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Inventory and flux of ^{210}Po and ^{210}Pb in the water column of southern South China Sea and Malacca Straits

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Abstract—Activities of ^{210}Po and ^{210}Pb were determined in dissolved (<0.45 μm) and particulate (>0.45 μm) fractions in water column from two different sampling locations as southern South China Sea (southern SCS) and Malacca Straits. Results obtained from analyzed samples showed that the activity of both nuclides in total phase (dissolved+particulate) is highly found in the Malacca Straits, while the opposite situations were shows by the calculated inventory and flux of ^{210}Po and ^{210}Pb. Calculated inventories and fluxes of ^{210}Po and ^{210}Pb in the water column at southern SCS and Malacca Straits were affected by the northeast and southwest monsoons, respectively with hundred times higher than the northern South China Sea.

Key words: inventory; flux; ^{210}Po; ^{210}Pb; southern South China Sea; Malacca Straits

Introduction

In the marine environment, ^{210}Po is mainly produced from the decay of ^{210}Pb deposited from the atmospheric. A small amount of ^{210}Po in the seawater originates from the atmospheric deposition of polonium itself (Uğur et al. 2002). While, ^{210}Pb is 22.3 years had β emitter largely produced from its effective parent, ^{226}Ra. ^{210}Pb is reached to the coastal waters via rivers and atmospheric fallout (Radakovitch et al. 1999, Smoak et al. 1999). Both of ^{210}Po and ^{210}Pb are well known to be particle-reactive in the marine environment (Tateda et al. 2003).

In the coastal environmental, there are many chemical reactions occurring that affect the flux of particle-reactive elements to the open ocean such as adsorption, desorption, precipitation of iron hydroxides, manganese oxides, and humic acids. The removal of these particle-reactive elements is accomplished by adsorption onto a solid phase or by aggregation of colloidal material (Smoak et al. 1996). Like others stable elements, the distribution pattern of natural radionuclides in water column are usually controlled by particle processes (Fowler and Knauer 1986).

Only a few studies were carried out on the natural radionuclides in the Malaysia coastal marine region. A research has been undertaken covering the geochemical behavior of ^{210}Po and ^{210}Pb in the Peninsular of Malaysia (Tee 2004). The aims of this study are to calculate the inventory and flux of ^{210}Po and ^{210}Pb in the southern SCS and Malacca Straits.

Materials and Methods

Water samples for the radiochemical analyses of ^{210}Po and ^{210}Pb were collected using a 10 L of Van Dorn water sampler at the chosen sites in Malacca Straits and Southern South China Sea as Kuala Selangor and Pulau Besar, and Pulau Redang, respectively (Fig. 1 and Table 1). About three times sampling were conducted at Kuala Selangor stations and used as referenced for flux and inventory of ^{210}Po and ^{210}Pb in Peninsular Malaysia because they are isolated from inter-boundary sources.

Seawater samples collected in the chosen sites were filtered through the 0.45 μm pore size of membrane filter paper and ^{209}Po was used as internal yield. Briefly, the methodology used for determine ^{210}Pb and ^{210}Po activities in water and suspended materials well described by Theng and Mohamed (2005) as including formation of precipitation for water sample and acid digestion of suspended material, spontaneous deposition of polonium isotopes onto a silver disk and measurement of ^{210}Po radioactive emission by the alpha spectrometry techniques. Then the activity of ^{210}Pb will be obtained after more than three months reach to equilibrium with their daughter (^{210}Po).

Results and Discussion

Dissolved and particulate of ^{210}Po and ^{210}Pb

Activity concentrations of ^{210}Po and ^{210}Pb in analyzed samples are summarized in Table 1 with decay-corrected to the sampling date. While the vertical profiles of both radionuclides in Malacca Straits were fluctuated with water depth because the thickness of water column for sampling stations located in Malacca Straits were not deep enough to assign likes the southern SCS but it enough to transport particles from the river to near-shore by tidal currents (Hoshika et al. 2003).

