Asessment of indoor radon distribution in the metropolitan region of Belo Horizonte, Brazil

ABSTRACT

Human beings are exposed to ionizing radiation from many natural sources. Radon and its progeny have been recognized as the most important contributors to the natural radioactivity dose, accounting for about half of all human exposure to ionizing radiation. Radon (^{222}Rn) is a a-radioactive noble gas derived from the natural series of uranium (^{238}U), which occurs in a wide concentration range in all geological materials, especially, in rocks, soils and waters. By diffusion and convection, radon migrates from the rocks and soils to atmosphere and through fissures, pipes and holes it may enter the dwellings and other buildings. Another important radon source in dwellings is its emanation from the construction material. The radon progeny concentration in dwellings has been receiving considerable global attention due to its potential effect in causing lung cancer if it deposited in upper respiratory tract when inhaled. This paper presents radon concentration distribution in dwellings in Metropolitan Region of Belo Horizonte - RMBH. The effective dose estimate is also presented for the RMBH inhabitants. The geological settings of the area are Archean rocks of Granitic Gnaissic Complex and of metasediments sequences of the great Precambrian unit of the Iron Quadrangle of Minas Gerais, Brazil. Radon concentration measurements were carried out with continuous detector AlphaGUARD PQ200PRO (Genitron), in passive mode and with passive detectos E-PERM Eletret Ion Chamber-EIC. The radon progeny concentration was carried out with a solid state alpha spectroscope, the DOSEman PRO (Sarad). It was found an indoor radon concentration varying in a large range from 18.5 to 2671.4 Bq/m-3, with an average value of 148.0 Bqm-3 and geometric mean equal to 128.2 Bqm-3. The variable results are due mainly to region geological factors and building material composition of dwellings. The equilibrium factor between radon and its progeny were determinated in dwellings, as 0.3 in average.

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INTRODUCTION

Human beings are exposed to ionizing radiation from natural sources. Some natural materials contain trace levels of radionuclides and are usually referred by NORM (Naturally Occurring Radioactive Material), which produces significant environment radon amounts depending on the radium concentration. Environmental radon and its progeny, on average, account for about half of all human exposure to ionizing radiation from natural sources [1]. For this, radon has been receiving considerable global attention by the researchers concerned about radon exposure and its health potential risks. [2, 3]

Radon (222Rn) which is a a-radioactive noble gas produced by the radium (226Ra) decay, member of uranium series (238U), occurs in a wide concentration range in all geological materials, especially, in rocks, soils and waters. Some radon atoms are released from the solid matrix of the material by recoil when the radium decays. By diffusion and advection, they are transported from the pore space to the atmosphere and through fissures, pipes and holes it may enter the dwellings and others buildings [4].

Radon concentration in soil and rocks is important to determine radon rates of entry into dwellings. It is estimated that 95% of the indoor radon comes from the soil and rocks [5]. The soil radon concentration depends on the: uranium and radium distribution in the bedrocks; the soil properties as permeability and porosity; and the meteorological parameters as temperature, humidity and atmospheric pressure. In general, areas of granitic bedrock have high concentration of natural radionuclides and consequently higher radon emanation power [4].

However, other mechanisms can affect the indoor environment radon concentration. Some construction materials can also act as significant radon source. Such materials may have the combination of raised 226Ra level and high porosity which allow radon emanation. Domestic water use constitutes radon source too, however, less significant [1].

The indoor radon exposure began to receive a global attention after 1970, when a survey on indoor radon made in several countries such as Austria, Czech Republic, Finland, France, Germany, Italy, Spain, Sweden and United Kingdom found a large variation of the radon level in dwellings, covering a range from few Bqm-3 to 100 000 Bqm-3 [3,6].

This way, high radon concentration may occur in indoor environments with reduced ventilation rates. The indoor environment radon concentration can represent a potential risk to the population health that goes or lives in such places. Radon decays by emitting alpha particles, generating a sequence of decay products known as radon progeny (218Po, 212Pb and 214Bi), which are metal atoms in ionic (+) form. Part of this radon decay product attaches to the surrounding aerosol particles in the air, forming what is termed attached radon progeny. The fraction radon progeny that do not attach to the aerosol particle in the air is termed the unattached state. If inhaled, both attached and unattached radon progenies may be deposited in the lung, especially in the upper respiratory tract, and irradiate to the lung tissue as they decay. The entry of radioactive aerosol into the respiratory tract depends on their size, larger particles stop in the nasal cavity, while smaller aerosols reach the lungs [2]. Epidemiologist studies of human population have confirmed the radon carcinogen effect, and currently International Agency of Research in Cancer (IARC) classifies radon as a class I carcinogen [5].

