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Article

Radon Levels in a Hospital in Niterói Municipality-RJ, Brazil

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Uranium and radium are present in soil, rocks, water and building materials, therefore the presence of ^{222}Rn in the air is natural, and its concentration is determined mainly by physical factors such as soil cover, altitude, porosity and soil particle size, and meteorological conditions. In rooms with poor ventilation, ^{222}Rn can accumulate to high concentrations, which increases the risk of developing lung cancer due to continuous exposure to this gas. In this work, ^{222}Rn was monitored, with the aid of a real-time radon monitor, RAD7, in offices and rooms at Hospital Universitário Antônio Pedro in order to evaluate the levels of ^{222}Rn to which people are exposed. In general, the values measured in this work are similar to values observed in other studies around the world. The obtained ^{222}Rn level of 40 Bq m^{-3} is close to the world average of 37 Bq m^{-3} defined by the United States Environmental Protection Agency (US EPA).

Keywords: radon, ionizing radiation, radio-induced cancer, RAD7

Introduction

The aging of the world population as a consequence of increased life expectancy permits chronic-degenerative diseases, such as cancer, in the epidemiological setting and as a public health problem.[1] Lung cancer, one of the most common of all malign tumors, is mostly associated with smoking;[2] however, exposure to ^{222}Rn also represents a significant risk factor.[3]

^{222}Rn is a natural radioactive noble gas. It is estimated that its abundance in Earth's atmosphere is about one part in 10^{21} (one part *per* sextillion).[4] It is one of the gases with higher density (1.217 g L^{-1}), being about eight times the density of the air. It has three radioactive isotopes: radon (^{222}Rn), half-life of 3.82 days; thoron (^{220}Rn), half-life of 55.6 s; and actinon (^{219}Rn), half-life of 3.96 s, which are formed by the decay of radium-226 (^{226}Ra), radium-224 (^{224}Ra) and radium-223 (^{223}Ra), respectively.[4] They all disintegrate by emitting alpha particles, producing polonium isotopes, which in turn decay by emitting alpha particles to originate the stable isotopes of lead.

Such isotopes are the major contributors to human exposure to natural radiations.[3] The typical concentration of ^{222}Rn in the soil varies from 4 to 40 kBq m^{-3}, considerably higher than that found in the atmosphere.[5] Because it is a gas, it presents high mobility, facilitating its dispersion to the terrestrial surface through the diffusion or convective currents through pores and fissures in the ground and by groundwater.[6] Outdoors, where it is diluted at low concentrations, it represents a significantly lower risk than inside buildings, where it can accumulate to high levels. The magnitude of the indoor ^{222}Rn concentration depends mainly on the building material used, the composition of the soil under and around the building, degree of ventilation of closed environments, and meteorological parameters, such as humidity, precipitation, atmospheric pressure and temperature.[6,7]

Recent studies have reported the risk of inhalation of ^{222}Rn to human health, since its decay products (solid ^{218}Po and ^{214}Po) lodge in the lungs where they can radiate and penetrate membranous cells, bronchi and other lung tissues. The lung cells can still undergo oxidative stress, inducing carcinogenesis.[8] The alpha particles released during the decay of the ^{222}Rn pass through the cytoplasm generating superoxide anions (O_2^-) and hydrogen peroxide (H_2O_2) in the intracellular environment that produces mutations and other lesions in the deoxyribonucleic acid (DNA).[9] By means of the "viewer effect", the cells affected by radiation

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can induce oxidative stress in adjacent non-irradiated cells. Researches have shown that with prolonged exposure and at low doses there is a larger hazard to human health than short-term exposures, even at high doses.[10,11] Oni *et al.*[12] emphasized the importance of monitoring and development of mitigating measures for closed environments that allow the accumulation of this gas, such as schools, offices, residences, hospitals.

Currently, the annual effective dose due to indoor ^{222}Rn is 10 mSv y^{-1}, which corresponds to the concentration of ^{222}Rn in the air of 300 Bq m^{-3}. However, it is recommended that indoor concentrations do not exceed 100 Bq m^{-3}.[13-15]

Considering the reasons given, this study aims to measure and discuss the levels of indoor ^{222}Rn present in different rooms of the Hospital Universitário Antônio Pedro (HUAP), the largest health facility in the city of Niterói, in addition to compare the concentrations found with the established limits by international regulatory agencies.

