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RESEARCH ARTICLE OPEN ACCESS

Evaluating the Indoor Radon Under Different Experimental Conditions in a Brazilian Geology Department

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ABSTRACT
This paper describes the characterization of the indoor radon (^{222}Rn) in a Geology Department located at the campus of UNESP-São Paulo State University, Rio Claro city, São Paulo State, Brazil. The RAD7 equipment from Durridge Co. was successfully used for the analysis of the indoor radon in two selected sites, as well as to monitor the continuous radon emanation from 745 g of gravels obtained from a granite sample exhibiting a total surface area of about 1100 cm^2, which were inserted in a cylindrical apparatus taking part in a closed circuit. The analytical data indicated indoor values below the yearly average concentration of 200 to 600 Bq/m^3 of ^{222}Rn in air, which corresponds to the optimized action levels relating to chronic exposure involving radon in dwellings, but values above the guideline reference value of 1000 Bq/m^3 of ^{222}Rn in air were rapidly reached in the experiments conducted with the granitic rock.
Keywords **-** natural radioactivity, radon emanation, granitic rock, UNESP-Rio Claro campus, Brazil

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I. Introduction

Radon (^{222}Rn, half-life = 3.83 days) is a colorless, odorless, tasteless, chemically inert and radioactive gas produced continuously in rocks and soils through α-decay of ^{226}Ra in the ^{238}U radioactive decay series (4n+2) (Fig. 1). It is subjected to recoil at "birth", with some atoms escaping to the surrounding fluid phase, such as air and groundwater.

The total surface area of rocks, minerals, sediments, and soils, the concentration and distribution of ^{238}U (^{226}Ra) in these matrices, as well as the microscopic properties such as the inhomogeneous ^{226}Ra distribution in them, network of nanopores, or surface roughness in natural systems are among the factors responsible by the emanated fraction of radon relatively to that produced in the solid phases [2].

A network of nanopores (100 - 200 Å wide) in minerals and rocks, intersecting the grain surfaces and increasing the internal surface area of the solids (~10 m^2 per cm^3, much higher than the external surface area calculated from the grain size), constitutes reliable paths to the radon diffusion into the atmosphere or water [3]. In addition to an extensive network of nanopores, Krishnaswami and Seidemann [4] pointed out that the ^{226}Ra enrichment in grain boundaries or crevices could regulate the supply of the radon gas to the surrounding fluid phases, such as air and groundwater, due to the high ^{222}Rn leakage from rocks and minerals.

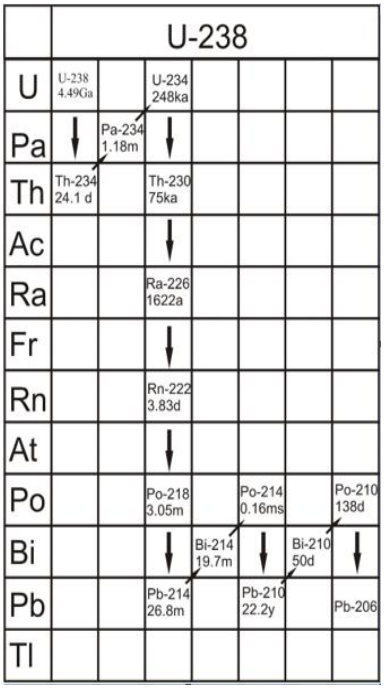


Fig. 1. The natural uranium (4n+2) decay series. Modified from [1].

^{222}Rn is of great concern to man. Radon exposure and its progeny are believed to be associated with increased risks of several kinds of cancer [5]. When radon or its progeny are inhaled, lung cancer accounts for most of the total incremental cancer risk. It is one of the most important sources of naturally occurring ionizing radiation that people are exposed to and is considered by the World Health Organization (WHO) to be the second largest cause of lung cancer after cigarette smoking [6].

Ingestion of radon in water is suspected of being associated with increased risk of tumors of several internal organs, primarily the stomach [5]. Inhalation of radon progeny accounts for about 89% of the individual risk associated with domestic water use, with almost 11% resulting from directly ingesting radon in drinking water [5].

