6 Evaluation of Sediment Traps with Naturally Occurring Radionuclides

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6.1 INTRODUCTION

Because of the flow of water relative to a sediment trap deployed in the ocean, it is possible for bias to occur in the measurement of sinking particle flux (SCOR, 1988; Knauer and Asper, 1989). Several of the members of the natural radioactive decay series have been suggested as tracers to evaluate the hydrodynamic bias and provide for calibration of sediment traps *in situ* (Table 6.1). The daughter nuclides that are listed have two important characteristics: (1) they are supplied to the oceanic water column by decay of their parent nuclides at rates that can be exactly known, and (2) they are chemically reactive in the sense that they are strongly adsorbed by marine particulate matter. All of the parent/daughter pairs show measurable amounts of radioactive disequilibrium in the oceanic water column, the daughter being deficient relative to the parent because of scavenging and removal by the sinking particles. In practice a calibration is based on a determination of the integrated deficiency of the daughter nuclide in the water column above the trap to be calibrated. From this the expected flux of the daughter at the depth of the trap is easily calculated. Comparison of measured flux with expected flux gives a measure of the trapping efficiency.

6.2 MOORED SEDIMENT TRAPS IN THE DEEP OCEAN

Bottom-tethered sediment traps are frequently used to measure the supply of sinking particles to the seafloor. For evaluating the performance of traps moored at great depth in the ocean, the longer-lived daughter nuclides, which show deficiencies throughout the entire water column, are the appropriate tracers to use. They include ^{210}Pb, ^{230}Th, and ^{231}Pa (Table 6.1). Of these the most important is ^{230}Th. It is produced in the oceanic water column at an exactly known rate from decay of ^{234}U, which is uniformly distributed throughout the ocean. The residence time of ^{230}Th is a few decades (Moore and Sackett, 1964; Anderson et al., 1983a),

Particle Flux in the Ocean
Edited by V. Ittekkot, P. Schäfer, S. Honjo and P. J. Depetris
 Published by John Wiley & Sons Ltd

Table 6.1 Naturally occurring parent/daughter radionuclide pairs that have been proposed for *in situ* calibration of sediment traps (Knauer et al., 1979; Brewer et al. 1980; Moore et al., 1981; Bacon et al., 1985). Half-lives are in parentheses.

Parent	Daughter
^{238}U (4.47 x 10^9 y)	^{234}Th (24.1 d)
^{234}U (2.48 x 10^5 y)	^{230}Th (7.52 x 10^4 y)
^{226}Ra (1.62 x 10^3 y)	^{210}Pb (22.3 y) [a]
^{210}Pb (22.3 y)	^{210}Po (138 d) [a]
^{228}Ra (5.75 y)	^{228}Th (1.91 y) [a]
^{235}U (7.07 x 10^8 y)	^{231}Pa (3.25 10^4 y) [a]

a: Produced via one or more intermediates.

and when averaged over that time scale the production of ^{230}Th by decay of ^{234}U and removal by sinking particles are in almost exact balance.

The assumption that there is a balance between production and removal is an important one. Bacon et al., (1985) showed evidence from a PARFLUX sediment trap (Honjo and Doherty, 1988) moored at 3200 m in the Sargasso Sea that there is a seasonal cycle in the flux of radionuclides, including ^{230}Th, similar to that observed for total particle flux (Deuser et al., in press). The measured fluxes of ^{230}Th varied from 25 to 101% of the integrated production in the water column overlying the trap, indicating clearly that on a 2-month time scale the production and removal of ^{230}Th are not in balance, and it was suggested that as a minimum a year-long record is needed to provide an average over the annual cycle. An average of the ^{230}Th flux taken over a one-year period from July 1980 to July 1981 gave an apparent trapping efficiency of 71%. However, there is an additional factor that must be considered for an accurate assessment of the trapping efficiency.

