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^{14}C, $\delta^{13}C$ and total C content in soils around a Brazilian PWR nuclear power plant

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ABSTRACT

Nuclear power plants release ^{14}C during routine operation mainly as airborne gaseous effluents. Because of the long half-life (5730 years) and biological importance of this radionuclide (it is incorporated in plant tissue by photosynthesis), several countries have monitoring programs in order to quantify and control these emissions. This paper compares the activity of ^{14}C in soils taken within 1 km from a Brazilian nuclear power plant with soils taken within a reference area located 50 km away from the reactor site. Analyses of total carbon, $\delta^{13}C$ and ^{137}Cs were also performed in order to understand the local soil dynamics. Except for one of the profiles, the isotopic composition of soil organic carbon reflected the actual forest vegetation present in both areas. The ^{137}Cs data show that the soils from the base of hills are probably allocthonous.

The ^{14}C measurements showed that there is no accumulation due to the operation of the nuclear facility, although excess ^{14}C was found in the litter taken in the area close to power plant. This indicates that the anthropogenic signal observed in the litter fall has not been transferred yet to the soil.

This study is part of an extensive research programme in which other samples including air, vegetation and gaseous effluents (taken in the vent stack of the Brazilian nuclear power reactors Angra I and II) were also analyzed. The present paper aimed to evaluate how ^{14}C emissions from the nuclear power plant are transferred and stored by soils present in the surroundings of the reactor site. This is the first study concerning anthropogenic ^{14}C in soils in Brazil.

1. Introduction

Nuclear power plants release ^{14}C during normal operation. The amounts and chemical forms released, such as hydrocarbons, CO and CO_2, depend on individual reactor design as well as operational parameters. For example, CANDU reactors are known to be the major emitters (UNSCEAR, 2000) while PWR reactors, which provide the focus for this study, release minor amounts of ^{14}C, mainly as hydrocarbons (Stenström et al., 1996; IAEA, 2004).

Although the amount of ^{14}C produced by nuclear power plants is much lower than that produced in nature (1500 TBq per year) and by nuclear weapons testing (which doubled the atmospheric ^{14}C concentration in the 1960s), this anthropogenic source nevertheless contributes to increasing ^{14}C atmospheric contents in the long term. Because of the long half-life of ^{14}C and its incorporation into the food chain via photosynthesis, a major effort has been employed by many countries aiming to quantify and control its emissions.

Different kinds of samples including air, vegetation and foodstuffs have been used to investigate the anthropogenic ^{14}C signal in the surrounds of nuclear power plants (e.g. Uchrin et al., 1998; Stenström et al., 1998, 2000; Molnár et al., 2002; Kim et al., 2003; Magnusson et al., 2004; Roussel-Debet et al., 2006). However, at a reactor site, very few studies had been reported concerning soil samples (Milton et al., 1995; Milton and Kramer, 1998).

The central nuclear facility in Brazil is named Admiral Álvaro Alberto (CNAAA) and is expected to have three PWR nuclear power reactors. So far, two units are in operation, Angra I (657 MW_{el}) and Angra II (1350 MW_{el}). The third unit named Angra III (1309 MW_{el}) is

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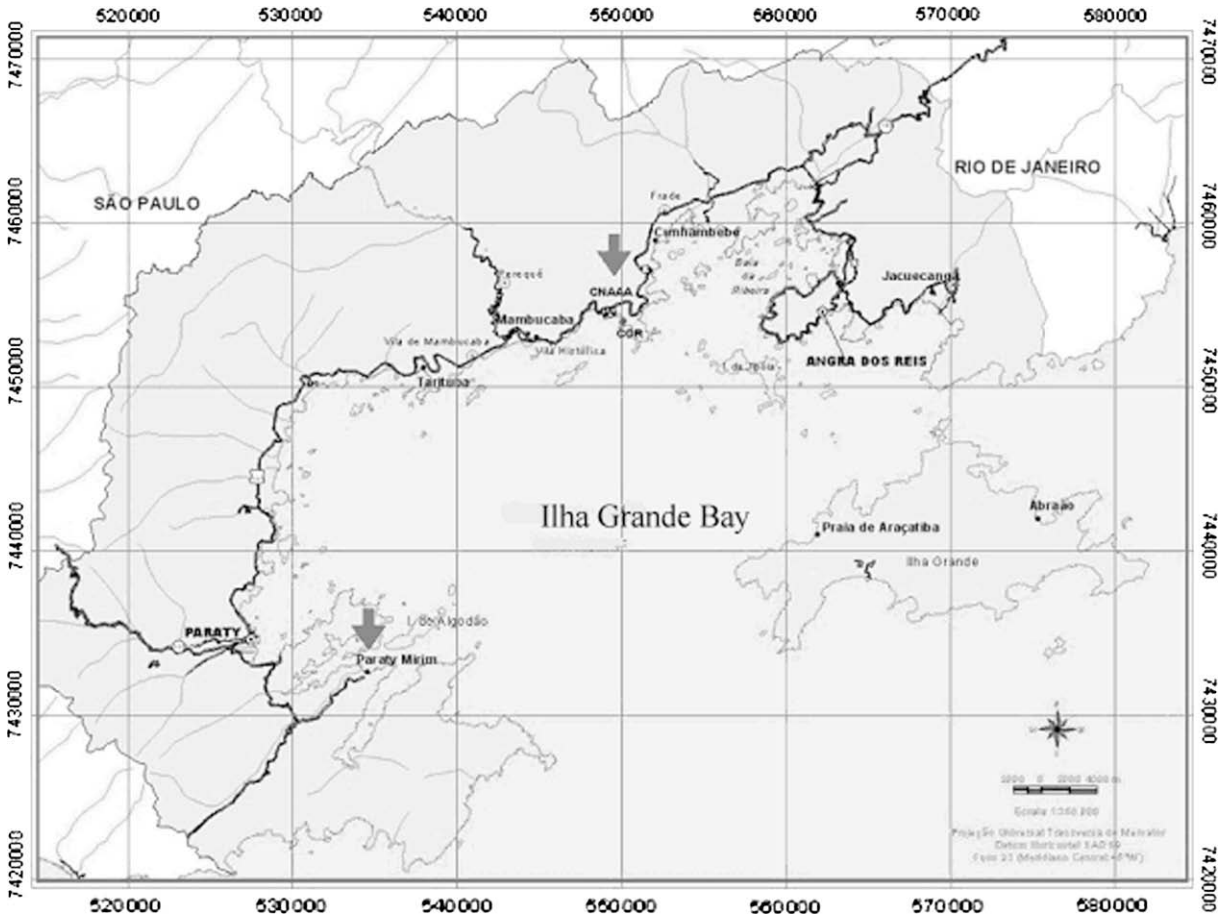

