ES01: การวัดปริมาณกัมมันตภาพรังสีรวมแอลฟาในน้ำทะเลจากอ่าวไทยและทะเลอันดามันด้วยวิธีการตกตะกอนร่วม

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บทคัดย่อ

ทำการศึกษาปริมาณกัมมันตภาพรังสีรวมแอลฟาในน้ำทะเล โดยเก็บตัวอย่างน้ำทะเลจากอ่าวไทยและทะเลอันดามัน จำนวน 100 ตัวอย่าง (50 สถานี) ทั้งในฤดูแล้งและฤดูฝน มาทำการวิเคราะห์ปริมาณกัมมันตภาพรังสีรวมแอลฟาด้วยวิธีการตกตะกอนร่วม นำผลการวิเคราะห์ที่ได้ไปเปรียบเทียบกับค่ามาตรฐานของปริมาณกัมมันตภาพรังสีรวมแอลฟาที่ยอมให้มีได้ในน้ำดื่ม (0.1 Bq/l) พบปริมาณกัมมันตภาพรังสีรวมแอลฟาในน้ำทะเลอยู่ในช่วง 0.015–0.178 Bq/l (เฉลี่ย 0.061±0.038 Bq/l) และ 0.001–0.201 Bq/l (เฉลี่ย 0.065±0.037 Bq/l) ในฤดูแล้งและฝน ตามลำดับ ซึ่งเมื่อเปรียบเทียบกับค่าปริมาณกัมมันตภาพรังสีรวมแอลฟาที่ได้ทำการศึกษาในอดีตทั้งในประเทศไทย (0.067-0.127 Bq/l) และ สเปน (0.058–0.082 Bq/l) พบว่ามีค่าใกล้เคียงกันและเมื่อเปรียบเทียบกับประเทศตุรกี (0.3-0.5 Bq/l) พบว่ามีค่าต่ำกว่า แสดงให้เห็นว่าน้ำทะเลของประเทศไทยอยู่ในสภาวะปกติ ผลการดำเนินงานในครั้งนี้ยังแสดงให้เห็นว่าน้ำทะเลของประเทศไทยส่วนใหญ่มีปริปริมาณกัมมันตภาพรังสีรวมแอลฟาไม่เกินค่ามาตรฐานที่กำหนดไว้ ถึงแม้จะพบน้ำทะเลที่เก็บจากบางสถานี (7 และ 4 สถานี สำหรับฤดูแล้ง และ ฝน ตามลำดับ) มีปริมาณกัมมันตภาพรังสีรวมแอลฟาเกินค่ามาตรฐาน แต่นิวไคลด์กัมมันตรังสีที่เป็นสาเหตุให้ปริมาณกัมมันตภาพรังสีรวมแอลฟาในน้ำทะเลจากสถานีดังกล่าวเกินค่ามาตรฐานน่าจะเป็นนิวไคลด์กัมมันตรังสีที่เกิดขึ้นเองตามธรรมชาติ เช่น ยูเรเนียม และเรเดียม ดังนั้นจึงสามารถสรุปได้ว่าน้ำทะเลทั้งจากฝั่งอ่าวไทยและทะเลอันดามันอยู่ในสภาพที่จะไม่ก่อให้เกิดผลกระทบทางรังสีต่อสิ่งแวดล้อมและประชาชน

คำสำคัญ: แอลฟา น้ำทะเล ประเทศไทย การตกตะกอนร่วม

The Determination of Gross-Alpha Radioactivity in Seawater from the Gulf of Thailand and the Andaman Sea, using the Coprecipitation Technique

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Abstract

Gross-alpha activity in seawater was chosen to be studied. The samples were collected from 50 stations located in the Gulf of Thailand and the Andaman Sea during the dry and wet seasons. Concentrations of gross-alpha radioactivity were analysed using the coprecipitation technique and were compared with the previous studies and with 0.1 Bq/l, a guideline value of gross alpha level permitted to contain in the drinking water. Gross-alpha concentrations range from 0.015 to 0.178 Bq/l with a mean of 0.061$\pm$0.038 Bq/l and from 0.001 to 0.201 Bq/l with an average of 0.065$\pm$0.037 Bq/l in the dry and wet seasons, respectively. The results obtained from the recent work were consistent with those values from the previous studies in Thailand (0.067-0.127 Bq/l) and Spain (0.058-0.082 Bq/l), and lower than the values from Turkey (0.3-0.5 Bq/l) indicating that our seawater is in normal condition. In addition, our results showed that the gross-alpha radioactivity levels of the majority of the seawater samples collected from both seasons have not exceeded the guideline level. Although 7 and 4 seawater samples collected in the dry and wet seasons, respectively presented high levels of gross-alpha activity, natural isotopes, uranium and radium for instances, are likely to be the main contributors causing this phenomena. This implies that seawater in the Gulf of Thailand and the Andaman Sea is clean and does not pose any radiation hazards to the environment and the public.

