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Determination of Radiation Hazard Arising from the ^{40}K Content of Bottled Mineral Water in Malaysia

(Penentuan Sebarang Bahaya Sinaran yang Timbul daripada Kandungan ^{40}K dalam Air Mineral Botol di Malaysia)

S.B. SAMAT* & C.J. EVANS

ABSTRACT

Eleven different brands of mineral water available in Malaysia were assessed in comparison with two criteria for ingested radiation dose. It is concluded that mineral water can only contribute a very small fraction of the typical daily intake of potassium, and that the radiation dose acquired from any of the brands can never exceed a small fraction of the recommended limits.

Keywords: Malaysia; mineral water; potassium–40

ABSTRAK

Sebelas jenama air mineral yang terdapat di Malaysia dinilai, secara perbandingan dengan dua kriteria untuk dos sinaran pemakanan. Disimpulkan air mineral hanya boleh menyumbang pecahan yang sangat kecil daripada kaliam harian biasa yang diambil oleh badan, dan dos sinaran yang diperolehi daripada mana-mana jenama tidak akan melebihi satu pecahan kecil had yang disyorkan.

Kata kunci: Air mineral; kaliam-40; Malaysia

INTRODUCTION

The report of UNSCEAR (2000) stated that doses of internal exposure from the intake of terrestrial radionuclides by ingestion are mainly due to ^{40}K and to the ^{238}U and ^{232}Th series present in foods and drinking water. The report also gives the average world wide exposure to natural radiation sources, namely 0.17 mSv/y for ingestion exposure of ^{40}K and 0.12 mSv/y for ingestion exposure of uranium and thorium series.

The present work investigates eleven brands of bottled mineral water for drinking that are commercially available in Malaysia. On the label of these bottles, a list of minerals that are present in the water is given, with their average concentration in mg/L. Among the three terrestrial radionuclides mentioned above namely potassium (K), uranium (U) and thorium (Th), only K is listed with other non-terrestrial radionuclide minerals. Minerals like U and Th are assumed not present in the eleven brands of the bottled mineral water as they are not listed on the labels.

K is an abundant element in the earth's crust and is an essential nutrient for all forms of life, although it can be toxic in large concentrations. Unfortunately, K is also radioactive because of a small proportion (0.0117%) of ^{40}K, and this presents a small radiation hazard. Therefore bottled mineral water for human consumption has to satisfy the specified restriction on the ingestion dose rate. This is given by either one the following two criteria, on the basis that an adult drinks 2 litres of water per day, or 730.5 litres per year (by taking 365.25 days/year): Criterion I (WHO 2004): the ingestion dose rate of ^{40}K should not exceed 0.1 mSv/y with the ^{40}K ingestion dose coefficient of 5×10^{-6} mSv/Bq, or Criterion II (Roessler 2009): the ingestion dose rate of ^{40}K should not exceed 0.04 mSv/y with the ^{40}K ingestion dose coefficient of 6.2×10^{-6} mSv/Bq. Two other reports (Delacroix et al. 2002; ICRP 1996) have also reported the ingestion dose coefficient of 6.2×10^{-6} mSv/Bq, but no values of permissible ingestion dose rate were given.

For the two criteria, the permissible limit of potassium concentration may be calculated as follows:

(i) For Criterion I:
Let D_{L-I}, I_{DC-I}, I_y, and $A_{SP,}$ respectively be the permissible ingestion dose rate for criterion I (= 0.1 mSv/y), ingestion dose coefficient for potassium for adults (= 5×10^{-6} mSv/Bq) for Criterion I, the ingested drinking water per year at the rate 2 litres per day (= 730.5 L/y) and the specific activity of ^{40}K per g of natural potassium (= 30.7 Bq/g of K ,WHO (2004)). If C_{L-I} is the permissible limit of potassium concentration for criterion I, $C_{L-I} = D_{L-I}/(I_{DC-I} \times I_y \times A_{SP})$ = 891.81 mg/L. Multiplying this value with 2 l/d (water consumed per day), we get the daily potassium intake of 1.7836 g of K per day.

(ii) For Criterion II.
Similarly, we now take D_{L-II} = 0.4 mSv/y, I_{DC-II} = 6.2×10^{-6} mSv/Bq, I_y = 730.5 L/y, and A_{SP} = 30.7 Bq/g of K. For criterion II, $C_{L-II} = D_{L-II}/(I_{DC-II} \times I_y \times A_{SP})$ = 287.68 mg/L This gives the daily intake of potassium

of 0.5754 g of K per day, which is in agreement with Roessler (2009).

The objective of this work was to determine whether the eleven brands of bottled mineral water, consumed in Malaysia, that contain radioactive ^{40}K, are of an appropriate quality for human consumption. Based on the K concentration per litre stated on the bottle's label, this work is to check whether they exceed: (a) the permissible K concentration limit of 891.81 mg/L (for criterion I) or 287.68 mg/L (for criterion II), (b) the permissible ingestion dose rate of 0.1 mSv/y (for criterion I), or 0.04 mSv/y (for criterion II), (c) the daily intake of K of 1.7836 g/d (for criterion I) or 0.5754 g/d (for criterion II). Checks on (b) and (c) above are based on an adult's consumption of 2 litres of water per day. As these three checks are dependent and are all calculated from the same basic data, a water sample is of an appropriate quality if it passes one of them (as it will automatically pass the other two).

