Natural radionuclides in the Arabian Sea and Bay of Bengal: Distribution and evaluation of particle scavenging processes

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Abstract. Vertical and temporal variations in the activities of ^{234}Th, ^{210}Po and ^{210}Pb have been measured, in both dissolved and particulate phases, at several stations in the eastern Arabian Sea and north-central Bay of Bengal. A comparative study allows us to make inferences about the particle associated scavenging processes in these two seas having distinct biogeochemical properties.

A common feature of the ^{234}Th profiles, in the Arabian Sea and Bay of Bengal, is that the dissolved as well as total (dissolved + particulate) activity of ^{234}Th is deficient in the surface 200 m with respect to its parent, ^{238}U. This gross deficiency is attributed to the preferential removal of ^{234}Th by adsorption onto settling particles which account for its net loss from the surface waters. The scavenging rates of dissolved ^{234}Th are comparable in these two basins. The temporal variations in the ^{234}Th-^{238}U disequilibrium are significantly pronounced both in the Arabian Sea and Bay of Bengal indicating that the scavenging rates are more influenced by the increased abundance of particles rather than their chemical make-up. In the mixed layer (0–50 m), the scavenging residence time of ^{234}Th ranges from 30 to 100 days.

The surface and deep waters of both the seas show an enhanced deficiency of dissolved ^{210}Po relative to ^{210}Pb and that of ^{210}Pb relative to ^{226}Ra. The deficiencies of both ^{210}Po and ^{210}Pb in the dissolved phases are not balanced by their abundance in the particulate form indicating a net loss of both these nuclides from the water column. The scavenging rates of ^{210}Po and ^{210}Pb are significantly enhanced in the Bay of Bengal compared to those in the Arabian Sea. The mean dissolved ^{210}Po/^{210}Pb and ^{210}Pb/^{226}Ra activity ratios in deep waters of the Bay of Bengal are ~0·7 and 0·1, respectively, representing some of the most pronounced disequilibria observed to date in the deep sea. The Bay of Bengal and the Arabian Sea appear to be the regions of most intense particle moderated scavenging processes in the world oceans. This is evidenced by the gross disequilibria exhibited by the three isotope pairs used in this study.

Keywords. Radionuclides; sea water; disequilibrium; particles; scavenging rates.

1. Introduction

Natural radionuclides of the uranium and thorium decay series have long served oceanographers as powerful tracers for studying the chemical scavenging processes and their kinetics. Among the particle-reactive daughter and passive-parent pairs, perhaps the most widely documented and utilized for studying the particle-associated scavenging processes (operative in ocean water) are ^{234}Th-^{238}U, ^{210}Po-^{210}Pb and ^{210}Pb-^{226}Ra (Bhat *et al* 1969; Broecker *et al* 1973; Craig *et al* 1973; Matsumoto 1975; Bacon *et al* 1976; Nozaki *et al* 1976; Santschi *et al* 1979; Kaufman *et al* 1981; Krishnaswami *et al* 1981).

The chemical scavenging processes are particularly important within the euphotic zone – a region of maximum biological production. It has been suggested (Coale and Bruland 1985) that the 'new production' rather than total primary production, may

determine net scavenging rates of reactive elements from oceanic surface waters. It is possible to use the production rates of radionuclides (from dissolved parents) and their export from the euphotic zone, both of which can be measured precisely, to constrain estimates of new production (Bruland and Coale 1986; Buesseler *et al* 1992). Recently, Sarin *et al* (1994) have measured vertical profiles of dissolved ^{210}Po and ^{210}Pb in the north-eastern Arabian Sea. By modeling the observed disequilibria between the ^{210}Po and ^{210}Pb within the surface $\sim 100\,m$, Sarin *et al* (1994) derived the 'effective vertical eddy-diffusion coefficient' and fluxes of nutrients into the euphotic zone from its base. These studies demonstrate the potential usefulness of particle reactive nuclides (^{234}Th and ^{210}Po) to derive net export fluxes of carbon and associated nutrients from the euphotic zone. However, a detailed characterization of the spatial and temporal distributions of the radionuclide tracers is necessary to directly compare this approach with independent estimates of new production.

In this paper, we present results on the distribution of three daughter-parent pairs, viz. ^{234}Th-^{238}U, ^{210}Po-^{210}Pb and ^{210}Pb-^{226}Ra measured in the same vertical profiles, for both the dissolved and particulate fractions, collected from the Arabian Sea and Bay of Bengal. A comparative study allows us to make inferences about the nature and intensity of chemical scavenging processes operative in these two seas.

2. Experimental methods

The Arabian Sea and Bay of Bengal are the two important regions of the north Indian Ocean that exhibit some unique biogeochemical properties. The Arabian Sea experiences extremes in atmospheric forcing that lead to the regular oscillation in primary production. It is also characterized by widespread suboxic conditions below the euphotic zone and perennial denitrification layers (Naqvi *et al* 1990) at intermediate depths (200–700 m). On the contrary, geochemical processes in the Bay of Bengal are influenced by buoyancy input of fresh water run-off and high sediment load of terrestrial origin. Thus the two seas, on either side of India, are ideal for studying the particle-associated scavenging processes.

2.1 *Sampling*

Samples for this study were collected during four different cruises, on board ORV 'Sagar Kanya' and FORV 'Sagar Sampada', to the eastern Arabian Sea and north-central Bay of Bengal. In the Arabian Sea, three vertical profiles were collected at stations M-12, K-11 and I-15 (figure 1) during Nov.-Dec. 1988. Two of these stations M-12 and K-11 were reoccupied during Feb. 1992 and numbered as 2500 and 2494, respectively. A vertical profile at Stn 2510, in the central Arabian Sea (figure 1), was also collected during the latter cruise. In the Bay of Bengal, vertical profiles at stations H-13, F-11, E-13 and A-12 were collected during Mar. 1991 and those at stations E-12 and C-12 were collected during Dec. 1991 (figure 1).

2.2 *Analytical techniques*

The seawater samples from different depths covering the entire water column, were collected using 30 litre Niskin samplers. All samples were filtered within 4–6 hrs
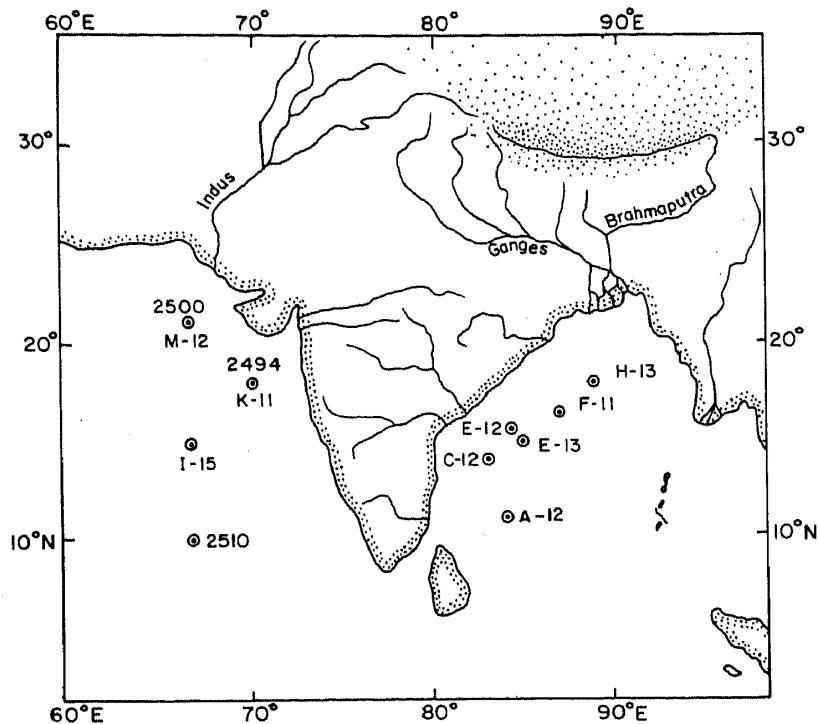
Figure 1. Station locations, sampling details are given in tables 1 and 2.

through 0·4 or 0·6 μm pore size Nuclepore filters and were analysed for ^{234}Th, ^{238}U, ^{210}Po, ^{210}Pb and ^{226}Ra. The analytical techniques used for the radiochemical separation and measurement of all these nuclides have been described in detail by Sarin *et al* (1992, 1994). The shipboard processing of samples was typically completed within 48 hours thereby minimizing the ingrowth of short-lived ^{234}Th and ^{210}Po from their parent nuclides ^{238}U and ^{210}Pb, respectively. In the laboratory, Th and Pb were radiochemically purified and final Th fractions were electroplated onto Pt discs (Sarin *et al* 1992). The purified Pb fractions were stored in plastic bottles for 8–10 months and the *in-situ* ^{210}Pb activity was measured by the ingrown activity of its grand daughter ^{210}Po. Uranium was measured on a separate filtered aliquot (~ 5 litre) at selected depths, based on which a linear relation between ^{238}U and salinity was derived. Radium from unfiltered seawater samples (~ 20 litre) was extracted on board using MnO_2 coated acrylan fibres (Moore 1976) and assayed in the laboratory via total alpha activity of ^{222}Rn. The activities of ^{234}Th were determined by a gas-flow type, low-background (~ 6 cph), circular counters operated in anti-coincidence with a large guard counter. The alpha-activities of U, Th and Po isotopes were determined on a calibrated silicon surface-barrier detectors (Sarin *et al* 1992, 1994).