The activity concentrations of ^{210}Po in both dissolved and particulate phases of Malacca Straits and southern SCS were ranging from 0.02 Bq m^{-3} to 11.86 Bq m^{-3} and 0.45×10^4 Bq m^{-3} to 141.01×10^4 Bq m^{-3}, respectively and mostly they are found in the particulate phases (Table 2). Then the activity concentrations of both dissolved and particulate phases of ^{210}Pb were ranged from 0.03 Bq m^{-3} to 6.17 Bq m^{-3} and 0.19×10^4 Bq m^{-3} to 82.61×10^4 Bq m^{-3}, respectively (Table 2). The activities of ^{210}Po and ^{210}Pb found in the southern SCS and Malacca Straits during this study is about ten times higher than northern SCS as reported by Chung and Wu (2005) because the studied locations received large input from neighboring place as external sources during monsoon seasons and internal source as biological remobilization by biogenic particulate (Wildgust et al. 1998, Mohamed and Kuan 2005).

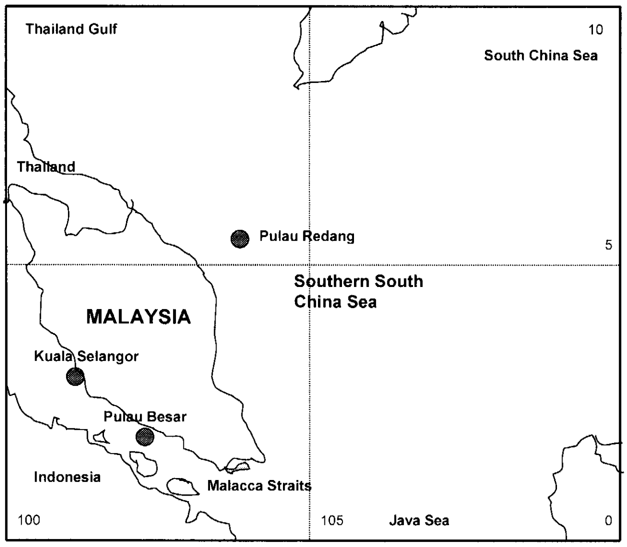

Fig. 1. Sampling station conducted during this study.

Meanwhile activity of ^{210}Pb obtained in the Malacca Straits is slightly low compare with southern SCS because Malacca Straits is as enclosed system with limited water movement (Ibrahim and Yangi 2004) and less received input from the original sources as from the Sumatera and Peninsular Malaysia. While the southern SCS is semi-closed system had large input from the neighboring countries (ASEAN) and western Pacific.

Inventory and Flux of ^{210}Po and ^{210}Pb in the Malacca Straits and southern South China Sea

Inventories of ^{210}Po and ^{210}Pb are useful parameters for assessing the accumulation process in the study area either in the southern SCS or Malacca Straits. The inventory of radionuclide in the water column of Malacca Straits stations is calculated from the measured activity at each layer of water column as follows (Ito et al. 2003):

Table 1. Sampling location conducted for the study.

Location	Sampling site (water depth)*	Station (water depth)	Latitude (N)	Longitude (E)
Malacca Straits	Kuala Selangor (2.5–15 m)	St. 1 (2.5 m)	3°20′25″N	101°15′22″E
		St. 2 (2.5 m)	3°21′08″N	101°14′07″E
		St. 3 (2.5)	3°19′77″N	101°13′50″E
		St. 4 (2.5 m)	3°18′20″N	101°13′04″E
		St. 5 (11 m)	3°16′93″N	101°12′46″E
		St. 6 (11 m)	3°15′55″N	101°12′11″E
	Pulau Besar (2–15 m)	St. 1 (2 m)	2°09′41″N	102°20′21″E
		St. 2 (2 m)	2°09′16″N	102°20′10″E
		St. 3 (7 m)	2°08′74″N	102°20′03″E
		St. 4 (10 m)	2°08′29″N	102°20′02″E
		St. 5 (15 m)	2°07′82″N	102°19′97″E
		St. 6 (15 cm)	2°07′29″N	102°19′99″E
		St. 7 (3.5 m)	2°06′88″N	102°20′19″E
Southern South China Sea	Pulau Redang (17–45 m)	St. 1 (17 m)	5°42′39″N	102°59′59″E
		St. 2 (30 m)	5°45′58″N	103°03′05″E
		St. 3 (35 m)	5°48′19″N	103°02′06″E
		St. 4 (35 m)	5°48′22″N	102°59′09″E
		St. 5 (30 m)	5°45′34″N	102°59′10″E
		St. 6 (40 m)	5°43′15″N	102°59′55″E

The (*) is the ranging thickness of water column at the sampling location.

