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CAVES OF PARQUE ESTADUAL TURÍSTICO DO ALTO RIBEIRA (PETAR), SP, BRAZIL: A STUDY OF INDOOR RADON LEVELS AND IMPACT OF SEASONAL TEMPERATURE AND HUMIDIDITY

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ABSTRACT

Radon is always present in the open atmosphere, but is found in higher concentrations in the confined atmospheres of underground workplaces like natural caves, where tour guide workers are exposed to this radionuclide. Radon concentrations in 11 galleries of the most visited caves of PETAR, Parque Estadual Turístico do Alto Ribeira (High Ribeira River Turistic State Park), were determined in order to evaluate the radon exposure to the tourist guides, as prolonged exposure to high levels increases the risk of developing lung cancer and leukaemia and may also have others harmful effects. Radon survey from October 2003 to November 2005, carried out with Makrofol E tracks detectors, showed radon average levels varying from 153 ± 44 $Bq.m^{-3}$ to 6358 ± 1619 $Bq.m^{-3}$. Beside the caves ventilation, in order to establish a relationship between radon levels and temperature and humidity, the results were evaluated together with temperature and humidity data covering the 25 months study, showing that radon concentrations inside the caves are strongly related with seasonal temperature variations but humidity.

1. INTRODUCTION

Radon and radon progeny are the greatest sources of natural radioactivity. It has been estimated that inhalation of short-lived radon progeny accounts for more than half of the effective dose from natural sources [1]. Prolonged exposure to radon may cause a negative effect on our health, causing lung cancer and bronchial tissue damage. At present, exposure to radon is considered as second most important cause of lung cancer, after smoking [2].

Concentrations of indoor radon and its progeny in caves vary from levels hardly higher to levels several thousand times higher than outdoor air concentrations. Radon monitoring at highly radioactive locations such caves or underground mines, is important to assess the radiological hazards to occupational workers and tour guides.

PETAR, Parque Estadual Turístico do Alto Ribeira (High Ribeira River Turistic State Park), created in 1958, is a conservation park with an area of 35,102.8 ha, situated on the left margin of the Ribeira river, south of São Paulo State, Brazil, with more than 180 recorded caves [3]. The park has four visit centers: Santana, Ouro Grosso, Caboclos and Casa de Pedra, receiving nearly 40,000 people annually [4].

Radon concentrations were determined for several cave galleries of Santana center and Ouro Grosso center. The radon measurements were performed for 2 years between October 2003

and November 2005. The study included the measurement of outside-inside temperature and humidity.

2. METHODOLOGY AND RESULTS

2.1. Methodology

The SSNTD used in this study is the policarbonate Makrofol E. Each detector is a small plastic square of 1 cm^2, loaded into a diffusion chamber type KFK detector, installed in the selected caves, at least 1 m away from the nearest roof. The exposure period was, at least, 3 months, in order to determine the long-term average levels of the indoor radon concentrations over varying seasons.

There are near 180 recorded caves in PETAR. The study was restricted to some show caves employing tour guides. Five caves of Santana center and one cave of Ouro Grosso center were chosen for measurements, cause the largest number of visitors. These are: Laje Branca cave, Água Suja cave, Couto cave, Santana cave, Morro Preto cave (Santana center) and Alambari de Baixo cave (Ouro Grosso center).

The SSNTD detectors were placed in those galleries opened for tourist visits, as follows: three points at Santana cave (Descanso Saloon, Torres Saloon and Cristo Saloon), two points at Morro Preto cave (Camarote Saloon next to entrance of cave and Chocalate Saloon at the end of the cave) and one point at each one of Laje Branca cave, Água Suja cave, Couto cave and Alambari de Baixo cave.

During the two years of surveillance, measurements of temperature and humidity in the caves were undertaken. Also, a research about climatic variation in the PETAR surroundings (in general, cities situated next to PETAR, which are: Eldorado, Capão Bonito, Cananéia, Jacupiranga and Registro) [5].

After exposure, the detectors were retrieved to the Environmental Radiometric Division, IPEN and processed. The Makrofol E detectors were etched for 2 hours with a PEW_{40} solution in a temperature-stabilized water-bath and mild stirring, at 70°C [6]. The track densities were read under a Zeiss/Axiolab optical microscope connected to a video camera and a personal computer [7].

2.2. Results

The radon levels are presented in Table 1. The radon concentrations lay in a range from 153 $Bq.m^{-3}$ to 6607 $Bq.m^{-3}$. The highest levels represent caves far-away from the gallery entrances, which were also observed in others studies all over the world [8]. The radon concentrations variations in karstic systems depend on a complex interrelation of different factors, both external and internal: outside-inside temperature differences, wind velocity, atmospheric pressure variations, humidity, karstic geomorphology and porosity and radium content of the sediments and rocks [9].

