REPORT RESULTS OF RADON DIFFUSION COEFFICIENT
(SAMPLES SYNTHESIA O-14015)

Laboratorio de Radiactividad Ambiental

Prof. Dr. Carlos Sainz Fernandez
Technical Director

CONTENTS

1.- INTRODUCTION

The interest for control of exposure to indoor radon in houses and workplaces presents a dual approach, both in the construction of new buildings in the prevention, as in existing, which is known as mitigation or remediation. Among the main strategies undertaken to reduce exposure to radon in dwellings are active soil depressurization, sealing surfaces in order to prevent access radon convection ventilation or living spaces, or water treatment when radon enters the home through this medium. To this goal it should be added one of the following treatments for prevention: passive soil depressurization, whose effectiveness depends on the optimization of aeration vent and ability to slightly depressurize the floor under housing, ventilation unoccupied spaces (air chambers between the land and housing) and the use of barriers or membranes between the building and the ground. In many cases, a combination of these actions provides the greatest reduction in radon concentration.

The choice of interventions for prevention or mitigation is often based on an analysis of cost-effectiveness. Prevention in new homes often better fulfill this relationship that mitigation in existing homes. In many countries, the use of waterproof membranes can reduce radon entry is considered a basic measure to protect buildings and their inhabitants, and is seen as the most interesting for new housing resource, because of its cost - effectiveness. The capacity to reduce the entry of radon in homes mainly depends on its chemical composition, mechanical properties, sealing joints and pipes and which are of sufficient durability.

When a hermetic barrier between the ground and the base of the housing is installed, convective transport is eventually disabled. Therefore, it is possible to assume that the rate of supply of radon indoors is influenced only by diffusion through the insulation. For these reasons, the protective properties of the membranes against the penetration of radon are usually expressed in terms of radon diffusion coefficient, which varies substantially with the chemical composition of the material, with values for water-impermeable materials and 10^{-15} 10^{-8} m^2 / s. The diffusion coefficient is a suitable parameter to characterize the effectiveness of the different barriers and their determination can be done by different methodological approaches.

2.- MATERIAL AND METHODS

2.1- Terms and definitions

- Diffusion length $l = \left(D/\lambda\right)^{1/2}$ where D is the diffusion coefficient of radon (m^2 / s) and λ is the decay constant of radon in s^{-1}.
- Exhalation rate $E = -D\frac{\partial C}{\partial x}$ expressed in units Bq m-2 s-1 where C is the concentration of radon in Bq m-3 and x is the distance from the exposed to radon in meters.
- Non stationary radon diffusion: Radon dependent diffusion time across the sample when the concentration of radon in it is variable and radon exhalation rate of the sample receiving container is also variable. It is described by Fick's law, which in the case of a radioactive gas such as radon can be expressed as:

$$\frac{\partial C}{\partial t} = D \cdot \frac{\partial^2 C}{\partial x^2} - \lambda \cdot C$$

Where t is the time in seconds and the rest of magnitudes are the same as those indicated in the above.

- Stationary radon diffusion: Radon Diffusion independent time through the sample. Is characterized by a distribution of independent radon time within the sample and therefore stable radon exhalation from the sample receiving container. Is described by the following equation

$$D \cdot \frac{\partial^2 C}{\partial x^2} - \lambda \cdot C = 0$$

- Decisive radon measurement is a measure of the temporal evolution of the concentrations of radon in the source and the receiving container used to calculate the diffusion coefficient of radon. Can be estimated, for membranes 1 mm thick and radon diffusion coefficient between 10-12 and 10-13, have a time to steady state of about 20 days.
- Radon permeability (m2 h-1) is the proportionality constant between the flux of radon from the surface of the sheet, the radon concentration difference on both sides of the barrier and the thickness thereof. It can be evaluated from the expression:

$$P = \frac{\lambda \beta d L}{\sinh\left(\frac{d}{L}\right)}$$

Where β is the coefficient of radon adsorption membrane material, d is the thickness thereof.

2.2.-Experimental set up

The experimental device used for determining the diffusion coefficient of various materials are based on placing the specimen between two characterize 2,5.10^{-2} m^3 airtight containers and the subsequent sealing of the joints to prevent foreign exchanges. Each container must be provided with a test area of 0.08 m2.

