Journal of Environmental Radioactivity xxx (2016) 1–11

Contents lists available at ScienceDirect

Journal of Environmental Radioactivity

journal homepage: www.elsevier.com/locate/jenvrad

Natural radionuclides in lichens, mosses and ferns in a thermal power plant and in an adjacent coal mine area in southern Brazil

Juliana Aparecida Galhardi [a,*], Rafael García-Tenorio [b], Inmaculada Díaz Francés [b], Daniel Marcos Bonotto [a], Marcelo Pinto Marcelli [c]

[a] UNESP, Rio Claro, São Paulo, Brazil
[b] Universidad de Sevilla, Sevilla, Spain
[c] Instituto de Botânica, São Paulo, Brazil

ARTICLE INFO

Article history:
Received 11 May 2016
Received in revised form
8 November 2016
Accepted 9 November 2016
Available online xxx

Keywords:
Bio-monitoring
Uranium
Thorium
Polonium
Coal-industry
Southern Brazil

ABSTRACT

The radio-elements ^{234}U, ^{235}U, ^{238}U, ^{230}Th, ^{232}Th and ^{210}Po were characterized in lichens, mosses and ferns species sampled in an adjacent coal mine area at Figueira City, Paraná State, Brazil, due to their importance for the assessment of human exposure related to the natural radioactivity. The coal is geologically associated with a uranium deposit and has been used as a fossil fuel in a thermal power plant in the city. Samples were initially prepared at LABIDRO (Isotopes and Hydrochemistry Laboratory), UNESP, Rio Claro (SP), Brazil. Then, alpha-spectrometry after several radiochemical steps was used at the Applied Nuclear Physics Laboratories, University of Seville, Seville, Spain, for measuring the activity concentration of the radionuclides. It was ^{210}Po the radionuclide that most bio-accumulates in the organisms, reaching the highest levels in mosses. The ferns species were less sensitive as bio-monitor than the mosses and lichens, considering polonium in relation to other radionuclides. Fruticose lichens exhibited lower polonium content than the foliose lichens sampled in the same site. Besides biological features, environmental characteristics also modify the radio-elements absorption by lichens and mosses like the type of vegetation covering these organisms, their substrate, the prevailing wind direction, elevation and climatic conditions. Only ^{210}Po and ^{238}U correlated in ferns and in soil and rock materials, being particulate emissions from the coal-fired power plant the most probable U-source in the region. Thus, the biomonitors used were able to detect atmospheric contamination by the radionuclides monitored.

1. Introduction

Radionuclides evaluation in areas affected by the coal industry is important for the assessment of human exposure to the natural radioactivity. The main concern about the air pollution associated with coal mining and coal-fired thermal power plants comes from the fact that fossil fuels may contain natural levels of toxic and radioactive elements (UNSCEAR, 2010) that can vary according to some chemical, physic-chemical and biological factors (Giblin et al., 1981).

UNSCEAR (2010) reported coal analysis in fifteen countries, giving a value of 20 Bqkg^{-1} for the average activity concentrations of ^{238}U and ^{232}Th. However, radionuclides can be found in greater concentrations like in coal from Rio Bonito Formation, Figueira city, Brazil, where Flues et al. (2006) found ^{238}U and ^{232}Th activity concentrations of 813–2609 Bqkg^{-1} and 22–40 Bqkg^{-1}, respectively.

The natural decay series initiating with ^{238}U, ^{235}U and ^{232}Th give rise to a variety of radioactive products, including ^{222}Rn and ^{210}Po. Although the main uranium carrier is water, dust and atmospheric particulate matter can act as alternative routes to this radio-element dispersion (Mkandawire, 2013). Human activities such as emissions from fertilizer industries, motor vehicles, coal mining and burning fossil fuels in thermal power plants can artificially increase the activity concentration of these radionuclides in the atmosphere (Flues et al., 2006; Papastefanou, 2010; Sert et al., 2011; Zhang et al., 2016).