Then, the health hazard from the radon is related to the air concentration of the potential alpha particle energy of the short lived products. The Potential Alpha Energy Concentration (PAEC) is the sum of the potential alpha energy of any mixture of short radon progeny present in a unit volume of air. The PAEC can be expressed in terms of the Equilibrium Equivalent Concentration (EEC) that means the activity concentration of radon in radioactive equilibrium with its short lived progeny that has the same PAEC as the actual non-equilibrium mixture. The ratio of the EEC and the radon concentration is called equilibrium factor. This factor characterizes the disequilibrium between the mixture of the short-lived progeny and their parent nuclide in the air in terms of potential alpha energy [6]. Equilibrium factor for most indoor atmospheres is in the range of 0.2 to 0.6 [7].

Having this global concern, the authors aim at performing the monitoring of the distribution of the radon concentration in dwellings and other buildings in the Metropolitan Region of Belo Horizonte - RMBH. The objectives of this work are to estimate the effective dose for RMBH inhabitants and to look for radon prone areas.

This study also aims at evaluating if the radon concentration level is above maximum limits recommended internationally by the United States Environmental Protection Agency (USEPA) and also by the International Commission of Radiological Protection (ICRP), which are 148.0 and 200.0 Bqm-3, respectively, so that intervention actions are justified.

MATERIALS AND METHODS

Studied Area

The RMBH is located in Minas Gerais, Brazil (Figure 1). It has about four millions of the inhabitants and is constituted by 34 cities, which cover an area equal to 9486.7 Km2 (Figure1). Belo Horizonte and some cities such as Betim, Contagem and Santa Luzia have a concentrated population. However, the biggest cities have an irregular urban area distribution. This characteristic was the most important methodology to prepare the investigation used in this work.

The indoor radon concentration is influenced by geological and meteorological factors and also by constructive typology of the buildings [8]. The RMBH presents geological characteristics that can provide high indoor radon concentration. The geological setting of this area is Archean rocks of Granitic Gnaissic Complex and of metasediments sequences of the great Precambrian unit of the Iron Quadrangle of Minas Gerais, Brazil [9]. The constructive typology has a great variety in RMBH, depending of the purpose (dwellings, public places, stores, etc) and its owners economic power.

Then, considering all information above mentioned, indoor radon concentration measurements are important to the ra-

diation protection view point for the RMBH population. Radon is considered the second most important risk factor for lung cancer after smoking, causing between 6 to 15% of all cases in the United States [3].
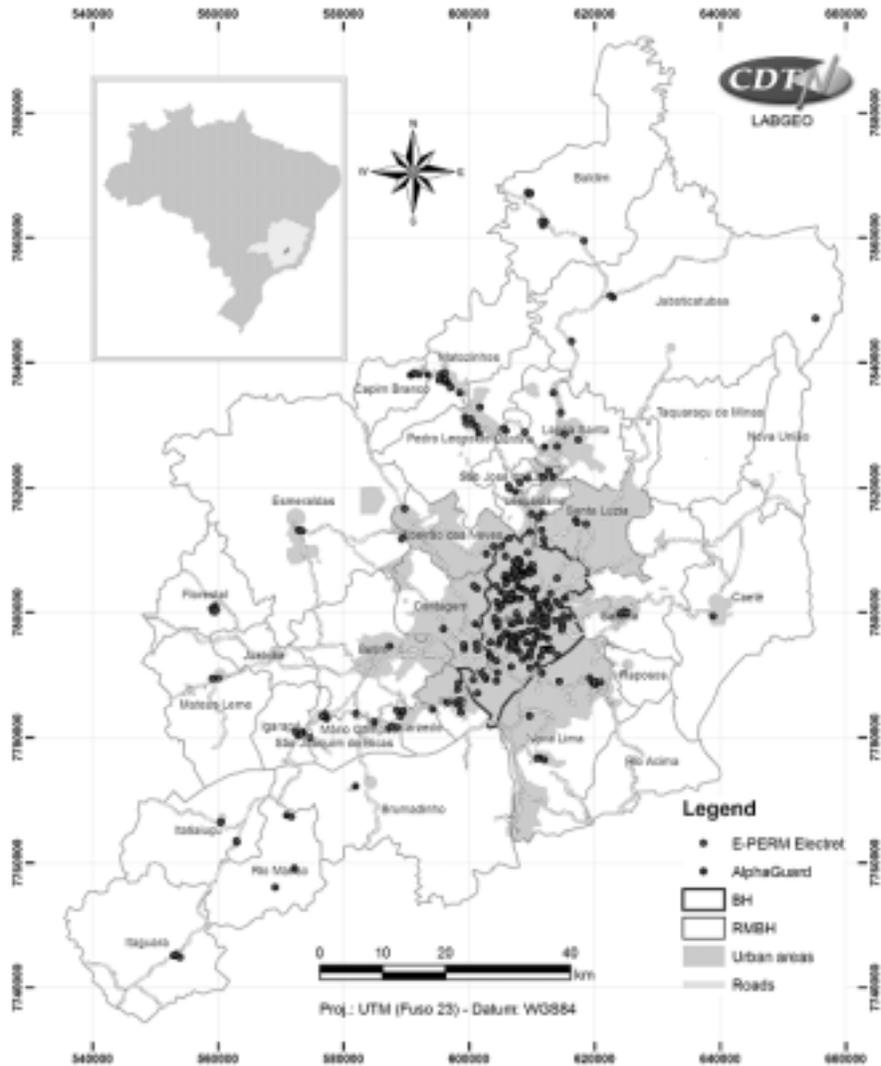