The primary container, which in this case corresponds to the lower chamber containing radon-emitting source capable of generating a high radon concentration throughout the duration of the measurement. Radon is transferred by diffusion through the membrane into the secondary container, which in this case is located at the top. Each container radon detector is placed continuously. Placing the detectors within the container has the advantages of eliminating the dependence of the measured potential of both the volumes of containers as on the location values of the detectors and avoid potential loss through transfer connections air measurement systems outside the chambers.

Analysis of equilibrium conditions is performed through a nonlinear fitting analysis conducted with statistical package Origin. The settings of this type provide insight essential characteristics of the measure are the equilibrium values in both chambers, the sealing of the containers and production of radon in the primary chamber in each case.

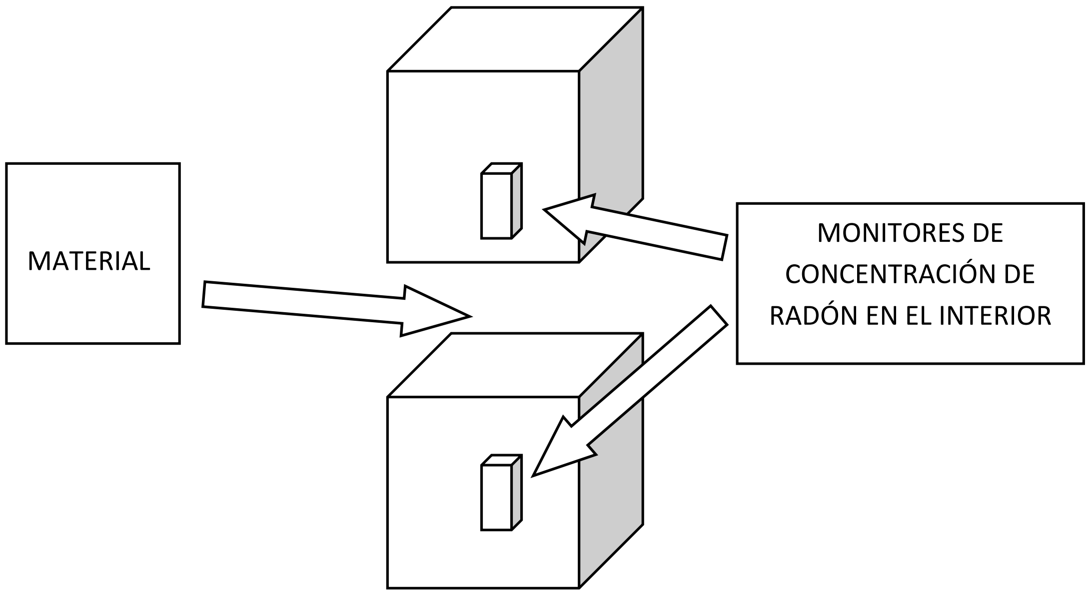


Figura 1: Experimental arrangement

Figura 2: Primary container full of radon source

In the laboratory are available from several sources controlled radon. On one hand, the ground are comprised of high 226Ra 238U and distributed over the surface of the base of the lower container, as shown in Figure 2. The production rate of ground radon depends and the total thickness thereof, having typical values of about 10 ± 2 kBq m^{-3} h^{-1}.

