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Gross alpha, gross beta and Ra-226 activity concentrations in bottled mineral waters sold in Bangkok Metropolitan area and their committed effective dose

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Abstract

The activity concentrations of gross alpha, gross beta, and Ra-226 in some bottled mineral water samples sold in Bangkok Metropolitan area were measured from the view point of internal radiation for Thai consumers. Concentration ranges of gross alpha, gross beta, and Ra-226 in imported bottled mineral, domestic bottled mineral, and domestic bottled drinking water were as follows; for gross alpha, N.D. to 0.09, N.D. to 0.58, and N.D. to 0.17 $Bq.l^{-1}$; for gross beta, N.D. to 0.44, N.D. to 0.45, and N.D. to 0.19 $Bq.l^{-1}$; for Ra-226, 0.51 to 5.919, 0.422 to 9.915, and 0.096 to 0.398 $mBq.l^{-1}$, respectively. On average, brands of domestic bottled mineral water contained the highest Ra-226 activity concentrations compared to those of imported bottled mineral and domestic bottled drinking water. However, all samples contained Ra-226 at concentration lower than the regulation limit for drinking water regulated by Thai Industrial Standard Institute (TISI), World Health Organization (WHO) and US. Environmental Protection Agency (US.EPA). The annual effective dose from intake of Ra-226 in waters to Thai different age groups (<1-17 y of age, and adults) was estimated. Group of infants and teens (10-17 y of age) child received the highest dose compared to all age group from the intake of Ra-226 in domestic bottled mineral water. These doses were approximately 25 times of that from intake of Ra-226 in domestic bottled drinking water and corresponded to 5.67-17% of the annual human exposure to radiation from water consumption (100 μSv) recommended by UNSCEAR (UNSCEAR 1993). Thus even though mineral waters contain useful elements needed especially during the period of maximum growth and development they can increase the risk of high exposures to human body due to ingest of Ra-226. Based on this study, while consumption is not a severe problem now, quality inspection of drinking water should be continued.

Key words : Gross alpha, gross beta, Ra-226, bottled mineral waters, committed effective dose

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Introduction

In Thailand, popularity on consuming of bottled mineral water has recently increased due to the perception that it is cleaner than tap water and can be served immediately. Some consumer believed that it is healthier than normal drinking or tap water because it contains higher minerals contents. However, there is a possibility that mineral water may be contaminated by natural radioactivity more than natural drinking water. This is resulted from that mineral water has long contact time with source rock. The occurrence of radionuclide in such water causes human internal exposure, due to the decay of radionuclide absorbed into the body through ingestion.

Natural radioactivity in mineral water varies over the wide range, mainly depending on the geological characteristics of the rock and soil.[1] However, the most radiotoxic and important among them is radium, which is a known carcinogen and exists in several isotopic forms.[2] High radiotoxicity of Ra-226 in water requires particular attention for human health. Even a small activity in a radioactive substance which can be ingested or inhaled into the body may produce a damaging biological effect and can create a serious health risk.[3] When radium is absorbed into body, its metallic behavior is similar to that of calcium and an appreciable fraction is deposited in the bone, and remaining fraction being distributed almost uniformly in the soft tissues.[4] When people are exposed to very high levels of radium for a long time, it may result in cancer of the bone and the nasal cavity in human beings.

For the general public, nature is the largest source for ionizing radiation in daily life as far as normal background radiation concerned. In 1991, US.EPA regulated 15 $pCi.l^{-1}$ maximum contamination levels for gross alpha activity and 4 $millirem.y^{-1}$ maximum annual effective doses due to contaminated gross beta activity in community water supplies and all non-transient, non-community public water systems.[5] US.EPA also regulated 5 $pCi.l^{-1}$ maximum contamination levels for combined radium (Ra-226 + Ra-228) if the gross alpha activity in water is more than 15 $pCi.l^{-1}$. World Health Organization (WHO)[6] legislation concerning the drinking water except the mineral water is 0.5 (instead of the former 0.1 $Bq.l^{-1}$)[7] and 1 $Bq.l^{-1}$ maximum contamination levels for gross alpha and gross beta activity, respectively. Thai standard for drinking water regulated by Thai Industrial Standard Institute (TISI)[8] is 0.1 and 1.0 $Bq.l^{-1}$ for gross alpha and gross beta activity, respectively. However, Thai standard specified that if in the case that gross alpha activity is exceeded the regulation limit (i.e. 0.1 $Bq.l^{-1}$), water could be considered safe for drinking if the maximum contamination levels for combined radium (Ra-226 + Ra-228) in such water is not more than 0.1 $Bq.l^{-1}$.