Keywords: Gross-alpha, Seawater, Thailand, Coprecipitation

1. Introduction

Radionuclides found in the marine environment have mainly two sources of origin which are natural and artificial radionuclides. The former, also called naturally occurring radioactive materials (NORMs), consists of; (i) primodial radionuclides (K-40 and Rb-87), (ii) primodial radionuclides of the three natural decay series (U-238, U-235, and Th-232), and (iii) cosmogenic radionuclides (Be-7, H-3, C-14, Cl-36, for example)[1]. The later is normally produced by nuclear activities such as atmospheric nuclear weapons tests, the nuclear waste reprocessing facilities, the nuclear accidents, and the nuclear power plants. These nuclear activities have released varying degrees of artificial radioactive materials in various forms leading to radioactive contaminations in the world's seas and oceans. Major radioactive components typically present in the marine environment are K-40, H-3, Rb-87, and Cs-137 etc. In addition to NORMs and artificial radionuclides, technically-enhanced naturally occurring radioactive materials (TENORMs) appear to play a vital role in the recent years in contributing radioactivity to the marine environment. TENORMs including Pb-210, Po-210, and Ra-226 etc. are from non-nuclear activities such as coal powered electricity production, oil and gas industries, and fertilizer industry[1].

Parts of Thailand are embraced by the Gulf of Thailand on the east coast and the Andaman Sea on the west coast. The Gulf of Thailand locates between latitude 6^{o}-13^{o}, 30'N and longitude 90^{o}-105^{o}. There are four major rivers including the Chao Phraya, the Bank Pakong, the Tha Chin, and the Mae Khlong, and many small rivers flowing into the gulf from both sides. Furthermore, the Andaman Sea is a part of the Bay of Bengal situating on the upper part of the Indian Ocean. The Irrawaddy river is the main river discharging fresh water from the north into the sea while, along the west coast, the sea receives fresh water from many short rivers running from the peninsula of Thailand[2]. Both have also been, without an exception, contaminated by several radionuclides mentioned above with different levels of radioactivity. There are, however, only few works previously carried out to investigate radioactivity in the marine environment of Thailand. Mahapanyawong[2] conducted the radioactivity monitoring program, in cooperation with IAEA, during 1989-1991. Anthoprogenic radioisotopes including Sr-90, Cs-137, Pu-239, 240, and Am-241, and natural radionuclides including K-40, C-14, and Po-210 were analysed in seawater, sediment, and marine biota (see more detail in Mahapanyawong[2]). After the completion of this study, the Pollution Control Department (PCD) conducted a monitoring survey on gross beta and alpha radioactivities in the seawater samples collected from 240 stations across the country. The survey period was between 1999 and 2002. This was due to the fact that the survey was a small part of their annual marine environmental monitoring program carried out every year. Until recently, there is no marine environmental radioactivity monitoring program performed. Even NORMs exist in the marine environment with constant levels, but the concentrations of TENORMs and artificial radionuclides have been changed over time. Therefore, the monitoring program is extremely important and required to determine radioactivity concentrations in the marine environment. This is in order to protect the environments and humans from radiation hazards.

The purpose of gross alpha measurement is to be used as an indicator to provide initial information whether or not additional radiological analyses are required[3]. There are two different techniques widely used for gross alpha determination including the standard method[3, 4, 5] and the coprecipitation approach[6, 7]. Nevertheless, when seawater samples are analysed, the coprecipitation technique appear to be more appropriate than the standard method. Because the coprecipitation approach has shown several advantages; (i) low thickness of the final precipitate, (ii) low MDA, (iii) high homogeneity of the final deposit, (iv) short measuring time, (v) the use of large volume sample (500 ml) providing adequate information, and (vi) high reproducibility of the final weight of the

residue[7]. In addition, this method has also been scientifically proven that it provides the final results of gross alpha radioactivity with high accuracy[6]. The coprecipitation technique is, therefore, used in this present work for gross alpha radioactivity determination in seawater.

The aims of the present study are (i) to determine gross-alpha radioactivity in seawater collected from the Gulf of Thailand and the Andaman Sea, (ii) to investigate whether or not the seawater samples have gross alpha radioactivity levels exceeding the guideline value, and (iii) to establish the national marine environmental radioactivity database

2. Materials and Methods

2.1 Sampling sites

Seawater samples were collected from fifty stations located in the Gulf of Thailand and the Andaman Sea. These sampling sites were chosen since gross-alpha radioactivity data from these locations, obtained from the previous work carried out by the Pollution Control Department (PCD), appeared to be higher than others. Seawater samples were collected twice a year during dry and wet seasons. All stations covered 21 provinces along the shore line. The locations and the distance between sea shore and the sampling sites were shown in Figure 1.

