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Abstract. In this work, a magnitude is proposed in order to compare the potential radiological risk due to radon exposition generated by different materials, and a method based in the [222]Rn accumulation technique is presented for its determination.. The obtained results indicate that the proposed magnitude and their corresponding measurement methodology are useful in order to take decisions about the management of different kinds of porous materials.

Keywords: Radon, radon potential, radiological risk, short time accumulation periods.
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INTRODUCTION

The radiological importance of the radon implies the necessity of its control on working places and/or housings. And for this control is important to evaluate the role and contribution of the different materials which can act as radon sources inside the working and residence buildings (soils, building materials, NORMs, wastes, etc.).

The classification of such materials as radon sources requires a common criterion in order to take decisions. The real input of radon to the atmosphere from these materials, in each case, will be influenced by many parameters as their [226]Ra concentration, their size and dimensions, their humidity and porosity, etc. In fact, the radon radiological risk associated with such materials will be influenced by their exhalation rate, the ventilation rate and the occupation factor in each particular case. Due to this fact, it is not possible to classify these materials in function of the real radiological risk which they represent, although it is possible and necessary to consider their potential radiological risk. This potential risk can be quantified by means of the "radon potential", Ω, (Eq. 1), magnitude which we propose in this work and that represents the radon activity generated inside the material that can be transported across the material towards the surrounding atmosphere.

$$\Omega = \varepsilon C_{Ra} \ (Bq kg^{-1}) \tag{1}$$

being ε the emanation factor of the material and C_{Ra} its [226]Ra concentration.

In opposition to the exhalation rate, the radon potential is a characteristic of the material and it is not influenced by the experimental conditions in its determination. The radon potential appears then as a suitable magnitude for classifying/comparing porous materials in relation with its potential radon radiological risk

THEORETICAL FRAMEWORK

In order to calculate the radon concentration inside an accumulation chamber, it is necessary to consider two fundamental processes: the radon transport through the sample and the radon accumulation inside the chamber. These processes are coupled in the sample-air interface. The analytical solution of the resulting system of differential equations can be made under certain constrains: a) only diffusive and monodimensional transport, and b) homogeneous radio concentration and diffusion coefficient.

The temporal variation of the radon concentration in the chamber generated by a material introduced inside can be described by an exponential law. If the sample thickness is smaller than length diffusion, the free exhalation rate (E_0) can be written as follow:

$$E_0 = \lambda_{Rn}\,\Omega \cdot \rho \cdot z = \lambda_{Rn}\,\Omega\frac{m}{S} \tag{2}$$

where ρ is the density (kg m^{-3}), z the sample thickness (m), Ω is the radon potential (Bq kg^{-1}), m is the mass (kg) and S is the exhalation surface (m^2).

But in the first hours of accumulation in the chamber it is possible to observe that the evolution of the radon concentration follow a lineal growth, and from its slope the radon potential can be determined, (Eq. 3).

$$\Omega = \frac{\left(b + \lambda_{eff}\,C_{Rn}^0\right)}{\lambda_{Rn}}\,\frac{V_c}{m} \tag{3}$$

where $\lambda_{eff} = \lambda_{Rn} + \lambda_v + \lambda_b$ represents the effective time constant , being λ_{Rn} the radon decay constant (s^{-1}), λ_v the leakage constant and λ_b the bound exhalation constant (s^{-1}) which is determined theoretically.

The use of the lineal approximation will include a systematic deviation between lineal and exponential laws which can be corrected by means of the *slope correction factor* (*SCF*) (Eq.4), where b_0 represents the real slope at initial time and b_{fitted} represents the fitted slope to an accumulation time (t_0).

$$SCF = \frac{b_0}{b_{fitted}} = \frac{\lambda_{eff}\,t_0}{1 - e^{-\lambda_{eff}\,t_0}} \tag{4}$$

MATERIALS

Three chambers have been made in our laboratory. The A chamber has a volume of 0.6 L and it has been made with aluminum. In turn, the material of the chambers B and C is high density polyethylene and they have volumes of 60 L and 220 L respectively.

In order to measure the radon concentration inside the chambers has been employed a commercial radon monitor, Alphaguard PQ2000PRO.