Experimental

Study area

The study was carried out in seven rooms of the HUAP, located in the city of Niterói, Rio de Janeiro. HUAP is one of the largest and most complex health units in the city of Niterói, being considered in the hierarchy of the Brazilian Unified Health System (Sistema Único de Saúde, SUS) as a tertiary and quaternary level hospital, that is, it presents a high complexity of treatment. Its area of coverage reaches an estimated population of more than two million inhabitants.[16]

The hospital facilities are distributed in eight floors, however, for this study only three (second, fourth, and sixth) floors have been selected. These environments had a moderate frequency of use by the employees, maximum 8 h a day, during the week, and remained closed for most of the study period, allowing the analysis of the gas behavior in the environment.

Instrumental analysis and sampling

Indoor ^{222}Rn concentration in hospital rooms was determined using a Durridge RAD7 solid-state radon detector (Figure 1). The measurement time was 72 h, following an adaptation of the methodology proposed by Tung *et al.*[18] However, instead of measuring outdoor ^{222}Rn, the background of the study area was simulated with analysis in a container laboratory. This environment was chosen since the container is made of materials with low ^{226}Ra content, as shown in Table 1.

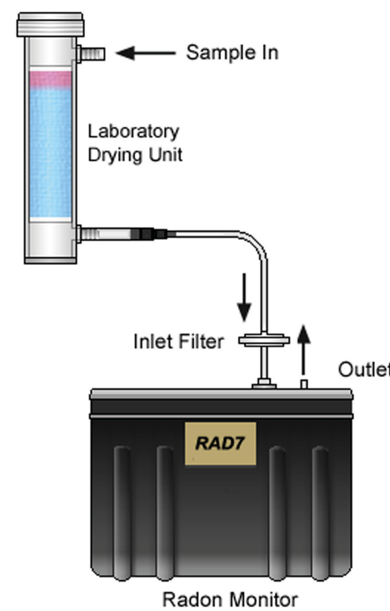

Figure 1. Schematic representation of RAD7 equipment used in ^{222}Rn monitoring (adapted from RAD7 manual,[17] p. 14).

Table 1. Description of the studied rooms

Room	Floor	Approximate room volume / m³	Building and covering material of rooms
Container laboratory	ground floor	30.0	steel sheet walls covered with PVC lining; wood floor
Respiratory physiopathology unit	second	37.0	walls and concrete floor; walls and ceiling coated with paint
Cardio-oncology unit	second	36.0	walls and concrete floor; walls and ceiling coated with paint
Hemodynamics sector (rest room)	second	46.0	concrete walls, coated with paint; drywall ceiling; floor covered by ceramics
Clinical pathology laboratory (CPL)	fourth	38.0	walls and concrete floor; walls and ceiling coated with paint
Immunopathology laboratory	fourth	95.0	walls and concrete floor; walls and ceiling coated with paint
Department of clinical medicine	sixth	28.0	walls and concrete floor; walls and ceiling coated with paint
Department of cardiology	sixth	36.0	walls and concrete floor; walls and ceiling coated with paint

PVC: polyvinyl chloride.

The equipment was placed approximately 1.5 m from the ground, being away from walls, windows and doors, minimizing possible interference by the air circulation. Before each measurement, 10 min of purging was performed to remove possible remnants of radon and its daughter nuclides from the analysis chamber.

Due to the high air humidity of the study region, an average of 76%,[19] it was required the use of drierite, a desiccant agent, in order to maintain this parameter lower than 10%, maximizing the equipment efficiency. However, some measurements required the use of an automatic correction through the Capture software,[20] which adapts the results to a lower humidity condition.

In this study, nine measurements were performed in seven different environments (second, fourth and sixth floors) from the HUAP, from May to August 2016, as listed in Table 1. Air conditioners were in use in all rooms monitored with the exception of the respiratory physiopathology unit and cardio-oncology, which can reduce the levels of ^{222}Rn and its daughter nuclides in these rooms.[21] Rooms were maintained closed, or with limited access during the measurements period, in order to minimize interference from the external environment.

Results and Discussion

The minimum, maximum and the average concentrations obtained are shown in Table 2.

The rest room, located in the newly constructed section of the HUAP, was built using different construction and structuring materials from the other rooms studied. For example, it has a low ceiling in comparison to the high ceiling seen in the other rooms and it is lined with phosphogypsum, which is widely used as a building material, replacing the natural gypsum.

It is known that phosphogypsum may contain impurities, such as uranium, thorium and radium, that can increase the natural radioactivity.[22,23] Studies about radiochemical characterization of Brazilian phosphogypsum has shown the ^{226}Ra content on this material can vary between 22 to 695 Bq kg^{-1}.[24,25] Although radium measurements on phosphogypsum were not performed in this study, it is possible to estimate, based on results found in other studies, that the indoor ^{222}Rn levels measured, above the hospital average, were influenced by radium presence in the building material used.

In order to confirm the values found, two more measurements were performed in the rest room, with different durations and on different days of the week, as can be seen in Table 3.

