



Radon dosimetry and water chemical and radiological characterization of Brazilian spas

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1. Introduction

In Brazil, there are several locations where water is used as a therapeutic resource [1, 2] and in Águas de Lindóia, in the state of São Paulo, and Poços de Caldas, in the state of Minas Gerais, municipalities, balneotherapy treatments are integrated into the Unified Health System (SUS), serving thousands of patients annually. In many of these places the water springs are considered radioactive and/or radiferous, highlighting the importance of a precise knowledge of the water composition and ²²²Rn for workers and public exposure.

This work has the general objective of evaluating the dose of radiation received by workers and members of the public due to ²²²Rn inhalation, who frequent the municipal spa located in Águas de Lindóia town (MSAL), state of São Paulo, and the spa Thermas Antônio Carlos, located in Poços de Caldas town (TAC), state of Minas Gerais, as well as to chemically and radiologically characterize their water springs.

2. Methodology

2.1 Sampling

The dosimetry of ²²²Rn in the air was carried out in the MSAL and TAC in the bathhouse, places where the concentration of radon in the air was significantly high considering the exposure of workers and also the places frequented by members of the public for treatment and/or recreation. In both balnearies, water samples were also collected for chemical and radiological characterization.

2.2 Detection of ²²²Rn in the air

Nuclear solid-state track detectors (SSNTDs) were used for radon measurement. After chemical treatment the tracks were observed using a ZEISS Axiolmager, a video camera Zeiss ICC-1, and a microcomputer. Radon-222 concentration was calculated according to the equation described in. The calibration factor was obtained experimentally equal 0.0672 tracks cm⁻² per Bq m⁻³ d⁻¹.

2.4 Effective dose calculation for ²²²Rn inhalation

To determine the effective dose of radiation due to radon inhalation in the spas studied, the procedures prescribed by ICRP 89 from the International Commission on Radiological Protection [4] were used,

2.3 Chemical and radiological water characterization

For chemical characterization, Instrumental neutron activation analysis (INAA) [5] and graphite furnace

atomic absorption spectrometry (GF-AAS) (Silva, 2022) was used. Activity concentrations of radionuclides were determined by gamma spectrometry. As complementary measurements for water characterization, the pH, and total dissolved solids were also measured.

3. Results and Discussion

3.1 Concentration levels of ^{222}Rn

In tables I and II, the activity concentrations of ^{222}Rn in the air measured in the MSAL and in TAC are presented. It can be seen that in MSAL, in the places with public access, the concentrations tend to be lower during summer and autumn seasons. Inside the spring rooms, except for the campaigns of 2016, a pattern could not be stated for the other three campaigns. In the TAC, as the water does not have direct contact with the air, unless the taps were opened, the ^{222}Rn activity concentration is low even in the closed room where the springs are located, and just a little bit higher than in the bathrooms.

Table I: Concentration levels of ^{222}Rn in the air in the municipal spa of Águas de Lindóia.

^{222}Rn concentrations in air (Bq m^{-3})				
<i>Measured point</i>	<i>apr-jul/2016 autumn</i>	<i>feb-jul/2017 summer/autumn</i>	<i>jul-oct/2017 winter</i>	<i>oct-dec/2017 spring</i>
WB	35 ± 5	26 ± 1	78 ± 16	49 ± 7
MB	38 ± 5	27 ± 1	58 ± 4	71 ± 5
SRE	27 ± 4	21 ± 1	56 ± 6	51 ± 8
F*	605 ± 45	11966 ± 298	8992 ± 936	8814 ± 918
C*	449 ± 27	11371 ± 207	13192 ± 1300	12142 ± 257
SR*	407 ± 36	16451 ± 298	8456 ± 446	14745 ± 2125

* Filomena, Currie, São Roque Springs, WB and MB, women and men bathroom

Table II: Concentration levels of ^{222}Rn in the air in the Thermas Antônio Carlos spa.

^{222}Rn concentrations in air (Bq m^{-3})			
<i>Measured point</i>	<i>mar-jul/2017 autumn</i>	<i>jul-oct/2017 winter</i>	<i>oct-mar/2018 spring/summer</i>
W B	55 ± 3	53 ± 4	35 ± 3
M B	70 ± 4	**	35 ± 3
Point 1*	145 ± 5	156 ± 4	119 ± 7
Point 2*	77 ± 6	71 1	51 ± 1

* Inside the room containing the piped springs. ** Lost detector, WB and MB, women and men bathroom.

The effective dose due to ^{222}Rn inhalation was calculated, based on the publication 23 [6] for three different scenarios: 1st Scenario, for common bath worker, working for 5.5 hours per day x 6 days x 50 weeks per year; 2nd Scenario, for maintenance workers, working for 8 hours per month x 12 months per year; and 3rd Scenario, for regular visitor, for 0.33h per day x 6 days x 50 weeks per year of exposure. Results are presented in Tables III and IV.