Table 2. Activities of ^{210}Po and ^{210}Pb were obtained in the analyzed samples.

Location	Sampling site	Sampling date	Station	Layer (m)	Dissolved (Bq m^{-3})		Particulate (×10^4 Bq m^{-3})	
					^{210}Po	^{210}Pb	^{210}Po	^{210}Pb
Malacca Straits	Kuala Selangor	21-8-2001	St. 1	0.5	0.52±0.24	0.09±0.05	8.24±0.35	1.50±0.07
				2.36	0.28±0.15	0.14±0.05	4.22±0.47	3.89±0.37
			St. 2	0.5	0.53±0.13	0.10±0.17	6.85±0.28	2.00±0.10
				1.68	0.29±0.11	0.85±0.36	8.77±0.34	2.74±0.11
			St. 3	0.5	0.19±0.08	0.20±0.06	7.43±0.47	1.86±0.21
				2.67	0.22±0.08	0.54±0.28	6.70±0.27	2.07±0.09
			St. 4	0.08	0.06±0.04	0.06±0.03	5.74±0.34	1.70±0.13
				2.96	0.15±0.05	0.50±0.17	3.39±0.18	1.22±0.08
			St. 5	0.17	0.16±0.05	0.12±0.11	2.83±0.49	2.57±0.82
				7.15	0.15±0.06	0.04±0.03	3.90±0.44	1.01±0.40
				13.58	0.02±0.05	0.15±0.04	4.74±0.29	1.65±0.17
			St. 6	0.21	0.28±0.07	0.17±0.18	2.72±0.37	0.33±0.39
				5.71	0.12±0.06	0.13±0.04	3.49±0.35	1.81±0.35
				12.84	0.15±0.05	0.12±0.04	4.28±0.23	1.41±0.14
		25-4-2002	St. 1	0.10	0.34±0.14	0.06±0.04	8.81±0.36	2.58±0.12
				1.64	0.41±0.13	0.22±0.08	7.67±0.30	2.20±0.09
			St. 2	0.09	0.53±0.13	0.10±0.17	6.85±0.28	2.00±0.10
				1.68	0.29±0.11	0.85±0.36	8.77±0.34	2.74±0.11
			St. 3	0.16	0.19±0.08	0.20±0.06	7.43±0.47	1.86±0.21
				2.67	0.22±0.08	0.54±0.28	6.70±0.27	2.07±0.09
			St. 4	0.08	0.06±0.04	0.06±0.03	5.74±0.34	1.70±0.13
				2.96	0.15±0.05	0.50±0.17	3.39±0.18	1.22±0.08
			St. 5	0.17	0.16±0.05	0.12±0.11	2.83±0.49	2.57±0.82
				7.15	0.15±0.06	0.04±0.03	3.90±0.44	1.01±0.40
				13.58	0.02±0.05	0.15±0.04	4.74±0.29	1.65±0.17
