J. health med. sci., 5(3):161-166, 2019.

Diagnosis and Remediation Measures for High Concentrations of Radon in Single-family House in Southern Spain

Diagnóstico y Medidas Correctoras para Altas Concentraciones de Radón en Viviendas Unifamiliares en el Sur de España

S. Cañete[1]; E. Gordo[1]; C. Iñiguez[2]; M. Pérez[3]; J. M. Pastor[3]; M. C. Dueñas[2] & R. Ruiz-Cruces[3]

CAÑETE, S.; GORDO, E.; IÑIGUEZ, C.; PÉREZ, M.; PASTOR, J. M.; DUEÑAS, M. C. & RUIZ-CRUCES, R. Diagnosis and remediation measures for high concentrations of radon in single-family house in southern Spain. *J. health med. sci., 5(3)*:161-166, 2019.

ABSTRACT: For years there has been an important concern and interest in the scientific community due to exposure to high levels of Rn inside homes, work centers and schools. This concern is spreading to the whole population and there are numerous references in press articles and media to this noble gas. It is well known that people who inhale high concentrations of radon have a higher risk of developing lung cancer, which is induced by the descendants of the inhaled gas. In this study, we present the most relevant data obtained in a single-family house in which the owners suspected of being subjected to high concentrations of radon. To carry out the study we used active systems, specifically 6 devices with diffusion chamber and silicon diode, Alpha E model of Saphimo and also an AlphaGuard 2000 Pro equipment. We also used passive systems using active carbon cartridges for measurements in gamma spectrometry equipment. The site of study was a house of 1550 m^2 distributed in two modules with two heights and basement conditioned as service housing. After an initial evaluation in the whole house, we detected high levels of radon in three rooms of the house, registering average values higher than 600 Bq m^{-3} in one of them, with a maximum value of 12535 Bq m^{-3} registered in an area not inhabited of the house. Corrective measures were carried out using waterproofing materials and forced extraction systems in the uninhabited area of the basement, reducing radon levels below 100 Bq m^{-3} as a mean value.

KEY WORDS: radon, diagnosis, remediation measures, house.

INTRODUCTION

The World Health Organization (WHO, 2009) qualifies radon as a carcinogenic agent of grade 1 (tested) and warns that the main risk derived from its inhalation is the appearance of lung cancer, being the responsible between the 3 and 14% of deaths due to lung cancer, since the radiation emitted by short-lived descendants is capable of altering the DNA of lung tissues. The dose of radiation due to radon is negligible compared to that provided by the short-lived descendants that adhere to the aerosols. The latest studies consider exposure to radon and its descendants as the second cause of development of this type of cancer after tobacco use. Therefore, the scientific and social interest in exposure to high concentrations of radon gas has increased exponentially in recent years (ICRP 126, 2014; Barbosa-Lorenzo *et al*., 2017; Ruano-Ravina *et al*., 2017). Evidence of this is the prominence acquired by radon control and measurement in Directive 2013/59 / EURATOM on Health Protection against Ionizing Radiation (EURATOM, 2014). It is important to highlight in this section what is included in articles 54, 74 and 103 of the aforementioned Directive, which must be transposed into the Spanish legal system in the month of February 2018.

[1] Research Support Central Services (SCAI), University of Malaga, Malaga, Spain.
[2] Department of Applied Physics I, Faculty of Sciences, University of Malaga, Malaga, Spain.
[3] Department of Radiology, Faculty of Medicine, University of Malaga, Malaga, Spain.

Article 74 states that member states will encourage the adoption of measures to identify those homes where the annual average of radon concentrations exceeds the reference level. They should also encourage the adoption of corrective measures to reduce such concentrations of radon in homes by technical resources or other types. Article 103 refers to the action plan for radon at the national level to address the long-term risks due to radon exposures in homes, public access buildings and workplaces for any radon entry route, either soil, building materials or water.