2.2 Seawater collection and preparation

One liter of seawater was collected (1 m below the surface water) using a water sampler. After the seawater was stored in a polyethylene bottle, 11M HCl (10 ml/l) was immediately added to avoid a loss of radionuclides due to adsorption to the container walls[8]. Temperature, pH, salinity, and location of the sampling site were also recorded during sampling. These information will provide additional data and enable us to be able to interpret results correctly.

A coprecipitation technique[7] with a minor modification was employed in this study to measure gross alpha radioactivity in seawater. Upon arrival, 500 ml of seawater was neutralized by adding 6M NH_4OH until the pH of the seawater becomes 7. Twenty μl of 1M H_2SO_4 were then added and the seawater was boiled and simultaneously stirred using a magnetic bar for 10 mins. Following the cooling down at room temperature for an hour, 1 ml of Ba^{2+} carrier (5 mg/ml) was added to the sample to precipitate the barium-radium sulphate. The solution was heated and stirred at 50^{o}C for 30 mins. After adding 3-5 drops of 0.1% bromocresol purple, an indicator, 1 ml of Fe^{3+} carrier (5 mg/ml) was immediately added to coprecipitate the actinides.

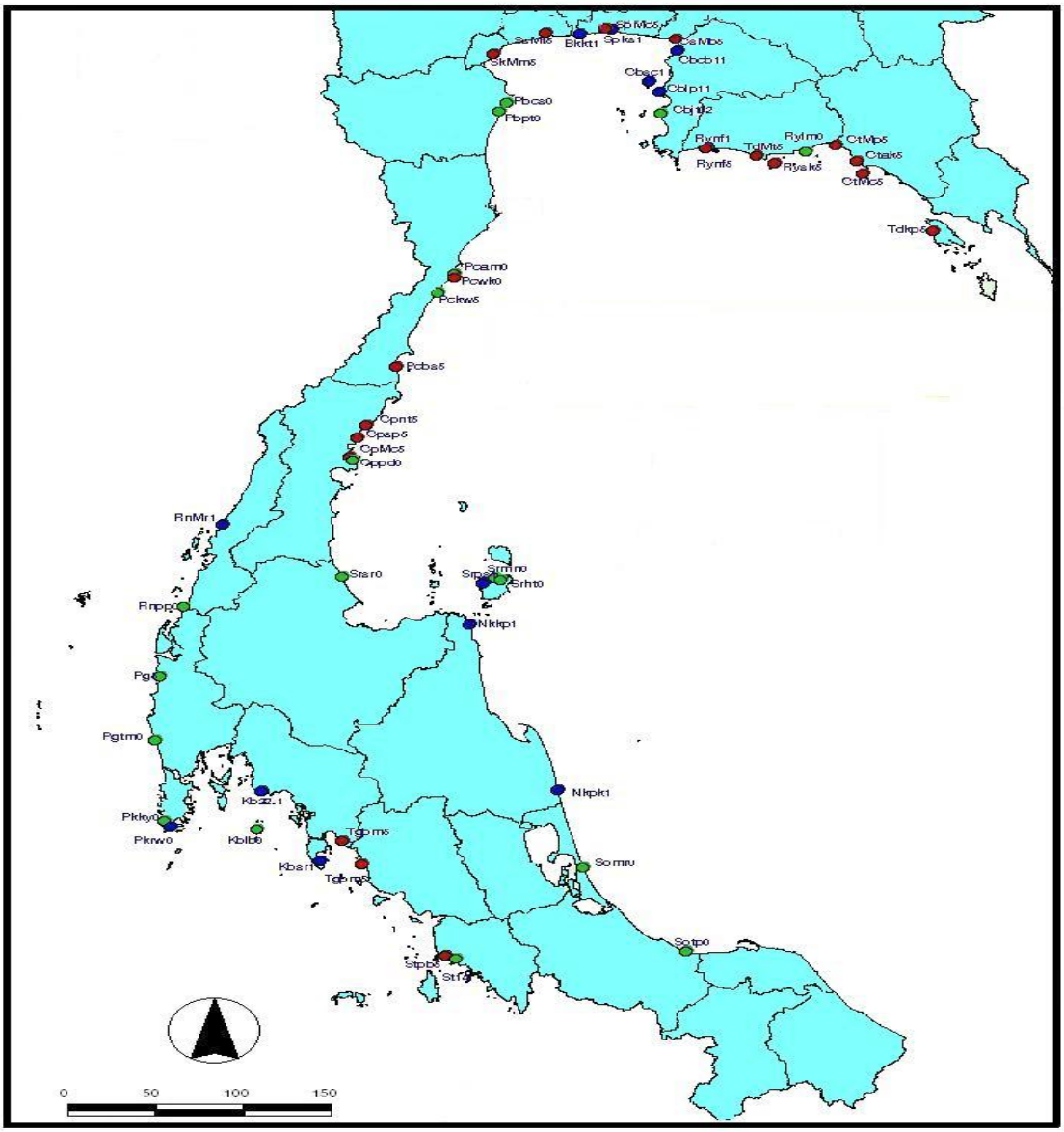

Figure 1 Illustration of the station and distance between sea shore and sampling sites

(modified from the map received from Pollution Control Department)

● 500 meters ● 100 meters ● 10 meters

Few drops of 6M NH_4OH were added until the solution turned purple. The sample heating and stirring continued at 50^{o}C for 30 mins. Then, the solution was covered using a watch grass and left overnight. The precipitate was deposited on a weighed glass filter paper with 4.7 cm of diameter (GF/A, Whatman) using the vacuum filtration system. Distilled water was used to rinse the precipitate from the funnel walls. The solution was then discarded while the filter with the precipitate was placed on the weighed planchet prior to drying under an infrared lamp. The dried

precipitate was left in a desiccator for at least two days to obtain a constant weight before weighing and counting. Furthermore, a set of blank samples (without samples) and standard samples (with Am-243) were prepared following the identical procedure. The former was for background counts while the later with different residual thicknesses was for an estimation of detector efficiency and self-absorption factors. All samples were counted for 100 mins, twice, using a Low-background gas flow proportional counter.

2.3 Calculations

2.3.1 Self-absorption

- Self-absorption factors can be calculated using the following equation:

$$F_a = \frac{E_x}{E_0} \qquad (7)$$