Table 1. Concentrations of ^{222}Rn in several caves of High Ribeira River Turistic State Park (PETAR)

		^{222}Rn Concentrations ($Bq.m^{-3}$)						
Month/year		Oct/03 - Mar/04	Mar - Jul/04	Jul - Oct/04	Oct/04-Jan/05	Jan - Mar/05	Mar - Jul/05	Jul - Nov/05
Caves	Galleries	Spring/Summer	Autumn	Winter	Spring	Summer	Autumn	Winter/Spring
Santana cave	Torres Saloon	4950	4649	1532	4158	5065	2754	1464
	Cristo Saloon	5811	3435	1841	4438	5337	2634	1684
	Descanso Saloon	6607	6358	1312	4080	6107	2706	1543
Morro Preto cave	Camarote Saloon	512	1223	363	677	492	354	----------
	Chocolate Saloon	1957	2177	417	805	1252	652	441
	Golfinho Saloon	----------	1674	406	1308	834	595	255
Laje Branca cave		1009	2568	1015	2414	3386	1325	1217
Alambari de Baixo cave		516	1327	970	610	382	342	370
Couto cave		----------	1110	611	704	342	153	230

The complex dynamics of radon in natural underground places makes continuous monitoring and study about influence of environmental changes.

Measurements of temperature and relative humidity inside the caves showed constant values overall studied period, ranging between 17°C and 19°C for temperature and between 96% and 100% for humidity.

The measurements of relative humidity in the caves were compared with the obtained results of a research about climatic variation in the PETAR surroundings, which presented similar values (between 90% and 100% for relative humidity) [5].

The internal temperature and humidity results were assessed together with outside temperature (temperatures of cities next to PETAR), were plotted graphics of radon concentrations in the caves versus minimum and maximum regional average temperature.

The behavior of radon levels variations as function temperature is showed for Santana cave (Figure 1), Laje Branca cave (Figure 2) and Morro Preto cave (Figure 3), which presents higher levels.

Água Suja, Alambari de Baixo and Couto are caves that presents similar configurations and strongly ventilated, as so as, its results were grouped (Figure 4).

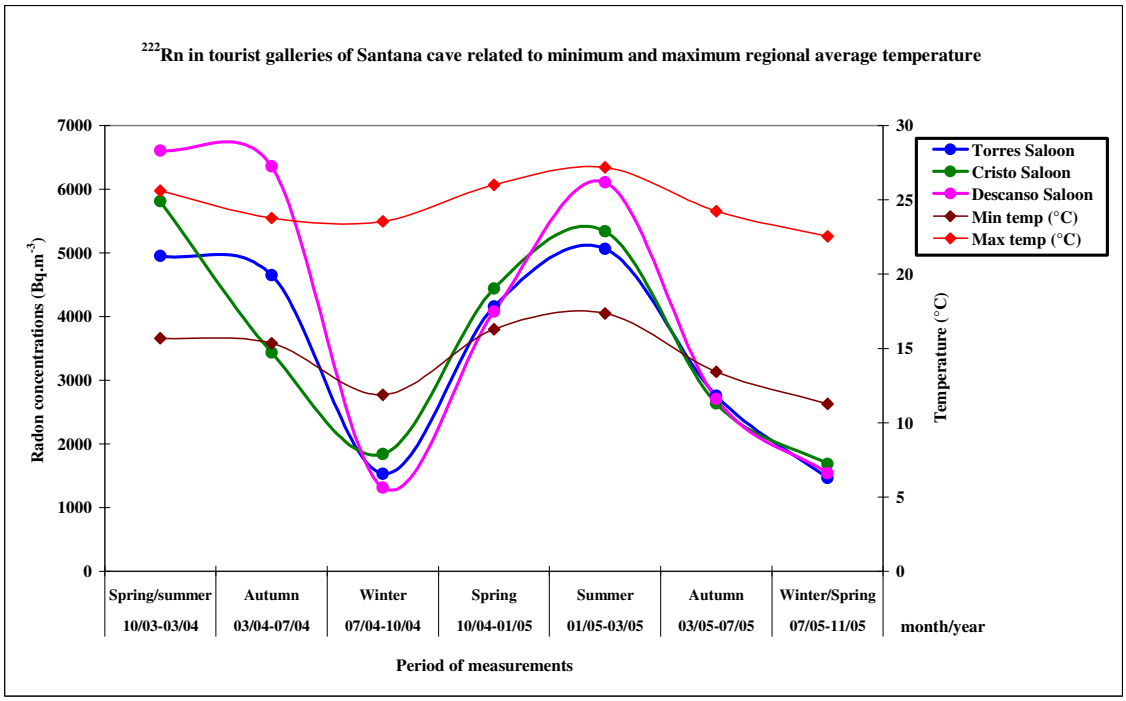

Figure 1. ^{222}Rn in tourist galleries of Santana cave related to minimum and maximum regional average temperature.