3. Results

The activity of ^{234}Th was measured on unfiltered samples collected from the stations 2500 and 2510 in the Arabian Sea. The total (dissolved + particulate) activities of ^{234}Th in these two profiles are given in table 1. These results alongwith the data on the dissolved activities of ^{234}Th measured in the profiles M-12, K-11 and I-15 (Sarin
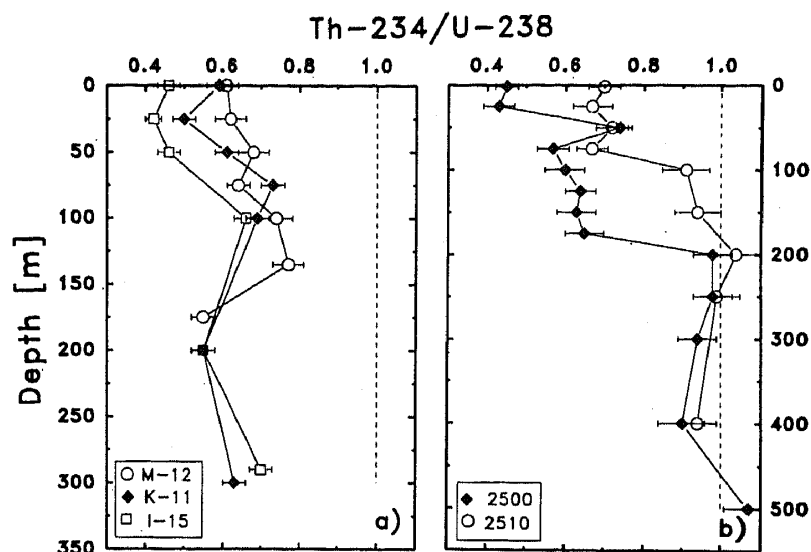
Th-234/U-238

Figure 2. Profiles of ^{234}Th/^{238}U activity ratios in the Arabian Sea measured on a) filtered samples (data from Sarin *et al* 1994) and b) unfiltered samples (this study). Ratios less than one indicate deficiency of ^{234}Th relative to ^{238}U. Profiles M-12 and 2500 are collected from same location (figure 1).
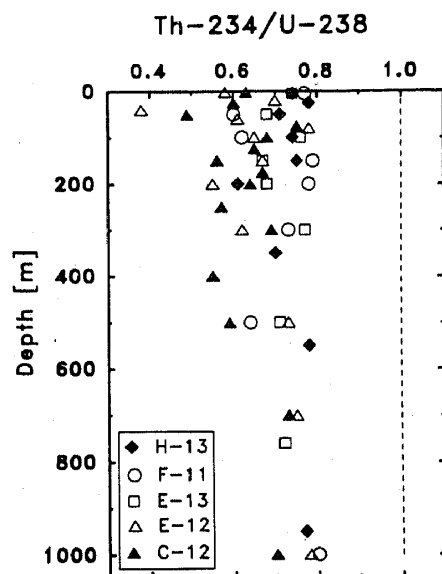
Th-234/U-238

Figure 3. Dissolved ^{234}Th/^{238}U activity ratios in the Bay of Bengal indicating deficiency of dissolved ^{234}Th all through the sampling depths.

et al 1994) are presented in figure 2. The dissolved activities of ^{234}Th in the profiles (H-13, F-11, E-13, E-12, C-12) from the Bay of Bengal are also listed in table 1 and presented in figure 3. The dissolved ^{238}U concentration (table 1) was measured at selected depths, based on which a ^{238}U-salinity relation was derived as: ^{238}U (dpm/l) = 0·06813 × S (‰) for the Arabian Sea (Sarin *et al* 1992) and ^{238}U (dpm/l) = 0·0697 × S (‰) for the Bay of Bengal (this study). The ^{238}U-salinity relation derived for these two oceanic regions is quite similar to that derived by Ku *et al* (1977) for the Pacific Ocean.

Results of the ^{210}Po and ^{210}Pb analyses in the dissolved and particulate samples are listed in tables 2 and 3. Figures 4 and 5 show the extent of disequilibrium between dissolved ^{210}Po and ^{210}Pb in the eastern Arabian Sea and north-central Bay of Bengal, respectively. The activities of these two nuclides in the particulate phase are compared in figure 6. The ^{226}Ra data measured at selected depths in the Arabian Sea and Bay of Bengal are presented in table 4. The distribution of dissolved ^{210}Pb and its pronounced deficiency with respect to ^{226}Ra in the deep water column is shown in figure 7.

The errors quoted for the dissolved activities of ^{234}Th, ^{238}U, ^{210}Po and ^{210}Pb (tables 1, 2 and 3) are $\pm 1\sigma$ (about ± 5–10%) calculated based on uncertainties arising
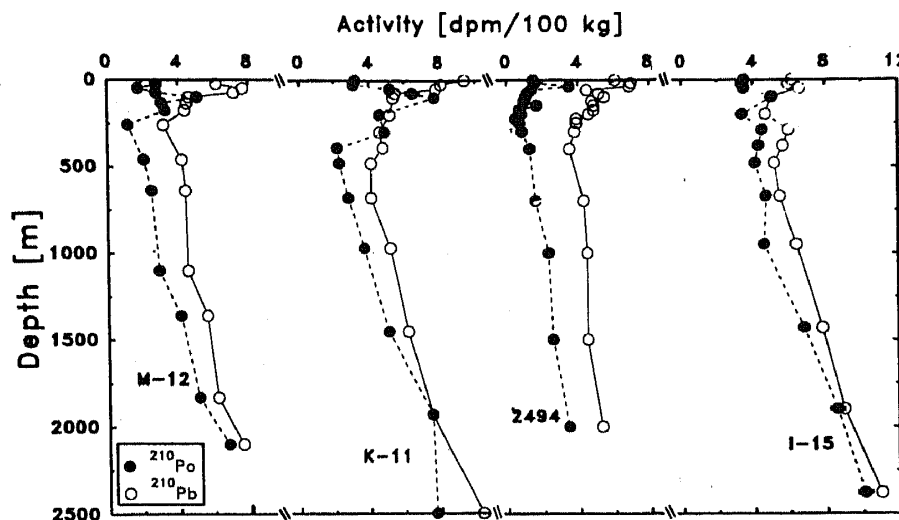
Figure 4. Dissolved ^{210}Po and ^{210}Pb profiles in the Arabian Sea showing deficiency of ^{210}Po (relative to ^{210}Pb) in surface and deep waters. Data for M-12, K-11 and I-15 are from Sarin *et al* 1994. Notice that the excess ^{210}Po centered at ~ 100 m (Stn K-11) is not observed at Stn 2494 (figure 1).
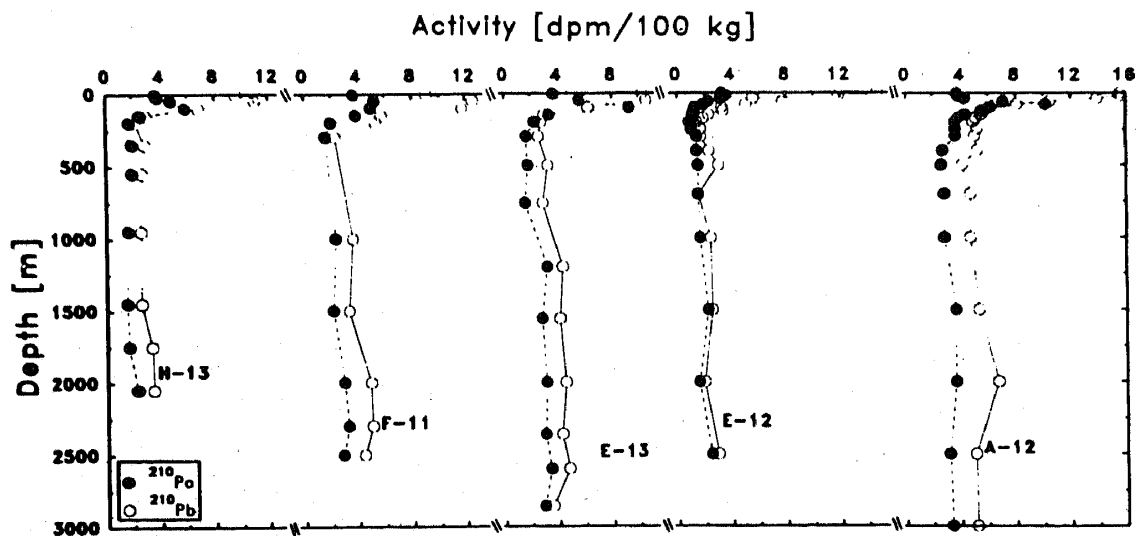
Figure 5. Dissolved ^{210}Po and ^{210}Pb profiles in the Bay of Bengal show almost identical activity of ^{210}Po in surface waters at all stations, but significantly less than that of its parent ^{210}Pb. Dissolved ^{210}Pb activity is relatively high in surface waters at Stn E-12 and A-12 sampled during Dec. 1991 (see text for discussion).
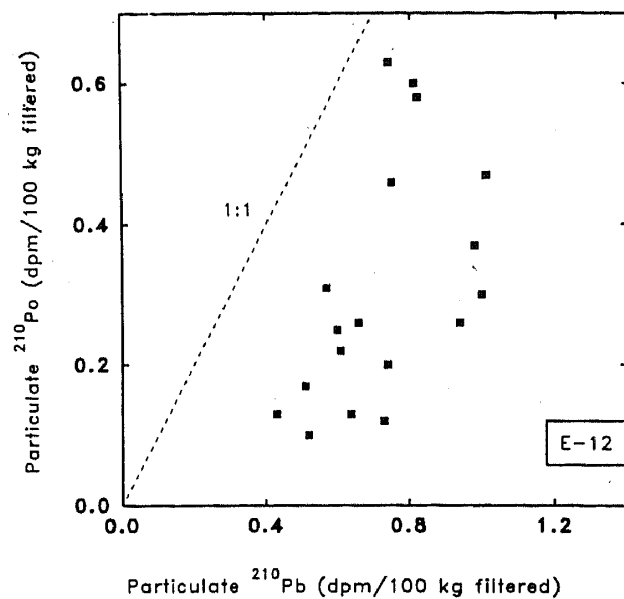
Figure 6. ^{210}Po-^{210}Pb relationship in the particulate phase showing ^{210}Pb excess rather than ^{210}Po excess. Low values of particulate ^{210}Po are measured in samples collected from shallow waters indicating that the standing crop of ^{210}Po in shallow waters is less than that of ^{210}Pb.
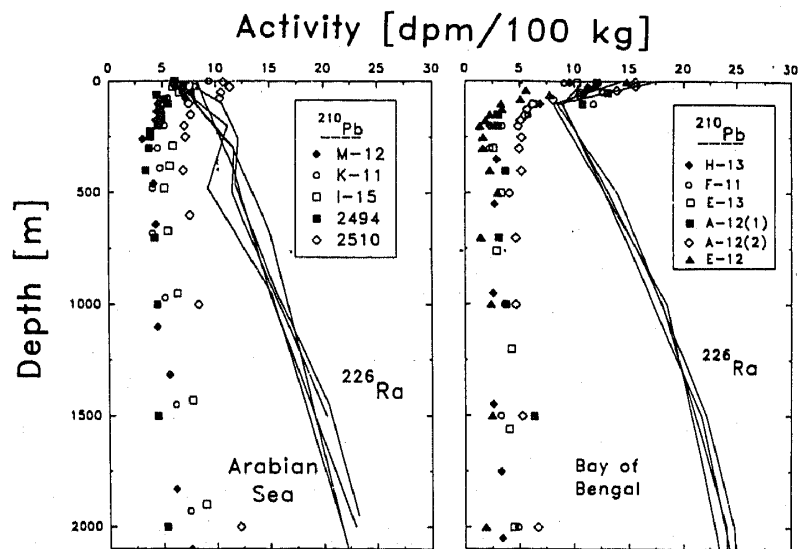
Figure 7. Dissolved ^{210}Pb and ^{226}Ra profiles from the Arabian Sea and Bay of Bengal. The gross deficiency of ^{210}Pb (relative to its parent ^{226}Ra) extends all through the water column in these two seas.

from counting statistics, tracer/carrier calibrations and blank corrections. The corresponding errors associated with the particulate phases (tables 2, 3) are in the range of 10–15%.