In this work, gross alpha, gross beta, and Ra-226 in imported, domestic bottled mineral and domestic bottled drinking water were measured and compared. Annual effective dose for different age group of Thai people due to ingest of Ra-226 were estimated using the ingestion dose conversion factor (DCF) for radionuclide ($Sv.Bq^{-1}$) taken from the annals of the ICRP publication 72.[9] Age-dependent daily water intake (DWI) was obtained from Bronzovic, Maja and Marovic, Gordana 2005.[10]

Materials and Methods

Materials

Five kinds of imported bottled mineral water (IMW), seven kinds of domestic bottled mineral water (DMW), and four kinds of domestic bottled drinking water (DDW) were purchased from supermarket in Bangkok Metropolitan Area during 2004. The countries and provinces, if domestic, of origin of water samples are shown in Table 1. Domestic bottled mineral water and bottled drinking water were produced from 10 provinces covering an area from the northernmost region, Chiang Rai

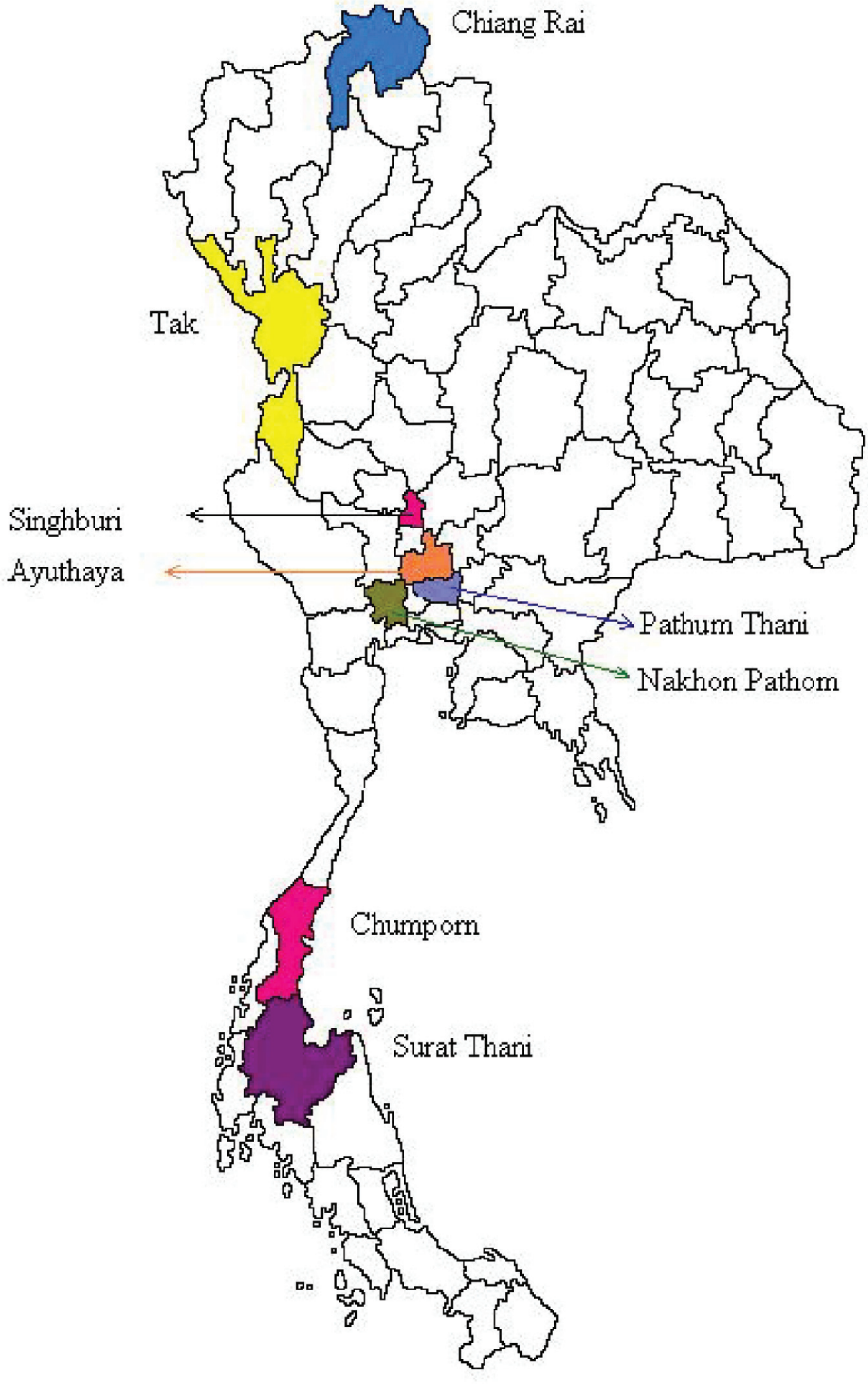

Fig. 1 Sampling locations of domestic mineral bottled water (DMW) and domestic drinking bottled water (DDW)

province, to the southernmost region, Surat Thani province, in Thailand. Locations of origin of domestic bottled mineral water and bottled drinking water are described in Fig. 1.

Analyses of water samples and Standard Reference Materials

Water samples were added with 1 ml conc. HNO_3 per liter of samples before evaporating and

Table 1 Comparison of the present results with certified values of gross alpha/beta in water WCC-238, and Ra-226 in water, WCC-267A and WCC-278.