			St. 6	0.21	0.28±0.07	0.17±0.18	2.72±0.37	0.33±0.39
				5.71	0.12±0.06	0.13±0.04	3.49±0.35	1.81±0.35
				12.84	0.15±0.05	0.12±0.04	4.28±0.23	1.41±0.14
		7-9-2002	St. 1	0.08	0.24±0.08	0.36±0.10	5.99±0.35	2.31±0.16
				2.35	0.40±0.10	0.37±0.09	0.54±0.25	1.10±1.18
			St. 2	0.37	0.22±0.07	0.21±0.07	6.33±0.32	2.40±0.14
				2.47	0.27±0.44	0.14±0.06	—	3.32±2.75
			St. 3	0.15	0.21±0.26	0.06±0.12	7.10±0.41	2.55±0.19
				2.10	1.12±0.38	0.48±0.10	6.35±0.26	2.12±0.10
			St. 4	0.32	0.18±0.07	0.18±0.07	5.10±0.58	1.82±0.25
				1.73	0.17±0.06	0.19±0.06	1.93±0.22	0.94±0.13
			St. 5	0.23	0.55±0.21	0.17±0.05	5.31±0.92	3.22±0.66
				4.97	0.09±0.21	0.25±0.09	3.90±0.74	1.82±0.30
				9.97	0.40±0.26	0.32±0.07	4.51±0.69	1.88±0.26
			St. 6	0.28	0.26±0.07	0.17±0.06	4.76±1.67	1.35±0.44
				5.07	0.17±0.05	0.23±0.09	4.22±0.46	1.67±0.18
				9.59	0.13±0.20	0.15±0.06	4.46±0.29	1.48±0.15
	Pulau Besar	19-1-2002	St. 1	0.13	0.35±0.09	0.03±0.02	4.37±0.39	1.57±0.17
				1.51	0.18±0.07	0.08±0.04	0.45±0.04	0.36±0.04
			St. 2	0.18	0.12±0.06	0.10±0.04	5.53±0.40	1.85±0.16
				1.72	0.27±0.07	0.08±0.03	2.68±0.11	0.94±0.05
			St. 3	0.11	0.15±0.06	0.05±0.03	5.18±0.54	1.98±0.23
				6.36	0.10±0.06	0.06±0.03	5.59±0.21	2.01±0.08
			St. 4	0.21	0.14±0.06	0.07±0.04	6.58±1.33	2.95±0.45
				4.93	0.17±0.06	0.08±0.03	5.19±0.62	2.24±0.27
				9.88	0.15±0.06	0.02±0.03	4.94±0.38	1.61±0.15
			St. 5	0.35	0.15±0.06	0.09±0.03	6.56±0.13	1.15±0.47
				5.10	0.12±0.06	0.05±0.04	5.17±0.99	2.35±0.52
				10.22	0.09±0.05	0.08±0.03	6.58±1.13	2.28±0.32
				13.35	0.22±0.07	0.05±0.03	6.45±0.69	2.43±0.20