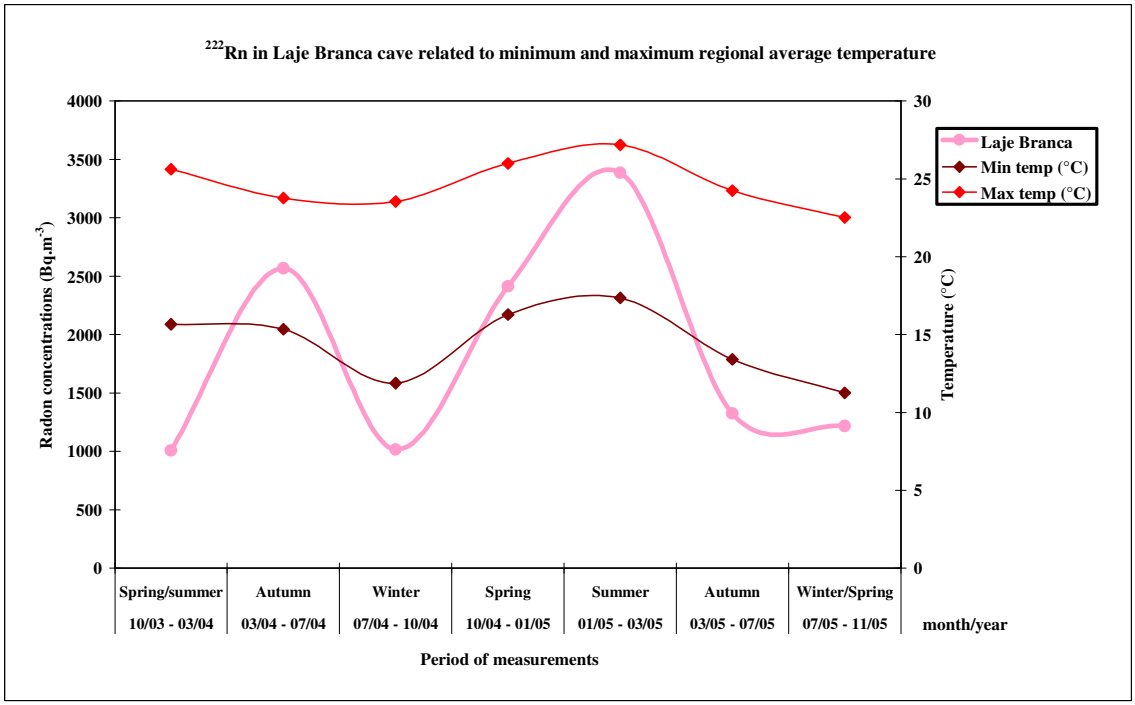

Figure 2. ^{222}Rn in Laje Branca cave related to minimum and maximum regional average temperature.