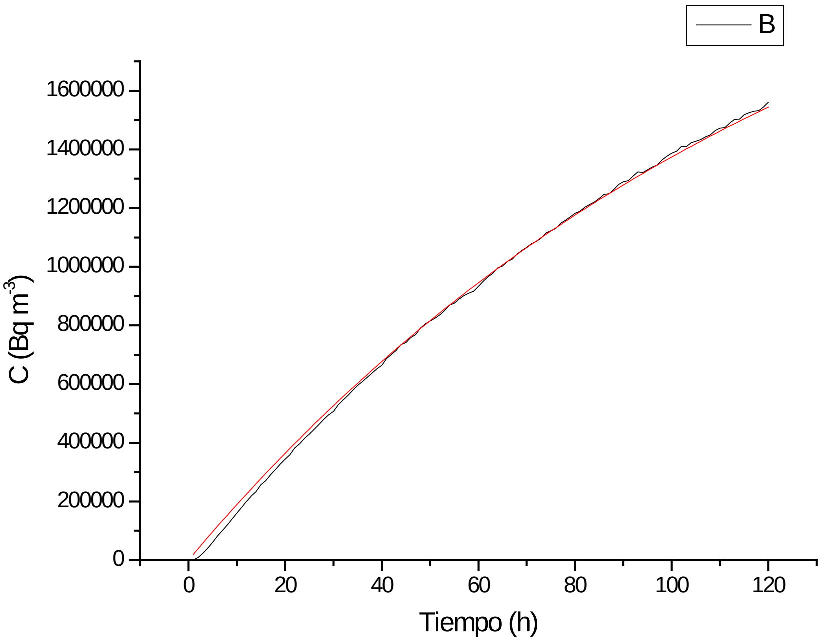


Figura 3: Radon production from source

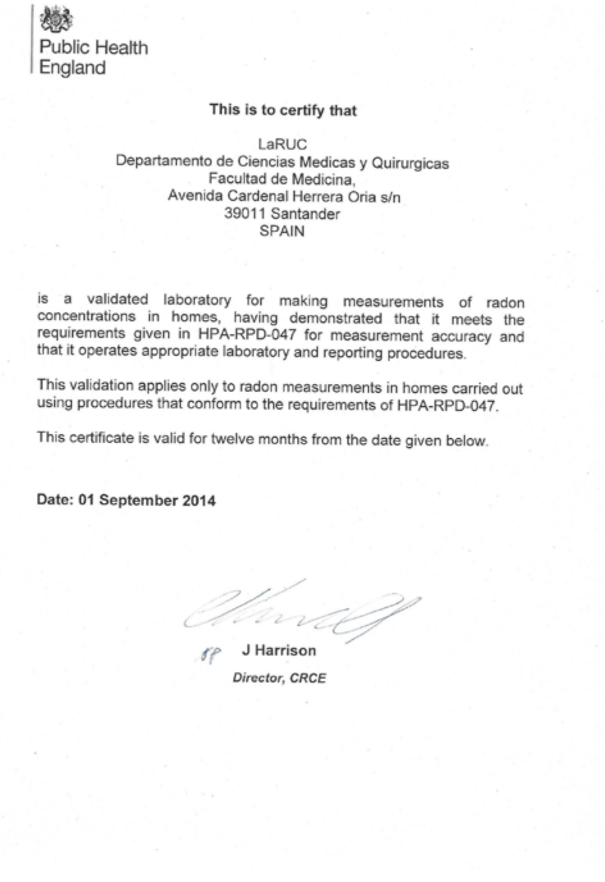
Radon monitors

With regard to radon detectors, several types of monitors continuously using different types of sensors including scintillation cells, ionization chambers or pulse current and silicon detectors solid state. All monitors contain processors that provide a summary report and often a record time, allowing recording temporal variations in the concentration of radon in the atmosphere studied.

The monitors used in the tests consist of a silicon detector capable of counting and sorting alpha particles from ^{222}Rn and their descendants airborne ^{218}Po and ^{214}Po accordance with their respective powers. The air inlet in the detector by diffusion. This tool also allows you to record the air temperature, relative humidity and barometric pressure. The maximum period during which you can record measurements is 3-4 months limited by the battery life, and the range of values between which the team works is 0-2 MBq / m^3, while the maximum error is located within the range of ± 5%.

3.- QUALITY ASSURANCE

The Environmental Radioactivity Laboratory of the University of Cantabria (LARUC) is certified ISO 9001: 2008 for different types of tests related to measures of environmental radioactivity and radon. Furthermore, it is not the only laboratory accredited by the English Public Health



Public Health England

This is to certify that

LaRUC
Departamento de Ciencias Medicas y Quirurgicas
Facultad de Medicina,
Avenida Cardenal Herrera Oria s/n
39011 Santander
SPAIN

is a validated laboratory for making measurements of radon concentrations in homes, having demonstrated that it meets the requirements given in HPA-RPD-047 for measurement accuracy and that it operates appropriate laboratory and reporting procedures.

This validation applies only to radon measurements in homes carried out using procedures that conform to the requirements of HPA-RPD-047.

This certificate is valid for twelve months from the date given below.