Table 2. (Continued).

Location	Sampling site	Sampling date	Station	Layer (m)	Dissolved (Bq m^{-3})		Particulate (×10^4 Bq m^{-3})	
					^{210}Po	^{210}Pb	^{210}Po	^{210}Pb
Malacca Straits	Pulau Besar	19-1-2002	St. 6	0.17	0.28±0.07	0.15±0.04	5.01±0.99	1.75±0.42
				5.13	2.33±0.11	1.44±0.08	19.84±1.40	12.08±0.67
				10.14	10.22±0.38	6.17±0.23	78.7±3.08	45.23±1.71
				14.66	4.69±0.18	3.03±0.12	11.73±0.55	7.18±0.35
			St. 7	0.13	6.80±0.24	5.65±0.21	94.43±3.73	58.15±2.20
				3.43	5.04±0.18	3.69±0.14	22.13±1.11	13.14±0.56
Southern South China Sea	Pulau Redang	21-7-2002 to 25-7-2002	St. 1	0.00	3.55±0.30	0.12±0.05	34.22±7.83	19.57±1.30
				5.00	5.80±0.40	0.22±0.09	78.74±16.39	12.66±3.50
				10.00	5.77±0.40	0.09±0.04	6.99±2.87	11.31±4.27
				15.00	6.78±0.45	0.26±0.06	8.92±2.68	6.87±0.88
			St. 2	0.00	4.63±0.33	0.57±0.08	88.36±6.73	4.25±1.11
				5.00	5.37±0.38	0.53±0.08	90.73±6.36	6.68±2.31
				10.00	5.33±0.39	0.47±0.08	97.57±7.35	6.48±1.53
				15.00	6.67±0.44	0.89±0.12	81.52±5.78	6.85±1.63
				20.00	7.12±0.45	0.89±0.10	77.36±5.05	2.43±0.64
				25.00	9.27±0.55	1.30±0.16	46.13±2.85	1.19±0.31
			St. 3	0.00	4.50±0.31	0.62±0.08	40.25±3.23	4.06±0.76
				5.00	5.59±0.37	1.06±0.11	56.70±4.23	2.05±0.73
				10.00	6.21±0.41	2.63±0.19	62.13±4.72	2.94±1.23
				15.00	11.86±0.65	0.43±0.14	69.99±4.76	3.84±0.79
				20.00	6.00±0.39	0.56±0.09	34.21±7.27	22.52±1.29
				25.00	8.32±0.47	0.55±0.09	141.01±7.09	82.61±3.11
				30.00	4.66±0.33	0.75±0.10	65.50±4.39	51.08±2.43
				35.00	5.66±0.39	0.81±0.10	98.61±5.25	65.52±2.62
			St. 4	0.00	3.04±0.25	0.20±0.08	75.23±5.43	5.07±1.43
				5.00	3.64±0.28	0.88±0.13	77.98±5.43	4.98±0.98
				10.00	6.86±0.46	0.29±0.07	75.84±4.81	3.63±0.71
				15.00	9.77±0.57	0.38±0.07	93.85±6.10	2.11±0.64
				20.00	4.10±0.32	0.17±0.05	69.85±5.17	5.60±1.92
				25.00	3.72±0.28	0.32±0.06	66.60±4.99	4.57±1.08
				30.00	4.36±0.33	0.15±0.05	62.69±4.68	3.44±1.17
				35.00	3.81±0.29	0.07±0.09	69.60±4.85	1.18±0.49
			St. 5	0.00	6.38±0.45	0.12±0.06	52.29±4.09	0.19±1.31
				5.00	9.57±0.55	0.03±0.07	73.65±5.09	0.97±0.51
				10.00	3.25±0.27	0.05±0.03	38.92±3.33	1.71±0.89
				15.00	4.98±0.36	0.12±0.05	74.89±5.72	1.04±0.58
				20.00	2.87±0.23	0.12±0.04	129.63±10.07	0.47±3.19
				25.00	2.94±0.25	0.22±0.10	161.44±11.01	3.87±1.44
				30.00	5.39±0.37	0.05±0.04	17.52±1.07	2.82±0.31
			St. 6	0.00	9.49±0.53	0.38±0.09	158.45±11.15	4.34±1.26
				5.00	3.54±0.29	0.24±0.06	107.11±8.75	5.22±1.44
				10.00	5.30±0.39	0.09±0.12	134.44±10.15	4.06±1.37
				15.00	4.54±0.34	0.14±0.06	95.66±8.57	9.54±3.95
				20.00	5.75±0.40	0.34±0.10	443.99±31.72	2.76±3.42
				25.00	5.65±0.40	0.24±0.06	160.83±11.49	4.68±2.41
				30.00	9.56±0.55	0.05±0.03	332.34±22.37	27.33±4.40
				35.00	4.27±0.34	0.05±0.03	7.81±2.27	15.23±2.84
				40.00	3.76±0.30	0.34±0.13	30.51±4.19	16.50±3.21

Table 3. Calculated inventories of ^{210}Po and ^{210}Pb were obtained during this study in the dissolved and particulate phases at each station of southern South China Sea and Malacca Straits.