Radon and decay product nuclei present in the indoor environment of spa facilities have been identified as a source of additional radiation burden for both bathers and working personnel [7, 8]. This additional burden has been studied by many researchers, resulting in the introduction of appropriate health regulations [8-10].

The International Commission on Radiological Protection (ICRP) recommended a limit reference level of 300 Bq/m³ for ^{222}Rn inhalation in all workplaces [11], which is the value adopted in 2013 by the European Council in the European Basic Safety Standards Directive (EU-BSS) [12]. In Brazil, according to standard CNEN-NN-4.01 [13] of the National Commission of Nuclear Energy (CNEN), the reference level for radon concentration in underground mines is 1000 Bq/m³, considering an equilibrium factor of 0.4, which is similar to that proposed by [14]. For values above this limit, CNEN can determine the implementation of mitigating measures or radiological remediation actions. According to Brazilian Standard CNEN-NN-3.01 [15], the annual effective dose adopted for occupationally exposed individuals (OEI) must not exceed the limit of 20 mSv/y. However, it has been recommended an intervention limit for workplaces of 3–10 mSv/y by [16].

Therefore, this short review highlighted the relevance of monitoring the radon presence in the environment due to the concerns associated with human health. This paper describes an investigation focusing in selected sites related to Geology teaching activities in a Brazilian university, in which the storage and handling of rocks and minerals are potential sources for increasing the radon release into the atmosphere and, consequently, favouring its inhalation by technicians, researchers, and students. The study case reported here represents typical environments available in Schools and Universities dedicated for training geologists and/or other Earth scientists elsewhere.

II. Study area

The experiments described in this paper were realized in different environments related to activities developed for undergraduate and graduate Geology teaching at UNESP-São Paulo State University, IGCE-Geosciences and Exact Sciences Institute, Rio Claro, São Paulo State, Brazil. The institute is one of the other units of UNESP spread across 24 cities in the São Paulo State. Rio Claro city is located between the following coordinates (Fig. 2): parallels 22°14’37” and 22°33’16” S; meridians 47°27’57” and 47°46’00” W.

The investigated sites are located in the Geology Department at IGCE-UNESP's Rio Claro Campus. They are: LAB-counting room of gamma ray spectrometry and alpha spectrometry of

LABIDRO-Isotopes and Hydrochemistry Laboratory (Fig. 3); LIT-rocks deposit (*litoteca*) (Fig. 4).

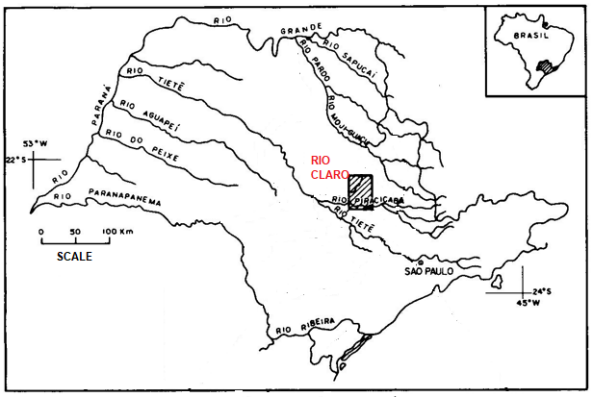


Fig. 2. Location of Rio Claro city, São Paulo State, Brazil.

III. Experimental

In this study, the measurements of radon exhaled into the air were performed with the RAD7 equipment from Durridge Co., which has a detector responsible for converting the energy of the alpha particles into electrical signals, whose accumulation results in a spectrum presented on an energy scale ranging from 0 to 10 MeV, suitable for readings of ^{222}Rn as data acquisition for this radionuclide occurs in the range of 6-9 MeV [17]. When radon decays inside the analysis chamber, it changes into ^{218}Po, which adheres to the surface of the detector. When ^{218}Po decays, alpha particles are released, forming ^{214}Pb, and, afterwards, ^{214}Po and ^{210}Pb are produced. These radionuclides release particles with different energy values that are converted into electrical signals, which can be distinguished by the equipment [17].

