Available online at www.sciencedirect.com
SCIENCE DIRECT®

Marine Chemistry 100 (2006) 354–365

MARINE CHEMISTRY

www.elsevier.com/locate/marchem

Experimental evidence for ^{234}Th bioaccumulation in three Antarctic crustaceans: Potential implications for particle flux studies

Alessia M. Rodriguez y Baena [a,b,*], Marc Metian [a], Jean-Louis Teyssié [a], Claude De Broyer [c], Michel Warnau [a]

[a] *International Atomic Energy Agency, Marine Environment Laboratory, 4 Quai Antoine 1er, MC-98000 Monaco, France*
[b] *DipTeRis, Università di Genova, Corso Europa 26, I-16132 Genova, Italy*
[c] *IRSNB, Department of Invertebrates, Rue Vautier 29, B-1000 Brussels, Belgium*

Received 18 February 2005; accepted 10 October 2005
Available online 3 February 2006

Abstract

^{234}Th is considered a valuable and useful tracer of oceanic biogeochemical processes occurring over timescales of days to weeks. While the geochemical behaviour of this radionuclide in the marine environment is well known, relatively few studies have explored its interactions with biota. To better understand biologically related ^{234}Th dynamics, bioaccumulation of ^{234}Th from the dissolved phase and its subsequent retention in small Antarctic crustaceans (the isopod *Natatolana oculata* and the amphipods *Orchomenella ultima* and *Uristes stebbingi*) was determined under controlled laboratory conditions. Despite morphological and behavioural differences, all three species displayed comparable concentration factors ($CF \geq 80$) and very long retention of ^{234}Th (biological half-life not significantly different from infinity). From 16% (isopod) to 49% (both amphipods) of accumulated ^{234}Th was associated with the animal soft parts, which is substantial when compared with reported values for other particle-reactive transuranic elements. The relevance of zooplankton as a potential modulator of ^{234}Th distribution in the water column is discussed in light of these findings. CF-based computations suggest that, for typical zooplankton biomass, biologically mediated interactions with particle flux models can be neglected. In contrast, in waters with very high crustacean biomass, such as krill schools, ^{234}Th distribution in the water column would be largely determined by these organisms. In such waters the biological compartment should be addressed as it could confound the reliability of vertical particle flux assessment using ^{234}Th as a proxy.

Keywords: Zooplankton; Amphipods; Isopods; ^{234}Th; Particle fluxes; Southern ocean

1. Introduction

Over the past few decades, ^{234}Th has been increasingly used to assess particle fluxes, especially particulate organic carbon (POC) out of surface waters (Coale and Bruland, 1985; Eppley, 1989; Buesseler et al., 1992; Charette and Moran, 1999; Cochran et al., 2000). Given the interest in climate change and the potential role of the oceans in sequestering C, this issue has taken on renewed attention (Buesseler et al.,

* Corresponding author. IAEA- Marine Environment Laboratory, 4 Quai Antoine Ier, MC-98000 Monaco, France. Tel.: +377 97 97 72 72; fax: +377 97 97 72 76.
E-mail addresses: aryb@yahoo.com (A.M. Rodriguez y Baena), m.metian@iaea.org (M. Metian), j.l.teyssie@iaea.org (J.-L. Teyssié), claude.debroyer@naturalsciences.be (C. De Broyer), m.warnau@iaea.org (M. Warnau).

0304-4203/$ - see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.marchem.2005.10.022

2004). Any oceanographic study that aims to investigate particle fluxes by means of a selected proxy requires the proxy's "biogeochemical" behaviour to be well known. The knowledge of its interactions with biological, geological and chemical compartments represents a sine qua non-condition for a reliable application of the tracer methodology.