In Spain, the Nuclear Safety Council has carried out numerous studies on radon in homes (Martín, 2004). In order to facilitate the development of the national plan of action against radon, the CSN has carried out, in collaboration with several Spanish universities, the mapping of radon potential in Spain (CSN, 2017) that categorizes the areas of the national territory according to their radon levels and, in particular, identify those in which a significant percentage of residential buildings have concentrations above 300 Bqm^{-3}. However, in no case, the information provided by the maps should be considered as a substitute for direct measurements, which are the most reliable indicator of the risk to which each individual is exposed in his or her home or place of work. A clear example of this is found in this work.

Radon levels inside a house will be affected by numerous factors, including the geological nature of the soil on which it is built, the state of the rock and its degree of fracturing, permeability of the land, type of housing (buildings or single-family houses, plants above or below grade), construction materials used, level of ventilation and air exchange (conditioned by reaching high levels of energy efficiency that can cause radon levels to rise in houses that are too hermetic) and meteorological factors. (Righi & Bruzzi, 2006; Sainz *et al*., 2009; Vásquez *et al*., 2011).

The content of ^{226}Ra is higher in siliceous soils, which increases the probability of high levels of radon in houses built on this type of soil. Table I shows the average contents of ^{226}Ra (Bqm^{-3}) and the gamma dose rate (mRh^{-1}) for the various types of soils (CSN, 2017).

MATERIAL AND METHOD

This study was carried out during 9 months of 2016 in a single-family house in the province of Malaga, in the south of Spain, specifically in an area categorized as siliceous soils, although in the mapping of the radon potential high values of radon concentration would not be expected.

It is a detached house of 1550 m^2 on a plot of 3500 m^2, the house is distributed in two symmetrical wings with a ground floor, and two floors above ground distributed in east-west orientation. The owners, who have just acquired the home, want to assess the radiation levels in the property without specifying the possibility of high levels of radon because they were unaware of the existence of it. The first visit to the property consisted of a radiological characterization of the same. Different radiation and contamination monitors were used, which are detailed below:

· Radiation monitor, Berthold LB123 uMo with environmental radiation probe LB1236 H*10.
· Contamination monitor Berthold LB 124
· Equipment for measurement of ^{222}Rn by ionization chamber. Genitron, Alfaguard PQ2000 PRO.
· Radiation monitor, Genitron, MiniTRACE Gamma S10.

After studying the values obtained in the first measurement campaign, lasting 10 days, we distributed 6 devices with diffusion chamber with silicon diode, Alpha E model of Saphymo and AlphaGuard 2000 Pro equipment, and passive systems by means of active carbon cartridges for measurements in gamma spectrometry equipment throughout the house.

Alpha E devices, due to their small size and light weight, can be used to measure personal exposure to radon and, therefore, control the dose. Thanks to the semiconductor detector associated with the diffusion chamber, a very good sensitivity is obtained, 3 cph at 100 Bqm^{-3}, which makes it possible to measure radon levels below 100 Bqm^{-3}, WHO recommendation (12 % uncertainty, 1 sigma/24 h). By means of an equilibrium factor, which can be adjusted by the user, it is possible to calculate a dose value. Radon-222 enters in the measurement chamber by diffusion while the generated particles are retained by the membrane. The silicon diode inside the chamber detects the disintegration of Rn-222.

Figure 1 shows the devices used in this study. They are periodically verified and have been used in intercomparison campaigns with other laboratories (CSN, 2010).

The Alpha E equipment was distributed throughout the house for a period of 20 days with continuous recording with acquisition of a radon concentration value,

Fig. 1. Equipment used in the study.

interior temperature, interior pressure and indoor humidity every 30 minutes. At the same time, we installed a weather station in the garden area to record the following meteorological variables: temperature, atmospheric pressure, relative humidity, wind speed and direction, and rainfall.

Once identified that there were very high levels of radon, we set out to propose corrective measures to achieve acceptable levels of radon in areas that exceeded the values of 300 $mBqm^{-3}$. To that end, there are different options such as: sealing of cracks and joints, treatment of non-habitable lower rooms, improvement of the ventilation of the air chamber, improvement of the ventilation of the house, active ventilation under floor, depressurization of the ground and protection barrier. To choose one of the numerous methods available to reduce the high levels of radon inside a house we have to take into account many factors such as: the type of construction, the form of foundations and the land on which it is built among others (Righi, & Bruzzi; Vásquez *et al*.)