Figure 1. Distribution of radon monitoring points in the RMBH.

Experimental Procedures

The radon concentration measurements were performed by two detectors: AlphaGUARD PQ2000PRO (Genitron) and E - PERM (Radelec, Inc.). AlphaGUARD, a pulse ionization chamber, was used for this work in diffusion mode at intervals of 60 minutes, so acted as a continuous passive detector [2]. The data were acquired and treated with DataExpert software. The E-PERM Electret ion chamber (EIC) consists of a stable electret (a charged Teflon disk) mounted inside chamber acting as a passive integrating ionization monitor. Radon concentration was acquired and calculated by E - PERM radon calculator software [10].

Potential Alpha Energy Concentration (PAEC) and the Equilibrium Equivalent Concentration (EEC) measurements were carried out by alpha spectrometry using a solid state alpha detector, DOSEman PRO (Sarad). The data were acquired and treated with Doseman 1.16 software.

Soils radon concentration measurements and some construction materials analyses were performed to associate indoor radon with its main sources. Then, soil gas radon concentration was determined by AlphaGUARD PQ2000PRO, to the depth of 0.70 m, in closed circuit and active mode, in some specific places in RMBH. The samples of the most used construction materials in the RMBH were collected, homogenized, weighed and analyzed for uranium and thorium activities using the TRIGA MARK I IPR-R1 Reactor by the Instrumental Neutron Activation Analysis (INAA).

In the first part of research, indoor radon measurements were carried out in dwellings and other buildings whose owners are partially known by the authors of

this paper. However, a geographic (spatial) analysis of the data shows that indoor radon measurements did not cover adequately all urban areas of the RMBH. Then, authors prepared a specific strategic based on some characteristics of the RMBH, such as, demography density and urban area distribution to select new points. Routes were prepared though mains roads to reach the interest points.

Equilibrium Factor and Effective Dose

The UNSCEAR 2000 Report methodoly for estimating doses due to radon and short-lived radon decay is derived from epidemiological studies and physical dosimetry. In addition to radon concentration, it is necessary to measure the equilibrium factor (F) between radon and its progeny to indoor radon dose assessment:

$$F = \frac{C_e}{C_o}$$

Where Ce is the equilibrium equivalent concentration and Co is the radon activity concentration in the air. UNSCEAR 2000 Report recommends the value of 0.4 for equilibrium factor to indoor atmospheres. The effective dose for indoor radon and its progeny was calculated by following the equation [4]:

$$H = Co \cdot F \cdot T \cdot k$$

Where T (hour per year) is the dwelling permanence time, T=7000 h and k is the conversion factor, k = 9 nSv (Bqhm3)-1 both established values used by UNSCEAR effective dose calculation [4].