Sampling	Sampling date	Station	Depth range	Inventory (Bq m^{-2})			
				^{210}Po		^{210}Pb	
				Dissolved	Particulate (×10^5)	Dissolved	Particulate (×10^5)
Kuala Selangor	21-8-2001	1	0–2.50	1.03	1.60	0.28	0.65
		2	0–2.50	1.29	2.34	0.38	0.43
		3	0–2.50	1.50	2.33	0.13	0.41
		4	0–2.50	0.61	1.74	0.22	0.33
		5	0–11.00	2.91	3.89	0.73	3.41
		6	0–11.00	3.78	5.61	0.58	2.89
	25-4-2002	1	0–2.50	0.96	2.02	0.41	0.58
		2	0–2.50	0.94	2.02	1.46	0.62
		3	0–3.00	0.62	2.11	1.14	0.59
		4	0–3.50	0.39	1.54	1.08	0.50
		5	0–15.00	0.82	4.05	0.90	1.27
		6	0–15.00	1.60	4.50	1.47	1.85
	7-9-2002	1	0–2.50	0.81	0.80	0.91	0.42
		2	0–2.50	0.60	0.90	0.45	0.70
		3	0–2.50	1.78	1.67	0.73	0.58
		4	0–2.50	0.44	0.81	0.46	0.33
		5	0–11.00	0.75	3.09	2.05	1.38
		6	0–11.00	1.17	3.32	1.44	1.19
Pulau Besar	19-1-2002	1	0–1.60	0.43	0.39	0.09	0.16
		2	0–1.80	0.34	0.75	0.16	0.26
		3	0–6.50	0.81	3.50	0.36	1.30
		4	0–10.00	0.86	2.77	0.27	1.06
		5	0–15.00	1.78	8.28	0.86	3.13
		6	0–15.00	71.04	49.0	43.50	28.4
		7	0–3.50	20.77	20.6	16.40	12.6
Pulau Redang	21-7-2002 to 25-7-2002	1	0–17.00	78.71	44.9	2.81	17.0
		2	0–25.00	132.62	207	18.58	12.6
		3	0–35.00	238.60	249	33.48	99.9
		4	0–35.00	179.38	260	11.63	13.7
		5	0–30.00	147.48	199	3.13	4.78
		6	0–40.00	226.18	688	7.55	39.6

$$I=\frac{1}{2}\left[\sum_{i=1}^{N}(C_{i+1}+C_i)(d_{i+1}-d_i)+2C_1d_1+2C_N(d_B-d_N)\right] \quad (1)$$

where the I is the inventory of radionuclide in water column (Bq m^{-2}), N is the number of sampling depths, C_i is the concentration of radionuclide in the seawater at depth i (Bq m^{-3}), d_i is the i-th sampling depth of sea water (m), d_1 is the first (surface) sampling depth (m), and d_B is the total depth to the bottom (m).

Meanwhile all stations located in the southern SCS which is containing more than layers were calculate using an equation 2 as follows, except for station 1 (Aoyama and Hirose 2003):

$$I=\frac{1}{2}\sum_{i=1}^{N}(C_{i+1}+C_i)(d_{i+1}-d_i) \quad (2)$$

The calculated inventories of ^{210}Po and ^{210}Pb in the southern SCS and Malacca Straits slightly fluctuated in all sampling stations were caused by the different thickness of water column (Table 3), where the highest inventory values was found at Pulau Redang stations in the southern SCS.

The activities of ^{210}Po and ^{210}Pb in southern SCS and Malacca Straits are dominated in the suspended particles materials (Tee and Mohamed 2005) and the actual total activities of both nuclides in water column at sampling site were calculated as follows:

$$\text{Total nuclides}=\text{Activity in dissolved}+[\text{Activity in SPM}\times\text{concentration SPM}\times10^{-6}]$$

Table 4. Values of inventories and fluxes in the southern South China Sea and Malacca Straits were calculated from the analyzed stations at different monsoon period.

Location	Sampling site	Monsoon [Number] (month)	SPM* (mg/L)	Dissolved* ($Bq\,m^{-3}$)		Particulate* ($\times 10^4\,Bq\,m^{-3}$)		^{210}Po** ($Bq\,m^{-3}$)	^{210}Pb** ($Bq\,m^{-3}$)	$^{210}Po/^{210}Pb$	Inventory site+ ($\times 10^5\,Bq\,m^{-2}$)		Flux site++ ($\times 10^4\,Bq\,m^{-2}\,yr^{-1}$)	
				^{210}Po	^{210}Pb	^{210}Po	^{210}Pb				^{210}Po	^{210}Pb	^{210}Po	^{210}Pb
Malacca Straits	Kuala Selangor	SWM [14] (August 2001)	762	0.22	0.23	5.24	1.84	40.15	14.25	2.82	2.92	1.35	53.36	0.42
		Intermonsoon [14] (April 2002)	521	3.50	0.22	0.23	5.52	4.70	28.98	0.16	2.71	0.90	49.49	0.28
		SWM [14] (September 2002)	1611	0.32	0.23	4.32	2.00	69.92	32.45	2.15	1.77	0.77	32.27	0.24
	Pulau Besar	NEM [19] (January 2002)	951	1.66	1.10	15.64	8.49	150.40	81.84	1.84	12.18	6.70	222.79	2.08
Southern South China Sea	Pulau Redang	SWM [42] (July 2002)	7.3	5.71	0.42	90.24	10.58	12.30	1.19	10.31	274.65	31.26	5022.00	9.72