RESULTS

Following we present the most outstanding results of this study. As we indicated in the previous section, we made a first visit to the house to make a radiological characterization of the same, which included the use of radiometric techniques beyond the one that is the object of this work but that helped us to identify the problem. Through the use of radiation monitors we found that the dose rate levels were higher in one of the areas of the house than in the rest, specifically in the -1 floor, called the basement apartment, in the east wing of the house, where we recorded higher dose rate values than in the rest, specifically a value of 0.42 mSv/h versus a background value of 0.12 mSv/h. Once the Alpha E dosimeters were distributed in different dependencies, we obtained the following average values indicated in Table II.

It is important to highlight the high concentration values found in the basement apartment and in the basement bathroom, with a maximum value of more than 10000 Bqm^{-3}. Contrasting with the value recorded in the gym area that is located on floor -1 but on the opposite wing of the house. These values do not keep the coherence that we would expect, and we carried out an in-depth inspection of the house, finding that next to the area described as the basement apartment there was an area excavated in mother stone without any type of insulation with the wall adjoining the basement apartment. Beyond partition material without insulating sheet, this area is identified as "cave". The area of this cave is 90 m^2 with a height of 2 meters without outside ventilation and at a height of +0.9 m compared to the basement apartment, which is accessed through a small

Table I. Average values of ^{226}Ra ($Bqkg^{-1}$) and gamma dose rate for different geological zones.

	Siliceous soils	Clay soils	Limestone soils
^{226}Ra	72	39	37
Gamma dose rate (μRh^{-1})	> 14	< 4	< 4

Table II. Concentration of ^{222}Rn (Bqm^{-3}) in different units of the house.

Location	Apartment (Basement)	Bathroom (Basement)	Kitchen	Gym	Master Bedroom	Children's room
Arithmetic Mean	1584	940	104	188	57	97
Geometric Mean	1218	816	103	181	51	96
Standard Deviation	532	338	17	48	28	14
Minimum	145	103	75	60	10	75
Maximum	3545	3124	133	310	164	114

door that always remains closed. This area acted as an authentic radon chamber, reaching a maximum value of 12535 Bq/m^3 with an average of 2350 Bq/m^3.

In order to solve the identified problem we chose to perform two actions in this area of high concentration of radon: on the one hand install an insulating sheet against radon to cover and isolate the parameters common to the areas identified as basement apartment and basement bathroom and, for another, install a ventilation system with mechanical extraction with exit to the façade of the house, at ground level, in windward direction to prevent the entry of extracted air, with high concentration of radon, to the house.

The sheet used was POLIMAT ANTIRADON which is a polymer modified bitumen membrane made with an elastoplastomeric mixture (BPP) with a structure formed by a sheet of embossed aluminum joined to a black veil.

For the extraction, a SIBER system was selected, specifically the AXC TP120 model with a power of 60W and a flow rate of 270 m^{3}h^{-1} with a low noise level < 38 dB (a). Table III shows the values registered in a period of 60 days after the intervention in the area called "cave"

Figure 2 shows the evolution of radon levels (Bq/m^3) in the "cave" and in the basement apartment after the correction measures adopted.

DISCUSSION

Following, we present the most outstanding conclusions of this study. A first visit to the house gave us a radiological characterization of the same, which included the use of radiometric techniques beyond the one that is the object of this work but that helped us to identify the problem. Contrasting with the value recorded in the gym area that was located on floor -1 but on the opposite wing of the house. These values do not keep the coherence that we would expect, and we carried out an in-depth inspection of the house, finding that next to the area described as the basement apartment there was an area excavated in mother stone without any type of insulation with the wall adjoining the basement

Table III. Concentration of ^{222}Rn (Bqm^{-3}) in different rooms of the house after the intervention.