Date: 01 September 2014

J Harrison
Director, CRCE

UKAS MANAGEMENT SYSTEMS
012

Certificate Number
8363

Date of initial registration
24 May 2011

Date of last issue
24 May 2011

Date of expiry
23 May 2014

REGISTRATION CERTIFICATE

BM TRADA CERTIFICATION

BM TRADA certify that the Quality Management System of

Laboratorio de Radioactividad Ambiental - LARUC
Cardenal Herrera Oria s/n
39011 Santander
Cantabria
Spain

complies with the requirements of ISO 9001:2008

Scope of Certification

- Measurement of radon exhalation from soil, building materials and sediments
- Concentration of radon in air
- Activity alpha (α) and beta (β) total in drinking water and continental
- Activity emitting gamma (γ) by spectrometry and biological solid matrices.

Signed on behalf of BM TRADA Certification Ltd
Dr Peter Beele, Chief Operating Officer
Chiltern House, Stocking Lane, High Wycombe, Buckinghamshire, HP14 4ND

Further clarification regarding the scope of this certificate and verification of the certificate is available through BM TRADA at the above address or at www.bmtrada.com

This certificate remains the property of BM TRADA Certification Ltd. This certificate and all copies or reproductions of the certificate shall be returned or destroyed if requested by BM TRADA Certification Ltd

For multisite clients the scope of certification shown above includes processes/activities that are performed by the network of sites shown in Appendix A

England for measuring indoor radon.

4. RESULTS

4.1- DIFFUSION COEFFICIENTS

- **Customer Data**

  - **Entity: SYNTHESIA**
  - **Address: c / Industry 7-13 08120 La Llagosta, Barcelona, Spain**
  - **Contact: Roberto García Juez**
  - **Tel: 933253158**
  - **e-mail: rgarcia@synte.es**

- **Scope of the report**

This report aims to present the results of the determination of radon diffusion coefficient obtained in the laboratory of radioactivity from the University of Cantabria.

- **Samples under test**

On October 30, 2014 have received a total of 13 samples:

- Poliuretan Spray S-BRG/71 (3 X 3.5 cm + 3 x 10.5 cm)
- Poliuretan Spray S-BRG/30 (3 X 3.5 cm + 3 x 10.5 cm)
- Poliuretan Spray S-BRG/71 + Urelast P-500 (1 X 3 cm)

- **Test Method**

The method has been set out in the Methodology section of this Final Report

- **Regulations regarding this test**

The customer does not indicate any relation to this type of assay specific legislation.

- **Date of report**

  March 19, 2015

- **Obtained results**

The results contained in this report only affect incoming materials. The following tables contain the results of the measure expressing all values in m2s-1 units for the diffusion coefficient

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Santander (Tfno: 942202207)

Technical Director LaRUC Carlos Sainz Fernández

REFERENCIA: 12324

Rev_0

SYNTHESIA POLIURETAN SPRAY S-35RGB/ECO/D45 (3 cm)