RESULTS AND DISCUSION

The first step in order to use this method is to determine the chambers leakage constants. For to do these determinations, it is necessary to study in each chamber the natural decay of an initial radon concentration and to fit the data to an exponential law This experiments should be repeated at least five times in each chamber. The obtained values are shown in Table 1

Chamber	λ_v (s^{-1})
A	$(4.5 \pm 0.7) \cdot 10^{-6}$
B	$(3.70 \pm 0.19) \cdot 10^{-7}$
C	$(2.81 \pm 0.14) \cdot 10^{-7}$

TABLE 1. Leakage constant and the standard deviation to five replicates.

In the figure 1.a. it is shown the comparison between the theoretical SCF (Eq. 4) and the experimental SCF which has been calculated for different times of accumulation in the chamber A by introducing inside phosphate rock as material to be analyzed. It is possible to see the good agreement between the experimental and theoretical values. This experience allows the use of this theoretical factor in order to correct the fitted slope to a selected accumulation time.

In order to prove the lineal dependence between the free exhalation rate and the sample thickness (Eq. 2), one experiment was carried out in the C chamber. The figure 1.b shows the free exhalation rate for several sample thickness. The mentioned dependence is in good agreement with the prediction as it is possible to deduce through the obtained correlation factor ($r^2 = 0.9801$). The independent term has no statistical significance, showing that there is no systematic offset, as expected.
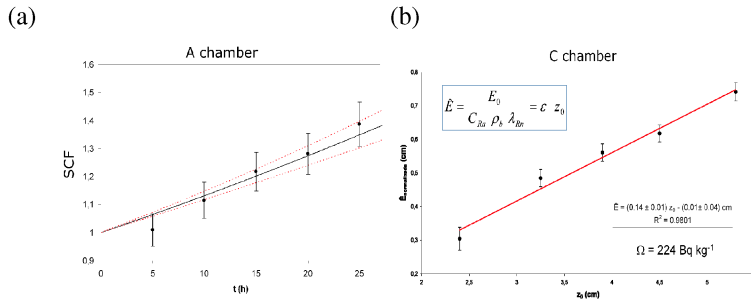
(a)   (b)

FIGURE 1. (a) Comparison between experimental and theoretical *SCF*.
(b) Variation of the exhalation rate with the sample thickness.

Table 2 shows the results of the reproducibility test which has been made in the determination of the "radon potential" of a sample of phosphate rock. This magnitude was measured ten times in each chamber. It can be seen that all the results agree within the statistical dispersion. This fact shows that the methodology is reproducible independently on the used chamber, and that small volume chambers produces higher precision in the results.

Finally, in Table 3 is shown the results obtained for the radon potential determined for different kind of materials when we work in normal operation mode.

TABLE 2. Radon potential determined for phosphate rock

Chamber	Ω (Bq kg^{-1})
A	227 ± 9
B	215 ± 13
C	222 ± 15

TABLE 3. Radon potential, radium concentration, emanation factor and minimum detectable radon potential with their standard deviations for different kind of materials. The number into brackets represents the number of analysed samples for each kind of materials.

Type	Ω (Bq kg^{-1})	C_{Ra} (Bq kg^{-1})	ε (%)	MΩD (Bq kg^{-1})
Huelva soils (10)	13 ± 1	32 ± 20	37 ± 11	3.0 ± 2.7
Chanary island soils(4)	12 ± 3	42 ± 16	29 ± 10	2.5 ± 1.0
PG cover material (9)	6 ± 3	22 ± 8	27 ± 7	2.9 ± 1.5
Phosphogypsum (15)	127 ± 29	656 ± 149	20 ± 4	8.9 ± 7.4
Phosphate rock (13)	227 ± 9	1600 ± 40	14 ± 1	9.7 ± 2.2
Uranium mining (3)	552 ± 404	5500 ± 3600	10 ± 2	9.2 ± 3.1
Building materials (10)	2.4 ± 1.3	*N.M.*	*N.M.*	2.1 ± 1.4

The materials arising from the uranium mining industry present an exposure risk five times higher than those generated in the production of phosphate fertilizers, which have in turn about thirty times higher values than typical soils. In contrast, the building materials from this zone have a radon potential similar to these soils.

CONCLUSION

A magnitude has been defined to express the potential ^{222}Rn radiological risk of the materials and a method to measure this magnitude with good precision has been presented. From the results it is possible to highlight that the proposed methodology is useful in order to compare the potential radiological risk due to the exposition to radon generated by different kind of materials.

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