where F_a = the absorption factor

E_x = the mean efficiency of the different points for the curve

E_0 = the mean efficiency of the first point of the curve

- Self-absorption curves were established by plotting self-absorption factors on the X axis and the weight of the final sample residues on the Y axis.

2.3.2 Gross-alpha radioactivity and standard deviation

- Gross-alpha radioactivity can be calculated using the following equation:

$$A = \frac{CPM_S - CPM_B}{60xExF_axV} \qquad (7)$$

where A = the gross-alpha radioactivity (Bq/l)

CPM_s = the averaged count rate of the sample (count per min)

CPM_B = the averaged count rate of the blank (count per min)

E = the alpha efficiency

V = the volume of the sample aliquot (L)

60 = the conversion factor from dpm to Bq

- Standard deviation can be computed using the following equation:

$$\sigma = \frac{\sqrt{\frac{CPM_S}{T_S} + \frac{CPM_B}{T_B}}}{60 x E x F_a x V} \qquad (8)$$

where σ = Standard deviation (Bq/l)

T_s = the measuring time of the sample (mins)

T_B = the measuring time of of the blank (mins)

2.3.3 Minimum detectable activity (MDA)

- Minimum detectable activity can be calculated using the following equation:

$$MDA = \frac{3.29}{60 x E x F_a x V} \sqrt{\frac{CPM_B}{T_S} + \frac{CPM}{T_B}} \qquad (7)$$

3. Results and Discussion

3.1 Sampling sites, seawater collection and general parameters

Seawater samples were taken from 37 and 13 stations located in the Gulf of Thailand and the Andaman Sea, respectively. The samples were collected during February-March 2008 (dry season) and June-July 2008 (wet season). In general, seawater should be collected at three different depths including the upper, middle, and lower levels. Because, in the recent work, seawater was from the shallow coastal areas where seawater mass at different depths is thoroughly mixed. Therefore, seawater at 1 m below the surface is acceptable as a representative for each sampling area. If, nevertheless, the future investigations will be carried out in deep seas or oceans, collecting seawater samples from different depths must be taken into consideration prior to sampling.

Seawater pH ranged from 8.3 to 7.4 (8.1±0.2) in the dry season (Table 1). While, those in wet season ranged from 8.3 to 6.9 (7.9±0.3) (Table 1). The difference of pH values between two sampling seasons was tested using ANOVA. The results revealed that they were not statistically different (P>0.05).

The seawater temperatures ranging from 26.6 to 32.7°C (29.6±1.4°C) and from 27.9 to 32.7°C (30.5±1.2°C) were recorded in the dry and wet seasons (Table 1), respectively. The statistic

test using ANOVA was performed revealing no significant differences (P>0.05) of the temperatures between the seasons.

