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# Polonium ($^{210}Po$) and lead ($^{210}Pb$) in marine organisms and their transfer in marine food chains

Fernando P. Carvalho*

*Instituto Tecnológico e Nuclear, Departamento de Protecção Radiológica e Segurança Nuclear, E.N. 10, 2686-953 Sacavém, Portugal*

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ABSTRACT

The determination of $^{210}Po$ and $^{210}Pb$ was performed in marine organisms from the seashore to abyssal depths, encompassing a plethora of species from the microscopic plankton to the sperm whale. Concentrations of those radionuclides ranged from low values of about $5 \times 10^{-1}$ Bq kg$^{-1}$ (wet wt.) in jellyfish, to very high values of about of $3 \times 10^{4}$ Bq kg$^{-1}$ (wet wt.) in the gut walls of sardines, with a common pattern of $^{210}Po > {}^{210}Pb$.These radionuclides are primarily absorbed from water and concentrated by phyto- and microzooplankton, and then are transferred to the next trophic level along marine food chains. Investigation in epipelagic, mesopelagic, bathypelagic and abyssobenthic organisms revealed that $^{210}Po$ is transferred in the marine food webs with transfer factors ranging from 0.1 to 0.7, and numerically similar to those of the energy transfer in the marine food chains. As $^{210}Po$ preferentially binds to amino acids and proteins, its transfer in food chains likely traces protein transfer and, thus, $^{210}Po$ transfer factors are similar to ecotrophic coefficients. $^{210}Pb$ is transferred less efficiently in marine food chains and this contributes to increased $^{210}Po$:$^{210}Pb$ activity ratios in some trophic levels.



## 1. Introduction

Polonium ($^{210}Po$) and radioactive lead ($^{210}Pb$) in marine organisms have attracted the attention of scientists because of their relatively high concentrations in comparison with those in terrestrial organisms and also because $^{210}Po$ concentrations in marine biota often are much enhanced in comparison to those of $^{210}Pb$, its radioactive grand parent (Cherry and Shannon, 1974; Parfenov, 1974). The first determinations of $^{210}Po$ in marine biota had shown high concentrations of largely unsupported $^{210}Po$ in plankton, 110 Bq kg$^{-1}$(dry weight), and soon other reports added information on unsupported $^{210}Po$ in marine fish, crustacean and whales (Holtzman, 1967; Schell et al., 1973). Early measurements did record also high $^{210}Po$ concentrations in some marine species, such as the lanternfish, and in certain internal organs such as the pyloric *caecca* of tuna fish (Folsom and Beasley, 1973; Hoffman et al., 1974). Pioneer data were reviewed by Cherry and Shannon (1974) who highlighted the importance of $^{210}Po$ as a major internal source of the radiation dose received in the tissues of marine organisms.

Further work revealed the distribution of $^{210}Po$ in crustacean tissues, including the euphausiid *Meganicthyphanes norvegica*, and the role of zooplankton in the removal of $^{210}Po$ from the ocean surface layer (Beasley et al., 1978; Cherry et al., 1975). Investigation on $^{210}Po$ and $^{210}Pb$ levels in other marine organisms, in the diet of crustaceans and fishes, and in the processes of bioaccumulation of these radionuclides from water and from food progressed (Bustamante et al., 2002; Carvalho and Fowler, 1993, 1994; Cherry et al., 1989; Heyraud and Cherry, 1979; Heyraud et al., 1988, 1994; Stewart et al., 2005, 2007; Wildgust et al., 2000). The current data base on these radionuclides distinctly expanded into more species, taxonomic groups and environments (Carvalho, 1988, 1995; Carvalho and Oliveira, 2008; Carvalho et al., 2010a,b; Charmasson et al., 1998; Dahlgaard, 1996; Godoy et al., 2008; Jeffree et al., 1997; Ryan et al., 1999; Skwarzec and Bojanowsky, 1988). Currently known $^{210}Po$ and $^{210}Pb$ activity concentrations in marine biota spread over several orders of magnitude, in an apparent chaos of values strikingly not related to sea water depths, ecosystems or geographic locations.

This paper provides new data for marine biota from all oceanic zones. Results for most species and in particular for the deep sea ones are reported for the first time. Furthermore, this paper places data on $^{210}Po$ concentrations and $^{210}Po$:$^{210}Pb$ concentration ratios in a perspective of marine food chains and proposes an interpretation of $^{210}Po$ activity concentrations based on the energy transfer coefficients across trophic levels.