It is also necessary to consider possible convergence or divergence of the ^{230}Th flux due to horizontal transport in the water column overlying the trap. A horizontal flux away from the ocean interior toward the margins could occur as a result of intensified scavenging at the margins, and this effect is known to be especially important for ^{231}Pa, another product of the decay of U in seawater (Anderson et al., 1983b; Bacon 1988). It would cause trapping efficiencies based on a simple vertical flux balance to be underestimated, as illustrated in Figure 6.1. The problem is to determine trapping efficiency E, which is given by

$$E = F/V = F/(P-H)$$

where F is the ^{230}Th flux measured by the trap (averaged over the annual cycle), P is the production in the water column integrated from the surface down to the depth of the trap, V is the true vertical flux, and H is the net horizontal flux away

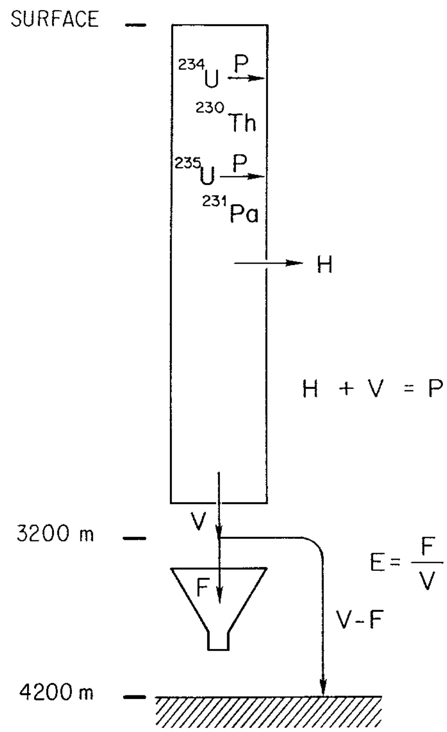


Figure 6.1 Illustration of material balance for ^{230}Th and ^{231}Pa used for *in situ* calibration of the sediment trap used in the Sargasso Sea study (Bacon et al., 1985). P = production rate integrated to the depth of the trap; V = true vertical flux; H = net horizontal transport; F = flux measured by trap; E = trapping efficiency.

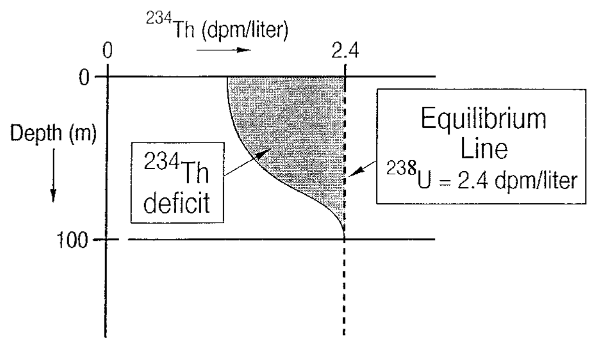
from the ocean interior. Neither V nor H is known *a priori*, but Anderson et al. (1983b) suggested a method whereby they could be determined by simultaneously satisfying material balances for both ^{230}Th and ^{231}Pa. When this method was applied to the Sargasso Sea data, E was determined to be 105 ± 17% (Bacon et al., 1985).

In a more recent study employing this method, Yu (1994) determined annual average fluxes of ^{230}Th and ^{231}Pa collected by sediment traps deployed in a variety of locations throughout the oceans. Results for the 10 deployments of PARFLUX traps at depths >1700 m gave trapping efficiencies ranging from 78 to 125%, with an average of 102%, indicating that these traps may be considered to be accurate to within ± 25%. At shallower depths (<1200 m), on the other hand, the results showed a significant tendency toward undertrapping, the results from 4 deployments ranging from 35 to 82%. The undertrapping at the shallower depths most likely results from the higher average flow velocities.

6.3 SEDIMENT TRAPS IN THE UPPER OCEAN

The export of particulate matter from the surface to the deep ocean is important to know for a variety of oceanographic studies. Sediment traps are often used to measure this flux, and for upper ocean studies they are usually deployed in a free-drifting mode. Allowing the traps to drift freely helps to reduce flow relative to the trap but does not eliminate it completely, and it is important to consider the possibility of hydrodynamic bias.