4. Discussion

4.1 ^{234}Th-^{238}U *disequilibrium*

4.1a *Arabian Sea*: Data on the $^{234}Th/^{238}U$ activity ratios measured in the samples from the north-eastern Arabian Sea are presented in figure 2. In all the profiles sampled, the $^{234}Th/^{238}U$ activity ratio is much less than the equilibrium value. At Stn M-12, K-11 and I-15, (figure 2), the deficiency of dissolved ^{234}Th (relative to ^{238}U) all through the top 300 m water column has been reported by Sarin *et al* (1994). The gross deficiency of ^{234}Th in the mixed layer (0–50 m) is reflected even in the unfiltered samples from Stn 2500 and 2510 (figure 2), the mean $^{234}Th/^{238}U$ activity ratios are 0·44 and 0·69 respectively (table 1). These results indicate an intense scavenging of ^{234}Th via rapidly sinking biogenic particles and a net export (loss) of ^{234}Th out of the mixed layer. The relatively low $^{234}Th/^{238}U$ ratios observed at Stn 2500 also suggest that the particulate scavenging of ^{234}Th (and hence of thorium) from the surface waters is more pronounced in the northern region of the Arabian Sea which is characterized by the high biological productivity (Qasim 1982). At depths below 200 m, the total activity (dissolved + particulate) of ^{234}Th at Stn 2500 and 2510 is close to equilibrium with its parent (^{238}U) and continues to be so throughout the rest of the deep water column (figure 2). For depths below 1000 m, the mean $^{234}Th/^{238}U$ ratio is 0·99 ± 0·05, suggesting that thorium is not removed from the deep waters on the time scales of less than 10–12 months.

The total activity of ^{234}Th at Stn 2500 and 2510, at depths below 200 m, is in marked contrast to the profiles measured at Stn M-12, K-11 and I-15 (figure 2). In the latter three profiles, dissolved ^{234}Th activity continues to show gross deficiency relative to ^{238}U upto the sampling depth of 300 m. These observations suggest that particulate scavenging of ^{234}Th occurs even in the intermediate waters. Also the temporal variations in $^{234}Th/^{238}U$ activity ratios become evident by intercomparing the profiles M-12 and 2500. The total (dissolved + particulate) activity ratio of $^{234}Th/^{238}U$ in the surface waters at Stn 2500 is 0·45 which is significantly less than the dissolved ratio of 0·61 measured during the sampling period of M-12 (table 1, figure 2). This is contrary to the expectation that the total $^{234}Th/^{238}U$ activity ratio should be more than that in the dissolved phase. These differences suggest that the distribution of a particle reactive tracer is dominated by seasonal changes in biological productivity. Similar results were reported by Tanaka *et al* (1983) based on the measurement of total ^{234}Th activity in a number of profiles collected over a period of one year in Funka Bay, Japan.

It is quite likely that the surface productivity was relatively enhanced when Stn 2500 was reoccupied during Feb. 1992. Primary productivity in the northern Arabian Sea suggests annual rates between 200 and 400 gC/m²/yr and daily rates exceeding 2 gC/m²/d reaching perhaps 6 gC/m²/d (Qasim 1982). Despite lack of simultaneous measurements of primary productivity, the main feature of our data is the noticeable decrease in the surface ^{234}Th activity along with nutrient levels such as nitrate. During

the sampling period, at Stn 2500, the $(NO_3 + NO_2)$ concentration levels in the mixed layer were found to be less than 1 μmole/l. Buesseler *et al* (1992) have reported similar observations based on their time series analysis of dissolved nitrate and ^{234}Th during the JGOFS North Atlantic bloom experiment. Their data show a strong depletion of ^{234}Th in surface waters together with a decrease in nitrate levels as the bloom activity progressively enhanced.

4.1b *Bay of Bengal*: Results of the dissolved ^{234}Th/^{238}U activity ratios in profiles H-13, F-11, E-13, E-12, and C-12 are presented in table 1 and figure 3. The measured ^{234}Th/^{238}U ratio in the surface waters at all five stations is fairly uniform, varying between a narrow range of 0·58 to 0·77. Unlike in the Arabian Sea, there is no distinct latitudinal trend observed in the Bay of Bengal. However, relatively low ^{234}Th/^{238}U ratios have been observed in the profiles collected at Stn E-12 and C-12 during Dec. 1991 (figure 3). During the south-west monsoon, the Bay of Bengal receives a large influx of fresh water and fluvial sediments via the six major rivers (figure 1) which most likely enhance the particle contents and particulate scavenging of ^{234}Th. The magnitude of temporal variations in the dissolved ^{234}Th/^{238}U ratio can be evaluated based on the data from profiles E-13 and E-12, collected at nearby locations (table 1, figure 3). At E-13, the dissolved ^{234}Th/^{238}U ratio in the mixed layer (0–50 m) varies from 0·68 to 0·74; whereas at E-12 (collected during Dec. 1991) the ratio varies from 0·38 to 0·70. Another notable feature observed in all the vertical profiles (figure 3) is the near constancy (0·70 ± 0·05) of the dissolved ^{234}Th/^{238}U ratio below 100 m. However, the deficiency of dissolved ^{234}Th, relative to ^{238}U, exists throughout the 1000 m of water column (figure 3), an observation similar to that in the surface 300 m of the Arabian Sea (figure 2).

4.1c ^{234}Th *scavenging rates*: The deficiency of ^{234}Th in the dissolved phase results from scavenging processes – adsorption onto suspended particles. The extent of disequilibrium between ^{234}Th and ^{238}U (figures 2 and 3) provides a measure of the relative intensity of scavenging processes in the Arabian Sea and Bay of Bengal. A simple scavenging model (Krishnaswami *et al* 1976; Coale and Bruland 1985; Sarin *et al* 1994) can be used to calculate the scavenging rate of dissolved ^{234}Th. Assuming advection and diffusion of ^{234}Th to be negligible (with respect to scavenging and decay), at steady state, the scavenging residence time (τ) of ^{234}Th (from dissolved to particulate phase) is given by the relation:

$$\tau = \frac{t_{Th}}{(A_U/A_{Th}) - 1} \tag{1}$$

where t_{Th} is the mean life of ^{234}Th, A_U and A_{Th} are the activities of ^{238}U and ^{234}Th (dpm/litre), respectively. It is implicit in equation (1) that scavenging of Th is irreversible. Such model calculations provide a measure of the scavenging rates of particle-reactive tracers in surface waters.

The mean τ values of dissolved ^{234}Th in the mixed layer for all the profiles (figures 2, 3) are given in table 5. In the Arabian Sea (figure 2), the scavenging residence time of dissolved Th in the mixed layer is lowest at I-15 compared to that at M-12 and K-11. Since the profiles M-12 and K-11 are collected from the regions associated with relatively high biological productivity, it is expected that the residence time of

Th should be relatively short at these sites. Sarin *et al* (1994) have interpreted that, at M-12 and K-11, Th is more effectively recycled from particles to solution in the mixed layer. Below the mixed layer, the mean scavenging residence time of dissolved Th is fairly uniform (table 5) at these three stations.

Equation (1) can be extended to calculate the removal residence time of total ^{234}Th from the surface waters at Stn 2500 and 2510 in the Arabian Sea. Assuming that the advection and diffusion terms are negligible relative to scavenging, at steady state, the removal residence time (τ_Σ) of total ^{234}Th is given by the relation:

$$\tau_\Sigma = \frac{t_{Th}}{(A_U/A_{\Sigma Th}) - 1} \tag{2}$$

where t_{Th} and A_U have been defined in equation (1), $A_{\Sigma Th}$ is the total ^{234}Th activity. The removal residence time of total ^{234}Th in surface waters at Stn 2500 is 28 days and that at Stn 2510 is 78 days (table 5).

The suspended particulate material in the surface waters of the north-eastern Arabian Sea are primarily of biogenic origin. Also as mentioned earlier, it is likely that biological productivity was enhanced when Stn M-12 was reoccupied during Feb. 1992. The short residence time of 28 days at Stn 2500 suggest that ^{234}Th is efficiently removed from surface waters by biogenic particles. These time scales may be too short for any significant desorption to occur (Coale and Bruland 1985) and thus the assumption of irreversible scavenging is valid to a first approximation. Below the mixed layer, the τ_Σ of ^{234}Th upto a depth ~ 175 m (using equation 2) at Stn 2500 is 63 days (table 5). The longer residence time at these depths can result due to the differences in the suspended particulate concentrations and/or the effective recycling/desorption of Th. The highest values of τ_Σ for Th in surface and intermediate waters are observed at Stn 2510 (table 5).

In the Bay of Bengal, the results (table 5) provide a broad spatial view of the intensity and temporal variability of the scavenging processes. The scavenging residence time of dissolved ^{234}Th at H-13, F-11 and E-13 (table 5) is fairly uniform (90 ± 10 days) all through the upper 500 m water column. The scavenging intensity of dissolved ^{234}Th at Stn E-12 and C-12 is relatively more pronounced during the sampling period (Dec. 1991). The scavenging residence time of Th in the mixed layer is ~ 45 days and that below the mixed layer is ~ 65 days at these two stations (table 5). The north-central Bay of Bengal receives a large influx of fluvial sediments during the south-west monsoon. This increase in the suspended particulate load in surface waters may account for the relatively shorter residence time of Th.

Recent studies (Bruland and Coale 1986; Murray *et al* 1989) have shown explicitly that a strong correlation exists between ^{234}Th scavenging rate and the measured rates of new production. Using this approach, Sarin *et al* (1994) have calculated the flux of particulate organic carbon out of the surface mixed layers at Stn M-12, K-11 and I-15 in the Arabian Sea, typical values being 0·10, 0·13 and 0·3 gC/m^2/d, respectively. Although, temporal variability is quite evident from the data (as discussed above) and steady-state conditions are not strictly attained, it is still possible to constrain estimates of particle production or export rates. A similar approach has been extended to the Bay of Bengal. The ^{234}Th scavenging rates ($1/\tau$) in the mixed layer range from 0·01 to 0·023 day^{-1} at Stn H-13, F-11, E-13, E-12 and C-12 (table 5). Assuming that ^{234}Th is efficiently removed by biogenic particles, these rates

correspond to relatively lower estimates of new production (0·06 to 0·14 g C/m²/d) in the Bay of Bengal.