Fig. 1. Location map of CNAAA with the soil sampling points indicated with red arrows (the map was provided by Eletronuclear (2005)).

planned to be built in the near future. A recent study by Dias et al. (2008) has demonstrated the presence of a clear ^{14}C anthropogenic signal within a radius of 5 km around the nuclear power plant, which is most prominent along a northeastwards line, following the direction of the prevailing wind.

The present paper is part of an extensive research programme involving investigaing ^{14}C released by nuclear power plants in Brazil, in which samples including air and vegetation, as well as gaseous effluents (source), were also analyzed. In the present study we have evaluated whether the anthropogenic signal observed in vegetation (Dias et al., 2008) is also recorded in soils near the nuclear power plant. For this purpose, soils were taken on a hill very close to the facilities and in a reference area located almost 50 km from reactors.

Since the soil carbon reservoir far exceeds the above-ground biomass and soil organic matter can be a sink or net source of atmospheric CO_2, it is of great interest to gain as much information as possible about the soil dynamics of carbon. For this reason, total carbon and stable carbon isotope composition ($\delta^{13}C$) were also investigated as part of the study. Moreover, in order to assess soil perturbation (Milton et al., 2001; Guo et al., 2003; Correchel, 2003), the samples were analyzed for ^{137}Cs concentrations.

2. Methods

2.1. Study areas

CNAAA is situated in a hilly area (local altitudes range from 0 to 1640 m[1]), therefore two hills, with maximal heights of 80 m relative to sea level, were chosen for this investigation. One of the hills is located within 1 km downwind from the reactor site. The other, used as a reference area, is located 50 km away from the reactors in a city named Paraty Mirim (Fig. 1). The soils along the slope of both hills are clayey (Utisols), while those at the base of the hills are more sandy, but still with high average clay contents. For practical purposes, the following codes will be used to identify the sampled soils:

PS: soils on the Slope of the hill, close to Nuclear Power Plant (Utisols).
PM: soils on the Middle of the hill, close to Nuclear Power Plant (Utisols).
PB: soils on the Base of the hill, close to Nuclear Power Plant (Utisols with lower clay contents).
RM: soils on the Middle of the hill, Reference Area (Utisols).
RB: soils on the Base of the hill, Reference Area (Utisols with less clay content).

In both areas the Mata Atlântica forest dominates, providing very homogeneous cover along both slopes. The exception is the base of the hill near to the nuclear power plants where there is denser vegetation with more roots and litter on the ground than higher up the hill. Soils from both hills developed from Precambrian granites and gneisses Climate in the region is humid tropical with maximum and minimum average temperatures of 27 °C and 19.9 °C, respectively, and average relative air humidity of 82%.[2]

2.2. Sampling

Samples were taken in September and November, 2004. Trenches measuring $20 \times 20 \times 20$ cm were dug on the slope, middle and base of the hills (Fig. 2). Approximately 300 g of soil were taken at depths of 0–5, 5–10 and 10–20 cm from the soil surface, after removal of litter residue. For each level, three trenches were dug, except for sampling site PS, located on the hillslope near the power plants. At this site only one trench was dug because of the very few areas available for soil sampling.

[1] Source: Soils Department of the Rural University of Rio de Janeiro.

[2] Source: http://www.angra-dos-reis.com/instrumentos_de_navegacao/dados_do_municipio.htm. Accessed in 01/04/2006.