The salinity values between 15.1 and 32.8 ppt (29.1±3.8 ppt) were measured in the dry season (Table 1). Whereas, the salinity ranging from 0.6 to 32.6 ppt (24.9±8.9 ppt) were recorded in the wet season (Table 1). ANOVA test showed that the salinity values from two different seasons were significant different (P<0.05). This phenomenon can be explained by the fact that a decrease of salinity in the seawater, especially in coastal areas, is caused by large amounts of freshwater from the seasonal rain and from the major and small rivers.

3.2 Standard and blank samples and Self-absorption factors

The alpha efficiency obtained from standard samples ranged between 12% and 25% (17.5±4.3%) and between 8% and 24% (17.9±1.9%) for the samples analysed in the dry season and the wet season, respectively.

The range of averaged background count rates obtained from blank samples was from 0.03 to 0.12 cpm (0.06±0.02 cpm) for the samples counted in the dry season. Whereas, the range of averaged background count rates was between 0.03 and 0.10 cpm (0.05±0.02 cpm) for the samples counted in the wet season.

The self-absortion factors (F_a) values obtained from this work were in the ranges of 0.53-9.47 and 0.53-25.28 for the sample batches analysed in the dry and wet seasons, respectively.

3.3 Gross-alpha radioactivity and minimum detectable activity calculation

For gross-alpha activity calculation, a 500 ml of seawater was prepared following the coprecipitation technique and counted (100 mins, 2 times). The range between 0.015 and 0.178 Bq/l (0.061±0.038 Bq/l) was observed when analysed the seawater samples collected in the dry season (Table 1). While, the range from 0.001 to 0.201 Bq/l (0.065±0.037 Bq/l) was obtained from the seawater sampled in the wet season (Table 1). Our results were consistent with the data obtained from the previous study carried out by Porntepkasemsan & Srisuksawad[6]. Five seawater samples were collected from Rayong province, Thailand in 1994 and analysed using the coprecipitation approach. Their results showed the range of gross-alpha radioactivity between 0.067 and 0.127 Bq/l. Nevertheless, the authors did not either perform an additional analysis or mention any possible reasons about gross-alpha activity exceeding the guideline of 0.1 Bq/l. We additionally compared

our findings with those in other countries. It is clear that the recent results are in agreement with gross-alpha radioactivities in the seawater from 5 Spanish coasts[7]. Gross-alpha radioactivities obtained from the present work are generally one magnitude lower than those (0.3-0.5 Bq/l) determined in the seawater samples in Turkey[4]. It can be concluded here that seawater in the Gulf of Thailand and the Andaman Sea is in a normal condition.

For minimum detectable activity (MDA), MDA was in the range of 0.003-0.048 Bq/l (0.024±0.012 Bq/l) when analysed the dry season samples. Whereas, a range of MDA between 0.001 and 0.052 Bq/l (0.018±0.015 Bq/l) was observed when the wet season samples were analysed.

3.4 Gross-alpha radioactivity interpretation

A difference of gross-alpha radioactivities from two different seasons was tested using ANOVA. The results showed that there was no seasonal variation (P>0.05). The results of the seawater samples collected from the same regions were grouped together creating 4 different geological groups. These groups consisted of the East (5 provinces), the Middle (4 provinces), the Eastern coast (6 provinces), and the Western coast (6 provinces). The East group showed gross-alpha radioactivity levels ranging between 0.030 and 0.106 Bq/l (0.062±0.024 Bq/l) and ranging between 0.015 and 0.094 Bq/l(0.063±0.028 Bq/l) in the dry and wet season samples, respectively (Figure 2). A range of gross-alpha radioactivities found in the Middle group was from 0.019 to 0.082 Bq/l (0.042±0.030 Bq/l) from the dry season samples. While, concentrations of gross-alpha activities were between 0.035 and 0.057 Bq/l (0.045±0.012 Bq/l) in the wet season samples (Figure 2). The Eastern coast group presented a range of 0.013-0.159 Bq/l (0.061±0.038 Bq/l) for gross-alpha radioactivities in the sample batch collected in the dry season. A similar average, 0.060±0.033 Bq/l, was obtained from gross-alpha concentrations ranging from 0.008 to 0.012 Bq/l in the sample batch collected in the wet season (Figure 2). Finally, the Western coast group revealed gross-alpha levels ranging from 0.007 to 0.127 Bq/l (0.067±0.050 Bq/l) and ranging from 0.034 to 0.201 Bq/l (0.087±0.056 Bq/l) in the sample batches collected in the dry and wet season, respectively (Figure 2). Several comparisons were conducted using ANOVA to test for a seasonal difference of gross-alpha radioacitivities in the same group. No significant differences were observed so the gross-alpha concentrations obtained from two different seasons of each group can be combined for a subsequent analysis. The integrated data from each group were paired and tested for any variations. ANOVA