RESULTS AND DISCUSS

The radon concentration distribution for indoor environments is presented in Figure 2. Indoor radon concentrations usually follow a log-normal distribution and this accounts for a wide variability in concentration observed in indoor air [3]. It was found an indoor radon concentration varying in a large range from 18.5 to 2671.4 Bqm-3, with an average value of 148.0 Bqm-3 and geometric mean equal 128.2 Bqm-3. Variability can be observed between regions, within regions and from buildings to buildings within individual towns and villages. In this case, the variable results are due mainly to region geological factors, building material composition and constructive typology of the dwellings in RMBH. The two high values, which are 1591.0 and 2671.4 Bqm-3, were removed for the best results representation.
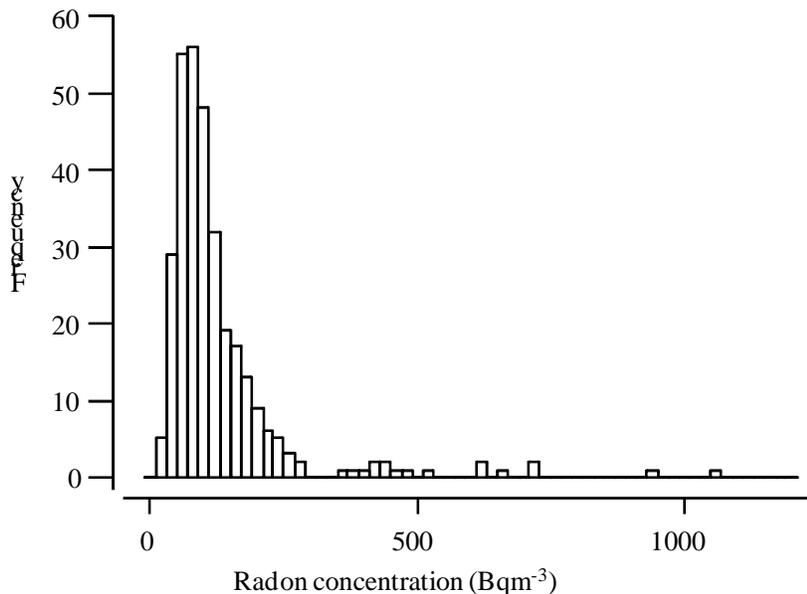

Figure 2. Radon distribution in dwellings and others buildings of RMBH.

About 19% of the indoor environments show values above the action level of the United States Environmental Protection Agency (USEPA) and of the International Commission of Radiological Protection (ICRP), which are 148.0 and 200.0 Bqm-3, respectively. The RMBH presents variable results for the indoor radon concentration as it was shown above. However, there are some regions such as Lagoa Santa and others, where radon concentration average is above the international action levels and the probability of finding high individual radon concentration has increased. This set of results suggests the existence of radon prone areas (Figure 3).
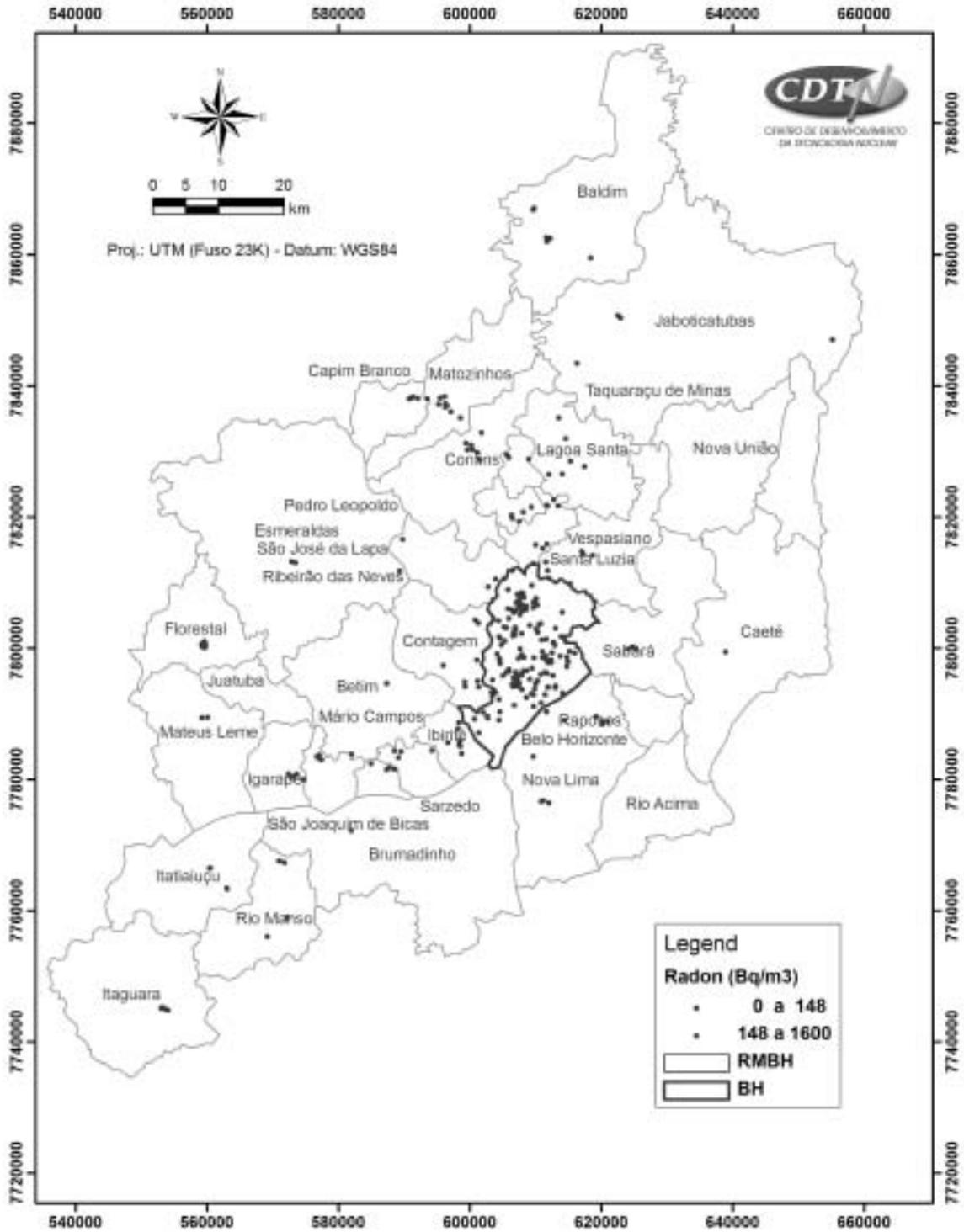
Figure 3. Points above the international action level in the RMBH.

