland, C., Skuterud, L., Andersen, L.F., Elvevoll, E.O., Hjeltnes, B., Hofshagen, M., Krogdahl, Å., Källqvist, T., Opsahl-Sorteberg, H.G., Rafoss, T., Skaar, I., Skåre, J.U., Steffensen, I-L., Vandvik, V., Wasteson, Y. and Hemre, G-I. (2017). Risk assessment of radioactivity in food. Opinion of the Scientific Steering Committee of the Norwegian Scientific Committee for Food Safety (2017). VKM report 2017:25, *VKM*, Oslo, 150.

Wise Uranium project (2022). Radiation Risk to Dose Converter. Access online on 05th April 2022. Retrieved from http://www.wise-uranium.org/rdcri.html.

WHO. (2017). Guidelines for Drinking -water Quality, 4^{th} edn. (Incorporating the first addendum), *WHO*, Interligar, 631.

Yii, M.W. (2019). Measurement of activity concentrations in powdered milk and estimation of the corresponding annual effective dose, *J. Radioanal. Nucl. Chem*. 320 (1):193–199.