In coal-fired power plants, a portion of the ashes and gases is released into the atmosphere (Baxter, 1993) and based on the property of being easily volatilized at low temperatures

* Corresponding author. UNESP, Avenida 24-A, No. 1515, 13506-900, CP 178, Rio Claro, São Paulo, Brazil.
E-mail address: julianagalhardi@yahoo.com.br (J.A. Galhardi).

http://dx.doi.org/10.1016/j.jenvrad.2016.11.009
0265-931X/© 2016 Elsevier Ltd. All rights reserved.

(approximately 70 °C), polonium plays an important role in the investigation of atmosphere pollution. The amount of natural radionuclides emitted to the atmosphere from a thermal power plant depends on some factors, such as their concentrations in coal, the content of ash in coal, the temperature of the combustion and the emission control efficiency (Delfanti et al., 1999; Sert et al., 2011). Tailing piles containing wastes originated during the mining activities also comprises additional sources of radionuclides to the environment (Fungaro and Izidoro, 2006). For example, due to the long half-life of ^{230}Th, the precursor of ^{226}Ra, tailing piles represent long sources of this radionuclide (Landa, 2003). In addition, effluents from coal mining may contain common contaminants of metallic minerals mining and also radioactive elements, such as ^{226}Ra, ^{210}Pb and ^{238}U (USEPA, 1995), which can be released into natural waters in accelerated rate due to the oxidation of sulfide minerals by natural processes in rocks that gives rises to acid mine drainage (Nordstrom, 2009).

In the context of environmental pollution related to coal industry, bio-indicators/bio-monitors, such as lichens and mosses, have been used to indicate the pollution levels in air quality studies (Markert, 2007) and to identify radionuclides, toxic metals and organic compounds in atmospheric particulate matter from natural or artificial sources (Beckett et al., 1982; Steinnes and Njastad, 1993; Bargagli et al., 1995; Berg et al., 1995; Nifontova, 1995; Steinnes, 1995; Delfanti et al., 1999; Heinrich et al., 1999; Fernandez et al., 2000 . Genoni et al., 2000; Jeran and Jacimovic, 2001; Conti and Cecchetti, 2001; Figueira et al., 2002; Kirchner and Daillant, 2002; Di Lella et al., 2003; Loppi et al., 2003; Tsikritzis et al., 2003; Ugur et al., 2004; Golubev et al., 2005; Belivermis and Çotuk, 2010; Sert et al., 2011; Van Der Wat and Forbes, 2015).

Lichens, or lichenized fungi, are formed by the symbiosis between a fungus and one or more algae or cyanobacteria (Conti and Cecchetti, 2001; Villarouco et al., 2007). This symbiotic association forms a certain structure (thallus) that has no roots and depends mainly on the atmospheric input of mineral nutrients (Garty et al., 2003). The main mechanism of radionuclides accumulation by lichens is due to the dry or wet deposition and they can accumulate and retain elements in concentrations that exceed their physiological requirements due to their relatively large surface area and slow growth rate (Golubev et al., 2005). Therefore, it has been assumed that the elements absorbed by lichens represent a fraction of the chemical composition of the atmosphere (Di Lella et al., 2003). These features of lichens, combined with their capability to grow in different environmental conditions and to accumulate mineral elements far above their needs, make them one of the greatest bioindicators of air pollution (Garty et al., 2003).

The rhizoid system of mosses allows these organisms to partially absorb the nutrients from soil and transport them to the leaves. However, these organisms generally do not have vascular and root systems to uptake elements from the soil and like the lichens they are strongly dependent of the material deposited through wet and dry deposition. As a result, mosses can also act as efficient air pollution indicators because they absorb chemical particles directly from the atmosphere (Elias et al., 2006) mainly in the leaf, which is the part of the plant that shows the greatest response to environmental variations (Rocha et al., 2014).