Belo Horizonte is considered an urban area. Then, the demography density was also used to select the news sampled points. There are regions with high demography density which may receive considerable attention during this work. However, some regions have already been sufficiently investigated based in their low demography density (Figure 4).
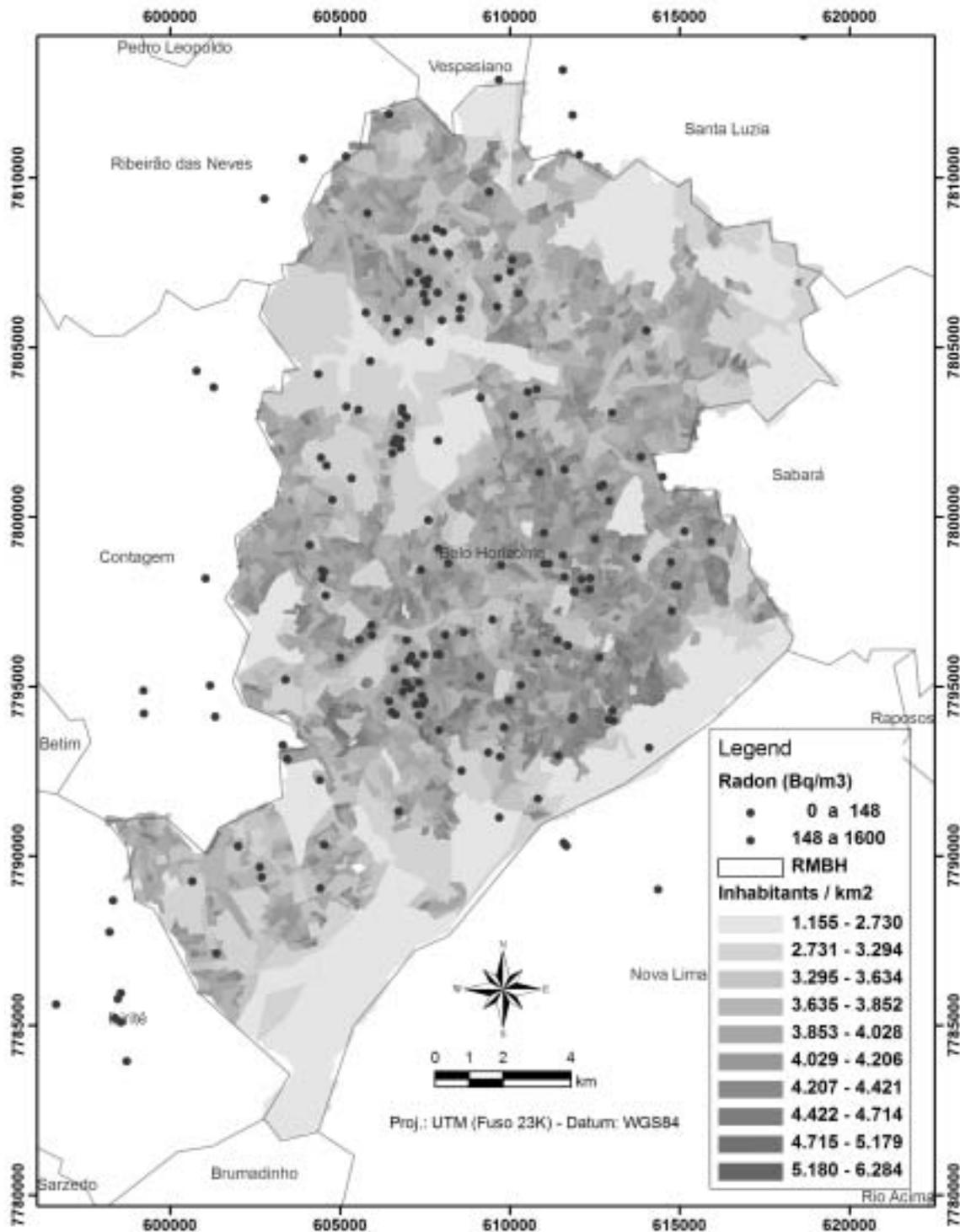
Figure 4. Measured points in RMBH overlayed demography density.