4.2 ^{210}Po-^{210}Pb *disequilibrium*

4.2a *Arabian Sea*: The dissolved ^{210}Po/^{210}Pb activity ratios for all the four profiles in the Arabian Sea, one measured in this study (Stn. 2494, table 2) and three reported earlier (Sarin *et al* 1994) are plotted in figure 4. A common feature of all these profiles (figure 4) is that all of them show a strong depletion of dissolved ^{210}Po in surface waters relative to ^{210}Pb, indicating a net uptake of ^{210}Po by the particles. This observation is typical of the surface waters of the oceans where ^{210}Po is generally found to be deficient with respect to ^{210}Pb (Nozaki and Tsunogai 1976; Bacon *et al* 1988; Chung and Finkel 1988). Another important feature of the data in figure 4 is that the ^{210}Po/^{210}Pb activities ratios tend to decrease towards the northern stations, indicating that the removal of ^{210}Po in surface waters is more effective in the north-eastern Arabian Sea, a region characterized by higher rates of biological productivity. The integrated dissolved ^{210}Po/^{210}Pb ratios in the mixed layer at Stn M-12, K-11 and I-15 are 0·34, 0·37 and 0·55 respectively (Sarin *et al* 1994). At Stn 2494 (reoccupation of the site K-11 during Feb. 1992), the mean dissolved ^{210}Po/^{210}Pb ratio is 0·32 which indicates enhanced scavenging of ^{210}Po (relative to ^{210}Pb) by particulate phases.

The profiles at Stn M-12, K-11 and I-15 display a common feature: a ^{210}Po excess in the subsurface layer centered at $\sim$ 100 m. This excess suggests that ^{210}Po is released from sinking particulate matter (Bacon *et al* 1976; Sarin *et al* 1994). In contrast, a similar excess of dissolved ^{210}Po, at 100 m, was not observed in the profile at Stn 2494. Instead, a ^{210}Po deficit of about 2–4 dpm/100 kg, relative to ^{210}Pb, exists below the mixed layer (table 2, figure 4). It is likely that the primary productivity was relatively enhanced during the sampling period of Stn 2494. Under these conditions, preferential removal of Po (over Pb) is more effective via rapidly settling biogenic particles. Also the dissolved ^{210}Po activities, measured in the profile 2494 at depths below 100 m, are systematically lower by a factor of about 2 to 5 (table 2, figure 4) than those in the profile K-11 (Sarin *et al* 1994). Thus suggesting an intense scavenging of dissolved ^{210}Po, all through the water column, by the suspended particles on short time scales. These temporal variations clearly indicate that the distribution of a particle reactive tracer is largely dictated by the seasonal changes in the primary productivity.

The most distinctive feature in the Arabian Sea is observed at Stn M-12, K-11 and I-15 where dissolved ^{210}Po deficiency is more pronounced in the intermediate waters (figure 4). Sarin *et al* (1994) have suggested that this secondary minimum of ^{210}Po activity spreads through the 200–500 m depth characterized by the oxygen minimum and NO_2 maximum concentrations (Naqvi *et al* 1990). It was also suggested that although the cause for the enhanced ^{210}Po scavenging at the core of the denitrification layer is unclear, it is possible that the *in situ* and boundary scavenging may be the important alternative processes. Recently, Naqvi *et al* (1993) have reported the occurrence of nepheloid layers within the suboxic waters and that these particle maxima are confined to the denitrifying zone. A high bacterial biomass appears to be responsible for the increased turbidity at these mid-depths in the Arabian Sea. It is very likely that these nepheloid layers with strong concentration gradient towards

the shelf and slope regions, may efficiently scavenge ^{210}Po. Similar to K-11, profile 2494 also shows a pronounced deficiency of ^{210}Po at 225 m depth where the lowest concentration of dissolved ^{210}Po (0.51 ± 0.12, table 2) and ^{210}Po/^{210}Pb ratio (0.13 ± 0.03) have been observed. Such an intense scavenging process may be attributed to the perennial existence of the nepheloid layer at intermediate depths.

The near-bottom ^{210}Po/^{210}Pb activity ratios at M-12, K-11 and I-15 are fairly constant at $\sim 0.90 \pm 0.10$ indicating a near equilibrium between dissolved ^{210}Po and ^{210}Pb in the deep waters. Comparatively, the deficiency of ^{210}Po is significantly pronounced even in the deep waters during the sampling period of Stn 2494, the observed ^{210}Po/^{210}Pb activity ratio at 2000 m is 0.64 ± 0.04 (table 2, figure 4). Such an observation is difficult to reconcile, the seasonal changes and enhanced surface water productivity seem to influence the chemical scavenging processes throughout the water column. It is noteworthy that the ^{210}Pb concentrations in the intermediate and deep waters of the profile 2494 are within 10–20% of those measured in the K-11 profile. This indicates that the low values of ^{210}Po/^{210}Pb activity ratio observed in profile 2494 mainly result from the pronounced removal of ^{210}Po relative to ^{210}Pb.

4.2b *Bay of Bengal*: The dissolved and particulate activities of ^{210}Po and ^{210}Pb in the profiles at Stn H-13, F-11, E-13, A-12 and E-12 are given in table 3 and plotted in figure 5. The most distinct feature of the data is that, all through the Bay of Bengal, the dissolved activity of ^{210}Po in surface waters shows a gross deficiency relative to ^{210}Pb. The dissolved ^{210}Po/^{210}Pb activity ratios in the mixed layer (~ 50 m) range between 0.23 to 0.4 (table 3). The observed ratios are relatively low compared to those in the surface waters of the Arabian Sea (figure 4). Also, unlike in the Arabian Sea, there are no pronounced latitudinal variations in the dissolved ^{210}Po/^{210}Pb ratios. The temporal variations in the water column scavenging processes are also evident by comparing the ^{210}Po/^{210}Pb data from profiles E-13 and E-12, (collected close to each other) during Mar. 1991 and Dec. 1991, respectively. The Stn A-12 was also reoccupied during Dec. 1991 (table 3 and figure 5). In general, the samples collected during the latter period show enhanced deficiency of ^{210}Po relative to ^{210}Pb. This enhanced removal of ^{210}Po from the surface mixed layer is attributed to the increased abundance of particulate matter (most likely the terrigenous supply via rivers) in the Bay of Bengal during the monsoon period. Cochran *et al* (1983) have reported a similar pattern of ^{210}Po-^{210}Pb disequilibrium in the sub-surface waters of the central and eastern Indian Ocean along the GEOSECS track. In intermediate and deep waters, dissolved ^{210}Po/^{210}Pb activity ratios do not exhibit any significant temporal and spatial variations (figure 5). Below 500 m depth, dissolved ^{210}Po/^{210}Pb ratio averages around 0.7 ± 0.1 indicating that preferential removal of ^{210}Po (relative to ^{210}Pb) onto particulate matter extends all through the water column.

The distribution of ^{210}Po between the dissolved and particulate phases can be understood based on its activity in these two phases (table 3). The measured particulate ^{210}Po activity in the profiles H-13, F-11, E-13 and A-12 have large errors due to the ingrowth of ^{210}Po (from ^{210}Pb) during the prolonged storage of samples in the laboratory. However, samples collected from Stn E-12 were analysed immediately on their return to the laboratory. The data show that a systematic ^{210}Po depletion (relative to ^{210}Pb) occurs, within the top 50 m, in the particulate phase (table 3). The ^{210}Po/^{210}Pb activity ratios are significantly less than one, and the particulate ^{210}Po values range from about 0.1 to 0.6 (figure 6). Also, the particulate ^{210}Po activity

accounts for only 10 to 30% of the dissolved activity. A distinct deficiency of total ^{210}Po (dissolved + particulate) observed at Stn E-12 suggest that the standing crop of ^{210}Pb is greater than that of ^{210}Po. Similar deficiency of ^{210}Po in particulate phase was reported by Chung and Finkel (1988) at some of the stations along the GEOSECS track in the western Indian Ocean.

4.2c ^{210}Po *Scavenging rates*: Using a simple box model calculation (similar to that discussed in section 4.1c), the mean residence time of dissolved ^{210}Po with respect to scavenging by particles in the surface mixed layer and deep waters has been computed. In the Arabian Sea, the integrated mean dissolved ^{210}Po/^{210}Pb activity ratios in the mixed layer yield scavenging residence times of 103, 117 and 244 days respectively at Stn M-12, K-11 and I-15. Below 300 m, the calculated scavenging residence time of ^{210}Po at these sites is significantly higher relative to that in surface waters, the values range from 1·3 to 3·4 years (Sarin *et al* 1994). The relatively shorter residence time of 1·3 years is typical of the deep north-eastern Arabian Sea. As discussed in the section 4.2a, the disequilibrium between ^{210}Po and ^{210}Pb is significantly pronounced in the profile 2494. The mean dissolved activity ratio of 0·24 in the mixed layer yields a scavenging residence time of 63 days, which is about a factor of two less than that derived for K-11 (Sarin *et al* 1994). Below 300 m, the integrated dissolved ^{210}Po/^{210}Pb activity ratio is 0·45 and the mean residence time of ^{210}Po with respect to its removal onto particles is only 0·4 years as compared to 1·3 years derived for K-11. Such short residence time of ^{210}Po in the deep Arabian Sea, compared to ~4 years derived for the deep Atlantic (Bacon *et al* 1976) is attributed to seasonal variations in the surface primary productivity that in turn controls the chemical scavenging processes in the water column.

Sarin *et al* (1994) have modelled the regeneration of ^{210}Po profile in the upper ~100 m at Stn K-11 and calculated the vertical eddy-diffusion co-efficient 'K' and the upward fluxes of NO_3 and PO_4 into the euphotic zone from its base. Such an approach could not be extended to the profile 2494, when Site K-11 was reoccupied during Feb. 1992. The characteristic ^{210}Po regeneration was not observed below the euphotic zone (figure 4). Prior to this study, temporal variations in the dissolved activities of ^{210}Po have been reported by Tanaka *et al* (1983). The large temporal variations in the ^{210}Po residence time, suggest that the steady-state conditions assumed in box-model calculations are not strictly valid in the oceanic regions that are characterized by large seasonal changes in biological productivity.

In the Bay of Bengal, the scavenging residence time of dissolved ^{210}Po in the surface waters (at Stn H-13, F-11, E-13 and A-12) is in the range of 130–160 days similar to that observed in surface waters of the northern Arabian Sea. However, unlike in the Arabian Sea, the latitudinal variations in removal rates are not pronounced. This suggests that scavenging in the Bay of Bengal waters is more uniform. It is important to note that the scavenging residence time of dissolved ^{210}Po at Stn E-12 and A-12 (reoccupied during Dec. 1991), is about a factor of two less than that derived from the data for E-13 and A-12, sampled during March 1991. This observation reemphasizes temporal variations in scavenging processes and the requirement to use non-steady-state models for studying particle-associated processes. In the intermediate and deep waters, dissolved ^{210}Po/^{210}Pb activity ratio (~0·70) is quite uniform all through the north-central region. This yields a residence time of about 1·3 years in the deep Bay of Bengal. A close similarity between the scavenging

rates derived for the two basins suggests that particulate abundance rather than its chemical nature dominates scavenging processes in the water column.