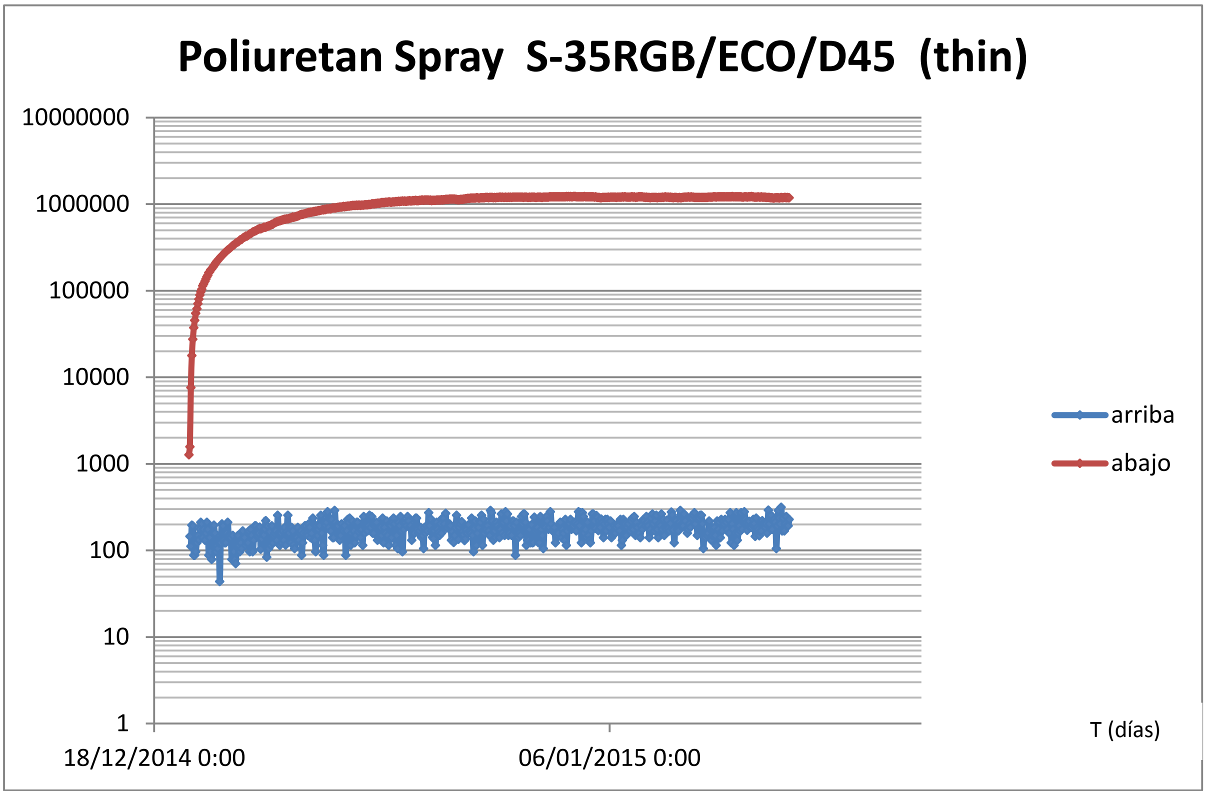
TEST PARAMETERS

Laboratory temperature: 19 ± 1 ºC

Equilibrium radon concentration primary chamber: 1191 ± 8 kBq m-3

Equilibrium radon concentration secondary camera: 215 ± 47 Bq m-3

Material tested thickness: 30 mm



TESTED MATERIAL	DIFFUSION COEFICIENT D(m^2s^{-1})	
	mean value	uncertainty
Poliuretan Spray S-35RGB/ECO/D45 (3 cm)	$1,4.10^{-10}$	$0,5.10^{-10}$

The measurement uncertainty is the error multiplied by the coefficient k = 2, which for a normal distribution corresponds to a coverage probability of approximately 95%

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SYNTHESIA POLIURETAN SPRAY S-35RGB/ECO/D45 (10 CM)