MATERIALS AND METHODS

Table 1 gives the water source location and the K concentrations for the eleven brands of the bottled mineral water. They are in the range of 0.56 to 4.3 mg/L. In doing all the three checks, we take the highest K concentration. This belongs to bottle no. *b7*, with concentration of 4.3 mg/L. In this case C_{b7} = 4.3 mg/L. Table 1 also gives the K concentrations for criteria I and II for comparison purposes.

CALCULATIONS AND DISCUSSION

Check on the permissible K concentration limit. As shown in Table 1, 4.3 mg/L is very much smaller than 891.81 mg/L (for criterion I) or 287.68 mg/L (for criterion II). The K concentration for *b7* therefore passes this check.

Check on the permissible ingestion dose rate. Let us assume D_{b7} is the ingestion dose due to *b7*.

i) For Criterion I
$D_{b7\text{-}I} = C_{b7} \times I_{DC\text{-}I} \times I_y \times A_{SP}$ = 4.3 mg/L × 5×10^{-6} mSv/Bq × 730.5 L/y × 30.7 Bq/g = 0.482 µSv/y. In comparison with the permissible dose of this criterion, it is only 0.48% (= 100% × $D_{b7\text{-}I}$ / $D_{L\text{-}I}$, where $D_{L\text{-}I}$ = 0.1 mSv/y).

ii) For Criterion II
Similarly, $D_{b7\text{-}II} = C_{b7} \times I_{DC\text{-}II} \times I_y \times A_{SP}$ = 4.3 mg/L × 6.2×10^{-6} mSv/Bq × 730.5 L/y × 30.7 Bq/g =

TABLE 1. Radioactive ^{40}K in drinking-water. Determination whether the water is of an appropriate quality for human consumption

Water source location	Bottle No.	Brand name (content mL)	Amount of K stated on the bottle's label (mg/L)	Drinking 2 litres of water per day: Calculated amount of K (g/d)	Calculated ^{40}K dose (µSv/y) and its percentage (%) to the annual dose limit, according to the specified criterion: Criterion I	Criterion II
Lot 5043, kg. Sompo, Jalan Setul Lenggeng, 71750 Lenggeng, Negeri Sembilan	*b1* *b2* *b3* *b4* *b5* *b6*	Aquarius(600) Mountain (500) Daisy Springs (500) Royal Spring (500) Bleu (600) Segar (500)	2	0.004	0.224, 0.22	0.278, 0.70
Kg. Titi Akar, sungai Tiang, 06750 Pendang, Kedah	*b7*	Marriott Putrajaya (500)	4.3	0.0086	0.482, 0.48	0.598, 1.49
Lot 919, Mukim Batang Kali, daerah Hulu Selangor, 44300 Selangor	*b8*	TRUE (500)	0.56	0.00112	0.063, 0.06	0.078, 0.19
Lot 904, Jalan Reservoir, Off Jalan Air Kuning, 34000 Taiping, Perak	*b9*	Spritzer (500)	2.7	0.0054	0.303, 0.30	0.375, 0.94
PTD 6386, Bukit Jintan, Mukim Tanjong Sembrong (VII), Batu Pahat, Johor	*b10*	Cactus (500)	1.6	0.0032	0.179, 0.18	0.222, 0.56
PT 4911, Jalan Reservoir, Off Jalan Air Kuning, 34000 Taiping, Perak	*b11*	Vistana Hotel (Spritzer) (500)	3.5	0.007	0.392, 0.39	0.487, 1.22
			891.81$^{(a}$	1.7826	100, 100	–
			287.68$^{(b}$	0.5754	–	40, 100

(a) & (b) These are the amounts of K if the dose limits for Criterion I and Criterion II are to be met.

0.598 μSv/y. In comparison with the permissible dose of this criterion, it is only 1.49% (= 100% × $D_{b7\text{-}II}$ / $D_{L\text{-}II}$, where $D_{L\text{-}II}$ = 0.04 mSv/y). As the ingestion dose rate of *b7* is less than 1.5% of the permissible limit specified by the two criteria, therefore the *b7* K concentration passes this check.

It would be useful to calculate the amount of water in *b7* that one needs to consume so that the ingestion dose rate could reach the permissible limit. For criterion I: Since the dose acquired from consuming 2 litres per day is only 0.48% of the recommended limit, it follows that, in order to achieve the dose limit, it would be necessary to consume 2 × 100/0.48 = 416.67 L/day. If each bottle contains 500 mL, the number of bottles that one needs to drink per day to reach this permissible ingestion dose rate is Z_y = (416.67 L/d)/0.5 L/bottle) = 833.3 bottle/d. This is certainly impossible. For criterion II: Similarly, in order to achieve the dose limit, it would be necessary to consume 2 × 100/1.49 = 134.2 L/day. This is equivalent to drinking 268.5 of the 500 mL bottles per day. This is impossible too.