Location	Cave (Basement)	Apartment (Basement)	Bathroom (Basement)	Kitchen	Gym	Master Bedroom	Children's room
Arithmetic Mean	351	148	156	99	75	55	75
Geometric Mean	368	153	135	103	56	45	58
Standard Deviation	180	115	130	16	44	30	46
Minimum	37	32	38	30	40	30	45
Maximum	876	408	346	124	260	144	184

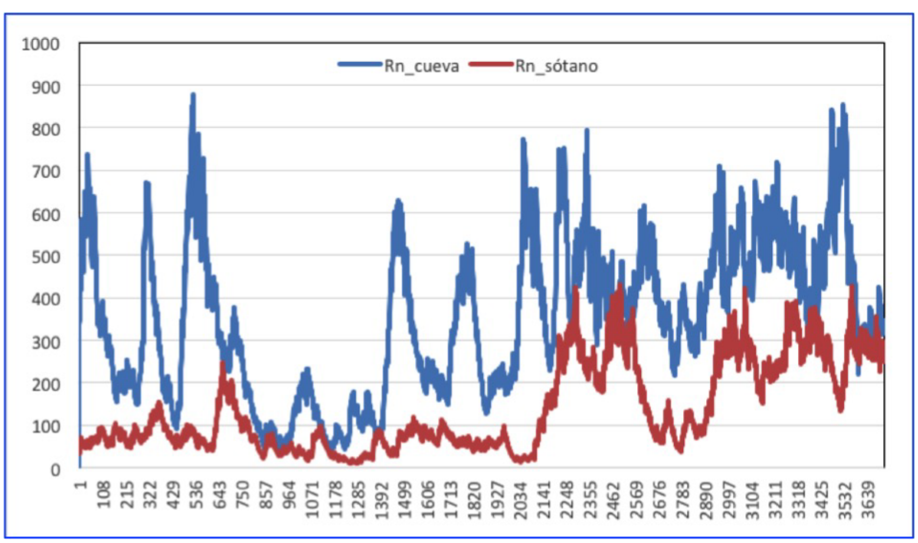

Fig. 2. Evolution of radon concentrations (Bqm^{-3}) after the intervention.

apartment. Beyond partition material without insulating sheet, this area was identified as "cave". The area of this cave was 90 m^2 with a height of 2 meters without outside ventilation and at a height of +0.9 m compared to the basement apartment, which was accessed through a small door that always remains closed. This area acted as an authentic radon chamber.

In order to solve the identified problem we chose to perform two actions in this area of high concentration of radon: on the one hand install an insulating sheet against radon to cover and isolate the parameters common to the areas identified as basement apartment and basement bathroom and, for another, install a ventilation system with mechanical extraction with exit to the façade of the house, at ground level, in windward direction to prevent the entry of extracted air, with high concentration of radon, to the house.

The sheet used was POLIMAT ANTIRADON which is a polymer modified bitumen membrane made with an elastoplastomeric mixture (BPP) with a structure formed by a sheet of embossed aluminum joined to a black veil.

For the extraction, a SIBER system was selected, specifically the AXC TP120 model with a power of 60W and a flow rate of 270 m^3h^{-1} with a low noise level < 38 dB (a)

This study has shown that the information provided by radon potential maps is very important but should not be considered as a substitute for direct measurements, which are the most reliable indicator of the risk to which each individual is exposed in their home or place of work. The distribution of the zones was carried out using the 90th percentile (P90) of the distribution of radon concentrations as a level greater than 90% confidence. The values obtained are represented grouped by ranges in the radon potential map (CSN, 2017).

Figure 3 shows the cartography of the radon potential of Spain (CNS, 2017) in which the study area is categorized as a low risk area. It is necessary to carry out more measures to provide feedback on radon potential mapping with massive measures of housing measures to delimit the mesh of the cartography and be able to identify more precisely the risk areas.