### 2. Material and methods

Marine biota was sampled in the North Atlantic from the shoreline to abyssal depths, by hand at the shoreline and from research vessels using plankton nets,

* Tel.: +351 219946332; fax: +351 219941995.
*E-mail address:* carvalho@itn.pt.

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**Table 1**
Average activity concentrations of $^{210}Po$ and $^{210}Pb$ and $^{210}Po:^{210}Pb$ activity ratios in filtered sea water and suspended particulate matter in samples of the North-East Atlantic.

| Region | n | $^{210}Po$ Dissolved | $^{210}Pb$ Dissolved | Po:Pb | $^{210}Po$ Particulate | $^{210}Pb$ Particulate | Po:Pb |
|---|---|---|---|---|---|---|---|
| | | mBq L$^{-1}$ ± 1 SD | mBq L$^{-1}$ ± 1 SD | | mBq L$^{-1}$ ± 1 SD | mBq L$^{-1}$ ± 1 SD | |
| Intertidal[a] | 5 | 0.82 ± 0.31 | 0.85 ± 0.18 | 0.96 | 1.12 ± 0.35 | 1.00 ± 0.59 | 1.12 |
| Coastal sea[b] | 1 | 1.70 ± 0.08 | 2.27 ± 0.16 | 0.75 | 0.85 ± 0.03 | 0.09 ± 0.002 | 9.44 |
| Intermediate water[c] Depth 1000 m | 1 | 0.85 ± 0.07 | 0.98 ± 0.04 | 0.87 | 0.30 ± 0.03 | 0.16 ± 0.02 | 1.87 |
| Bottom water[d] Depth 4600m | 1 | 0.35 ± 0.03 | 1.26 ± 0.05 | 0.28 | 0.24 ± 0.01 | 0.13 ± 0.04 | 1.85 |

[a] Surf zone on the rocky shore North of Lisbon.
[b] Surface water off the Portuguese coast.
[c] At the Porcupine Abyssal Plain region.
[d] Deep water, 100m above sea floor, at the Porcupine Abyssal Plain.

Isaacs-Kidd midwater trawls, Agassiz trawls and baited traps. Many fish samples were obtained from commercial fishing boats as well. Sea water samples were collected by hand in the surf zone, near Cascais at the west coast of Portugal, and from the North-east Atlantic from several depths. Water samples were passed through 350 μm mesh size plankton net to remove large particles and immediately filtered through 0.45 μm pore size membrane filters, and the filtered water and suspended particulate matter (SPM) analyzed separately (Carvalho, 1995; Carvalho et al., 2010b).

Large organisms were generally dissected for analysis of radionuclides in internal tissues. Molluscs were analyzed for soft tissues only. Analysis of biota were performed generally on aliquots of freeze dried samples, following addition of $^{209}Po$ tracer, total dissolution of the samples in $HNO_3$, HCl and $H_2O_2$, and polonium plating

**Table 2**
Average activity concentrations of $^{210}Po$ and $^{210}$ Pb and $^{210}Po:^{210}Pb$ activity ratios in marine organisms collected in the intertidal zone of the Portuguese coast, North of Cascais. D:*W* = Dry: Wet weight ratio. *W* = average whole body wet weight.