4.3 ^{226}Ra *profiles*

The data on vertical profiles of ^{226}Ra measured in the Arabian Sea and Bay of Bengal are presented in table 4. The surface water ^{226}Ra concentrations in the Arabian Sea range from (6·0 ± 0·5) to (8·3 ± 0·3) dpm/100 kg. In the Arabian Sea, the only published data for ^{226}Ra are the profiles at GEOSECS Stn 416 and 417 (Chung and Finkel 1987). The surface ^{226}Ra activities at M-12 and K-11 are about 1 to 2 dpm/100 kg higher than those at I-15 and GEOSECS Stn 416, 417. It has been suggested that the lateral transport of ^{226}Ra from slope sediments could lead to the higher concentration at sites M-12 and K-11 (Sarin *et al* 1994). A noteworthy feature, at Stn 2500 and 2494 is the identical nature of ^{226}Ra profiles with those at sites M-12 and K-11 except for minor differences in near surface ($\leqslant$ 100 m) concentrations (table 4, figure 7).

The ^{226}Ra profiles in the Bay of Bengal (table 4, figure 7) are similar to those from the Arabian Sea (Sarin *et al* 1994) and from the equatorial Indian Ocean (Cochran *et al* 1983; Ostlund *et al* 1987) but for the higher activities of ^{226}Ra in surface waters. Its activity in the surface waters of the Bay ranges from 10·7 ± 0·7 to 17·3 ± 0·7 dpm/100 kg. This is attributed to the enhanced input of ^{226}Ra via rivers to the Bay of Bengal. The surface salinities in the Bay of Bengal are significantly lower than those in the Arabian Sea. Based on the Ra isotope measurements in the Ganga-Brahmaputra system, Carroll *et al* (1993) estimated that $9·5 \times 10^{14}$ dpm of ^{226}Ra is released into the Bay of Bengal annually through the process of desorption from the fluvial sediments.

The most striking feature observed in all the profiles of the Bay of Bengal (table 4, figure 7) is the ^{226}Ra minimum at $\sim$ 100 m. At GEOSECS Stn 446, Cochran *et al* (1983) reported ^{226}Ra value of $\sim$ 13 dpm/100 kg in surface waters and a similar minimum in ^{226}Ra concentration within top $\sim$ 200 m. Below 100 m, all profiles have comparable activities of ^{226}Ra and its distribution is essentially identical (figure 7). The ^{226}Ra activity at $\sim$ 100–200 m depth is about 9 dpm/100 kg and the waters at this depth have salinities in the range of 34·5 to 35·3‰. Both the equatorial Indian Ocean and Arabian Sea surface waters that circulate into the Bay of Bengal (Shetye *et al* 1993) have salinities and ^{226}Ra content quite similar to the waters at 100–200 m in the Bay. It appears that mixing of waters of thermocline region of the Bay of Bengal can be conveniently studied using ^{228,226}Ra alongwith standard physical oceanographic parameters.

4.4 ^{210}Pb-^{226}Ra *disequilibrium*

4.4a *Arabian Sea*: The ^{210}Pb and ^{226}Ra profiles collected from the Arabian Sea are shown in figure 7. The data from Stn 2494 and 2510 are given in table 2, rest are from Sarin *et al* (1994). A common feature of the data is that ^{210}Pb activities are in gross deficiency with respect to ^{226}Ra except in surface waters at site K-11 where ^{210}Pb is in excess of ^{226}Ra. However, this excess ^{210}Pb is not observed in the profile 2494 (reoccupation of K-11).

The ^{210}Pb concentration in surface waters of the ocean is mainly derived from the atmospheric sources. The deficiency of ^{210}Pb observed in surface waters of the Arabian

Sea is unlike its excess concentration (over ^{226}Ra) which is often observed in the open-ocean surface waters (Bacon *et al* 1976; Nozaki *et al* 1976). This suggests that either the atmospheric ^{210}Pb flux is relatively small or the scavenging of ^{210}Pb in surface waters of the Arabian Sea is extremely rapid. Sarin *et al* (1994) have shown that the standing crop of ^{210}Pb excess (i.e. ^{210}Pb derived from atmospheric fall-out) is about 2, 4 and 8 dpm/cm^2 at Stn M-12, K-11 and I-15 respectively. These derived values are significantly lower .than the expected ^{210}Pb standing crop of about 30 dpm/cm^2 in the water column at these sites. Based on this observation, Sarin *et al* (1994) have suggested that about 70–90% of the ^{210}Pb supplied via atmospheric deposition has been removed by scavenging processes in the water column. The scavenging residence time for ^{210}Pb in the mixed layer, with respect to atmospheric input of ~ 1 dpm/cm^2/yr, is calculated to be about 150 days.

The ^{210}Pb/^{226}Ra activity ratios range from 0·27 to 1·34, the low values occurring in the intermediate and deep waters. Also a systematic northward decreasing trend in the ^{210}Pb/^{226}Ra ratio can be seen from the data for profiles M-12, K-11 and I-15 (table 2, Sarin *et al* 1994). The mean ^{210}Pb/^{226}Ra activity ratios in waters below 300 m at M-12, K-11 and I-15 are 0·3, 0·34 and 0·44 respectively. Using a steady-state box-model calculation described earlier, the scavenging time of ^{210}Pb with respect to its removal onto particles is estimated to be ranging from 14 to 25 yrs at these locations (Sarin *et al* 1994); which is less than that reported for the deep Atlantic and Pacific (Bacon *et al* 1976, Nozaki and Tsunogai 1976). Similar to the enhanced ^{210}Po scavenging at the core of the denitrification layer (200–500 m depths at Stn M-12 and K-11), the ^{210}Pb scavenging also seems to be affected as evident from its constant deficiency at these depths. A composite pattern of the ^{210}Pb distribution (figure 7) at intermediate depths shows that the dissolved activity of ^{210}Pb varies within a range of $\sim 3\cdot5$–$5\cdot5$ dpm/100 kg at all stations.

The extent of temporal variation in the distribution of dissolved ^{210}Pb can be gauged by comparing the data from profiles K-11 and 2494 (table 2). Data from profile 2494, indicate pronounced ^{210}Pb deficit (relative to ^{226}Ra) below 100 m depth. The ^{210}Pb deficit ranges from ~ 5 dpm/100 kg at 100 m to ~ 18 dpm/100 kg at 2000 m. This is because the dissolved ^{210}Pb activities below 100 m depth have remained fairly uniform (3·5 to 5·3 dpm/100 kg, table 2). The particulate ^{210}Pb is about 5% of the dissolved ^{210}Pb (table 2, figure 8). The increased deficiency of dissolved ^{210}Pb with depth is not balanced by increase in the particulate ^{210}Pb activity. In near-surface waters, the total ^{210}Pb activity (dissolved + particulate) at Stn 2494 is less than that of ^{226}Ra, suggesting removal of ^{210}Pb by settling particles. In the central Arabian Sea, at Stn 2510 (table 2), total ^{210}Pb activities in surface waters are ~ 50% higher than those at northern stations (M-12, K-11 and 2494). The total ^{210}Pb activities in surface waters, when compared with ^{226}Ra profile at nearby Stn I-15, show excess of ^{210}Pb over ^{226}Ra, quite similar to that observed in other oceanic areas. Also, the ^{210}Pb deficiency in deep waters of the central Arabian Sea is less pronounced compared to that in northern regions.

4.4b *Bay of Bengal*: The dissolved and particulate ^{210}Pb data for the vertical profiles in the Bay of Bengal are given in table 3. A composite plot of all dissolved ^{210}Pb–^{226}Ra profiles is shown in figure 7 and the common features are: (1) The dissolved ^{226}Ra activities below 100 m and their variations with depth are almost identical (figure 7). (2) The dissolved ^{210}Pb activities in surface waters range from (9·1 $\pm$ 0·3) to (15·6 $\pm$ 0·4) dpm/100 kg (table 3). A systematic northward decreasing trend in surface ^{210}Pb

activities is quite evident, the lower values occurring in the northern most Stn H-13 and F-11 (table 3). The surface ^{210}Pb activities at southern locations (A-12, E-12) are generally about 60% higher. This implies that either the atmospheric ^{210}Pb flux is relatively small at northern locations or the removal rate of ^{210}Pb is significantly enhanced. This removal processes may be associated with the enhanced input of fluvial sediments via rivers (which may act as efficient scavengers) and/or the ^{210}Pb uptake at the shallow sediment/water interface. (3) The dissolved ^{210}Pb activities, below 100 m, exhibit a pronounced deficiency with respect to ^{226}Ra (figure 7), the values range from about 1·5 to 6·5 dpm/100 kg. The relatively low values occurring in the deep waters of the northern Bay of Bengal, indicate intense scavenging similar to that in the surface waters.

The dissolved ^{210}Pb activities in the surface waters of the Bay of Bengal are significantly higher than those in the Arabian Sea. However, its activity in deep waters is almost a factor of 2 to 3 less than that in the northern profiles (M-12, K-11, 2494) of the Arabian Sea (figure 7). This is clearly evident from the data for E-12 profile where the dissolved ^{210}Pb activities are uniformly low all through the water column (table 3, figure 7). Station E-12 was sampled during the post-monsoon conditions in the Bay of Bengal, when the abundance of fluvial sediments is expected to be high. Data collected from time-series sediment traps deployed at two depths (809 and 1750 m) in the northern Bay of Bengal show that the maxima in total particulate matter fluxes occur during July–September. This is due to the lateral input or scavenging of sediments derived from the delta and shelf regions which are resuspended with increasing water discharge of Ganga–Brahmaputra (Reemtsma *et al* 1993). The pronounced deficiency of ^{210}Pb can also be ascertained by taking its activity difference with ^{226}Ra (i.e. ^{210}Pb-^{226}Ra). For E-12 Stn, at 2000–2500 m depth, the water column activity difference is about 22 dpm/100 kg. Cochran *et al* (1983) have reported similar observations for Bay of Bengal GEOSECS Stn 446, where the activity difference is 30 dpm/100 kg at the bottom-most depth of ∼ 3000 m. These observed values are comparable to some of the high productivity areas such as the Gulf of California (Bruland *et al* 1974) and Santa Barbara Basin (Krishnaswami *et al* 1975).

The particulate activities of ^{210}Pb in all the profiles have generally ranged between 1 to 30% of its dissolved activities (table 3, figure 8). However, at Stn E-12, the particulate ^{210}Pb activity varied from ∼ 5 to 70% of the dissolved activity. The extremely low activities of ^{210}Pb in the dissolved phase (figure 7), at depths 200–300 m of the E-12 profile, are somewhat balanced by the increase in particulate ^{210}Pb activities. Unless a very rapid mechanism of particle sinking is evoked, the particulate ^{210}Pb profiles and the observed gross deficiency will not be consistent with the steady-state scavenging models. Also, the temporal variations in the distribution of ^{210}Pb activities between the dissolved and particulate phases can be seen by comparing the data from E-13 and E-12, collected during different seasons (table 3, figures 7, 8). At E-12 the decrease in dissolved ^{210}Pb activity is paralleled by increase in particulate activity.