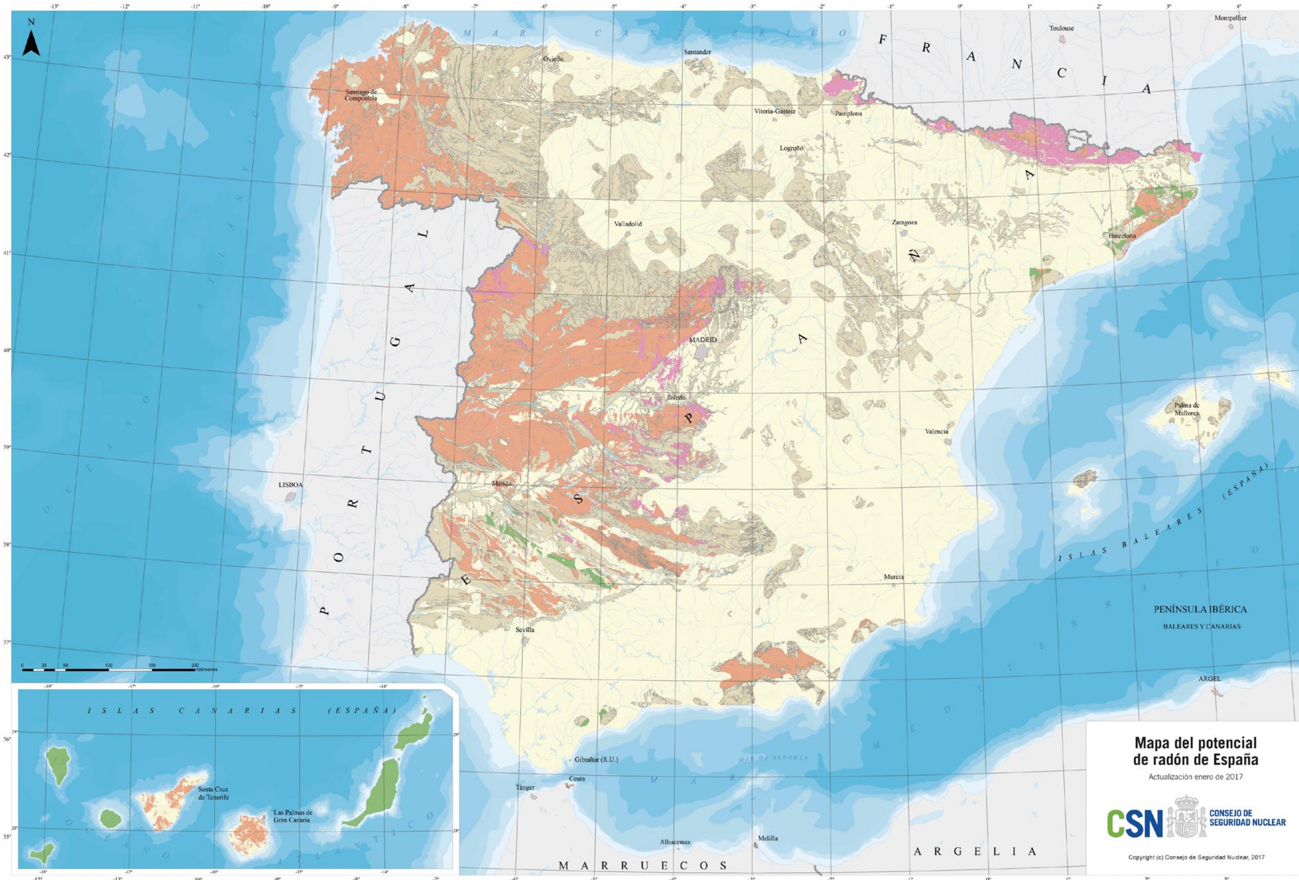

Fig. 3. Cartography of radon potential in Spain. Figure taken from CSN (2017).

The availability of direct measurement equipment using a silicon diode diffusion chamber, as well as the equipment used in this study (Saphimo's Alpha_E model), are essential to be able to make fast and reliable determinations with real-time recording of the evolution of the concentration of radon and thus facilitate the adoption of remedial measures.

Through the use of waterproofing sheets and extraction systems, reductions of radon concentrations greater than 90% are achieved at a low economic cost.