Table 1 General parameters and gross-alpha radioactivity (Bq/l) in seawater collected from the Gulf of Thailand and the Andaman Sea in 2008

Stations	Code	pH		Temperature (°C)		Salinity (ppt)		Gross-alpha activity ± SD (Bq/l)	
		DS	WS	DS	WS	DS	WS	Dry season (DS)	Wet season (WS)
1.Kao Chang (Had Klong Phrao), Trad (500 m)	Tdkp5	8.1	7.9	32.1	30.7	32.2	31.2	0.070±0.013	0.013±0.001
2.Pak Mae Num Trad-Lham Sok (Ban Poo) (500 m)	TdMt5	7.8	7.3	32.7	29.6	27.1	2.0	0.058±0.015	<0.049
3.Pak Mae Num Pung Rad, Chantaburi (500 m)	CtMp5	8.2	7.9	31.9	32.2	31.4	26.6	<0.015	0.055±0.002
4.Ao Kung Kra Ben, Chantaburi (500 m)	Ctak5	8.1	7.9	31.5	30.0	31.4	26.9	<0.015	0.074±0.002
5.Pak Mae Num Chantaburi, Chantaburi (500 m)	CtMc5	8.1	7.5	31.1	30.2	32.0	9.7	<0.016	0.064±0.002
6.Ban Nong Fab, Rayong (100 m)	Rynf1	8.2	7.9	30.6	27.9	31.6	31.4	0.076±0.023	0.015±0.001
7.Ban Nong Fab, Rayong (500 m)	Rynf5	8.2	8.0	30.8	28.6	32.1	32.6	0.058±0.012	0.093±0.002
8.Had Sai Kaew, Kao Samed, Rayong (500 m)	Rysk5	NA	NA	NA	NA	NA	NA	0.106±0.023	0.094±0.002
9.Lham Mae Pim, Rayong (10 m)	Rylm0	8.2	8.0	30.9	29.9	32.5	25.3	0.087±0.021	0.079±0.002
10.Ao Chonburi, Chonburi (100 m)	Cbcb11	8.0	7.6	29.7	30.3	32.3	20.6	0.030±0.007	0.071±0.002
11.Sri Chang (station), Chonburi (100 m)	Cbsc11	8.2	8.2	29.0	31.3	32.0	31.1	<0.031	0.045±0.001
12.Hua Lham Chabung, Chonburi (100 m)	Cblp11	8.2	8.2	29.9	31.6	32.8	31.0	0.037±0.009	<0.002
13.Had Jom Tein (Klang), Chonburi, (10 m)	Cbjt02	8.3	8.1	29.7	32.7	32.2	32.6	0.065±0.017	0.088±0.002
14.Pak Mae Num Bang Pra Kong, Chachengsao (500 m)	CsMb5	7.4	6.9	29.3	31.0	31.7	0.6	0.036±0.001	<0.007
15.Pak Klong 12 Thanva, Samut Prakan (100 m)	Spks1	7.4	7.2	28.5	30.1	24.7	9.4	<0.037	0.034±0.001
16.Pak Mae Num Chao Pra Ya, Samut Prakan(500 m)	SpMc5	7.8	7.2	27.8	30.5	25.0	5.8	0.046±0.013	0.052±0.002
17.Bang Khun Tein (100 m)	Bkkt1	8.2	7.5	28.1	31.9	28.6	15.0	0.082±0.021	0.035±0.001
18.Pak Mae Num Tha Jen (500 m)	SsMt5	7.8	7.3	29.2	31.2	19.0	1.8	0.020±0.008	<0.006
19.Pak Mae Num Maeklong (500 m)	SkMm5	7.9	7.6	28.9	31.0	17.7	8.8	0.019±0.005	0.057±0.001
20.Had Chao Sum Ran, Phetchaburi (10 m)	Pbcs0	8.2	8.2	28.1	32.0	28.2	28.8	0.068±0.012	<0.002
21.Had Puk Tein, Phetchaburi (10 m)	Pbpt0	8.1	8.2	27.6	31.8	28.3	28.6	0.041±0.011	0.020±0.001
22.Ao Manao, Klongbin 53, Prachoubkirikhun (10 m)	Pcam0	8.3	8.1	27.3	30.6	29.6	30.1	0.017±0.005	<0.030

23.Pak Klong Wan, Prachoubkirikhun (500 m)	Pckw5	8.2	7.9	26.6	30.5	30.0	29.9	0.033±0.001	<0.050

Table 1 (Cont.) General parameters and gross-alpha radioactivity (Bq/l) in seawater collected from the Gulf of Thailand and the Andaman Sea in 2008