It is observed, according to Table 2, that as the pavement changes, there is a tendency to decrease the concentrations found, corroborating the observation made by the United States Environmental Protection Agency (US EPA),[11] where concentrations of this gas would be higher in the basement and first floor.

Table 2. Average, minimum and maximum concentrations of indoor ^{222}Rn

Hospital room	Minimum concentration / (Bq m^{-3})	Average concentration / (Bq m^{-3})	Maximum concentration / (Bq m^{-3})
Background	0.1	2.5	4.7
Respiratory physiopathology unit	6.0	11.8	21.2
Cardio-oncology unit	3.0	10.6	15.6
Hemodynamics sector (rest room)	14.8	39.3	67.9
Immunopathology laboratory	5.0	11.2	32.9
Clinical pathology laboratory (CPL)	1.0	3.8	8.5
Department of clinical medicine	4.4	9.7	17.6
Department of cardiology	2.3	9.5	17.6

Table 3. Triplicate determination of ^{222}Rn concentration in the rest room

Date	Measurement time / h	Minimum concentration / (Bq m^{-3})	Average concentration / (Bq m^{-3})	Maximum concentration / (Bq m^{-3})
06 June to 07 June	26.4	11.2	34.5	60.7
17 June to 20 June	74.1	19.6	47.6	77.1
04 August to 05 August	34.0	13.5	35.4	65.8
Standard deviation	–	3.5	5.9	6.8
RSD / %	–	24.0	14.9	10.1

RSD: relative standard deviation.

Besides the types of building materials used, the climatic parameters also influence the accumulation of indoor ^{222}Rn in rooms with low ventilation.[7,22,26] Analyzing the meteorological parameters that can influence the levels of indoor ^{222}Rn found, it is noticed that during the measurement months there were abrupt fluctuations of temperature (differences of up to 17 ^{o}C), rainfall and relative humidity of the air. These data were obtained from the Brazilian National Institute of Meteorology (Instituto Nacional de Meteorologia, INMET)[19] and are presented in Figure 2, in which the behavior of the gas accumulation in the rooms studied as a function of the meteorological conditions is presented.

Due to the low precipitation on the sampling days, it was not possible to determine a relationship between this parameter and the indoor ^{222}Rn concentration. The data indicate that, in general, an increase in rainfall and, consequently, humidity has the effect of decreasing the concentration of ^{222}Rn, as can be seen on the respiratory physiopathology unit, where an increase of rainfall caused a decrease in 30% of indoor ^{222}Rn. However, a significant linear correlation was not observed between indoor ^{222}Rn levels and meteorological conditions, therefore a detailed analysis was not possible.

The International Commission on Radiological Protection (ICRP) and the World Health Organization (WHO) recommend that concentrations of ^{222}Rn in residences should be less than 100 Bq m^{-3}, not exceeding the maximum limit of 300 Bq m^{-3}, and in workplaces, where the occupancy time is around 2000 h *per* year, such limits are in the range of 500 and 1500 Bq m^{-3}, which corresponds to an effective annual dose range of 3 to 10 mSv.[27]