| Species/tissues | | D:*W* | $^{210}Po$ | $^{210}Pb$ | Po:Pb |
|---|---|---|---|---|---|
| | | | Bq kg$^{-1}$ ± 1 SD | Bq kg$^{-1}$ ± 1 SD | |
| Algae | | | | | |
| *Ulva lactuca* (Chlorophyceae) | | 0.18 | 2.7 ± 0.1 | 1.35 ± 0.04 | 2.0 |
| *Codium tomentosum* (Chlorophyceae) | | 0.13 | 2.0 ± 0.1 | 0.29 ± 0.01 | 6.7 |
| *Ploccamium cartilagineum* (Rhodophyceae) | | 0.13 | 5.2 ± 0.2 | 3.18 ± 0.12 | 1.6 |
| *Gelidium sesquipedale* (Rhodophyceae) | | 0.18 | 8.6 ± 0.2 | 0.85 ± 0.02 | 10.1 |
| *Fucus vesiculosus* (Phaeophyceae) | | 0.27 | 9.1 ± 0.3 | 1.77 ± 0.61 | 5.1 |
| *Sacchoriza polyschides* (Phaeophyceae) | | 0.19 | 1.6 ± 0.1 | 0.42 ± 0.01 | 3.8 |
| Molluscs (soft tissues) | | | | | |
| *Patella aspera* | | 0.19 | 11.6 ± 0.3 | 4.2 ± 0.1 | 2.8 |
| *Mytilus galloprovincialis* | | 0.14 | 132 ± 5 | 2.6 ± 0.1 | 51 |
| *Littorina littorea* | | 0.30 | 283 ± 10 | 5.2 ± 0.2 | 54 |
| *Gibbula umbilicalis* | | 0.27 | 53 ± 2 | 4.7 ± 0.1 | 11 |
| *Ensis siliqua* | | 0.20 | 45 ± 1 | 2.2 ± 0.1 | 21 |
| *Cerastoderma edule* | | 0.20 | 5.8 ± 0.3 | 5.6 ± 0.3 | 1 |
| *Tapes decussatus* | | 0.20 | 152 ± 19 | 2.9 ± 0.1 | 52 |
| *Cassostrea angulata* | | 0.20 | 10 ± 1 | 0.5 ± 0.07 | 20 |
| Crustaceans | | | | | |
| *Leander serratus* *W* = 0.32 ± 0.08 g, *n* = 4 | Whole body | 0.28 | 25.1 ± 0.8 | 0.43 ± 0.01 | 57 |
| *Balanus* sp. *W* = 1.0 ± 0.2 g, *n* = 10 | Soft tissues | 0.14 | 50 ± 3 | – | – |
| Fish | | | | | |
| *Coryphoblennius galerita* | Muscle | 0.23 | 2.8 ± 0.1 | 2.1 ± 1.3 | 1.3 |
| Montagu's blenny, *n* = 5 | Liver | 0.51 | 91 ± 3 | 31 ± 2.9 | 2.9 |
| *W* = 4.0 ± 0.6 g | Gonad | 0.60 | 51 ± 1 | 8.3 ± 6.1 | 6.1 |
| | Bone | 0.36 | 16.7 ± 0.5 | 4.2 ± 3.9 | 3.9 |
| | Gut | 0.21 | 64 ± 2 | 2.9 ± 22 | 22 |
| | Caecca | 0.59 | 220 ± 7 | 58 ± 3.8 | 3.8 |
| | Remains | 0.28 | 2.6 ± 0.1 | 0.29 ± 8.8 | 8.8 |
| | Whole body | 0.24 | 6.2 | 1.22 | 5.1 |
| *Blennius trigloides* | Muscle | 0.23 | 1.5 ± 0.1 | 0.37 ± 4.0 | 4.0 |
| Stare-eyed blenny, *n* = 5 | Liver | 0.36 | 35.9 ± 0.9 | 3.1 ± 11.5 | 11.5 |
| *W* = 10.0 ± 1.8 g | Gonad | 0.18 | 35.4 ± 1.7 | 18.3 ± 2.9 | 2.9 |
| | Bone | 0.39 | 5.9 ± 0.2 | 0.65 ± 9.1 | 9.1 |
| | Gut | 0.22 | 61 ± 2 | 1.60 ± 38 | 38 |
| | Caecca | 0.39 | 42 ± 2 | 7.5 ± 5.6 | 5.6 |
| | Remains | 0.31 | 5.3 ± 0.1 | 1.9 ± 2.8 | 2.8 |
| | Whole body | 0.25 | 6.6 | 1.62 | 4.1 |
| *Blennius pholis* | Muscle | 0.23 | 1.5 ± 0.1 | 0.21 ± 7.2 | 7.2 |
| Common blenny, *n* = 3 | Liver | 0.52 | 14.8 ± 0.6 | 11.6 ± 1.3 | 1.3 |
| *W* = 29 ± 14 g | Gonad | 0.25 | 6.8 ± 0.2 | 0.90 ± 7.5 | 7.5 |
| | Bone | 0.45 | 9.0 ± 0.4 | 2.5 ± 3.5 | 3.5 |
| | Gut | 0.23 | 51.2 ± 2.1 | 13.1 ± 3.9 | 3.9 |
| | Remains | 0.32 | 8.9 ± 0.4 | 0.76 ± 0.04 | 11.9 |
| | Whole body | 0.31 | 7.9 | 1.50 | 5.3 |