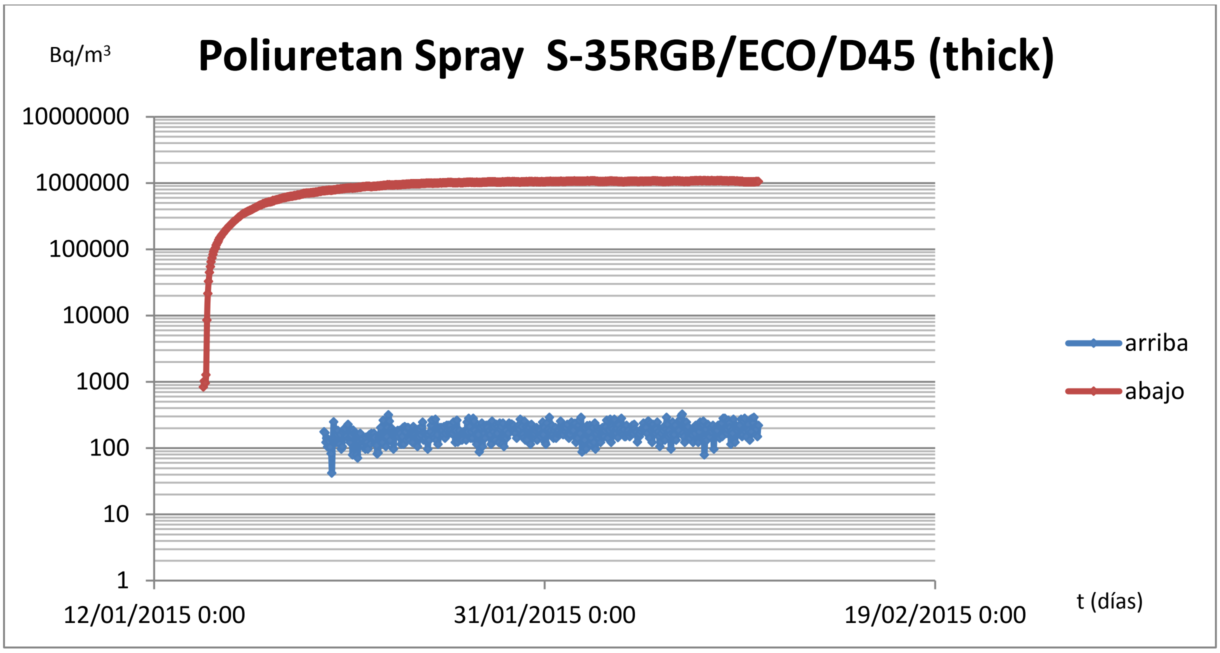
TEST PARAMETERS

Laboratory temperature: 22 ± 1 ºC

Equilibrium radon concentration primary chamber: 1050 ± 10 kBq m-3

Equilibrium radon concentration secondary chamber 206 ± 49 Bq m-3

Thickness tested Material: 110 mm



TESTED MATERIAL	DIFFUSION COEFICIENT D(m^2s^{-1})	
	mean value	uncertainty
Poliuretan Spray S-35RGB/ECO/D45 (10 cm)	$1,5.10^{-10}$	$0,5.10^{-10}$

The measurement uncertainty is the error multiplied by the coefficient k = 2, which for a normal distribution corresponds to a coverage probability of approximately 95%

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SYNTHESIA POLIURETAN SPRAY S-35RGB/ECO/D30 (3 CM)

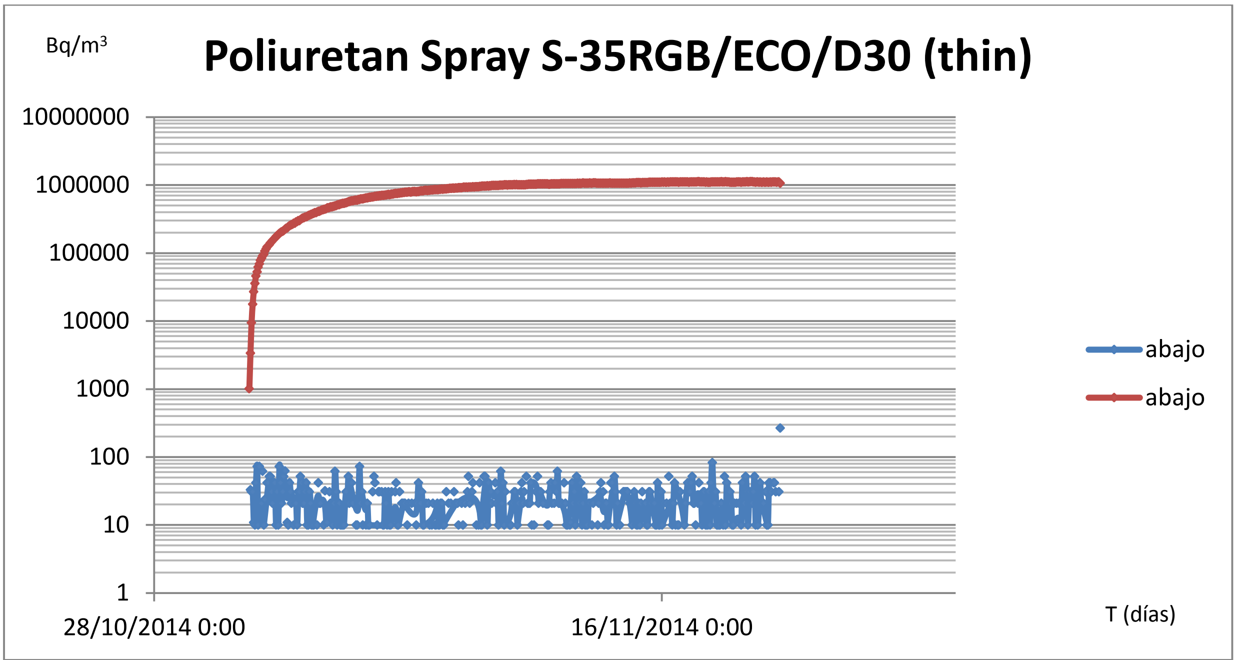
TEST PARAMETERS

Laboratory temperature: 21 ± 1 ºC

Equilibrium radon concentration primary chamber: 1111 ± 10 kBq m-3

Equilibrium radon concentration secondary chamber: 23 ± 16 Bq m-3

Material tested thickness: 30 mm



TESTED MATERIAL	DIFFUSION COEFICIENT D(m^2s^{-1})	
	mean value	uncertainty
Poliuretan Spray S-35RGB/ECO/D30 (3 cm)	$3.2.10^{-11}$	$1.2.10^{-11}$

