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Assessment of Natural Radioactivity in a Residence in Belo Horizonte

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Abstract: Natural radioactivity comes from natural radionuclides present in rocks and soil and from cosmic rays. In addition to gamma-emitting radionuclides, radon stands out, which is a carcinogenic gas. In nature, radon occurs as radioisotopes: ^{222}Rn (half-life time, $t_{1/2}$,of 3.83 d), ^{219}Rn ($t_{1/2}$ = 3.92 s) and ^{220}Rn (or thoron, $t_{1/2}$ = 54.5 s). The World Health Organization (OMS) recommends that it be measured in homes, with the recommended limit being 100 Bq/m^3 and the maximum limit being 300 Bq/m^3. This work evaluates the origin of natural radiation in a residence in Belo Horizonte, Minas Gerais, Brazil, in which was observed radon concentrations above the limits established by the OMS. The detectors used were: nuclear trace detectors type CR-39, electrets (E-PERM), AlphaGUARD (AG) and the detector RS-230. The result of the ^{222}Rn concentration measured in the electrets in the rooms of the residence varied from 14,8 Bq/m^3 to 932 Bq/m^3. At this highest point, the result of the average concentration of AlphaGUARD was from 4.78 kB/m^3, with a maximum value of 8.5 kBq/m^3. The concentration of ^{220}Rn varied Bq/m^3 Bq/m^3. As this is a basement-type room, the bedroom next door was investigated, in which it is highlighted that the radon concentration of the detector CR-39 was from 445 Bq/m^3, AG of 198.2 Bq/m^3 with a maximum value of 350 Bq/m^3, and electret of 29.6 Bq/m^3. Gamma scanning with the RS-230 indicates higher counts on uncoated walls. Measurements of radon in the water showed background concentrations. It is concluded that poor ventilation of the location must be the biggest contributor to the high concentration of ^{222}Rn, which originates mainly from the soil. The thoron concentration was higher in construction materials due to the measurement method. The instrumentation used allows a complete and comparative study between detectors in order to find the origin of natural radionuclides and subsequently suggest appropriate mitigation measures. In future studies, radon concentration in the soil and radon progeny will be measured.

Keywords: Instrumentation, Radon, Residences.

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Avaliação da Radioatividade Natural em uma Residência de Belo Horizonte

Resumo: A radioatividade natural provém de radionuclídeos naturais presentes em rochas e solos e de raios cósmicos. Além dos radionuclídeos emissores gama, destaca-se o radônio, que é um gás cancerígeno. Na natureza, o radônio ocorre como radioisótopos: 222Rn (tempo de meia-vida, t1/2, de 3,83 d), 219Rn (t1/2 = 3,92 s) e 220Rn (ou tório, t1/2 = 54,5 s). A Organização Mundial da Saúde (OMS) recomenda que seja medida em residências, sendo o limite recomendado de 100 Bq/m3 e o limite máximo de 300 Bq/m3. Este trabalho avalia a origem da radiação natural em uma residência em Belo Horizonte, Minas Gerais, Brasil, na qual foram observadas concentrações de radônio acima dos limites estabelecidos pela OMS. Os detectores utilizados foram: detectores de traços nucleares tipo CR-39, eletretos (E-PERM), AlphaGUARD (AG) e o detector RS-230. O resultado da concentração de 222Rn medida nos eletretos nos cômodos da residência variou de 14,8 Bq/m3 a 932 Bq/m3. Neste ponto mais alto, o resultado da concentração média do AlphaGUARD foi de 4,78 kB/m3, com valor máximo de 8,5 kBq/m3. A concentração de 220Rn variou de Bq/m3 Bq/m3. Por se tratar de um cômodo do tipo subsolo, foi investigado o quarto ao lado, no qual se destaca que a concentração de radônio do detector CR-39 foi de 445 Bq/m3, AG de 198,2 Bq/m3 com valor máximo de 350 Bq/m3, e eletreto de 29,6 Bq/m3. A varredura gama com o RS-230 indica contagens mais altas em paredes não revestidas. As medições de radônio na água mostraram concentrações de fundo. Conclui-se que a ventilação deficiente do local deve ser o maior contribuinte para a alta concentração de 222Rn, que se origina principalmente do solo. A concentração de torônio foi maior em materiais de construção devido ao método de medição. A instrumentação usada permite um estudo completo e comparativo entre detectores para encontrar a origem dos radionuclídeos naturais e, posteriormente, sugerir medidas de mitigação apropriadas. Em estudos futuros, a concentração de radônio no solo e a progênie de radônio serão medidas.

