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FOLLOW UP OF THE NATURAL RADIATION EXPOSURE FROM GAMMA RAYS IN THE CITY OF SÃO PAULO, BRAZIL

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Abstract
The effective doses received by the general population from the natural radioactivity in the city of São Paulo, Brazil, were assessed from 2007 to 2013, as, apart from the variation from place to place, the background gamma levels in air are not constant in time. The outdoor gamma radiation levels were carried out with thermoluminescent dosimeters, TL, quarterly exposed, using twelve monitoring stations, covering both places frequented daily by people with emphasis in the most populated districts and outskirts areas, with no influences from man-made ionizing radiation sources. The average annual effective dose in the city of São Paulo, found as 1.3 ± 0.1 mSv, is below the annual global *per caput* effective dose due to natural radiation sources of 2.4 mSv and within the annual effective doses range of 1 to 3 mSv, expected to be received by 65% of major population.

Keywords
gamma radiation levels; natural radiation sources; effective dose; thermoluminescent dosimetry

1. Introduction

The exposure of mankind to ionizing radiation from natural sources is a continuing and inescapable feature of life on the earth, considering the low levels exposures to radiations and its possible biological effects in the human population, which are still not properly quantified.

The estimates of radiation have been based primarily on the submissions to the United Nations Scientific Committee on the Effects of Atomic Radiation, UNSCEAR databases for assessment of doses to the public and workers. According to the UNSCEAR publications more data on exposure from natural, man made and occupational sources at low levels are needed to contribute to the knowledge of radiation stochastic effects [1, 2].

The identification of radiation levels in the environment, in a particular place, is important to carry out potential implementations of the protection measures. Furthermore, it is possible to obtain an average exposure value from the natural gamma radiation outdoors, to which the population as a whole is submitted.

Brazil is a large country with a huge population and very diversified ways of life. Great part of published data about Brazilian natural radiation refers to high levels natural radiation, such as Guarapari, where there is large concentration of thorium minerals, and the volcanic soils in the state of Minas Gerais. Nevertheless, there are no systematic studies about low level natural radiation in others Brazilian areas [3].

This study aims to estimate the dose received by the population in São Paulo, which is the most populated Brazilian city. The dose were assessed from environmental outdoor gamma radiation levels, since 2007 over a period of nearly six years.

2. Methodology

The measurement of the environmental outdoor gamma radiation levels (direct radiation from the environment) was carried out by using thermoluminescent dosimeters (TLDs) of $CaSO_4$:Dy produced by the Instituto de Pes-

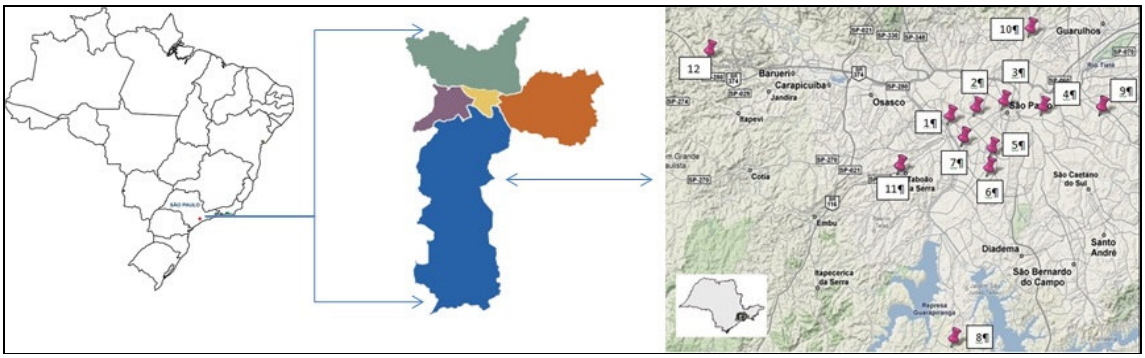

Figure 1. Map of Brazil highlighting the Sao Paulo state, its geographic subdivisions and the monitoring stations numbered according to Table 1 (Google Maps)

Table 1. Annual Effective dose for each of the 12 studied regions of São Paulo city and annual average effective dose for the whole city, from October 2007 to the end of 2013.

Region/District	***Hab/km²***	***Annual effective dose (mSv/y)***					
		2007-2008	***2009***	***2010***	***2011***	***2012***	***2013***
1. Alto de Pinheiros	5,600	1.03	1.32	1.15	1.02	1.54	1.16
2. Consolação	15,504	1.26	1.48	1.25	1.05	1.53	0.97
3. Pça da República	24774	1.22	1.37	1.34	1.09	1.52	1.47
4. Móoca	9,834	1.27	1.47	1.32	1.07	1.19	1.19
5. Pq Ibirapuera	9,263	1.08	1.16	1.14	1.13	1.55	1.19
6. Campo Belo	7,472	1.24	1.54	1.3	1.19	1.4	1.21
7. Pinheiros	8,171	1.26	1.48	1.22	1.09	1.31	1.12
8. Parelheiros	855	1.35	1.54	1.35	1.51	1.51	1.23
9. Carrão	11,104	1.53	1.87	1.55	1.41	1.81	1.10
10. Tucuruvi	10,938	0.93	1.23	1.01	0.87	0.95	1.53
11. Taboão da Serra	11,949	1.36	1.51	1.42	1.25	1.38	1.20
12. Aldeia da Serra	469	1.21	1.4	1.25	1.03	1.32	1.29
Average annual ± SD		1.23±0.16	1.45±0.18	1.28±0.15	1.14±0.18	1.42±0.22	1.22±0.14