Check on the daily intake of K For one year, this intake $K_{i\text{-}y} = C_{b7} \times I_y$ = 4.3 mg/L × 730.5 L/y = 3.14115 g/y. Or for one day, this $K_{i\text{-}d} = K_{i\text{-}y}$/365.25 = 0.0086 g/d. As this is much smaller than 1.7836 g/d (for criterion I) or 0.5754 g/d (for criterion II), the daily intake of K for *b7* passes this check. The corresponding results for all eleven brands of bottled mineral water are shown in Table 1: (a) the intake of potassium resulting from drinking 2 L/d, they are in the range of 0.004 – 0.0086 g/day, and (b) to reach the limit specified by criteria I & II they would have to be respectively 1.7826 g/day and 0.5754 g/day.

If these are compared with statement by Roessler (2009) that “The typical daily potassium intake for a reference person is 3.3 g/day (ranging from 1.43 to 6.54 g/day)”, clearly none of the mineral water samples comes anywhere near these values. The whole range of typical daily intake, however, exceeds the limit set by criterion II, and most of the range exceeds the limit set by criterion I. It is reasonable to ask why the reference person is not subjected to an excessive radiation dose from the total potassium consumed in all types of food and drink. The reason is that the body is able to regulate very closely the amount of potassium stored in it (Johansen 2003; Roessler 2009), so that it would be unlikely to be increased appreciably however much additional potassium was consumed.

It is interesting to note here that the dose limits specified by the two criteria for drinking water are quite low, in comparison with (a) the annual dose for ingestion exposure of ^{40}K of 0.17 mSv/y reported by UNSCEAR (2000); they are only 58.82% (= 100×0.1/0.17) for criterion I and 23.53% (= 100×0.04/0.17) for criterion II.; (b) the estimated ^{40}K annual internal body dose of 0.18 mSv/y (Shapiro 1981); they are only 55.56% (= 100×0.1/0.18) for criterion I and 22.22% (= 100×0.04/0.18) for criterion II. The reason is perhaps because there is a distinction between the “base-line” dose – due to the potassium permanently stored in the body – and the “ingestion” dose – due to additional input. Note that this additional input does not only come from drinking water, but also food. The foods that contain ^{40}K are well documented for 38 selected foods (Rutherford 2002); 23 foods (CNS 2008) and 19 foods (OCRWM 2009).

The calculation of the ingestion dose rate due to *b7* ($D_{b7\text{-}I}$ and $D_{b7\text{-}II}$) is similar to the assessment of internal dose (Stabin 2008; Gomez-Ros et al. 2008), that is, it is not free from uncertainty. Blanchardon (2007) has mentioned that one of the two factors that contributed to the large uncertainty in the assessment of internal doses is the assumptions made by the expert. The only source of the uncertainty in the formulae of $D_{b7\text{-}I}$ and $D_{b7\text{-}II}$ is the specific activity of ^{40}K, and in this work, we assume it to be A_{SP} = 30.7 Bq/g (WHO 2004). Slightly different results for $D_{b7\text{-}I}$ and $D_{b7\text{-}II}$ may be obtained if any other values of A_{SP} (in Bq/g) were used such as 30 (Armstrong 2007), 30.18 ± 0.72 (Samat et al. 1997), 30.266 (Johansen 2003; Rutherford 2002), 30.5 (Kramer 2009), 31.00 ± 0.33(Samat et al. 1997), 31.72 (Strom et al. 2009) and 32.0 (CNS 2008).

It is still possible that drinking potassium-rich water can affect the radioactive dose. This could occur if the mineral water acquired its potassium content while percolating through rocks in which the isotopic ratio had been modified by fractionation or biological processes. We can imagine processes that could either enrich the potassium (increase the proportion of ^{40}K) or deplete it (decrease the proportion of ^{40}K). If a large quantity of enriched or depleted potassium was consumed, then some of it would be exchanged with the potassium already in the body, and the radiation dose acquired would be increased or reduced, respectively. Information available in the literature (too many references to list) all seems to point to a fairly consistent composition in which ^{40}K constitutes 0.0117% of the total potassium. Further work is needed to determine whether any mineral water does in fact contain appreciably enriched or depleted potassium.

Conclusion

If the 500 mL bottled mineral water that has highest potassium concentration (4.3 mg/L) were taken as a representative of all the eleven brands of the bottled drinking mineral water, we conclude the following: (a) the annual ingestion dose is very small (that is less than 0.6 μSv/y or less that 1.5% of the permissible dose stated by criteria I and II). The eleven brands of the bottled mineral water therefore are of appropriate quality for long-life human consumption; (b) an adult person could only exceed the recommended radiation limit by: (i) drinking 833 bottles (for criterion I), or 268 bottles (for criterion II) of mineral water a day and (ii) retaining all the potassium in their body.

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S.B. Samat*
School of Applied Physics
Universiti Kebangsaan Malaysia
43600 UKM Bangi, Selangor D.E.
Malaysia

C.J. Evans
Department of Physics
Swansea University
Singleton Park, Swansea SA2 8PP, UK

*Corresponding author; email: sbsamat@ukm.my

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