Thus, the RAD7 uses electrostatic collection of alpha-emitting radon progeny (^{218}Po, ^{214}Po) onto a silicon detector. The equipment draws air at about 1 liter/minute through the detector chamber, utilizing electrostatic collection and alpha-particle counting and operating in two modes: *SNIFF* (for quick location of sources by detecting ^{218}Po) or *NORMAL* (for detailed measurement of ^{218}Po/^{214}Po). The key steps include running a purge to remove moisture and setting the test parameters, such as cycle time and number of cycles [17].

Fig. 3. Front door of LABIDRO (Isotopes and Hydrochemistry Laboratory) (LAB), Geology Department, IGCE-UNESP-Rio Claro Campus.

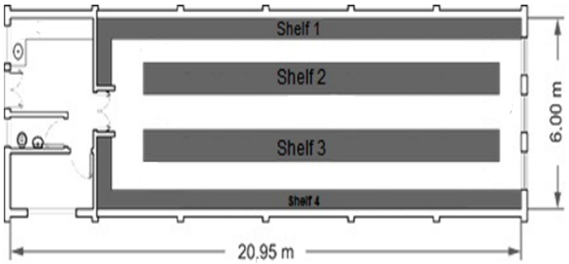


Fig. 4. Simplified plan of *litoteca* (LIT), Geology Department, IGCE-UNESP-Rio Claro Campus.

The readings of the radon decay products in the LAB (Fig. 5) and LIT (Fig. 6) were done by continuously pumping air through a filter. The measurements at LAB took place between 24/10/2025 (16:16 h) and 25/10/2025 (15:47 h), whereas at LIT from 22/10/2025 (15:27 h) to 23/10/2025 (14:57 h).

Fig. 5. Set up of RAD7 at LABIDRO (Isotopes and Hydrochemistry Laboratory) (LAB), Geology Department, IGCE-UNESP-Rio Claro Campus.

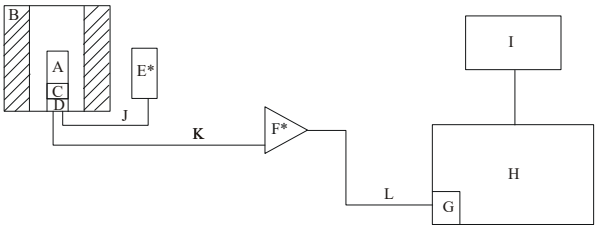
Fig. 6. Set up of RAD7 at *litoteca* (LIT), Geology Department, IGCE-UNESP-Rio Claro Campus.

In addition, laboratory time-scale experiments were conducted on gravels from a granite sample (Fig. 7). The material was cut in fragments of about 1-2 cm size, weighing 745 g (specific surface area ~1.48 cm^2/g; total surface area ~1100 cm^2), and inserted into the device shown in Fig. 8, which possesses an input and output for coupling into the RAD7 meter. The measurements of the radon emanated occurred between 17/10/2025 (10:26 h) and 19/10/2025 (9:27 h).

Fig. 7. Granite sample (GRA) used for radon exhalation experiments conducted at LABIDRO, Geology Department, IGCE-UNESP-Rio Claro Campus.

Fig. 8. Gravels of the granite sample (GRA) used for measurement of the radon exhalation conducted at LABIDRO, Geology Department, IGCE-UNESP-Rio Claro Campus.

The granite sample was also analyzed by gamma-ray spectrometry, following the analytical protocol described by [18]. One bench-top spectrometer from EG&G ORTEC featuring a NaI(Tl) scintillation crystal, was used for the reading, with the detector inserted within a lead shielding of 1 ton weight (Fig. 9). The calibration in energy of the γ-spectrometer was done using known γ-energy radiation sources, whereas the calibration in concentration of uranium equivalent (eU=^{226}Ra, in ppm) was realized utilizing the same standards described by [19], consisting of uraninite + pure silica. The gamma-ray of 1764.5 keV (^{214}Bi) was used for data acquisition [20]. The sample for analysis (44.7 g) was crushed to 0.177-0.053 mm grain size and inserted in a 62-mm diameter and 23-mm high cylindrical can to perform the reading in the NaI(Tl) detector. The counting time was about 28 hours.