Palavras-chave: Instrumentação, Radônio, Residências.

1. INTRODUCTION

Natural radioactivity comes from natural radionuclides present in different environmental compartments and cosmic rays. Radon is one of these natural elements. It is a noble, tasteless, odorless and colorless gas. Furthermore, it is the only radionuclide in gaseous form in the uranium decay series, being derived from the decay of radium, through the emission of an alpha particle. Radon comes in the form of three main radioisotopes: ^{222}Rn (half-life time, $t_{1/2}$, of 3.83 d), the decay product of ^{238}U; ^{219}Rn ($t_{1/2} = 3.92$ s), the decay product of ^{235}U; and ^{220}Rn (or thoron, $t_{1/2} = 54.5$ s), the decay product of thorium (^{232}Th) [1,2].

Some factors favor high radon concentrations in indoor environments, such as poorly ventilated housing, higher levels of uranium and thorium present in the soil, the presence of thermal insulation, and the levels of radioactivity in construction materials, among others [3]. Due to the fact that construction materials – such as brick, concrete, ceramics, mortar, among others – are made from components taken from the soil, these natural radionuclides are present in them [11]. The flow of radon atoms from the soil depends on the concentration of ^{226}Ra, its activity concentration, and the permeability that the soil offers to the diffusion of the gas [5, 9].

The amount of U, Th and K will influence the emission of ionizing radiation from rocks and soil. The radon content depends on the uranium concentration. In this way, soils enriched with uranium are a basic condition for the creation of geological substrates that favor the release of radon. It should be noted that soil moisture influences the rate of emanation and diffusion of radon through the soil. Other characteristics of the soil also affect emanation, such as porosity, permeability, granulometry [6].

Due to population growth, there has been an increase in demand for construction materials of natural origin in deeper soils, which can contain high concentrations of natural element activity [3, 9]. This considerable increase in the amount of deep underground materials used in civil construction [6, 7] causes an increase in radiation dispersed by radon gas inside buildings, as well as on the earth's surface. The balance between the entry and exit of the gas through windows, cracks, joints, holes or similar elements that allow its passage is also a decisive factor for the level of radon concentration inside buildings [7].

The biggest problem associated with ^{222}Rn occurs due to inhalation of its decay products, which can be quite harmful, as its radioactive decay can occur inside the body, through the emission of an alpha particle. Therefore, its short half-life children, known as radon progeny, cause most of the doses and damage: the radioisotopes Polonium (^{218}Po), Lead (^{214}Pb) and Bismuth (^{214}Bi), which can be deposited in the lungs and can lead to the development of cancerous tumors or neoplasms and progress to lung câncer [5]. The problem related to radon is so significant that it is considered the second cause of lung cancer, behind only cigarettes [5].

Therefore, in cases where there are high levels of radon in the environment, remedial measures are highly justified and recommended [3]. With this in mind, international organizations have established ^{222}Rn concentration values in the air to assist in decision-making on whether or not mitigating measures are necessary. A ccording to the World Health Organization [5], a house with radon concentration above 100 Bq/m^3 presents a first alert to a possible radon risk, and mitigation measures in homes should be taken when the average annual concentration in the inhabited area exceeds 300 Bq/m^3. In Brazil, values found inside homes vary between 200 and 600 Bq/m^3, demonstrating that in some places concentrations are high [7,8,9]. Due to the risk presented by this radioactive gas, it is of fundamental importance to measure and understand the behavior of radon in indoor environments, since exposures are prolonged and damage to the body can be high [10]. In Brazil, there is insufficient statistical data for effective mapping, which provides precise information on regions with the highest concentration of radon or specification of materials that act as a barrier to the exhalation of the gas. In this scenario, the objective of this study was to evaluate the natural radioactivity in a residence in Belo Horizonte and identify the relevance and potential for continuing these studies.