The extent of ^{210}Pb–^{226}Ra disequilibrium in the water column reveals that the penetration depth of excess ^{210}Pb (derived from atmospheric sources) ranges from about 200 to 800 m, the lower values are found in the northern stations (H-13, F-11). This is in marked contrast to the observations reported for central Indian Ocean and Pacific Ocean (Cochran *et al* 1983; Nozaki *et al* 1976). If the atmospheric input of ^{210}Pb is considered to be ∼ 1 dpm/cm^2/yr, then the removal residence time of
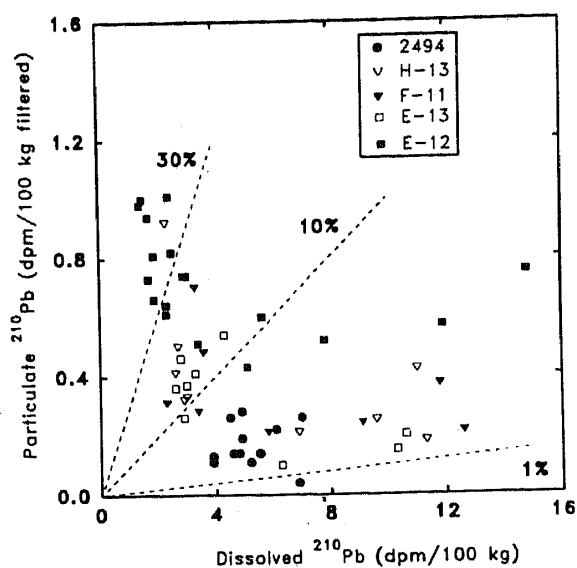
Figure 8. Comparison between particulate ^{210}Pb and dissolved ^{210}Pb activities. Most of the data fall between 1% and 30% lines indicating that particulate ^{210}Pb activities are less than 30% of its dissolved activities. In E-12 profile, as much as 70% of the dissolved ^{210}Pb activity is seen in the particulate phase.

excess ^{210}Pb in surface waters of the northern Bay of Bengal is comparable to that derived for the northern Arabian Sea. Using the steady-state scavenging model, the scavenging residence time of dissolved ^{210}Pb in deep waters ranges between 6 to 10 years. It is interesting to note that the residence time of ^{210}Pb in deep waters, during the sampling period of E-12, is ~ 4 years. This residence time is about a factor of two less than that derived for other stations sampled during Mar. 1991. Although the steady-state conditions assumed are not valid, these calculations suggest that an intensive scavenging and rapid removal of ^{210}Pb occurs in the deep waters of the north Bay of Bengal.

5. Conclusions

The naturally occurring daughter-parent pairs such as ^{234}Th-^{238}U, ^{210}Po-^{210}Pb and ^{210}Pb-^{226}Ra are potential tracers for studying the particle-associated scavenging processes in the ocean water column. We have analysed several vertical profiles of these nuclides in the eastern Arabian Sea and north-central Bay of Bengal. The important results of this study are:

1. a) Deficiency of dissolved ^{234}Th, relative to ^{238}U, extends all through the water column over the sampling depths, whereas the activity of total ^{234}Th is in equilibrium with ^{238}U at depths below 200 m in the Arabian Sea.

   b) In the Arabian Sea and Bay of Bengal, the integrated mean dissolved ^{234}U/^{238}U activity ratios in the mixed layer are 0·55 and 0·65 and the scavenging residence times of ^{234}Th are 45 and 65 days, respectively. However, the large temporal variations in the activity ratios suggest that the steady-state conditions are not strictly attained in the water column.

2. The surface water ^{226}Ra concentrations in the Bay of Bengal are generally a factor of two higher than those in the Arabian Sea. This is attributed to the enhanced input of dissolved ^{226}Ra, via rivers, to the Bay of Bengal. Below 100 m, ^{226}Ra profiles in the Bay of Bengal are essentially identical.

3. a) The vertical profiles show a gross deficiency of ^{210}Po and ^{210}Pb all through the water column relative to their respective parent nuclides, ^{210}Pb and ^{226}Ra. The deficiencies of ^{210}Po and ^{210}Pb are somewhat pronounced in the Bay of Bengal. A characteristic regeneration of ^{210}Po in the Arabian Sea, as seen in a sub-surface layer maximum centered at ~ 100 m, seems to be a seasonal phenomena.

   b) The deficiencies of ^{210}Po and ^{210}Pb in the dissolved phases is not balanced by the enrichment in the particulate phases, indicative of enhanced removal of both the nuclides by rapidly settling particles in both these basins. The mean dissolved ^{210}Pb/^{226}Ra activity ratio in the deep water of the Bay of Bengal is 0·1 based on which the removal residence time of ^{210}Pb is ~ 4 yrs. Although the steady-state conditions are not strictly valid, these calculations provide information on the removal rates of reactive tracers. It is suggested that the fluvial sediments of the Bay of Bengal are efficient scavengers of ^{210}Pb relative to the biogenic particles in the Arabian Sea.

4. In the world oceans, Bay of Bengal and eastern Arabian Sea appear to be *the* regions of the most intense particulate scavenging processes as evidenced by the lowest ratios of ^{234}Th/^{238}U, ^{210}Po/^{210}Pb and ^{210}Pb/^{226}Ra.

APPENDIX

Table 1. 234-Th and 238-U results from cruises in the Arabian Sea and Bay of Bengal.

Depth (m)	S (‰)	234-Th (dpm/l)	238-U (dpm/l)	234-Th/238-U A.R.
		Arabian Sea		
2500 (21°N, 66° 56′E) S, Date: 15.2.92, Water depth: 2300 m				
2	36·42	1·11 ± 0·06	2·48 ± 0·07	0·45 ± 0·03
25	36·60	1·06 ± 0·06	2·49 ± 0·07	0·43 ± 0·03
50	36·76	1·85 ± 0·09	2·50 ± 0·07	0·74 ± 0·04
75	36·70	1·43 ± 0·07	2·50 ± 0·07	0·57 ± 0·03
100	36·43	1·48 ± 0·10	2·48 ± 0·07	0·60 ± 0·04
125	36·24	1·59 ± 0·12	2·47 ± 0·07	0·64 ± 0·05
150	36·06	1·54 ± 0·08	2·46 ± 0·07	0·63 ± 0·04
175	36·01	1·60 ± 0·10	2·45 ± 0·07	0·65 ± 0·05
200	35·96	2·40 ± 0·11	2·45 ± 0·07	0·98 ± 0·05
250	36·07	2·40 ± 0·15	2·46 ± 0·07	0·98 ± 0·05
300	36·03	2·30 ± 0·10	2·45 ± 0·07	0·94 ± 0·05
400	35·91	2·21 ± 0·13	2·45 ± 0·07	0·90 ± 0·06
500	35·78	2·61 ± 0·11	2·44 ± 0·07	1·07 ± 0·06
700	35·59	2·46 ± 0·15	2·43 ± 0·07	1·01 ± 0·07
1000	35·39	2·30 ± 0·10	2·41 ± 0·07	0·95 ± 0·05
1500	35·06	2·35 ± 0·10	2·39 ± 0·07	0·98 ± 0·05
2000	34·82	2·35 ± 0·14	2·37 ± 0·07	0·99 ± 0·07

(Continued)

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Table 1. (*Continued*)

Depth (m)	S (‰)	234-Th (dpm/l)	238-U (dpm/l)	234-Th/238-U A.R.
2510 (10°N, 67°E)$, Date: 24.2.92, Water depth: 4407 m				
2	35·61	1·70 ± 0·08	2·43 ± 0·07	0·70 ± 0·04
25	35·60	1·62 ± 0·10	2·42 ± 0·07	0·67 ± 0·05
50	35·60	1·76 ± 0·09	2·43 ± 0·07	0·72 ± 0·04
75	36·27	1·66 ± 0·08	2·47 ± 0·07	0·67 ± 0·04
100	36·31	2·25 ± 0·14	2·47 ± 0·07	0·91 ± 0·06
150	35·45	2·27 ± 0·14	2·41 ± 0·07	0·94 ± 0·06
200	35·30	2·49 ± 0·11	2·40 ± 0·07	1·04 ± 0·06
250	35·24	2·26 ± 0·14	2·40 ± 0·07	0·99 ± 0·06
400	35·28	2·26 ± 0·10	2·40 ± 0·07	0·94 ± 0·05
600	35·28	2·20 ± 0·13	2·40 ± 0·07	0·92 ± 0·06
1000	35·22	2·25 ± 0·10	2·40 ± 0·07	0·94 ± 0·05
2000	34·81	2·45 ± 0·15	2·37 ± 0·07	1·03 ± 0·07

Bay of Bengal

Depth (m)	S (‰)	234-Th (dpm/l)	238-U (dpm/l)	234-Th/238-U A.R.
H-13 (18°N, 88° 58'E)*, Date: 15.3.91, Water depth: 2150 m				
5	32·18	1·69 ± 0·07	2·27 ± 0·06 +	0·74 ± 0·04
25	32·17	1·71 ± 0·08	2·20 ± 0·06	0·78 ± 0·05
50	32·95	1·59 ± 0·06	2·25 ± 0·07	0·71 ± 0·03
100	34·64	1·78 ± 0·08	2·41 ± 0·06 +	0·74 ± 0·04
150	34·88	1·79 ± 0·07	2·38 ± 0·07	0·75 ± 0·04
200	34·96	1·44 ± 0·07	2·38 ± 0·07	0·61 ± 0·04
350	35·00	1·66 ± 0·06	2·38 ± 0·06 +	0·70 ± 0·03
550	34·99	1·85 ± 0·09	2·38 ± 0·07	0·78 ± 0·04
950	34·92	1·91 ± 0·09	2·47 ± 0·07 +	0·77 ± 0·05
F-11 (16° 27'N, 86° 57'E)*, Date: 20.3.91, Water depth: 2650 m				
5	32·10	1·71 ± 0·06	2·22 ± 0·06 +	0·77 ± 0·04
50	33·76	1·37 ± 0·07	2·30 ± 0·07	0·60 ± 0·04
100	34·51	1·45 ± 0·06	2·35 ± 0·06 +	0·62 ± 0·03
150	34·77	1·88 ± 0·08	2·37 ± 0·07	0·79 ± 0·04
200	34·89	1·85 ± 0·09	2·38 ± 0·07	0·78 ± 0·04
300	34·99	1·74 ± 0·07	2·38 ± 0·07	0·73 ± 0·04
500	35·00	1·52 ± 0·08	2·38 ± 0·07	0·64 ± 0·04
1000	34·90	1·90 ± 0·07	2·38 ± 0·07	0·80 ± 0·04
E-13 (14° 48'N, 85° 13'E)*, Date: 24.3.91 Water depth: 3010 m				
5	32·25	1·62 ± 0·08	2·20 ± 0·06 +	0·74 ± 0·04
50	33·22	1·54 ± 0·06	2·26 ± 0·06	0·68 ± 0·03
100	34·66	1·80 ± 0·09	2·36 ± 0·07	0·76 ± 0·04
150	34·88	1·59 ± 0·06	2·38 ± 0·07	0·67 ± 0·03
200	34·95	1·63 ± 0·08	2·38 ± 0·07	0·68 ± 0·04
300	35·00	1·84 ± 0·09	2·38 ± 0·07	0·77 ± 0·04
500	34·99	1·70 ± 0·07	2·38 ± 0·07	0·71 ± 0·04
760	34·95	1·70 ± 0·08	2·38 ± 0·07	0·72 ± 0·04
E-12 (15° 34'N, 84° 38'E)*, Date: 13.12.91 Water depth: 2980 m				
2	32·06	1·29 ± 0·08	2·22 ± 0·06 +	0·58 ± 0·04
20	32·75	1·55 ± 0·07	2·23 ± 0·07	0·70 ± 0·04
40	33·94	0·88 ± 0·06	2·31 ± 0·07	0·38 ± 0·03
60	34·51	1·44 ± 0·07	2·35 ± 0·07	0·61 ± 0·04