Radionuclide	WCC-238		WCC-267A		WCC-278	
	Present result	Certified value	Present result	Certified value	Present result	Certified value
Gross alpha	13.3 ± 0.3	15 ± 5	–	–	–	–
Gross beta	46.1 ± 0.1	44 ± 5	–	–	–	–
Ra-226	–	–	9.6 ± 0.6	9.9 ± 1.5	15.5 ± 0.06	15.0 ± 2.3

analysis using the following procedures.[11]

Gross alpha and gross beta radioactivity

Transfer to a beaker, an aliquot of water sample of a volume size that contains no more than 100 mg of total water solids (about 250 ml). Evaporate the aliquot to near dryness on a hot plate. To the sample residue in the beaker, add 5 ml portions of conc. HNO_3 and evaporate to near dryness. This step is to convert chloride to nitrate salts. The chloride salts will react with stainless steel and increase the sample solid. Add 1 ml 1M HNO_3 to the beaker and swirl to dissolve the residue. Quantitatively transfer to a tarred 2-inch stainless steel counting planchet. Dry the sample residue in a drying oven at 105°C for at least 2 hours, cool in a desiccators, weight, and count.

The alpha- beta counting system used was low background alpha/beta counting system (LB 5100 series IV, Tennelec Nucleus Inc.). Am-241 (specific activity of 6.02 $nCi.g^{-1}$) and Cs-137 (specific activity of 13.09 $nCi.g^{-1}$) both from US.EPA were used as standards for gross alpha and gross beta activity, respectively. For quality control, inter-comparison water samples, WCC-238, were obtained from US.EPA.

Ra-226 radioactivity

5 liters of water sample was evaporated on the hot plate into 500 ml with occasionally rinsed with 0.6 M HNO_3 then filtered before analysis. Water sample were determined by radiochemical analysis. The radium in the water sample was collected by co-precipitation with barium sulfate in EDTA solution at pH 3-4. Ra-226 in barium radium sulfate co-precipitate was converted to carbonate salt by adding with 30 ml of 3N Na_2CO_3 solution and heating in water bath for 30 minutes. Dissolved the carbonate salt in conc. HNO_3 and then purified by extraction with solution of 10% Thenoyl Trifluoro Acetone (TTA) in benzene. Re-precipitated radium on barium sulfate and alpha counted in low background alpha, beta counting system.

Ra-226 Standard Solution (IPL-7226) from Isotope Products Laboratories was used as standards for Ra-226 activity concentration determinations. Intercomparison water sample from US.EPA, WCC-267A and WCC-278, were used for quality control.

Evaluation of the effective dose

The annual effective dose due to intake of radionuclides from drinking water can be estimated as below.[10]

$$D = 365 \times DWI \times DCF \times C$$

Where

D = Ra-226 effective dose per year for specific age group from ingestion of Ra-226 in water (Sv);

C = Mean value of Ra-226 concentration in water ($Bq.l^{-1}$);

DWI = Daily water intake for specific age group ($l.d^{-1}$);

DCF = Dose conversion factor for Ra-226 for specific age group ($Sv.Bq^{-1}$)

Results and Discussion

Accuracy and precision of the analytical techniques

In order to check the accuracy and precision of the present method, three kinds of intercomparison water samples (gross alpha/beta in water WCC-238 and Ra-226 in water, WCC-267A and WCC-278) were analyzed. Their results and the certified values are shown in Table 1. All results were in very good agreement with the values of intercomparison water samples within + 5% except for gross alpha (±11.3%) of WCC-238. This was due to sensitivity to interference from self-absorption when counting alpha particle activity that is more affect to the count rate than when counting beta activity.[11]

Comparison of gross alpha activity between imported and domestic water

Gross alpha activity in water samples are shown in Table 2. Statistical values were calculated by substituting the N.D. value with one half of the detection limit (0.024 $Bq.l^{-1}$) to get away from over estimation. Range and geometric mean of gross alpha activity (N.D. to 0.17 $Bq.l^{-1}$ and 0.089 $Bq.l^{-1}$) of domestic bottled drinking water were higher than those of mineral water both imported and domestic brands. Chemical contaminations can enhance the count rate of alpha and beta radioactivity.[12] In this situation chemical composition of water samples may alter alpha and beta particles count rate. For those of bottled mineral water, range and geometric mean of domestic brand (N.D. to 0.58 $Bq.l^{-1}$ and 0.059 $Bq.l^{-1}$) is higher than those of imported brand (N.D. to 0.09 $Bq.l^{-1}$ and 0.040 $Bq.l^{-1}$). Gross alpha radioactivity in some brands of domestic bottled drinking water, DDW1 (0.171 $Bq.l^{-1}$) and DDW4 (0.153 $Bq.l^{-1}$) and domestic bottled mineral water, DMW2 (0.575 $Bq.l^{-1}$) and DMW3 (0.137 $Bq.l^{-1}$) were higher than Thai standard for drinking water.[8] However, the results obtained for Ra-226 concentrations in all samples were lower than the standard limit of Thai drinking water which is 100 $mBq.l^{-1}$ for combined radium (Ra-226+228). Tumnoi[12] determined gross alpha radioactivity in domestic water samples including groundwater, mineral water and bottled drinking water and the results shown in Table 3, the results are comparatively lower than the present result.