2. MATERIALS AND METHODS

2.1. Study location

The study residence is located in the West Region of Belo Horizonte, Minas Gerais, Brazil (BH). That residence voluntarily was registered in the "Indoor Environment Monitoring Campaign – Belo Horizonte", a campaign promoted by the Natural Radioactivity Laboratory of the Nuclear Technology Development Center (LRN/CDTN), also located in Belo Horizonte. The campaign was carried out by installing CR-39 nuclear trace detectors (a passive detector) in volunteer homes for a minimum period of 3 months and during two distinct seasonal seasons. The residence of this study was identified as one of the 2.8% that had a radon concentration above 300 Bq/m^3; so, it was selected for this research. The CR-39 detector installed in that residence was placed in a bedroom on the first floor, located next to a basement, since the house was built partly supported on the ground and partly suspended. During the exposure time - 3 months in the dry period and 3 months in the rainy period - the radon concentrations were 445.0 Bq/m^3 and 231.2 Bq/m^3, respectively. The most studied room in the residence was the semi-suspended basement located between the first floor/ground floor and the second floor. It has 3.0 m x 2.0 m in área and 1.5 m in hight.

The basement entrance is inside a bedroom. It should be noted that the room does not have any ventilation or air outlet other than a small door measuring approximately 1.0 m x 0.6 m. Previous study [6], using electrets, have already indicated that in the basement of this same residence the value of 159.1 ± 7.4 Bq/m^3 was recorded.

Figure 1: Residence object of the study

2.2. Detectors

The detectors used to measure radionuclides in their respective environments were: i) for ^{222}Rn in the air, it was used the electret ionization chamber equipment, the AlphaGUARD®, and the CR-39 detectors; ii) for ^{222}Rn and ^{220}Rn measurements in the air and water, the RAD7 was used; iii) for uranium, thorium and potassium in the soil and rocks, the equipment was the RS-230® (BGO) (Table I and following topics).

Table I: Detectors used in this residence

Detector	Radionuclides	Photo
AlphaGuard	^{222}Rn	
Electrets Detectors	^{222}Rn	
CR-39 Detectors	^{222}Rn	
Rad7	^{222}Rn e ^{220}Rn	
RS-230	Uranium, thorium, potassium	

2.2.1 AlphaGUARD

The evaluation of the radioactive gas radon was carried out with the AlphaGUARD® (AG), model PQ2000Pro, from Genitron (continuous detector), which is an ionization chamber, in diffusion mode, acting as a passive detector. The radon in the environment diffuses through a large surface glass fiber filter into the ionization chamber. As the basement had a higher concentration of radon, a measurement was taken with the AG detector. The room remained closed and without ventilation and the monitoring lasted approximately 24 hours, logging data every 10 minutes. Detector data were read into the (DataExpert software).

2.2.2 Eletrodo Ion Chamber

For short-term measurement, Electrode Ion Chamber (EIC) detectors of the Electret Passive Environmental Radon Monitor (E-PERM®) type (Rad Elec Inc.) were placed. Twelve electrets were distributed throughout the residence over three days. The environments in which the electrets were placed remained with as little ventilation as possible. The locations were: basement, room near the basement, bathroom, outside room and outside bathroom (first floor); bedroom, office, living room, kitchen, bathroom (second floor); office (third floor).

2.2.3 CR-39

The long-term detectors, type CR-39 (Baryotrak/Fukuvi), were placed in the same locations as the electrets for two months. After removing the detectors, they were subjected to a chemical attack with a solution of NaOH + 2% alcohol for 14 hours in a water bath. Images of the detectors surfaces were taken using an optical microscope and processed in a software called Quantikov, to count the traces. From counting the traces and using a conversion factor using the Image-Pro Plus program, it was possible to obtain the radon concentration measured by the detector.