(*Continued*)

Table 1. (*Continued*)

Depth (m)	S (‰)	234-Th (dpm/l)	238-U (dpm/l)	234-Th/238-U A.R.
80	34·70	1·84 ± 0·12	2·36 ± 0·07	0·78 ± 0·06
100	34·87	1·54 ± 0·08	2·38 ± 0·07	0·65 ± 0·04
150	34·96	1·59 ± 0·10	2·38 ± 0·07	0·67 ± 0·05
200	34·98	1·32 ± 0·07	2·38 ± 0·07	0·55 ± 0·03
300	35·02	1·48 ± 0·10	2·39 ± 0·07	0·62 ± 0·05
500	35·01	1·74 ± 0·09	2·39 ± 0·07	0·73 ± 0·04
700	34·98	1·78 ± 0·11	2·38 ± 0·07	0·75 ± 0·05
1000	34·92	1·85 ± 0·12	2·38 ± 0·07	0·78 ± 0·06

C-12 (14°N, 83°E)* Date: 8.12.91, Water depth: 3300 m

Depth (m)	S (‰)	234-Th (dpm/l)	238-U (dpm/l)	234-Th/238-U A.R.
2	33·82	1·45 ± 0·07	2·30 ± 0·07	0·63 ± 0·04
25	33·82	1·39 ± 0·09	2·30 ± 0·07	0·60 ± 0·04
50	33·83	1·13 ± 0·06	2·31 ± 0·07	0·49 ± 0·03
75	34·97	1·78 ± 0·12	2·38 ± 0·07	0·75 ± 0·06
100	34·94	1·61 ± 0·07	2·38 ± 0·07	0·68 ± 0·04
125	34·90	1·55 ± 0·09	2·38 ± 0·07	0·65 ± 0·04
150	34·94	1·33 ± 0·06	2·38 ± 0·07	0·56 ± 0·03
175	34·96	1·60 ± 0·10	2·38 ± 0·07	0·67 ± 0·05
200	34·98	1·52 ± 0·07	2·38 ± 0·07	0·64 ± 0·04
250	35·02	1·37 ± 0·08	2·39 ± 0·07	0·57 ± 0·04
300	35·04	1·64 ± 0·07	2·39 ± 0·07	0·69 ± 0·04
400	35·02	1·30 ± 0·08	2·39 ± 0·07	0·55 ± 0·04
500	35·02	1·41 ± 0·06	2·39 ± 0·07	0·59 ± 0·03
700	34·98	1·75 ± 0·11	2·38 ± 0·07	0·73 ± 0·05
1000	34·92	1·66 ± 0·08	2·38 ± 0·07	0·70 ± 0·04

$In the Arabian Sea, [234]Th measurements made on unfiltered samples thus representing total activity, see figure 2. Stn 2500 (figure 1) is similar to M-12 sampled by Sarin *et al* 1994.

*Results from Bay of Bengal represent [234]Th activity measured on filtered samples, figure 3.

+ Indicates measured activity of [238]U, all other values are calculated from [238]U salinity relation [[238]U (dpm/l) = 0·06813 × S‰], Sarin *et al* 1992, 1994.

Table 2. 210-Po and 210-Pb results from Arabian Sea.

Depth (m)	210-Po (dpm/100 kg) Dissolved	210-Pb(dpm/100 kg) Dissolved	210-Pb(dpm/100 kg) Particulate +	210-Po/210-Pb Dissolved A.R.
2494 (18°N, 70° 6′E)*, Date: 10.2.92, Water depth: 2500 m				
2	1·5 ± 0·1	6·1 ± 0·2	0·22 ± 0·02	0·25 ± 0·02
20	1·6 ± 0·1	7·0 ± 0·3	0·26 ± 0·02	0·22 ± 0·02
40	3·5 ± 0·2	6·9 ± 0·2	0·04 ± 0·01	0·51 ± 0·03
60	1·4 ± 0·1	4·5 ± 0·2	0·26 ± 0·02	0·32 ± 0·03
80	1·2 ± 0·1	5·2 ± 0·2	0·11 ± 0·01	0·22 ± 0·02
100	1·1 ± 0·2	5·5 ± 0·2	0·14 ± 0·02	0·20 ± 0·03
125	1·0 ± 0·1	4·8 ± 0·2	0·14 ± 0·01	0·21 ± 0·03
150	1·7 ± 0·1	4·9 ± 0·2	0·28 ± 0·02	0·35 ± 0·03
175	0·74 ± 0·13	4·9 ± 0·3	0·19 ± 0·02	0·15 ± 0·03
200	0·84 ± 0·12	4·6 ± 0·2	0·14 ± 0·02	0·18 ± 0·03
225	0·51 ± 0·12	3·9 ± 0·2	0·11 ± 0·01	0·13 ± 0·03

Table 2. (*Continued*)

Depth (m)	210-Po (dpm/100 kg) Dissolved	210-Pb(dpm/100 kg) Dissolved	210-Pb(dpm/100 kg) Particulate +	210-Po/210-Pb Dissolved A.R.
250	0·75 ± 0·10	3·9 ± 0·2	0·13 ± 0·02	0·19 ± 0·03
300	0·88 ± 0·12	3·8 ± 0·2		0·23 ± 0·03
400	1·3 ± 0·2	3·5 ± 0·2		0·36 ± 0·05
700	1·6 ± 0·2	4·3 ± 0·2		0·38 ± 0·04
1000	2·3 ± 0·2	4·5 ± 0·2		0·51 ± 0·05
1500	2·5 ± 0·2	4·5 ± 0·2		0·55 ± 0·04
2000	3·4 ± 0·2	5·3 ± 0·2		0·64 ± 0·04

2510 (10°N, 67°E)\$, Date: 24.2.92, Water depth: 4407 m

Depth (m)		210-Pb Dissolved		
2		10·7 ± 0·3		
25		11·3 ± 0·3		
50		10·5 ± 0·3		
75		10·4 ± 0·2		
100		7·5 ± 0·2		
150		7·7 ± 0·2		
200		7·1 ± 0·2		
250		7·2 ± 0·2		
400		7·0 ± 0·2		
600		7·6 ± 0·2		
1000		8·4 ± 0·2		
2000		12·2 ± 0·3		

+ Activity on particulate phases is expressed as volume of filtered water.
*Stn. 2494 (figure 1) is similar to K-11 sampled by Sarin *et al* 1994.
\$210-Pb activity is measured on unfiltered samples.

Table 3. 210-Po and 210-Pb results from cruises in the Bay of Bengal.

Depth (m)	210-Po (dpm/100 kg) Dissolved	210-Po (dpm/100 kg) Particulate +	210-Pb(dpm/100 kg) Dissolved	210-Pb(dpm/100 kg) Particulate +	210-Po/210-Pb Dissolved A.R.
H-13 (18°N, 89°E)*					
5	3·7 ± 0·1	0·19 ± 0·05	9·6 ± 0·3	0·25 ± 0·04	0·39 ± 0·02
25	3·8 ± 0·1	0·21 ± 0·07	11·3 ± 0·4	0·18 ± 0·03	0·34 ± 0·01
50	4·8 ± 0·2	0·71 ± 0·08	11·0 ± 0·3	0·42 ± 0·05	0·44 ± 0·02
100	5·9 ± 0·2		6·9 ± 0·2	0·21 ± 0·03	0·86 ± 0·04
150	2·6 ± 0·1		3·0 ± 0·3	0·33 ± 0·03	0·87 ± 0·09
200	1·8 ± 0·1	0·18 ± 0·08	2·3 ± 0·1	0·92 ± 0·05	0·78 ± 0·05
350	2·0 ± 0·1	0·05 ± 0·06	2·9 ± 0·1	0·32 ± 0·03	0·69 ± 0·04
550	2·0 ± 0·1	0·16 ± 0·07	2·7 ± 0·1	0·50 ± 0·04	0·74 ± 0·05
950	1·7 ± 0·1		2·6 ± 0·1	0·41 ± 0·03	0·65 ± 0·04
1450	1·6 ± 0·1		2·6 ± 0·1		0·62 ± 0·04
1750	1·7 ± 0·1		3·3 ± 0·1		0·52 ± 0·03
2050	2·3 ± 0·1		3·4 ± 0·1		0·68 ± 0·04
F-11 (16°27′N, 86°57′E)*					
5	3·7 ± 0·1	0·22 ± 0·06	9·1 ± 0·3	0·24 ± 0·03	0·41 ± 0·02
50	5·3 ± 0·2	0·83 ± 0·13	12·6 ± 0·4	0·21 ± 0·03	0·42 ± 0·02
100	5·0 ± 0·1	0·72 ± 0·10	11·8 ± 0·4	0·37 ± 0·04	0·42 ± 0·02
150	3·9 ± 0·1	0·03 ± 0·05	5·8 ± 0·2	0·21 ± 0·03	0·67 ± 0·03
200	2·0 ± 0·1	0·03 ± 0·06	3·4 ± 0·1	0·28 ± 0·04	0·59 ± 0·03

Table 3. (*Continued*)