Comparison of gross beta activity between imported and domestic water

Gross beta activity in water samples were shown in Table 2. Same as gross alpha activity, the statistical values were calculated by substituting the N.D. value with one half of detection limit (0.122 $Bq.l^{-1}$). For imported bottled mineral water, range and geometric mean of gross beta activity (N.D. to 0.44 $Bq.l^{-1}$. and 0.175 $Bq.l^{-1}$) were the highest compare to those of domestic brands. For those of domestic brands, range and geometric mean (N.D. to 0.19 $Bq.l^{-1}$ and 0.140 $Bq.l^{-1}$) of bottled drinking water were higher than those of bottled mineral water (N.D. to 0.45 $Bq.l^{-1}$ and 0.127 $Bq.l^{-1}$). All samples contained gross beta radioactivity lower than Thai standard for drinking water[8] which is 1.0 $Bq.l^{-1}$. Results of surveillance of gross beta radioactivity in domestic water samples[12] were shown in Table 3. The same as gross alpha radioactivity, the results shown are comparatively lower than the present result.

Comparison of Ra-226 concentrations between imported and domestic water

Ra-226 concentrations in water samples were shown in Table 2. Range and geometric mean of Ra-226 in bottled mineral water both of imported (0.51 to 1.11 $mBq.l^{-1}$ and 1.015 $mBq.l^{-1}$) and domestic brand (0.42 to 6.67 $mBq.l^{-1}$ and 1.459 $mBq.l^{-1}$) were higher than those of domestic bottled drinking water (0.10 to 0.40 $mBq.l^{-1}$ and 0.162 $mBq.l^{-1}$). Regular consumption of mineral water

Table 2 Gross alpha, gross beta, and Ra-226 activity concentrations in bottled mineral water and drinking water tested.

No.	Product Brand	Type	Container	Source	Gross alpha activity (Bq.l-1)	Gross beta activity (Bq.l-1)	Ra-226 (mBq.l-1)
1	IMW1	Mineral	Plastic	France	ND(2)	.156 ± .024(2)	.521 ± .062(2)
2	IMW2	Mineral	Plastic	France	ND(2)	.166 ± .057(2)	.613 ± .159(2)
3	IMW3	Mineral	Plastic	France	.085 ± .046(2)	.119 ± .061(2)	5.919 ± .334(2)
4	IMW4	Sparking	Glass	Italy	ND(2)	ND(2)	.513 ± .038(2)
5	IMW5	Ozonated glacial spring	Plastic	Canada	.085 ± .032(2)	.436 ± .373(2)	1.110 ± .021(2)
6	DMW1	Mineral	Plastic	Chieng Rai	ND(2)	.102 ± .078(2)	1.130 ± .339(2)
7	DMW2	Mineral	Plastic	Tak	.575 ± .031(2)	ND(2)	9.915 ± .378(2)
8	DMW3	Mineral	Plastic	Ayuthaya	.137 ± .045(2)	.449 .246(2)	.422 ± .062(2)
9	DMW4	Mineral	Plastic	Singhaburi	ND(2)	ND(2)	.590 ± .048(2)
10	DMW5	Mineral	Plastic	Pathum thani	.036 ± .013(2)	.171 ± .123(2)	1.466 ± .891(2)
11	DMW6	Mineral light	Plastic	Chumporn	.063 ± .007(2)	.037 ± .006(2)	6.674 ± .956(2)
12	DMW7	Mineral	Plastic	Surat thani	ND(2)	ND(2)	.515 ± .127(2)
13	DDW1	Drinking	Plastic	Ayuthaya	.171 ± .120(2)	.159 ± .072(2)	.124 ± .020(2)
14	DDW2	Drinking	Plastic	Nakorn Pathom	.103 ± .055(2)	ND(2)	.096 ± .017(2)
15	DDW3	Drinking	Plastic	Singhburi	ND(2)	.193 ± .185(2)	.145 ± .043(2)
16	DDW4	Drinking	Plastic	Not specified	.153 ± .072(1)	.104 ± .067(1)	.398 ± .091(1)

Note: Number in parenthesis is the number of samples to be analyzed.

LLD for gross alpha is 0.048, gross beta, 0.244 $Bq.l^{-1}$ and Ra-226 is 0.242 $mBq.l^{-1}$.