The measurement uncertainty is the error multiplied by the coefficient k = 2, which for a normal distribution corresponds to a coverage probability of approximately 95%

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SYNTHESIA POLIURETAN SPRAY S-35RGB/ECO/D30 (10 CM)

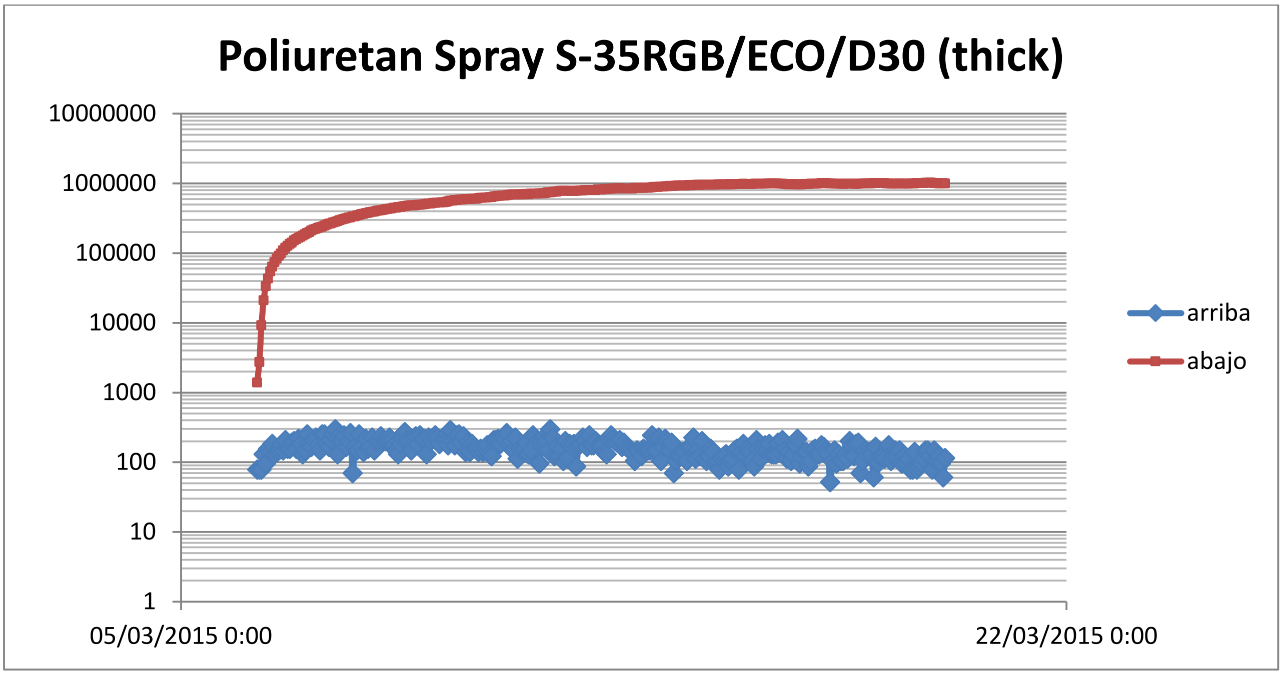
TEST PARAMETERS

Laboratory temperature: 20 ± 1 ºC

Equilibrium radon concentration primary chamber: 1008 ± 11 kBq m-3

Equilibrium radon concentration secondary camera: 111 ± 26 Bq m-3

Thickness tested Material: 110 mm



TESTED MATERIAL	DIFFUSION COEFICIENT D(m^2s^{-1})	
	mean value	uncertainty
Poliuretan Spray S-35RGB/ECO/D30 (10 cm)	$4.1.10^{-11}$	$1.5.10^{-11}$

The measurement uncertainty is the error multiplied by the coefficient k = 2, which for a normal distribution corresponds to a coverage probability of approximately 95%