The shorter-lived radionuclides are the most appropriate tracers for validating traps deployed in the upper ocean, and the one used most extensively is ^{234}Th, which is produced by decay of the ^{238}U in seawater (Table 6.1). A deficit of ^{234}Th relative to ^{238}U is usually observed in the euphotic zone, and from this it is a simple matter to determine the export of ^{234}Th on sinking particles at the base of the euphotic zone for comparison with the flux measured in a sediment trap (Figure 6.2). Buesseler (1991) reviewed all of the published data that allowed this comparison to be made and found that measured fluxes of ^{234}Th differed substantially from the expected fluxes, often by more than a factor of 3, suggesting large hydrodynamic biases. Both positive and negative biases (over- and undertrapping) were observed but tended always to be in the same direction for multiple deployments within the same study.



$$\text{Th Export} = \text{Production} - \text{Decay}$$
$$= \lambda\,(^{234}\text{Th Deficit})$$
$$= \lambda \int_0^{100} (^{238}\text{U} - {}^{234}\text{Th})\,dz$$
$$\lambda = \ell n\,2 / 24.1\ \text{d} = 0.0288\ \text{d}^{-1}$$

Figure 6.2 Idealized profile of ^{234}Th and material balance used to calibrate sediment traps placed at the base of a 100-m euphotic zone.

Use of ^{234}Th in the surface ocean is subject to the same considerations discussed for the use of ^{230}Th in the deep ocean: temporal and spatial variations in particle flux can cause estimates based on a simple steady-state vertical flux balance to be in error. These factors, which could not be quantified, might explain some of the discrepancies noted by Buesseler (1991). Recognizing this, Buesseler et al. (1994) carried out a three-dimensional time-series study of ^{234}Th distributions and fluxes in the Sargasso Sea off Bermuda. Two independent VERTEX-type trap arrays (Knauer et al., 1979) were used to measure particulate ^{234}Th flux at 95 and 97 m depths over a 4-day period in May 1992. Horizontal transport of ^{234}Th and temporal variation of the ^{234}Th inventory were evaluated explicitly. The results showed consistent overtrapping during the 4-day period of the study. Evidence from long-term measurements at the same site, however, suggested that the traps underestimate the annual flux, and Buesseler et al. (1994) suggest that the traps overestimate flux during low flux periods and underestimate it during high flux periods.

6.4 CONCLUSIONS

Measurements of natural decay-series radionuclides in sediment-trap samples can provide useful limits on the degree of hydrodynamic bias that may have occurred during a deployment. Proper interpretation, however, requires recognition of the effects of horizontal transport and temporal variability on the balance between supply and removal of the reactive daughter nuclide. If good agreement is found between measured and expected fluxes, then it can be taken as evidence that hydrodynamic bias is small. When hydrodynamic biases do occur, it may be possible to apply corrections based on the tracer results, but this would have to be based on the assumption that the nuclide chosen is an unbiased tracer of the whole spectrum of particles that make up the passive settling flux. This assumption needs to be further examined by measurements in samples that have been fractionated according to size, type, or settling velocity. It should also be added that, in addition to hydrodynamic biases, there can also be biases due to poor sample preservation or the presence of swimmers that cannot, in general, be evaluated with the tracers discussed here.

The evidence to date, based on ^{230}Th and ^{231}Pa, suggests that properly designed sediment traps moored in quiescent conditions in the deep ocean (away from boundary currents) can be considered accurate to within ± 25% or better. On the other hand, for traps deployed in the upper ocean, the evidence indicates that significant hydrodynamic bias may occur and that further work is needed to delineate the conditions under which reliable results can be obtained.

6.5 ACKNOWLEDGMENTS

I am indebted to the National Science Foundation for generous financial support of my research, most recently from Grant OCE-9022284.

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