3.3 Chemical and radiological water characterization

The pH of MSAL springs varied from 6.82 to 8.01, mainly neutral to mild alkaline, and from TAC was almost constant, around 10, alkaline, for the three springs. The total solid content in MSAL, below 20 mg L⁻¹, indicates a hypo saline water and main inorganic constituents are Na and Ca. The water from TAC

presented total solid content, below 100 mg L⁻¹, that classify it as low mineral content being its main inorganic constituent's Na, Br, Ca, Cl, Fe and Rb. In all the samples Na was the element in higher quantity. Comparing the water from both localities MSAL has the lower content of all the analyzed elements and TAC samples presented higher salinity.

Table III: Effective doses for inhalation in Águas de Lindóia balneary considering according to the three stated scenarios

<i>1st Scenario</i>				
Effective Radiation Doses (mSv y⁻¹)				
<i>Measured point</i>	<i>apr-jul/2016 autumn</i>	<i>feb-jul/2017 summer/autumn</i>	<i>jul-oct/2017 winter</i>	<i>oct-dec/2017 spring</i>
WB	0.17	0.12	0.37	0.24
MB	0.18	0.13	0.28	0.34
ESR	0.13	0.10	0.27	0.24
<i>2nd Scenario</i>				
F	0.18	3.60	2.70	2.65
C	0.16	3.40	3.95	3.65
SR	0.12	4.95	2.55	4.45
<i>3rd Scenario</i>				
WB	0.01	0.01	0.02	0.01
MB	0.01	0.01	0.02	0.02
ESR	0.01	0.01	0.02	0.02

In samples from both, MSAL and TAC, the activity concentration of ²¹⁰Pb was below the detection limit. The activity concentrations measured for ²²⁶Ra, ²²⁸Ra and ²²⁸Th are shown in Table 4.

In MSLA the activity concentration of ²²⁸Ra was below the detection limit while the activity concentrations for ²²⁸Th and ²²⁶Ra were higher than that found in TAC spring water. Results for MSLA are in good agreement with previous reports by Silva et al., 2015.

Table IV: Effective doses for inhalation in Thermas Antônio Carlos, Poços de Caldas, considering according to the three stated scenarios

<i>1st Scenario</i>			
Effective Radiation Doses (mSv y⁻¹)			
<i>Measured point</i>	<i>mar-jul/2017 autumn</i>	<i>jul-oct/2017 winter</i>	<i>oct-mar/2018 spring/summer</i>
WN	0,26	0,25	0,17
MB	0,33	**	0,17
<i>2nd Scenario</i>			
	<i>1^o Campanha</i>	<i>2^o Campanha</i>	<i>3^o Campanha</i>
Point 1*	0,09	0,09	0,07
Point 2*	0,05	0,04	0,03
<i>3rd Scenario</i>			
	<i>1^o Campanha</i>	<i>2^o Campanha</i>	<i>3^o Campanha</i>
WB	0,02	0,02	0,01
MB	0,02	**	0,01

* Inside the room containing the piped springs. ** Lost detector

Table V: Activity concentration in Águas de Lindóia and Thermas Antônio Carlos balnearies.

	MSLA	TAC
	mBq L ⁻¹	
²²⁸ Ra	<DL	24 ± 11
²²⁸ Th	59 ± 17	5 ± 2
²²⁶ Ra	63 ± 13	13 ± 2

4. Conclusions

Águas de Lindóia and Poços de Caldas municipalities water were evaluated for ²²²Rn inhalation dose received by workers and members of the public. In MSAL and TAC, radon activity concentrations in the air is below 100 Bq m⁻³ in the public environments where treatment takes place. In the closed spring source of MSLA concentration reaches values as high as 16400 Bq m⁻³. Effective dose due to ²²²Rn inhalation for members of the public visiting the balnearies for leisure or treatment are about 1.5%, for workers, working in the bath areas, 28% of the mean dose due to outdoor radon inhalation. For maintenance workers in MSAL, the dose may be higher than the global average. The TAC water is more alkaline, pH around 10, with a higher salinity than that from MSAL, pH around neutral, and hyposaline, with total solid content below 20 mg L⁻¹ mainly due to Na and Ca presence. In TAC, the main inorganic constituents are Na, Br, Ca, Cl, Fe and Rb, besides sulfur, not determined in this work but noticeable due to the strong sulfur smell in the water. The determined activity concentrations of ²²⁶Ra and ²²⁸Ra indicate that the waters from MSAL and TAC do not exceed the recommendation for drinking water of 0.5 Bq L⁻¹ and 1 Bq L⁻¹ for gross alpha and gross beta, respectively and are in good agreement with literature reported previous values.

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