The SWM and NEM are the southwest monsoon and northeast monsoon, respectively.
The [Number] is the numbers of samples analyzed in the study.
The (*) is mean value calculated from analyzed samples. The (**) is calculated nuclide in water column from surface to bottom for each sampling site Total nuclide=Activity in dissolved+[Activity in SPM×concentration SPM×(1×10^{-6})].
The (+) is the actual inventory of analyzed nuclide at sampling site as Inventory site=[Inventory all stations at all layers in the dissolved phase+Inventory all stations at all layers in SPM]/ [Number of stations analyzed].
The (++) is the values calculated from the inventory values.

Where the Total nuclides is the actual total of studied nuclides in water column at sampling site (Bq m^{-3}); the activity in dissolved is the mean contents of dissolved nuclides in all layers at sampling site (Bq m^{-3}); the activity in SPM is the mean activities of studied nuclides in all layers at sampling site (Bq m^{-3}); and the 10^{-6} is the conversion unit from gram to the meter cubic.

The actual activities of studied nuclides in the southern SCS and Malacca Straits are slightly various from each monsoon season especially during the north east monsoon as showed by Pulau Besar sampling stations (Table 4). The activity studied nuclides recorded during north east monsoon is >100 Bq m^{-3} and >50 Bq m^{-3} for ^{210}Po and ^{210}Pb, respectively because large sources of both nuclides were transported through the atmosphere especially ^{210}Pb. On the other hand, to confirm those monsoons affected in the study area, sampling was also conducted in the southern SCS during the south west monsoon for calculate their inventory and flux.

The distribution chlorophyll and primary productivity in the SCS are influenced by the monsoons season (Liu et al. 2002). Then the highest mean inventory recorded in the southern SCS to be $>200\times10^5$ Bq m^{-2} and $>20\times10^5$ Bq m^{-2}, respectively for ^{210}Po and ^{210}Pb (Table 4) whereas in the northern SCS was to be 543 Bq m^{-2} and 700 Bq m^{-2} for ^{210}Po and ^{210}Pb, respectively (Chung and Wu 2005).

Fluxes for both nuclides also calculated from an equation of $F=I\lambda$, where F (Bq m^{-2} year^{-1}) is the flux of analyzed radionuclide, I (Bq m^{-2}) is the inventory and λ (year^{-1}) is the radionuclide decay constant (Legeleux et al 1996). The calculated fluxes of ^{210}Po and ^{210}Pb in the water column at the southern SCS were the highest values compared with other location in the Malacca Straits (Table 4) because the southern SCS received large input sources from the neighboring area such as from Indo-China by atmospheric transport, and northern SCS and western Pacific by ocean water circulation.

As we known, ^{222}Rn decays to ^{210}Pb, which rapidly adheres to atmospheric particles or aerosols and is washed from the atmosphere by rain. Therefore, ^{210}Pb fluxes to ocean surface are controlled by proximity to large landmasses, atmospheric circulation and rainfall (Henderson and Maier-Reimer 2002). During the North-east Monsoon, heavy rainfall might be contributed in ^{210}Pb and ^{210}Po fluxes at Pulau Redang, which transport of the continental air mass from inland and wind-driven. Meanwhile, the atmospheric circulation in east coast of Peninsular Malaysia has a rapid movement due to its open system compared to west coast of Peninsular Malaysia. As for ^{210}Po, this discrepancy may be reflected the differences in primary productivity in the water column between the two sites besides the rainfall and atmospheric circulation. Moreover, Tateda et al (2003) has observed that ^{210}Po enrichment relative to ^{210}Pb in atmospheric deposition was significant during the rainy season.

Conclusion

The inventory and flux in studied area such as southern South China Sea and Malacca were affected by the variation of monsoon seasons. The north east monsoon was the major vehicle to transport both nuclides from the original region into the southern SCS.

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