Stations	Code	pH		Temperature (°C)		Salinity (ppt)		Gross-alpha activity ± SD (Bq/l)	
		DS	WS	DS	WS	DS	WS	Dry season (DS)	Wet season (WS)
24.Had Wanakorn, Prachoubkirikhun (10 m)	Pcwk0	8.2	7.8	28.4	30.6	29.8	30.3	0.102±0.022	<0.011
25.Bang Sa Pan, Prachoubkirikhun (500 m)	Pcbs5	8.1	7.9	27.6	31.9	15.1	25.9	0.064±0.014	<0.009
26.Ban Na Tub, Ao Bang Son, Chumporn (500 m)	Cpnt5	8.3	7.9	31.0	29.9	28.9	30.3	0.034±0.008	0.112±0.002
27.Ban Sa Pli, Ao Sa Pli, Chumporn (500 m)	Cpsp5	8.2	7.8	31.2	29.6	29.2	30.1	0.074±0.024	0.008±0.001
28.Pak Mae Num Chumporn, Ao Pak Had, Chumporn (500 m)	CpMc5	8.1	7.6	31.1	30.0	20.9	21.9	0.029±0.007	0.067±0.002
29.Had Paradonpap, Chumporn (10 m)	Cppd0	8.1	7.9	29.4	29.0	29.0	29.8	0.058±0.015	0.073±0.002
30.Had Sumred, Surathani (10 m)	Srsr0	8.0	7.8	27.3	26.7	27.6	29.4	0.159±0.029	0.082±0.002
31.Thareao Na Ampeo, Koa Samui, Surathani (100 m)	Srps1	7.7	7.8	29.2	29.0	29.4	28.1	0.120±0.025	0.030±0.001
32.Tarad Maenum, Ban Maenum, Surathani (10 m)	Srmn0	8.3	7.9	27.3	29.8	29.4	29.4	0.067±0.013	0.074±0.002
33.Ban Hua Thanon, Kao Samui, Surathani (10 m)	Srht0	8.3	8.2	28.0	30.8	27.9	29.7	0.013±0.003	<0.035
34.Rong Faifa Khanom, Nakorn Sri Thamarat (100 m)	Nkkp1	8.2	7.7	29.3	29.6	29.5	28.6	0.065±0.016	<0.001
35.Ban Pak Klong, Nakorn Sri Thamarat (100 m)	Nkpk1	8.2	7.9	30.8	30.7	28.3	21.5	0.041±0.010	0.087±0.002
36.Had Maharach, Song Khla (10 m)	Somr0	8.2	7.8	30.1	31.7	28.5	29.9	0.032±0.009	0.048±0.002
37.Had Thepa, Song Khla (10 m)	Sotp0	8.3	7.8	30.9	29.4	28.7	29.8	0.086±0.018	<0.049
38.Had Chan Dum Ri, Pak Num Ranong (100 m)	RnMr1	7.7	7.6	29.8	30.1	27.9	20.1	0.178±0.029	0.034±0.001
39.Had Prapas, Ranong (10 m)	Rnpp0	8.2	8.3	30.8	31.6	31.6	28.1	0.072±0.016	<0.025
40.Tai Muang, Pak Klong Tublamu, Phanga (10 m)	Pgtm0	7.6	8.3	29.4	30.9	31.1	31.0	0.034±0.010	0.082±0.002
41.Ban Num Kem, Phanga (10 m)	Pg5	7.7	8.2	30.0	31.3	30.3	22.4	0.007±0.002	<0.001
42.Had Kata Yai (South), Phuket (10 m)	Pkky0	8.3	8.2	29.4	28.9	31.5	31.0	0.022±0.005	0.201±0.003
43.Had Ravai (Moo Ban Chao Pramong), Phuket (100 m)	Pkrw0	8.3	8.0	29.5	28.3	31.5	29.6	0.052±0.011	0.048±0.001
44.Had Nopharathara, Pak Klong Hang, Krabi(100 m)	Kb22.1	8.2	8.2	28.4	30.1	30.9	30.0	0.117±0.020	0.109±0.002

45.Ao Lobakao, Krabi (10 m)	Kblb0	8.1	8.2	28.1	31.2	31.3	31.2	0.014±0.004	<0.026
46.Had Chumchon Sri Ra Ya, Krabi (100 m)	Kbsr1	8.2	8.3	28.6	30.4	31.1	30.4	0.093±0.018	<0.022

Table 1 (Cont.) General parameters and gross-alpha radioactivity (Bq/l) in seawater collected from the Gulf of Thailand and the Andaman Sea in 2008