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Rev_0

SYNTHESIA POLIURETAN SPRAY S-35RGB/ECO + URELAST P-500

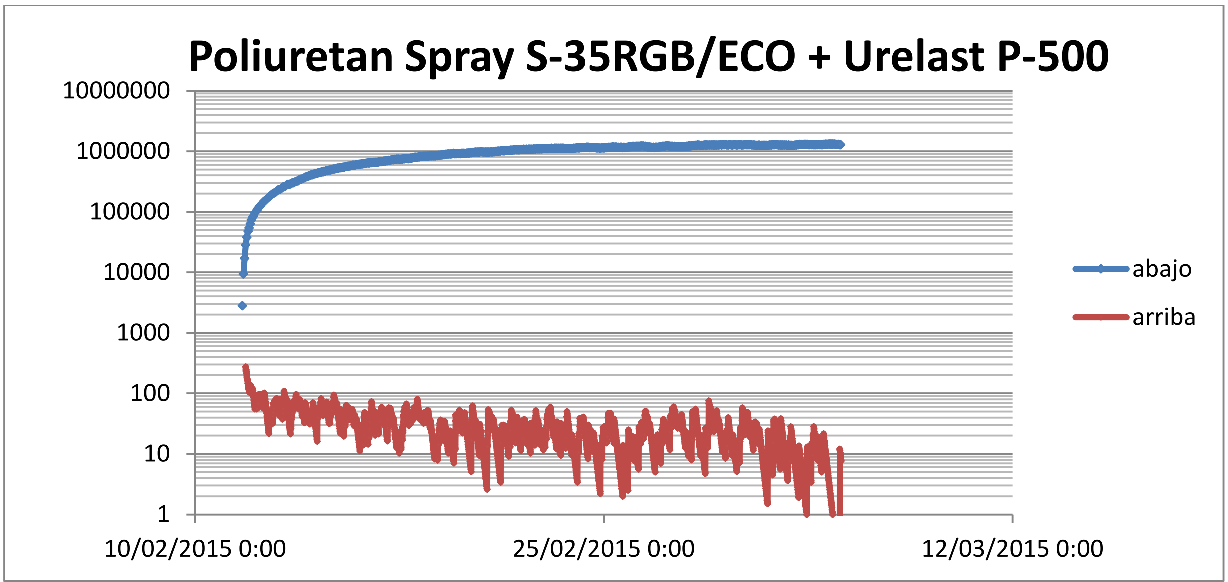
TEST PARAMETERS

Laboratory temperature: 21 ± 1 ºC

Equilibrium radon concentration primary chamber: 1302 ± 16 kBq m-3

Equilibrium radon concentration secondary camera: 8 ± 6 Bq m-3

Material tested thickness: 30 mm



TESTED MATERIAL	DIFFUSION COEFICIENT D(m^2s^{-1})	
	mean value	DL
Poliuretan Spray S-35RGB/ECO + Urelast P-500	< DL	$1.0.10^{-12}$

The detection limit (DL) corresponds to the experimental conditions used (source intensity, volumes, sample thickness, etc ...)

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4.2.- SUMMARY OF DIFUSSION COEFICIENTS

MATERIAL	DIFUSSION COEFICIENT (m^2 s^{-1})	L (mm)
Poliuretan Spray S-35RGB/ECO/D45 (3 cm)	$1{,}4.10^{-10}$	5.9 – 11.1
Poliuretan Spray S-35RGB/ECO/D45 (10 cm)	$1{,}5.10^{-10}$	6.0 – 11.2
Poliuretan Spray S-35RGB/ECO/D30 (3 cm)	$3.2.10^{-11}$	2.5 – 5.3
Poliuretan Spray S-35RGB/ECO/D30 (10 cm)	$4.1.10^{-11}$	2.7 – 6.1
Poliuretan Spray S-35RGB/ECO + Urelast P-500	< LD	0.3 - 1.0

The diffusion length range contains the error multiplied by the coefficient k = 2, which for a normal distribution corresponds to a coverage probability of approximately 95%

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5. RECOMMENDATIONS

• The three types of test materials have low diffusion coefficients

• As expected, the thickness does not significantly influence the diffusion coefficient being prepared samples with the same material.

• Facing the approval in other markets, any 3 materials have good barrier properties of radon, the most waterproof the **Poliuretan Spray S-35RGB/ECO/D30** and the combination **Poliuretan Spray S-BRG/71 + Urelast P-500**