Table 3 Gross alpha/gross beta radioactivity ($Bq.l^{-1}$) in some domestic collected water samples.[12]

No.	Type	Gross alpha	Gross beta
1	Groundwater	0.010	0.120
2	Groundwater	0.010	0.070
3	Groundwater	0.010	0.090
4	Groundwater	0.010	0.080
5	Groundwater	0.010	0.120
6	Groundwater	0.010	0.100
7	Groundwater	0.010	0.070
8	Drinking water	0.010	0.020
9	Bottled drinking water	0.010	0.020
10	Bottled drinking water	0.010	0.020
11	Bottled drinking water	0.010	0.020
12	Bottled drinking water	0.010	0.020
13	Mineral water	0.026	0.055
14	Mineral water	0.006	0.085
15	Mineral water	0.007	0.092
	Geometric mean	0.010 ± 0.305	0.053 ± 0.738

Table 4 Comparison of Ra-226 concentration range in drinking waters with previous measurement from different countries.[13]

Country	Concentration range ($mBq.l^{-1}$)	References
France	7-700	14
Finland	10-49,000	15
Germany	1-1,800	16
Italy	0.2-1,200	17
Poland	1.7-4.5	18
Spain	20-4,000	19
Turkey (Istanbul)	11-36	20
Turkey (Eastern Black Sea)	3-45	21
United States	0.4-1.8	22
This study	0.1-10	

could mean that more amounts of Ra-226 were intake and the higher exposure doses to human body than that of normal drinking water.

Gross alpha and gross beta radioactivity measurements are screening method to determine whether it is necessary to analyze samples for specific radionuclide or not. Usually, gross alpha radioactivity is believed to be most contributed by Ra-226. In this study, however, no relationship was found between gross alpha radioactivity to Ra-226

Table 5 Age-dependent daily water intake (DWI).[10]

Age	Mean normal body weight[a] (kg)	DWI (ml)
<=1	<=10	1,000
2	13	1,170
3	15	1,260
4	17	1,326
5	19	1,349
6	21	1,365
7	23	1,495
8	25	1,550
9	28	1,624
10	31	1,705
11	35	1,750
12	40	1,960
13	45	2,115
14	51	2,346
15	57	2,508
16	62	2,666
17	66	2,706
>=18	70[b]	2,000

[a]Mean normal weight in boys (Scoot 2003)

[b]Body weight of a Reference Man (ICRP 1974)

(R^2 = 0.050). Therefore Ra-226 activity concentrations in sample could not be estimated based on gross alpha activity in such sample.

The Ra-226 concentration values obtained were compared with those by other workers (Table 4). The measured Ra-226 activity concentrations are lower than the concentrations observed in France[14], Finland[15], Germany[16], Italy[17], and Spain[18] and are in the same range of those in Poland[19] and Turkey[20-21] and higher than those in United States.[22]

Dose estimation from intake of Ra-226

Annual effective dose for different age groups of Thai people due to ingested of Ra-226 in tested water sample were estimated using age-dependent daily water intake (DWI), in Table 5, obtained from Bronzovic, Maja and Marovic, Gordana 2005.[10]

According to the annals of the ICRP publication 72[9], the dose conversion factor (DCF) is 4.7×10^{-6} $Sv.Bq^{-1}$ for the infants, 9.6×10^{-7} $Sv.Bq^{-1}$ for children between 1 and 2 y of age, 6.2×10^{-7} $Sv.Bq^{-1}$ for children between 3 and 7 y of age, 8.0×10^{-7} $Sv.Bq^{-1}$ for children between 8 and 12 y of age, 1.5×10^{-6} $Sv.Bq^{-1}$ for children between 13 and 17 y of age, and 2.8×10^{-7} $Sv.Bq^{-1}$ for adults.

Ra-226 effective doses per year from consumption of tested waters for different age groups are presented in Table 6.

The assessed effective doses per year for children under 10 y of age from consumption of

Table 6 The assessed Ra-226 effective doses per year (μSv) for infants, children younger than 10, teens (children aged between 11-17), and adults (>18).