2.2.4 Rad7

Thoron was evaluated using the Electronic Radon Detector (Rad7®) from DURRIDGE Company Inc. in "sniff" mode, with the detector inlet tube very close to the measured point. Fourteen measurements were taken, being one in the external environment in order to identify the background, nine inside the basement to try to identify the origin of the thoron, and three in the rooms, close to the basement. Measurements of radon in water were also carried out with the Rad7® detector (the protocol used was the Water-250), according the manufacturing manual. Three samples were collected: the first was from the water tank without thermal heating, the second was from the water tank with thermal heating, and the third was water that came directly from the city supply company.

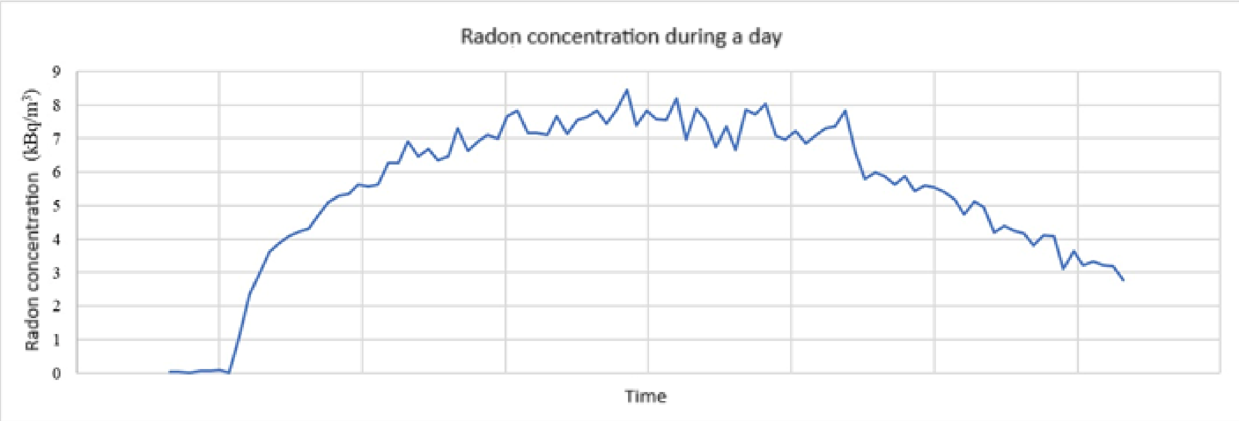
2.2.5 RS-230

The measurement of gamma radiation from uranium, thorium and potassium was peformed with the RS-230® detector (Radiation Solutions Inc.), by scanning.

3. RESULTS AND DISCUSSIONS

Radon monitoring with a continuous detector, AlphaGUARD®, is shown in Fig. 2. The maximum value recorded was 8448 Bq/m^3. After 24 hours the room was opened and the radon concentration decreased. According to NN. CNEN (2014), the maximum value in a work environment such as underground mines should be 1000 Bq/m^3. Therefore, as it is a room in a residence (even if unusable), it is a high value to consider carrying out mitigation measures, since radon can spread to the next room as well as to other areas of the house.

Figure 2: Radon monitoring curve by the AG continuous detector.



The results of radon concentration in the air (CR-39 and electrets) can be seen in Table 2. All detectors placed in the basement showed a radon concentration higher than the limit established by the WHO (up to 300 Bq/m^3). On the first floor, the bathroom showed a high concentration of radon measured by the electret, however, in CR-39 it did not. This is possibly because the electret was exposed in a condition of zero ventilation for three days, whereas the CR-39 was exposed in a routine condition, in which the bathroom had ventilation sometimes.

The ground floor room had a radon concentration measured by the electret below the limit, but the concentration recorded by CR-39 was above. The same happened with another room that is outside. In this case, the CR-39 result prevails and it is emphasized that the electret is a short-term investigation, with the CR-39 detector being more recommended. The other rooms of the house did not present values above the value recommended by the WHO (up to 100 Bq/m^3).