Depth (m)	210-Po (dpm/100 kg) Dissolved	Particulate +	210-Pb(dpm/100 kg) Dissolved	Particulate +	210-Po/210-Pb Dissolved A.R.
300	1·6 ± 0·1	0·11 ± 0·06	2·3 ± 0·1	0·31 ± 0·03	0·70 ± 0·04
1000	2·3 ± 0·1	0·31 ± 0·08	3·6 ± 0·1	0·48 ± 0·05	0·64 ± 0·03
1500	2·1 ± 0·1	0·90 ± 0·11	3·3 ± 0·1	0·70 ± 0·05	0·64 ± 0·04
2000	2·9 ± 0·1		4·9 ± 0·2		0·59 ± 0·03
2300	3·2 ± 0·1		5·0 ± 0·2		0·64 ± 0·03
2500	2·8 ± 0·1		4·4 ± 0·1		0·64 ± 0·03
E-13 (14° 48′N, 85° 13′E)*					
5	3·7 ± 0·1		10·3 ± 0·3	0·15 ± 0·03	0·36 ± 0·01
50	5·6 ± 0·2		10·6 ± 0·4	0·20 ± 0·03	0·53 ± 0·03
100	9·3 ± 0·3		6·3 ± 0·2	0·10 ± 0·03	1·48 ± 0·07
150	3·4 ± 0·1		3·0 ± 0·1	0·37 ± 0·04	1·13 ± 0·05
200	2·3 ± 0·1		2·8 ± 0·1	0·46 ± 0·04	0·82 ± 0·05
300	1·7 ± 0·1		2·6 ± 0·1	0·36 ± 0·04	0·65 ± 0·05
500	1·8 ± 0·1		3·3 ± 0·1	0·41 ± 0·05	0·55 ± 0·03
760	1·6 ± 0·1		2·9 ± 0·1	0·26 ± 0·04	0·55 ± 0·04
1200	3·2 ± 0·1		4·3 ± 0·1	0·54 ± 0·06	0·74 ± 0·03
1560	2·8 ± 0·1		4·1 ± 0·1		0·68 ± 0·03
2000	3·1 ± 0·1		4·5 ± 0·2		0·69 ± 0·04
2360	3·0 ± 0·1		4·2 ± 0·1		0·71 ± 0·03
2600	3·4 ± 0·1		4·7 ± 0·2		0·72 ± 0·04
2860	2·9 ± 0·1		3·5 ± 0·1		0·83 ± 0·04
A-12 (11°N, 83° 54′E)*					
5	4·9 ± 0·2		12·1 ± 0·4	0·71 ± 0·07	0·40 ± 0·02
50	5·2 ± 0·2		13·1 ± 0·4	0·38 ± 0·05	0·40 ± 0·02
100	3·5 ± 0·1		10·8 ± 0·2	0·48 ± 0·07	0·32 ± 0·01
200	1·3 ± 0·1		3·0 ± 0·1	0·71 ± 0·05	0·43 ± 0·03
400	2·0 ± 0·1		3·7 ± 0·1	0·51 ± 0·04	0·54 ± 0·03
700	1·9 ± 0·1		3·1 ± 0·1	0·55 ± 0·04	0·61 ± 0·04
1000	2·8 ± 0·1		3·8 ± 0·1	0·70 ± 0·14	0·74 ± 0·03
1500	5·1 ± 0·2		6·4 ± 0·2		0·80 ± 0·04
2780	4·1 ± 0·2		5·7 ± 0·2		0·72 ± 0·04
A-12 (11°N, 84°E)**					
2	3·7 ± 0·1		15·6 ± 0·4		0·24 ± 0·01
20	3·8 ± 0·1		15·6 ± 0·4		0·25 ± 0·01
40	4·3 ± 0·1		13·9 ± 0·5		0·31 ± 0·02
60	7·1 ± 0·2		10·5 ± 0·4		0·68 ± 0·04
80	10·2 ± 0·3		8·1 ± 0·2		1·26 ± 0·05
100	6·1 ± 0·2		6·2 ± 0·2		0·99 ± 0·04
125	5·5 ± 0·2		5·7 ± 0·2		0·96 ± 0·04
150	4·3 ± 0·1		5·5 ± 0·2		0·78 ± 0·04
175	3·8 ± 0·1		5·1 ± 0·2		0·75 ± 0·03
200	3·6 ± 0·1		4·9 ± 0·2		0·75 ± 0·03
250	3·6 ± 0·1		5·2 ± 0·2		0·70 ± 0·03
300	3·6 ± 0·1		5·0 ± 0·1		0·72 ± 0·03
400	2·7 ± 0·1		5·2 ± 0·2		0·52 ± 0·03
500	2·6 ± 0·1		4·1 ± 0·1		0·63 ± 0·03
700	2·8 ± 0·1		4·7 ± 0·2		0·60 ± 0·03
1000	2·8 ± 0·1		4·7 ± 0·2		0·59 ± 0·03
1500	3·6 ± 0·1		5·3 ± 0·2		0·68 ± 0·04

Table 3. (*Continued*)

Depth (m)	210-Po (dpm/100 kg) Dissolved	Particulate +	210-Pb(dpm/100 kg) Dissolved	Particulate +	210-Po/210-Pb Dissolved A.R.
2000	3·6 ± 0·1		6·7 ± 0·2		0·68 ± 0·04
2500	3·1 ± 0·1		5·0 ± 0·2		0·61 ± 0·03
3000	3·3 ± 0·1		5·1 ± 0·2		0·64 ± 0·03
E-12 (15° 34'N, 84° 38'E)**					
2	3·3 ± 0·1	0·46 ± 0·04	14·8 ± 0·3	0·75 ± 0·04	0·23 ± 0·01
20	3·6 ± 0·1	0·31 ± 0·03	11·9 ± 0·3	0·57 ± 0·04	0·30 ± 0·01
40	3·2 ± 0·1	0·25 ± 0·03	5·6 ± 0·2	0·60 ± 0·03	0·57 ± 0·03
60	2·3 ± 0·1	0·10 ± 0·02	7·8 ± 0·2	0·52 ± 0·03	0·30 ± 0·02
80	1·9 ± 0·1	0·13 ± 0·02	5·1 ± 0·2	0·43 ± 0·03	0·36 ± 0·02
100	1·3 ± 0·1		3·3 ± 0·1		0·39 ± 0·03
125	1·2 ± 0·1	0·17 ± 0·03	3·4 ± 0·1	0·51 ± 0·04	0·35 ± 0·03
150	1·1 ± 0·1	0·13 ± 0·03	2·3 ± 0·1	0·64 ± 0·04	0·48 ± 0·04
175	1·1 ± 0·05	0·26 ± 0·03	1·9 ± 0·1	0·66 ± 0·04	0·56 ± 0·04
200	0·9 ± 0·05	0·37 ± 0·04	1·4 ± 0·1	0·98 ± 0·05	0·67 ± 0·05
250	1·0 ± 0·05	0·26 ± 0·03	1·7 ± 0·1	0·94 ± 0·05	0·62 ± 0·04
300	1·4 ± 0·1	0·12 ± 0·03	1·7 ± 0·1	0·73 ± 0·05	0·78 ± 0·05
400	1·4 ± 0·1	0·22 ± 0·03	2·3 ± 0·1	0·61 ± 0·04	0·62 ± 0·04
500	1·5 ± 0·1	0·20 ± 0·03	3·0 ± 0·1	0·74 ± 0·05	0·52 ± 0·03
700	1·5 ± 0·1	0·30 ± 0·04	1·5 ± 0·1	1·00 ± 0·06	0·95 ± 0·07
1000	1·6 ± 0·1	0·47 ± 0·05	2·4 ± 0·1	1·01 ± 0·06	0·67 ± 0·04
1500	2·2 ± 0·1	0·58 ± 0·04	2·5 ± 0·1	0·82 ± 0·05	0·87 ± 0·05
2000	1·5 ± 0·1	0·60 ± 0·05	1·9 ± 0·1	0·81 ± 0·05	0·81 ± 0·05
2500	2·4 ± 0·1	0·63 ± 0·05	2·9 ± 0·1	0·74 ± 0·06	0·83 ± 0·05

+ Activity on particulate phases is expressed as volume of filtered seawater.
*Stations occupied during ORV Sagar Kanya Cruise #63 (Mar. 1991), see table 1.
**Stations reoccupied during ORV Sagar Kanya Cruise #70 (Dec. 1991). Station details are given in table 1, water depth at Stn. A-12 is 3500 m.

Table 4. Dissolved [226]Ra data from Arabian Sea and Bay of Bengal[1].

			Arabian Sea		
Depth[2] (m)	M-12*	K-11*	I-15*	2500$	2494$
0	—	7·0 ± 0·4	6·0 ± 0·5	7·8 ± 0·3	8·3 ± 0·3
25	8·1 ± 0·7	—	—	—	—
100	10·6 ± 0·4	8·1 ± 0·3	—	8·2 ± 0·3	8·0 ± 0·6
300	12·1 ± 0·5	11·6 ± 0·4	11·1 ± 0·5	11·7 ± 0·5	—
400	—	—	—	—	11·7 ± 0·5
500	11·8 ± 0·6	—	9·3 ± 0·3	11·5 ± 0·3	—
700	—	15·1 ± 0·8	—	—	—
1000	15·7 ± 0·6	—	15·2 ± 0·6	—	15·4 ± 0·6
1200	—	14·7 ± 0·4	—	—	—
1500	20·5 ± 1·7	—	—	20·3 ± 0·8	—
1800	—	20·7 ± 0·6	—	—	—
2000	23·3 ± 1·3	—	21·7 ± 0·8	—	23·0 ± 0·8
2500	—	24·6 ± 1·7	—	—	—
3000	—	—	21·8 ± 1·8	—	—
3850	—	—	25·7 ± 1·0	—	—

Table 4. *(Continued)*

	Bay of Bengal				
	H-13 +	F-11 +	A-12 +	E-12 +	A-12 +
2	12·2 ± 0·5	12·2 ± 0·5	10·7 ± 0·7	14·2 ± 1·0	17·3 ± 0·7
100	8·8 ± 0·4	8·9 ± 0·3	9·0 ± 0·4	8·1 ± 0·4	8·5 ± 0·4
500	14·2 ± 0·5	13·2 ± 0·6	12·9 ± 0·5	12·9 ± 0·5	14·0 ± 1·1
1000	14·4 ± 0·6	18·2 ± 0·7	—	18·6 ± 0·7	11·9 ± 0·4
1500	22·1 ± 0·8	—	21·7 ± 0·9	18·4 ± 0·7	22·2 ± 1·5
2000	—	24·1 ± 1·0	—	23·0 ± 0·9	24·8 ± 0·9
2500	—	24·2 ± 0·9	26·2 ± 1·1	24·9 ± 0·8	25·3 ± 1·0

[1] Concentration expressed as dpm/100 kg sea water.
[2] ^{226}Ra measured at selected depths.
*Data from figure 2 of Sarin *et al* 1994.
$Stn reoccupied during Feb. 92 similar to M-12 and K-11 (figure 1).
+ Stn occupied in the Bay of Bengal during Mar. and Nov. 1991 (details given in table 1, 3).

Table 5. Mean activity ratios and scavenging residence time of Th.

Station No.	Depth interval (m)	234-Th/238-U A.R.	τ(days)
	Arabian Sea		
M-12$	0–50	0·64	62
	50–175	0·68	74
K-11$	0–50	0·57	46
	50–300	0·65	65
I-15$	0–50	0·45	28
	50–300	0·64	62
2500*	0–25	0·44	28
	25–175	0·64	63
2510*	0–25	0·69	78
	25–150	0·81	153
	Bay of Bengal		
H-13	0–50	0·74	100
	50–500	0·72	90
F-11	0–50	0·69	78
	50–500	0·71	86
E-13	0–50	0·71	86
	50–500	0·72	90
E-12	0–50	0·55	43
	50–500	0·66	67
C-12	0–50	0·57	47
	50–500	0·64	63

$Data from Sarin *et al* (1994).
*Measurements made on unfiltered samples.

Acknowledgements

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