^{234}Th distribution in the water column has been studied throughout the world, from the poles to the tropics (Cochran et al., 2000; Benitez-Nelson et al., 2001; Rutgers van der Loeff et al., 2002), and its chemistry has been investigated extensively (Santschi et al., 1980; Burd et al., 2000; Dai and Benitez-Nelson, 2001; Quigley et al., 2001). In contrast, available information regarding ^{234}Th interactions with organisms is surprisingly sparse. With the exclusion of some studies that have indicated how sinking fecal pellets produced by zooplankton influence vertical flux rates of ^{234}Th (e.g., Krishnaswami et al., 1985; Fisher et al., 1987), only a few studies have dealt with ^{234}Th uptake by biota directly (Ishikawa et al., 2004). Among these, even fewer address aspects of its bioaccumulation (Santschi et al., 1983; Fisher et al., 1987; Ishikawa et al., 2004). Moreover, results of these different investigations vary. For instance, Dunne et al. (2000) suggest that ^{234}Th contamination due to zooplankton accidentally caught in sediment traps (swimmers) is negligible because the ^{234}Th activity : mass ratio measured in swimmers is always much lower than in trapped particles (Dunne et al., 2000). However, other studies have measured activity values up to 560 dpm ^{234}Th g^{-1} dry wt. in zooplankton (Krishnaswami et al., 1985; Coale, 1990), a significant activity : mass ratio when compared to that reported for sinking particles, which typically ranges from 1000–4000 dpm g^{-1} dry wt. (e.g., Coale, 1990; Murray et al., 1996; Rodriguez y Baena et al., unpubl. data). This activity : mass ratio may be species dependent. Recently, significant values of natural ^{234}Th were also reported in different marine benthic organisms, reaching 17 dpm g^{-1} dry wt. in barnacle soft parts, 26 dpm g^{-1} dry wt. in ascidian liver (Ishikawa et al., 2004) and 284–462 dpm g^{-1} dry wt. in red algae (CRIIRAD, 2004). ^{234}Th bioaccumulation is not surprising if one considers the body of literature of experimental studies reporting that related transuranic elements such as ^{237}Pu, ^{241}Am, and ^{252}Cf are accumulated in a wide range of organisms (e.g., Fisher et al., 1983; Carvalho and Fowler, 1985; Fowler et al., 1986; Warnau et al., 1996).

The different applications of ^{234}Th with regards to particle fluxes, and C export studies in particular (e.g., sediment trap calibration, assessment of sedimentation and bioturbation rates or of major component export), merely consider the chemical and geological properties of the radionuclide (Buesseler et al., 1994; DeMaster et al., 1994; Rutgers van der Loeff et al., 2002). These studies generally overlook the biological aspects, most likely due to the lack of available information (Benitez-Nelson and ^{234}Th-Group, 2004). However, when examining the few data reported on ^{234}Th activities in organisms, it is possible that they may contain a significant fraction of ^{234}Th within their tissues and hence play a role in the behaviour of ^{234}Th in the water column.

The objective of our study is to better understand ^{234}Th interactions with marine zooplankton, and then to discuss the relative importance of these interactions in the framework of particle flux studies. This work examines the bioaccumulation of ^{234}Th in three different species of common, small-sized crustaceans from Antarctica, a region of concern due to its potential influence on climate change through C uptake and sequestration (Feely et al. 2001) and an area where ^{234}Th has been used to understand vertical C fluxes (e.g. Buesseler et al., 2004).

2. Methods

2.1. Organism collection and acclimation

During the *R/V Polarstern* expedition ANT XXI/2 (Nov. 17th 2003–Jan. 18th 2004), baited fish traps were moored for 102 h (from Dec 10th to 14th) on the eastern Weddell Sea shelf (stations PS 65/103 FT and PS 65/104 FT, 70°48.86′S 10°40.81′W; 372 m depth). Among the 20 small-sized crustacean taxa collected (for a complete list, see De Broyer et al., 2005), the three most abundant species were selected for this study: the Cirolanidae isopod *Natatolana oculata* and the Lysianassidae amphipods *Orchomenella ultima* Bellan-Santini and *Uristes stebbingi* Walker. Thirty to fifty individuals of each species were isolated and maintained on-board for 4 weeks in closed circuit 50 L aquaria (natural Antarctic seawater constantly gently aerated; De Broyer et al., 2004).

On completion of the expedition, the organisms were shipped in a 150 L isothermic container to our laboratory in Monaco where they were acclimated for five weeks to laboratory conditions (constantly aerated open circuit 700 L aquarium, 5% water renewal h^{-1}, salinity: 36 p.s.u., temperature: -1.5 ± 0.3 °C, darkness). A subgroup of 10 similar sized individuals of each species (mean individual wet wt.: 1.60 ± 0.32 g for *N. oculata*, 0.17 ± 0.04 g for *O. ultima* and