Epiphytism corresponds to the growing of plants over others, especially trees, without connection to soil and without parasitism (Dubuisson et al., 2009). Some ferns species are epiphytic, comprising one of the major components of the rainforest biodiversity spreading in the tropics (Mohlenbrock, 2006; Dubuisson et al., 2009). These ferns species cannot live without a host plant because they have no attachment to the ground and grows upon another plant merely for physical support (Mohlenbrock, 2006). This is the case of the specie *Microgramma squamulosa* (Kaulf.) de la Sota, which is a neotropical epiphytic fern commonly found in Brazil and in other latinoamerican countries, like Peru, Bolivia, Argentina, Paraguay, and Uruguay.

Microgramma squamulosa (Kaulf.) de la Sota can be found in trees of primary and secondary forests and in isolated trees in urban and rural environments (Rocha et al., 2014). This native species is considered a potential bio-indicator, since some morphological adaptations were found in it in polluted environments, like a decrease in the stomata area to minimize the pollutants uptake by the plant (Alves et al., 2001). Rocha et al. (2014) suggested that controlled studies involving active exposure to pollutants may contribute to increase the knowledge about *Microgramma squamulosa* (Kaulf.) de la Sota as a potential bioindicator of atmospheric air pollution.

The bio-monitoring can be made passively when the studied species already occur in the investigated site. In areas of extraction, processing and coal burning, the application of the passive biomonitoring method focusing on radioactive elements becomes attractive as the use of bio-indicators offers some advantages when compared to conventional methods for air monitoring. This is because they provide information about continuous accumulation of radioactive elements over the time, whereas the sampling of air, rainwater and the material deposited on the filters and collectors provide instantaneous and prompt information regarding a period corresponding only to the sampling time (Alencar, 2008). For example, many moss species live for 2–5 years, allowing their application in long-term studies (Sert et al., 2011).

Conventional sampling methods of air and pluvial water may be attractive in the case of toxic metals monitoring, but for uranium, thorium and other radio-elements, it may be more suitable to get information integrated over a longer time period and, according to Leonardo et al. (2011), other advantages associated with biomonitoring are the easy sampling work, less expensive equipment and lower operational and maintenance costs.

Only a few investigations of power plant emissions, airborne pollutants and lichens as biomonitors were performed in tropical zones compared to temperate ones (Garty et al., 2003). Their climatic characteristics, environmental and weathering processes, nutrients recycling and the radionuclides uptake or absorption by living organisms differ significantly (IAEA, 2010). Seed et al. (2013) showed that climate factors can control the lichen distribution and abundance but effects of climatic changes on lichens and mosses species from tropical areas is often unknown, since most of the studies were conducted in the developed countries under temperate climate. According to Carreras et al. (2009), it is essential to hold studies in cities from developing countries and in tropical areas where the socio-demographic-economic characteristics of local population differ considerably from those in developed and temperate countries.

In Brazil, some researchers reported the efficiency of lichens as bioindicators of the air pollution by radionuclides in areas of fertilizer production (Alencar, 2008; Leonardo et al., 2013), affected by a thermoelectric plant (Martins et al., 2008) and close to a lead and tin industries (Leonardo et al., 2011). There isn't any investigation to evaluate the air pollution by radionuclides using lichens, mosses and ferns as bio-indicators in Paraná State, southern Brazil, where there is the third largest coal reserve of the country. Risks associated with the coal industry at Figueira city, Paraná State, may be more critical as the coal horizons are associated with a uranium deposit.

In this context, the objective of this research was to evaluate the absorption of ^{234}U, ^{238}U, ^{232}Th, ^{230}Th and ^{210}Po by ferns, lichens and mosses in the coal mining and coal-fired power plant areas at Figueira city, Paraná State, Brazil, as an aid to a better understanding of the radionuclides absorption by ferns, lichens and mosses in tropical areas.

Please cite this article in press as: Galhardi, J.A., et al., Natural radionuclides in lichens, mosses and ferns in a thermal power plant and in an adjacent coal mine area in southern Brazil, Journal of Environmental Radioactivity (2016), http://dx.doi.org/10.1016/j.jenvrad.2016.11.009