Table 2: Results of radon concentration in the air.

Level	Local	Radon concentration (Bq/m³)	
		Electrets	CR-39
Basement	Point 1	932.4	3491.0
	Point 2	854.7	3125.3
	Point 3	*	3050.5
1º	Bathroom	266.4	48.5
	Room	29.6	158.8
	Outside room	14.8	110.8
2º	TV room	14.8	16.2
	Kitchen	14.8	61.4
	Living room	14.8	77.3
	Desk	14.8	25.9
	Bathroom	14.8	84.5
	Room	14.8	48.5
3º	Desk	14.8	22.8

*No measurements were taken on site.

The rooms located on the first floor had higher concentrations of radon, including values above 100 Bq/m^3. The second floor presented concentrations within the established limits. The third floor also has measurements within limits. This reinforces the influence of soil as a primary source of radon.

The result for thoron/^{220}Rn concentration ranged from 31.4 ± 151 Bq/m^3 to 1530 ± 503 Bq/m^3. The monitoring point inside the basement, which is the concrete block, presented the highest radon measurement and the lowest measurement was in the bathroom. The results can be seen in Table 3. According to the literature, soil is the main contributor to radon in indoor environments. In the case of the basement, the soil is properly covered with construction materials, meaning that not all radon exhaled from the soil reaches the floor surface. In contrast, construction materials, such as concrete blocks, are in their raw form.

This may justify the high concentrations of both radon and thoron. The covered wall, which has one of the highest values, has earth on the other side and the ceiling has sparse covering.

Table 3: Toronium measurements.

Point		Toronium measure (Bq/m³)
Jardim / Background		0.0 ± 123
Inside the basement	Floor	624 ± 348
	Concrete brick gap - front	1400 ± 485
	Concrete block	1530 ± 503
	Coated wall	1470 ± 497
	Roof	1470 ± 497
	Wall gap	806 ± 384
	Earth on the wall	806 ± 384
	Pipe in the ceiling	682 ± 359
	Central beam	686 ± 361
Location where the camera was		281 ± 260
Little room floor		218 ± 249
Bathroom		31.4 ± 151

The result of the radon concentration in three different samples of water from the residence had an average of 65.7 Bq/m^3, a maximum of 131.00 Bq/m^3 and the standard deviation between 65.7 and 75.8 in samples 1 and 2, as shown in table 4.

Table 4: Result of radon concentration in water.

Sample	Collection date/time	Reading date/time	Radon concentration (Bq/m³)			S.D*
			Minimum	Maximum	Average	
1	07/11 20h	08/11 16h	0.00	131.00	65.7	75.8
2	07/11 20h	08/11 14h	0.00	131.00	65.7	65.7
3	08/11 08h	09/11 10h	0.00	0.00	0.00	0.00

The results of the gamma scan with the RS-230, Figure 3, indicate higher counts on the uncoated walls. The number of uranium, thorium and potassium counts was low, without showing any anomalies.

Figure 3 - Gamma scan result.

4. CONCLUSIONS

The instrumentation utilized enabled a thorough comparative study of various detectors in order to trace the origin of natural radionuclides and subsequently recommend effective mitigation strategies. It was concluded that poor ventilation of the site is the primary contributor to the high concentrations of ^{222}Rn, which originates mainly from the soil. Additionally, higher levels of thoron (^{220}Rn) were detected in construction materials. It is imperative to conduct more detailed studies during the pre-design phase of construction projects, which should include careful consideration of site selection, building layout and functionality, material choices, and construction techniques. In parallel with these issues, it is crucial to advocate for the development of specific standards and regulations aimed at safeguarding public health from radon exposure. Implementing technical standards and legislation based on international guidelines is essential for regulating engineering projects and ensuring effective radon management.

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CONFLICT OF INTEREST

All authors declare that they have no conflicts of interest.

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