A - NaI(Tl) 2"x 2" crystal
B - Lead shielding
C - Photomultiplier
D - Pre - amplifier
E - HV power supply (1000V)
F - ORTEC amplifier (model 485)
G - ACE 2k ORTEC (model 916A)
H - Microcomputer
I - Printer
J, K e L - Cables
* NIM BIN

Fig. 9. The gamma-ray spectrometric system for measuring the eU (=^{226}Ra) concentration in the granite sample.

IV. Results and Discussion

Fig. 10 shows the gamma-ray spectrum obtained during the data acquisition, which highlights a larger ^{40}K photopeak compared to the ^{214}Bi photopeak (eU) in the sample, as normally expected for granitic samples [20]. From the gamma-ray spectrum, it was possible to get an eU concentration of 41 ppm, which is within the range of values often reported for igneous rocks [21].

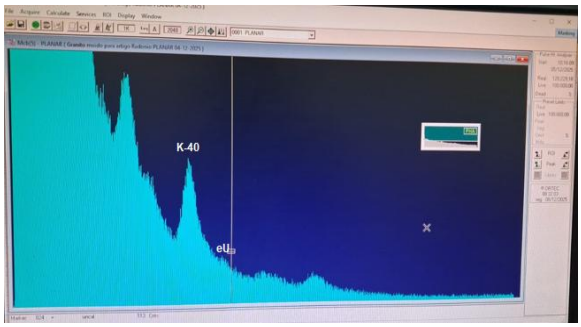


Fig. 10. Gamma-ray spectrum obtained for the granite sample (GRA) analyzed in this study.

The results obtained in the radon readings are summarized in Table 1 and plotted in Figs. 11-13. It is possible to verify that the lowest mean radon concentration was found at LIT (9.75 Bq/m^3), whereas the highest radon concentration emanated from the granite sample (1390 Bq/m^3).

Table 1. Summary of the results obtained in the radon monitoring in this study. All data in Bq/m^3.

Value	LAB	LIT	GRA
Minimum	0.06	<0.01	812
Maximum	42.20	27.90	1780
Mean	16.40	9.75	1390
St. Dev.	9.98	7.90	242
Cycles	48	48	48

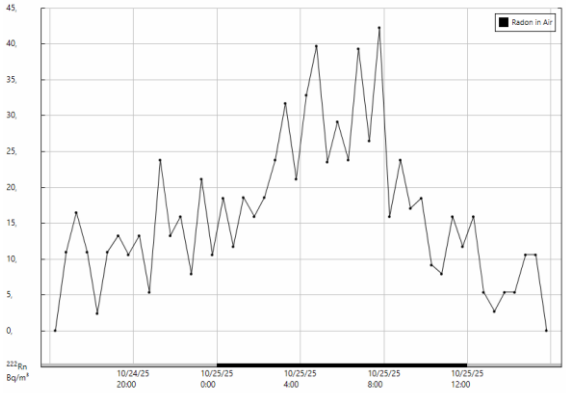


Fig. 11. Radon monitoring in the air of LABIDRO (Isotopes and Hydrochemistry Laboratory) (LAB), Geology Department, IGCE-UNESP-Rio Claro Campus. Duration of each measurement cycle = 30 minutes.