For indoor radon measurements in RMBH, the equilibrium factor values for 13 dwellings were from 0.2 to 0.5, and the arithmetic mean of the F was 0.3. These values are in accordance with literature [7].

By using Equation 2, the effective dose was calculated and the values range from 1.1 to 11.6 mSv. A mean value for effective dose of 2.9 mSv averaged by demography density was estimated. This value is a first estimate because the calculation of the effective dose to the critical cells of the res-

piratory tract depends also on the some parameters that were not considered in this work such as aerosol characteristics and the air exchange rate [2]. The measurement of all these parameters will be researched for the authors in futures works.

Radon measurements in soil gas carried out in 34 places of urban area with AlphaGUARD PQ2000PRO range from 2.9 to 183.3 kBqm-3 with average value of the 31.3 kBqm-3, which also suggests the existence of some radon prone areas. Some soil radon concentrations are above the limit value of the 50 kBqm-3, suggested by Åkerblom (1994). The international action levels established that dwellings can be exceeded in places that have soil radon concentration above this value and present rocks with high or intermediate permeability [8].

The results in Table 1 show uranium and thorium content of different construction material samples, which present the same order of magnitude, as it is found in literature for this kind of material [11]. Then, the main radon source in indoor environments is soils and rocks.

Table 1. Specific Activities of 232Th and 238U in the construction material of RMBH

Samples	Specific Activities (Bqkg^{-1})	
	Neutron Activation	
	^{232}Th	^{238}U
Sand	56.8 ± 4.1	61.8 ± 12.4
Rock	40.6 ± 4.1	98.8 ± 24.7
Cement	20.3 ± 4.1	160.6 ± 24.7
Dust of rock	36.5 ± 4.1	49.4 ± 12.4
Roofing tile	134.0 ± 8.1	86.5 ± 24.7
Brick	105.6 ± 8.1	172.9 ± 24.7
Brick of flagstone	113.7 ± 8.1	111.2 ± 24.7

CONCLUSIONS

Most of the values measured from radon concentration are in the low range when compared with same studies carried out in a tempered climate country [12, 13]. In the present study, such lower results were expected due to the semitropical climate of the RMBH area, where indoor environments are well ventilated even during the winter time.

Some indoor environments show values above the action levels of the USEPA and ICRP, which indicate the existence of radon prone areas. However, there is the necessity to have more radon measurement points in soil gas and in dwellings indoor air with short and long term radon passive detectors in these areas.

As expected, the main indoor radon source constitutes rocks and soils. Some soil gas radon concentration measurements show values in range classified by the Swedish criteria as "high" [14]. There is still the necessity to adapt the Swedish criteria for a tropical country.

There are some regions of RMBH that were not investigated. However, it has been part of the authors' researches.

Further studies were also carried out for a better comprehension of the radioactivity from the radon in the RMBH. It is important to realize the identification of radon prones areas, the association between radon and its main sources and assessment of the effective dose received by the inhabitants.

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