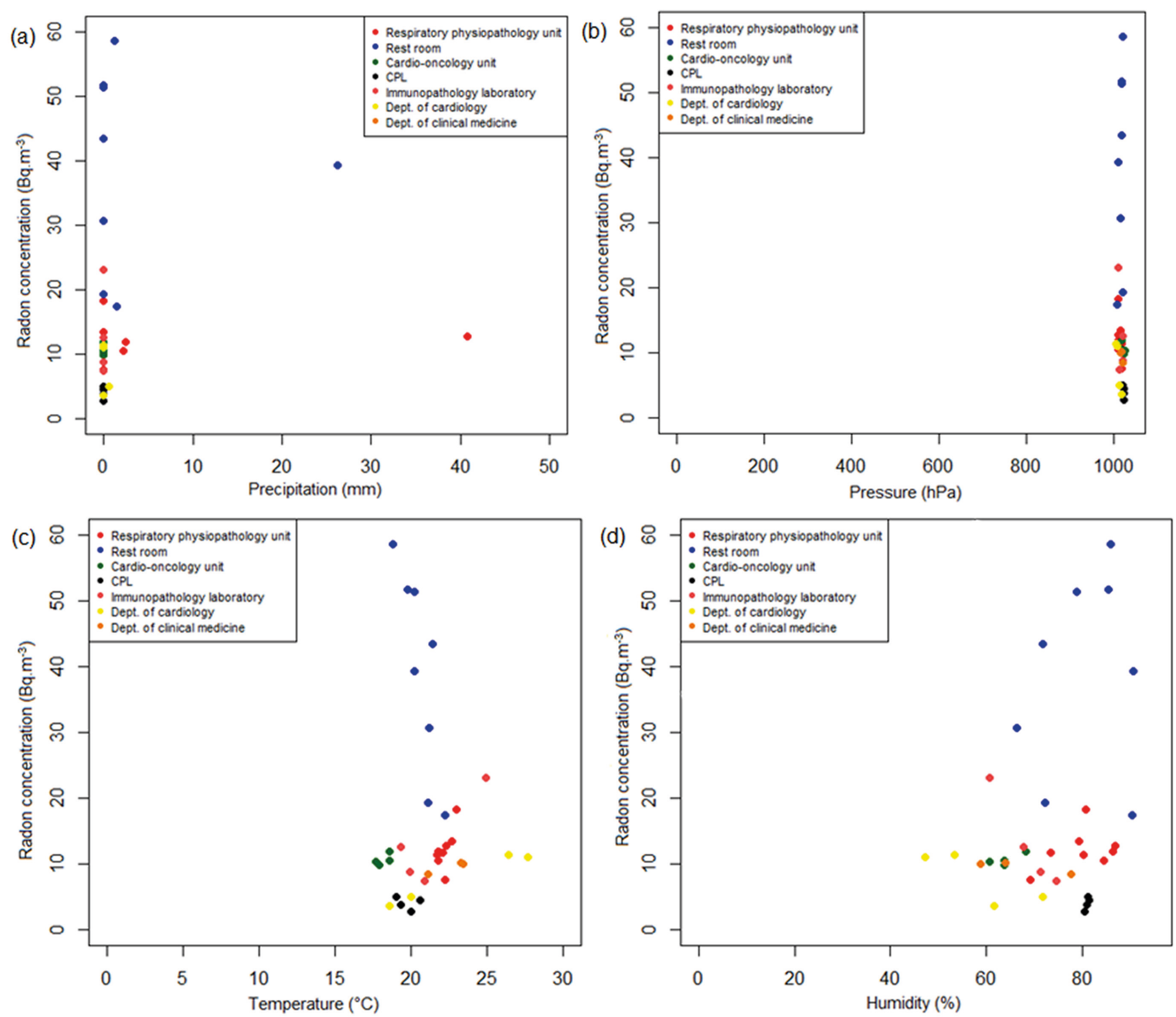

Figure 2. Variation of ^{222}Rn concentration measured in HUAP rooms between May and August 2016, depending on the meteorological conditions presented on measurement days. (a) Variation between ^{222}Rn and precipitation; (b) variation between ^{222}Rn and pressure; (c) variation between ^{222}Rn and temperature; and (d) variation between ^{222}Rn and humidity.

Table 4. Comparison of the concentrations of ^{222}Rn found in the literature with those obtained in this study

Study area	Country	^{222}Rn level / (Bq m^{-3})	Reference
HUAP	Brazil	3.8 to 47.6	this study
Residences in Baixada Santista	Brazil	56.0 to 168.0	Geraldo *et al.*[28]
Residences in Natal	Brazil	5.0 to 160.0	Marcon *et al.*[29]
Residences in Poços de Caldas	Brazil	16 to 1645	Antoniazzi *et al.*[1]
Residences in Rio de Janeiro	Brazil	< 5 to 200	Magalhães *et al.*[30]

HUAP: Hospital Universitário Antônio Pedro.

The concentrations of ^{222}Rn in the offices and rooms studied are below the maximum limit recommended by both the ICRP and WHO, and the values obtained are similar to the results found in other studies in the country, as can be observed in Table 4. Thus, mitigative measures are not required. However, it is recommended that there be subsequent studies and periodic monitoring of these sites, in particular the room in the hemodynamics sector, in order to ensure that the levels of indoor ^{222}Rn do not exceed the established limits.

Conclusions

Records and data on the effects of inhalation of indoor ^{222}Rn for human health are more recurrent in countries with cold weather, where there is a decrease in the ventilation in the winter that is propitious for the accumulation of gas. And in countries with a tropical weather, such as Brazil, studies about the risks of ^{222}Rn accumulation and its relation to human health, are often incipient, especially those that investigate the association of climatic parameters and radon concentration in poor ventilation environments. Locations as hospitals, where a restricted air circulation offers a potential health risk due to increase of indoor ^{222}Rn, should be better investigated.

The concentrations found were all below the limit established by the WHO, of 100 Bq m^{-3}, therefore, not needing mitigating actions. However, the rest room of the hemodynamics sector requires attention since it presented high levels of this gas and a possibility to exceed the levels considered as safe in an analysis with longer study time.

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