Stations	Code	pH		Temperature (°C)		Salinity (ppt)		Gross-alpha activity ± SD (Bq/l)	
		DS	WS	DS	WS	DS	WS	Dry season (DS)	Wet season (WS)
47.Ban Bo Mung, Trang (500 m)	Tgbm5	8.2	8.2	30.2	31.4	31.5	28.5	0.127±0.028	<0.001
48.Ban Pak Meng, Trang (500 m)	Tgpm5	8.1	8.2	30.0	31.1	30.7	28.7	0.031±0.022	<0.004
49.Had Ban Pakbara, Satul (500m)	Stpb5	8.2	8.2	30.0	31.3	31.0	28.3	0.067±0.023	0.052±0.001
50.Ban Pak Bang, Satul (10 m)	St14	8.3	8.1	30.8	31.0	32.2	29.6	0.055±0.010	0.082±0.002

Note: ppt = part per thousand, DS = dry season, WS = wet seasons, Bq = Becquarel, SD = Standard deviation (1 sigma), MDA = 0.003-0.048 Bq/l (Dry season) and 0.001-0.052 Bq/l (Wet season)

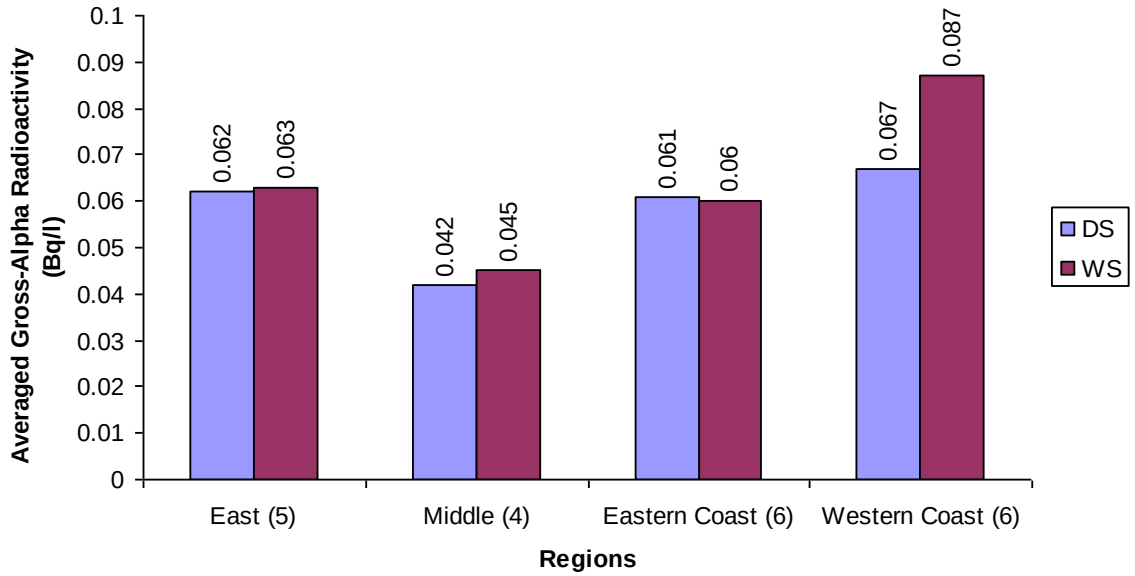

Figure 2 Illustration of the averaged gross-alpha activities in seawater collected in the dry (DS) and wet (WS) seasons from different regions

test presented no statistic differences (P>0.05) between all pairs, except, when the East, Middle, and Eastern coast were tested against the Western coast. A significant variation (P<0.05) was observed. Therefore, an additional investigation is required to reveal possible causes leading to a significantly high level of gross-alpha radioactivity.

The gross-alpha radioactivity results gained in this study (Table 1) were compared with 0.1 Bq/l[9]. The comparison revealed that a majority of the seawater samples was below the guideline value. No further analysis is hence required to reveal the origins of alpha activities. However, there were 7 (in dry season) and 3 (in wet season) stations showing exceeding levels of gross-alpha radioactivity when compared with the guideline (Table 1). A similar finding was reported by Kaharan *et al*. (2000). The authors suggested that uranium and radium isotopes are the main contributors to gross alpha activities in natural water. Hence, elevated concentrations of gross alpha radioactivity found in this work may possibly be caused by those two natural radionuclides, not by artificial radionuclides, Pu-239 or Am-241 for examples. It can be suggested here that the second gross-alpha analysis for these particular samples should be carried out in order to confirm the existing results. Appropriate approaches such as chemical analysis should subsequently be conducted, if needed, to reveal specific radionuclides contributing high levels of alpha activities. In spite of exceeding concentrations of gross-alpha activity in some locations, it can be generally concluded that seawater in the Gulf of Thailand and the Andaman Sea is radiologically safe and does not pose any radiation hazards caused by alpha emitting radioisotopes to marine environment.

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