Type of	Age(years)																	
water	<1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	>18
DCF*	4.70E-06	9.60E-07	6.20E-07	6.20E-07	6.20E-07	6.20E-07	6.20E-07	8.00E-07	8.00E-07	8.00E-07	8.00E-07	8.00E-07	1.50E-06	1.50E-06	1.50E-06	1.50E-06	1.50E-06	2.80E-07
DWI**	1.000	1.170	1.260	1.326	1.349	1.365	1.495	1.550	1.624	1.705	1.750	1.960	2.115	2.346	2.508	2.666	2.706	2.000
IMW1	8.94E-01	2.14E-01	1.49E-01	1.56E-01	1.59E-01	1.61E-01	1.76E-01	2.36E-01	2.47E-01	2.59E-01	2.66E-01	2.98E-01	6.03E-01	6.69E-01	7.15E-01	7.60E-01	7.72E-01	1.06E-01
IMW2	1.05E+00	2.51E-01	1.75E-01	1.84E-01	1.87E-01	1.89E-01	2.07E-01	2.77E-01	2.91E-01	3.05E-01	3.13E-01	3.51E-01	7.10E-01	7.87E-01	8.42E-01	8.95E-01	9.08E-01	1.25E-01
IMW3	1.02E+01	2.43E+00	1.69E+00	1.78E+00	1.81E+00	1.83E+00	2.00E+00	2.68E+00	2.81E+00	2.95E+00	3.02E+00	3.39E+00	6.85E+00	7.60E+00	8.13E+00	8.64E+00	8.77E+00	1.21E+00
IMW4	8.80E-01	2.10E-01	1.46E-01	1.54E-01	1.57E-01	1.58E-01	1.74E-01	2.32E-01	2.43E-01	2.55E-01	2.62E-01	2.94E-01	5.94E-01	6.59E-01	7.04E-01	7.49E-01	7.60E-01	1.05E-01
IMW5	1.90E+00	4.55E-01	3.17E-01	3.33E-01	3.39E-01	3.43E-01	3.76E-01	5.02E-01	5.26E-01	5.53E-01	5.67E-01	6.35E-01	1.29E+00	1.43E+00	1.52E+00	1.62E+00	1.64E+00	2.27E-01
Means	1.74E+00	4.16E-01	2.89E-01	3.05E-01	3.10E-01	3.13E-01	3.43E-01	4.59E-01	4.81E-01	5.05E-01	5.19E-01	5.81E-01	1.18E+00	1.30E+00	1.39E+00	1.48E+00	1.50E+00	2.07E-01
DMW1	1.94E+00	4.63E-01	3.22E-01	3.39E-01	3.45E-01	3.49E-01	3.82E-01	5.11E-01	5.36E-01	5.63E-01	5.77E-01	6.47E-01	1.31E+00	1.45E+00	1.55E+00	1.65E+00	1.67E+00	2.31E-01
DMW2	1.70E+01	4.06E+00	2.83E+00	2.98E+00	3.03E+00	3.06E+00	3.35E+00	4.49E+00	4.70E+00	4.94E+00	5.07E+00	5.67E+00	1.15E+01	1.27E+01	1.36E+01	1.45E+01	1.47E+01	2.03E+00
DMW3	7.24E-01	1.73E-01	1.20E-01	1.27E-01	1.29E-01	1.30E-01	1.43E-01	1.91E-01	2.00E-01	2.10E-01	2.16E-01	2.42E-01	4.89E-01	5.42E-01	5.79E-01	6.16E-01	6.25E-01	8.63E-02
DMW4	1.01E+00	2.42E-01	1.68E-01	1.77E-01	1.80E-01	1.82E-01	2.00E-01	2.67E-01	2.80E-01	2.94E-01	3.01E-01	3.38E-01	6.83E-01	7.58E-01	8.10E-01	8.61E-01	8.74E-01	1.21E-01
DMW5	2.51E+00	6.01E-01	4.18E-01	4.40E-01	4.48E-01	4.53E-01	4.96E-01	6.64E-01	6.95E-01	7.30E-01	7.49E-01	8.39E-01	1.70E+00	1.88E+00	2.01E+00	2.14E+00	2.17E+00	3.00E-01
DMW6	1.14E+01	2.74E+00	1.90E+00	2.00E+00	2.04E+00	2.06E+00	2.26E+00	3.02E+00	3.16E+00	3.32E+00	3.41E+00	3.82E+00	7.73E+00	8.57E+00	9.16E+00	9.74E+00	9.89E+00	1.36E+00
DMW7	8.83E-01	2.11E-01	1.47E-01	1.55E-01	1.57E-01	1.59E-01	1.74E-01	2.33E-01	2.44E-01	2.56E-01	2.63E-01	2.95E-01	5.96E-01	6.61E-01	7.07E-01	7.52E-01	7.63E-01	1.05E-01
Means	2.50E+00	5.98E-01	4.16E-01	4.38E-01	4.45E-01	4.51E-01	4.94E-01	6.60E-01	6.92E-01	7.26E-01	7.45E-01	8.35E-01	1.69E+00	1.87E+00	2.00E+00	2.13E+00	2.16E+00	2.98E-01
DDW1	2.13E-01	5.08E-02	3.54E-02	3.72E-02	3.79E-02	3.83E-02	4.20E-02	5.61E-02	5.88E-02	6.17E-02	6.34E-02	7.10E-02	1.44E-01	1.59E-01	1.70E-01	1.81E-01	1.84E-01	2.53E-02
DDW2	1.65E-01	3.94E-02	2.74E-02	2.88E-02	2.93E-02	2.97E-02	3.25E-02	4.34E-02	4.55E-02	4.78E-02	4.91E-02	5.49E-02	1.11E-01	1.23E-01	1.32E-01	1.40E-01	1.42E-01	1.96E-02
DDW3	2.49E-01	5.94E-02	4.13E-02	4.35E-02	4.43E-02	4.48E-02	4.91E-02	6.56E-02	6.88E-02	7.22E-02	7.41E-02	8.30E-02	1.68E-01	1.86E-01	1.99E-01	2.12E-01	2.15E-01	2.96E-02
DDW4	6.83E-01	1.63E-01	1.13E-01	1.19E-01	1.22E-01	1.23E-01	1.35E-01	1.80E-01	1.89E-01	1.98E-01	2.03E-01	2.28E-01	4.61E-01	5.11E-01	5.47E-01	5.81E-01	5.90E-01	8.14E-02
Means	2.78E-01	6.64E-02	4.62E-02	4.86E-02	4.94E-02	5.00E-02	5.48E-02	7.33E-02	7.68E-02	8.06E-02	8.27E-02	9.27E-02	1.87E-01	2.08E-01	2.22E-01	2.36E-01	2.40E-01	3.31E-02