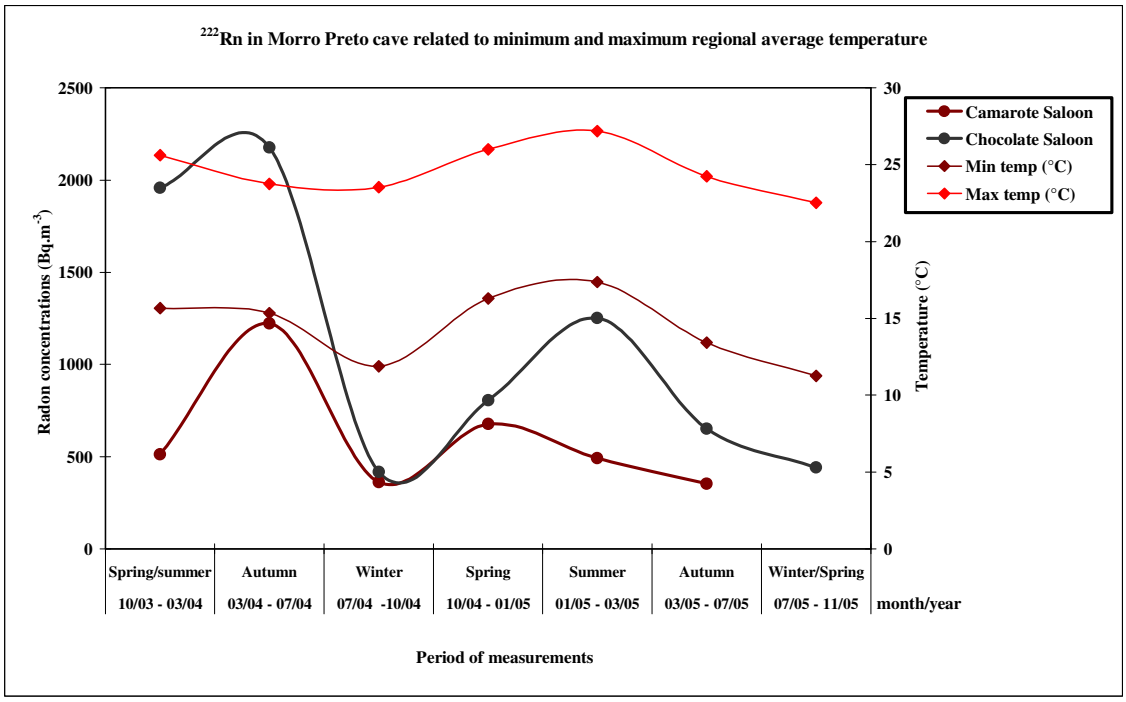

Figure 3. ^{222}Rn in Morro Preto cave related to minimum and maximum regional average temperature.

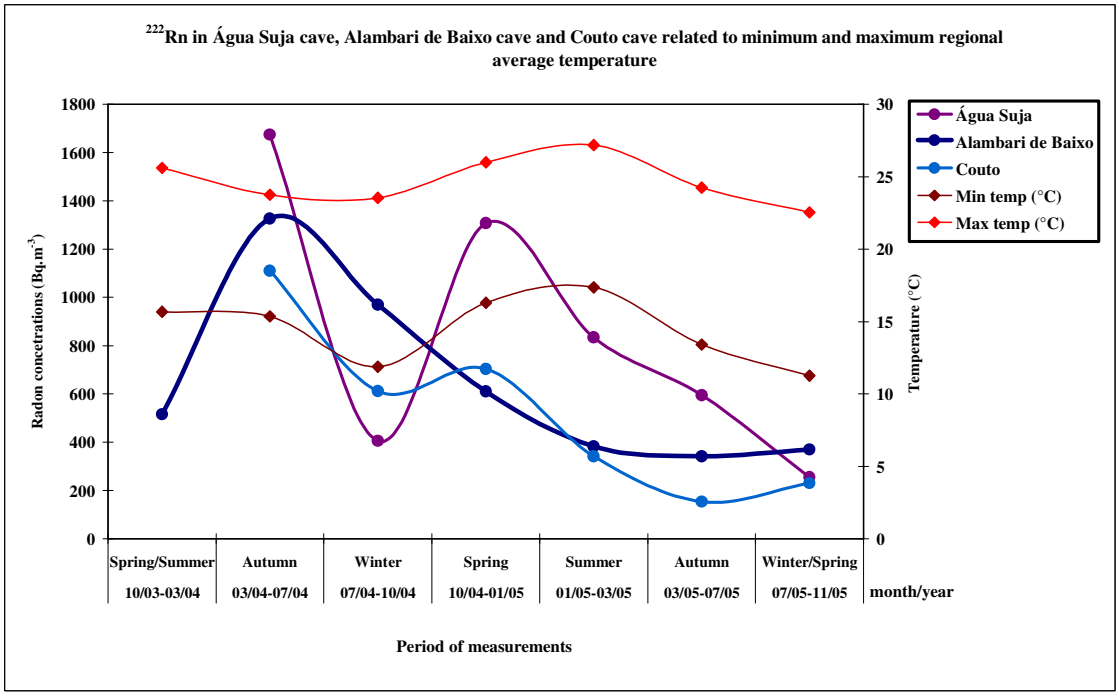

Figure 4. ^{222}Rn in Água Suja cave, Alambari de Baixo cave and Couto cave related to minimum and maximum regional average temperature.

3. CONCLUSIONS

As expected, for the strongly ventilated Água Suja, Alambari and Couto caves, the radon levels are lower than the ones obtained for the Santana, Laje Branca and Morro Preto caves with no external communication. However, we can observe that, for external chilly weather, the radon levels inside the caves decrease, as there is a temperature gradient between the higher temperature inside the caves and the external temperature, helping the escape of radon from the confined atmosphere.

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