SD - standard deviation

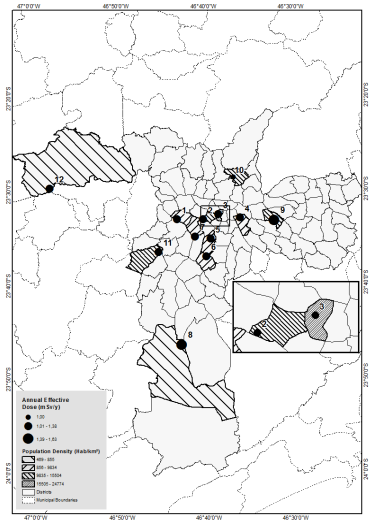

Figure 2. Map of São Paulo city, with the annual effective doses and the population density for the twelve assessed regions, according to Table 1 (ArcGIS software)

quisas Energéticas e Nucleares, IPEN (Nuclear and Energy Research Institute [4].

The measurements were carried out quarterly from October 2007 to the end of 2013, observing the four seasons of the year. The local arrangement set up uses one TL dosimeter protected by a PVC plastic envelope, placed atop a 2 ½ inches diameter PVC pole, 1m above the soil surface and buried 400mm into ground [5].

The standard procedure for placement and subsequent quarterly substitutions requires two dosimeters for each point: the field dosimeter, and a control dosimeter which is kept inside a thick lead shielded container, except when accompanying the field dosimeter during transportation, or waiting for readout.

The TL sensitivity of this material is about 20 μC Sv^{-1}, the Tl responses repeatability is better than ±4.34% and the lower detection limit is around 50 μSv [6].

2.1 The city of São Paulo – selection of the monitoring stations

Great São Paulo is the metropolitan region of São Paulo State, southeast of Brazil with an urban accumulation of 19 million inhabitants, whose population is distributed over an area of 7944 km^2 [7-9].

In order to cover a large and representative area of the town, twelve monitoring locations were selected, considering mainly the occupancy of each region (urban area) and the daily people frequency. One of twelve points is situated in a county (12, Aldeia da Serra) with low population density. All stations are located in safely recessed places, with no known influence from man-made ionizing radiation sources. For illustration and location, the Figure 1 shows the map of Brazil highlighting the São Paulo state, its geographic subdivisions district and the monitoring stations numbered according to Table 1 [9].

2.2 Dose assessment – effective dose

The absorbed dose in air (kerma) was evaluated through the outdoor direct gamma radiation carried out quarterly, for all monitoring stations. In order to evaluate the annual effective doses, kerma in air was converted into effective dose by use of a suitable conversion coefficient [10].

The annual effective doses were calculated from the sum of all quarterly values for each considered year. The average annual effective dose in the city of São Paulo is the mean value of the twelve annual effective doses. The values obtained were compared with annual dose limits for general public as proposed by the radiological protection standards [11, 12].

3. Results e Discussion

3.1 Public exposure to natural radiation – annual effective dose

The annual effective dose for each of the 12 studied regions of São Paulo city and the annual average effective doses with the standard deviations for the whole city, covering the evaluated period, are shown in Table 1 and Figure 2.

The observed deviations between the average doses observed in the same year have less than 2% of discrepancy.

The results obtained of the environmental outdoor gamma radiation in terms of external exposure ranging from 0.93 mSv/y (Tucuruvi) to 1.87 mSv/y (Vila Carrão); net values obtained after subtracting of the control dosimeter value.

This study showed that the dose distributions results for the São Paulo population during the considered six years remained in the range for São Paulo city [3,5]. According to the UNSCEAR 2000 and 2008 Reports [1, 2] estimate that the typical range for total external terrestrial radiation is 0.3-1.0 mSv and about 65% of individuals have exposure between 1 and 3 mSv, so, the values from Table 1 are consistent.

The Figure 2 shows a map of São Paulo city, with the annual effective doses and the population density for the twelve assessed regions, according to Table 1.

4. Conclusions

The effective dose (natural background exposure) showed relatively small variations among the twelve monitoring stations repre-

senting the city of São Paulo city over six years.

However, for a possible correlation between dose levels and various components that should increase exposures such as environmental conditions or weather peculiarities, altitudes and latitudes and population density, more efforts will be required to detail the dose distribution among population groups.

It is important to remember that the data presented here represent average outdoor dose values for the São Paulo Metropolitan Region population. The limited number of measurements available is probably more influent on the uncertainties associated with the external outdoor dose assessment from natural radiation sources than the complexity of the dosimetric system itself.

In terms of effective dose the contribution of outdoor gamma radiation to the annual effective dose in São Paulo city is about (1.30±0.13) mSv. The value of the estimated average exposure should not be taken to be too precise, since broad averaging is involved.

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