Note: DCF=Dose Conversion Factor for ingestion of Ra-226 (Sv/Bq)
DWI= Daily Water Intake(L/day)

all types of tested water showed satisfactory low value. Highest effective dose was received by infants under 1 y of age from 1-y consumption of domestic mineral water. In this case, infants, by consumption of domestic mineral water could be exposed to maximum dose 17.0 $\mu Sv.y^{-1}$. This dose was apparently low and corresponded to 17% of doses recommended by UNSCEAR.[23] The assessed Ra-226 effective doses per year for the consumption of all types of tested water for children between 10 and 17 y increased with increasing age while as those of adults showed abruptly low. However, all values were well below 100 $\mu Sv.y^{-1}$.

Dependence on age of the averaged values of assessed Ra-226 effective doses per year from intake of imported mineral, domestic mineral and domestic drinking waters was given in Fig. 2.

Conclusions

Radioactivity levels in imported and domestic bottled mineral water and domestic drinking water were checked from the view points of internal radiation dose to Thai peoples. The mean values of Ra-226 concentrations in imported mineral, domestic mineral and domestic drinking bottled waters range from 0.1 to 10 $mBq.l^{-1}$. The highest values related to domestic mineral waters which may depend of a source rock and on purifying processes which precede the process of packing water into the bottles.

Annual effective doses per year ranging up to 17.0 $\mu Sv.y^{-1}$, are acceptable to all age groups because they are lower than the recommended value.

The highest annual effective doses were related to domestic mineral waters to infants and teens (10-17 y of age). These doses were approximately 25 times of those related to domestic drinking waters and corresponded to 5.67-17% of the recommended value by UNSCEAR. Based on this study it could be suggested that, even though mineral waters contain useful elements needed especially during the period of maximum growth and development (such as calcium) they may increase the risk of high exposures to human body due to ingest of Ra-226.

Adults and especially elderly people are much less susceptible to the presence of Ra-226.

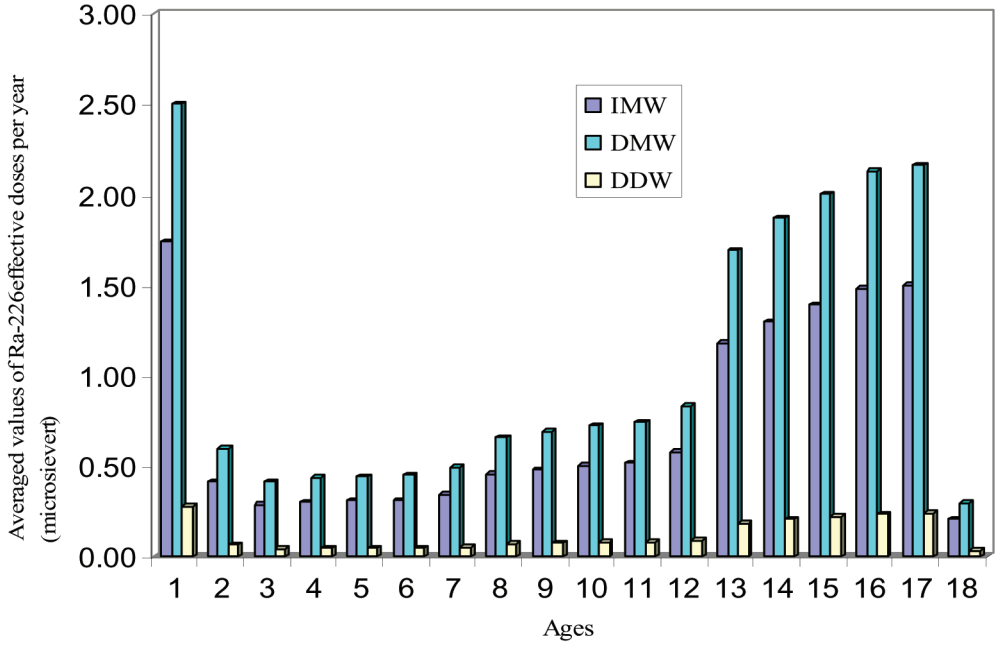

Fig. 2 Averaged (geometric means) values of Ra-226 effective doses per year (μSv) from ingestion of imported mineral, domestic mineral, and domestic drinking waters

Their Ra-226 effective doses per year were considerably low (max. 2 $\mu Sv.y^{-1}$).

Determination of Ra-226 content in bottled water is useful for the purpose of the prevention of unnecessary exposure of humans to natural radiation. Based on this study, while consumption is not a severe problem now, quality inspection of drinking water should be continued.