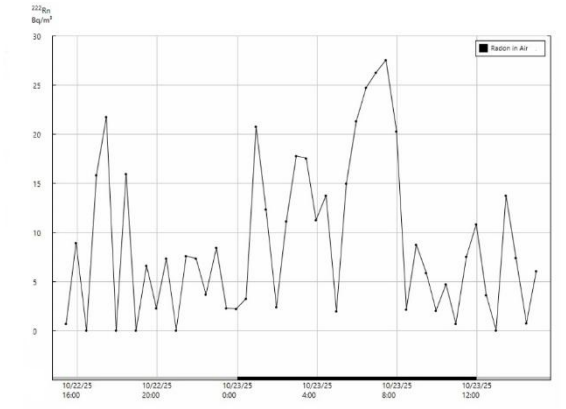


Fig. 12. Radon monitoring in the air of *litoteca* (LIT), Geology Department, IGCE-UNESP-Rio Claro Campus. Duration of each measurement cycle = 30 minutes.

Contrary to expectations, the higher radon value in the air at LAB compared to LIT can be explained by the fact that there is ventilation in the *litoteca*, thus, favoring the gas diffusion into the atmosphere. On the other hand, the door and windows of LABIDRO remain closed overnight, justifying the increased values in that period (Fig. 11) and implying on the enhanced mean radon level.

Fig. 13. Plotting of the radon emanation data of the granite sample (gravels). Duration of each measurement cycle = 1 hour.

The optimized action levels relating to chronic exposure involving radon in dwellings should, in most situations, fall within a yearly average concentration of 200 to 600 Bq/m^3 of ^{222}Rn in air [22]. On the other hand, the action level for remedial action relating to chronic exposure situations involving radon in workplaces is a yearly average concentration of 1000 Bq/m^3 of ^{222}Rn in air [22]. Therefore, the average indoor radon concentration of 16.4 and 9.75 Bq/m^3, respectively, at LAB and LIT is much lower than these limiting guideline values and, consequently, the inhalation of this gas is not a significant radiation burden in both sites for working personnel and students.

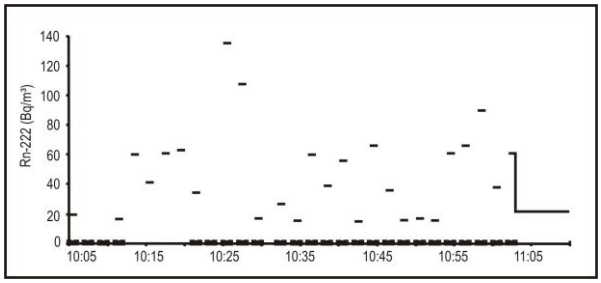


Fig. 14. Variation of the indoor radon concentration at LAB. Date of the measurement: 15th December 2006.

Figs. 14 and 15 show the air radon concentrations at LAB and LIT as measured by [23] using an Alpha Guard PQ2000PRO (Genitron GmbH) equipment (afterwards Saphymo GmbH), following a protocol proposed by the manufacturer [24]. Alpha Guard is an ionizing chamber that also measures radon via alpha spectrometric techniques. The mean values corresponded to 19.6 Bq/m^3 (LAB) and 17.2 Bq/m^3 (LIT), not much different of the value now reported for LAB (16.4 Bq/m^3, Table 1).

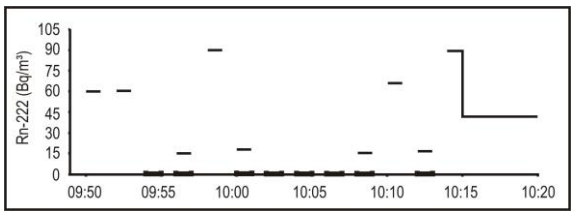


Fig. 15. Variation of the indoor radon concentration at LIT. Date of the measurement: 22nd December 2006.

One relevant finding of the results obtained in this study is the inverse relationship between the air temperature and radon concentration monitored at LIT, as shown in Fig. 16. The Pearson correlation coefficient is r = -0.30, and the two-tailed P-value (N = 48) equals 0.0392, whose difference is considered to be statistically significant, by conventional criteria. Thus, ventilation (aeration) together with increasing air temperature favors the radon release into the atmosphere, reducing its indoor concentration, as expected.

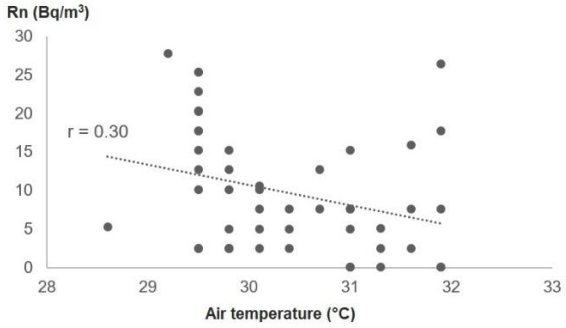


Fig. 16. Relationship between the air temperature and radon concentration monitored at LIT.

The eU concentration of 41 ppm in the granite sample is enough to yield significant radon emanation from the exposed rock surfaces, reaching a level of 1780 Bq/m^3 after an accumulation time of 48 hours in conditions of a closed system. Fig. 17 shows that there is a linear relationship between the radon accumulated and the time elapsed since the beginning of the experiment. The initial value after 1 h of accumulation is 812 Bq/m^3, which is already above the yearly average levels of 200 to 600 Bq/m^3 related to chronic exposure involving radon in dwellings [22]. Such radon activity concentration is close to 770.5 Bq/m^3, as determined by [25] in the

Amando Simões PI-08 coal mine, Figueira city, Paraná State, Brazil. The yearly average concentration of 1000 Bq/m^3 of ^{222}Rn in air associated with chronic exposure situations involving radon in workplaces is rapidly reached (~3 h), consequently, indicating the need for actions aiming its release into open areas, for instance, ventilation, to avoid health hazards for people staying with the radon source in confined conditions.

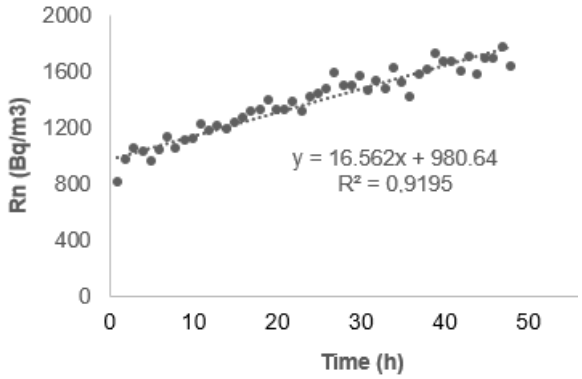


Fig. 17. Evolution of the radon accumulated in a closed system according to the time elapsed since the beginning of the experiment.

V. Conclusion

The noble gas radon (^{222}Rn) is radioactive, resulting from decays in the ^{238}U decay series, and is a matter of great concern to human health. It is one of the most important sources of naturally occurring ionizing radiation that people are exposed to and is considered by the World Health Organization (WHO) to be the second largest cause of lung cancer. Activities developed for undergraduate and graduate Geology teaching at UNESP-São Paulo State University, IGCE-Geosciences and Exact Sciences Institute, Rio Claro, São Paulo State, Brazil, require attention for radon emanated from rocks. Three experiments were conducted in the institute, aiming to evaluate its indoor release under different experimental conditions. The radon activity concentration ranged from 0.06-42.20 Bq/m^3 in the counting room of the laboratory dedicated to nuclear spectrometry (LABIDRO) and from <0.01-27.90 Bq/m^3 in a large room of the Geology Department (*litoteca*) utilized for storing different rock types with variable content of natural radionuclides. However, much higher levels ranging from 812 to 1780 Bq/m^3 were found in experiments conducted with gravels of a granite sample possessing 41 ppm of eU (equivalent uranium) and inserted in a closed system. An inverse relationship was found between the air temperature and radon concentration monitored at the *litoteca*, indicating that the increasing air temperature favors the radon release into the atmosphere, reducing its indoor concentration. The obtained dataset is relevant for actions involving the human protection against the radon inhalation as its release in confined conditions reaches the guideline reference values in a short time scale of up to 3 h for the radon source utilized in the experiments (granitic rock).

Acknowledgements

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