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บทคัดย่อ

กัมมันตรังสีแอลฟา กัมมันตรังสีบีตา และเรเดียม-๒๒๖ ในน้ำแร่บรรจุขวดบางชนิดที่มีจำหน่ายในกรุงเทพมหานครและปริมณฑล และปริมาณรังสีต่อร่างกาย

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ได้ทำการตรวจวิเคราะห์ปริมาณกัมมันตรังสีแอลฟา กัมมันตรังสีบีตา และเรเดียม-๒๒๖ ในน้ำแร่บรรจุขวดที่จำหน่ายในกรุงเทพมหานครและปริมณฑล ผลการตรวจวิเคราะห์พบว่าปริมาณรังสีแอลฟา มีค่าตั้งแต่ ต่ำกว่าค่าที่วิเคราะห์ได้ ถึง ๐.๐๕, ๐.๕๘ และ ๐.๑๗ เบคเคอเรลต่อลิตร ปริมาณรังสีบีตามีค่าตั้งแต่ ต่ำกว่าค่าที่วิเคราะห์ได้ ถึง ๐.๔๔, ๐.๔๕ และ ๐.๑๕ เบคเคอเรลต่อลิตร และเรเดียม-๒๒๖ มีค่าตั้งแต่ ๐.๕๑ ถึง ๕.๕๑๕, ๐.๔๒๒ ถึง ๕.๕๑๕ และ ๐.๐๕๖ ถึง ๐.๓๕๘ มิลลิเบคเคอเรลต่อลิตร ในน้ำแร่บรรจุขวดนำเข้า น้ำแร่บรรจุขวดในประเทศ และน้ำดื่มบรรจุขวดในประเทศ ตามลำดับ เมื่อพิจารณาจากค่าเฉลี่ย พบว่าน้ำแร่บรรจุขวดในประเทศมีปริมาณกัมมันตรังสีเรเดียม-๒๒๖ สูงสุด อย่างไรก็ตามทุกตัวอย่างมีปริมาณกัมมันตรังสีเรเดียม-๒๒๖ ต่ำกว่าปริมาณกัมมันตรังสีสูงสุดที่อนุญาตให้มีได้ในน้ำดื่มบรรจุขวดกำหนดโดยสำนักงานมาตรฐานผลิตภัณฑ์อุตสาหกรรม มาตรฐานน้ำเพื่อการบริโภคกำหนดโดยองค์การอนามัยโลก และมาตรฐานน้ำดื่มกำหนดโดยองค์การพิทักษ์สิ่งแวดล้อมแห่งประเทศสหรัฐอเมริกา เมื่อประเมินปริมาณรังสีที่ร่างกายได้รับจากเรเดียม-๒๒๖ ในน้ำจากการบริโภค พบว่ากลุ่มประชากรที่ได้รับปริมาณรังสีสูงสุด คือกลุ่มเด็กทารกที่มีอายุต่ำกว่า ๑ ปี และกลุ่มวัยรุ่นในช่วงอายุ ๑๐-๑๗ ปี และพบว่าปริมาณรังสีสูงสุดได้รับจากการบริโภคน้ำแร่บรรจุขวดที่ผลิตในประเทศ โดยพบว่าปริมาณรังสีสูงสุดที่ร่างกายจะได้รับเมื่อบริโภคน้ำแร่บรรจุขวดที่ผลิตในประเทศเป็นประจำมีค่าสูงถึง ๒๕ เท่าของปริมาณรังสีสูงสุดที่ร่างกายจะได้รับเมื่อบริโภคน้ำดื่มบรรจุขวดที่ผลิตในประเทศ และมีค่าเป็น ๕.๖๗-๑๗% ของปริมาณรังสีสูงสุดที่อนุญาตให้ร่างกายรับได้จากการบริโภคน้ำดื่มมีค่าเท่ากับ ๑๐๐ ไมโครซีเวิร์ทต่อปี กำหนดโดย UNSCEAR ดังนั้น ถึงแม้ว่าน้ำแร่อาจประกอบด้วยแร่ธาตุที่มีความจำเป็นต่อการเจริญเติบโตของร่างกายในช่วงระยะเวลาที่มีการเติบโตและพัฒนาการมากที่สุด แต่ก็อาจเพิ่มความเสี่ยงต่อการได้รับปริมาณรังสีที่สูงขึ้นต่อร่างกาย ดังนั้น ควรหลีกเลี่ยงการบริโภคน้ำแร่เพียงอย่างเดียวในชีวิตประจำวัน จากผลของการศึกษานี้พบว่าถึงแม้การบริโภคน้ำแร่และน้ำดื่มบรรจุขวดจะยังไม่เกิดปัญหาในด้านการเป็นอันตรายจากรังสี การตรวจติดตามคุณภาพของน้ำดื่มก็เป็นสิ่งจำเป็นและควรกระทำ

คำสำคัญ : กัมมันตรังสีแอลฟา กัมมันตรังสีบีตา เรเดียม-๒๒๖ น้ำแร่บรรจุขวด ปริมาณรังสีต่อร่างกาย