CAÑETE, S.; GORDO, E.; IÑIGUEZ, C.; PÉREZ, M.; PASTOR, J. M.; DUEÑAS, M. C. & RUIZ-CRUCES, R. Diagnóstico y medidas correctoras para altas concentraciones de radón en viviendas unifamiliares en el sur de España. *J. health med. sci., 5(3)*:161-166, 2019.

RESUMEN: Durante años, la comunidad científica ha tenido interés y preocupación por los altos niveles de exposición de Rn dentro de los hogares, centros de trabajo y escuelas. Esta inquietud se ha propagado entre la población y se han hecho numerosas referencias a este gas noble en artículos de prensa y otros medios. Es bien sabido que aquellas personas que inhalan altas concentraciones de radón tienen mayores riesgos de contraer cáncer pulmonar, inducido por los descendientes del gas inhalado. En este estudio presentamos la información más relevante obtenida de una vivienda unifamiliar en la que se cree que los habitantes han sido expuestos a altas concentraciones de radón. Para llevar a cabo este estudio utilizamos sistemas activos, específicamente 6 dispositivos con cámara de difusión y con diodos de silicio, modelo Alpha E de Saphimo además de un equipo profesional Alphaguard 2000. También se utilizaron sistemas pasivos utilizando cartuchos de carbón activo para mediciones en equipos de espectrometría gamma. El lugar de estudio era una casa de 1550 m^2 distribuida en dos módulos de diferentes alturas y un sótano acondicionado como servicio de alojamiento. Después de una evaluación inicial en toda la casa, detectamos altos niveles de radón en 3 de sus habitaciones, una de ellas registraba un valor promedio mayor a los 600 Bq m^{-3} y con un valor máximo de 12535 Bq m^{-3} en un área no habitada de la casa. En la zona inhabitada del sótano se llevaron a cabo acciones correctivas utilizando materiales a prueba de agua y sistemas de extracción forzada, reduciendo los niveles de radón a menos de 100 Bq m^{-3} como valor medio.

PALABLAS CLAVE: radón, diagnóstico, medidas de remediación, vivienda.

REFERENCES

Consejo de Seguridad Nuclear (CSN). Guía de Seguridad 11.01. Directrices sobre la competencia de los laboratorios y servicios de medida de radón en aire. Consejo de Seguridad Nuclear, 2010. Disponible en: http://piramidenormativa.sne.es/Repositorio/CSN/gs-11.01.pdf.

Consejo de Seguridad Nuclear (CSN). Cartografía del potencial de radón de España. Consejo de Seguridad Nuclear, 2017. Disponible en: https://www.csn.es/mapa-del-potencial-de-radon-en-espana.

Comunidad Europea de la Energía Atómica (EURATOM). Directiva 2013/59/EURATOM del consejo, de 5 de diciembre de 2013, por la que se establecen normas de seguridad básicas para la protección contra los peligros derivados de la exposición a radiaciones ionizantes, y se derogan las Directivas 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom y 2003/122/Euratom. Diario Oficial de la Unión Europea. Diario Oficial de la Unión Europea, L 13:1-73, 2014. Disponible en: https://www.boe.es/doue/2014/013/L00001-00073.pdf.

Barbosa-Lorenzo, R.; Ruano-Ravina, A: Cerdeira-Caramés, S: Raíces-Aldrey, M. & Barros-Dios, J. M. Residential radon and lung cancer: a cohort study in Galicia, Spain. Cad. Saude Publica, 33(6):e00189415, 2017.

World Health Organization (WHO). WHO Handbook on Indoor Radon: A Public Health Perspective. World Health Organization, 2009. Disponible en: https://apps.who.int/iris/bitstream/handle/10665/44149/9789241547673_eng.pdf;jsessionid=A34D75409C56B055B518E3E8A63B09FD?sequence=1

International Commission on Radiological Protection (ICRP 126). Radiological Protection against Radon Exposure. ICRP Publication 126. *Ann. ICRP, 43(3)*, 2014. Disponible en: https://journals.sagepub.com/doi/pdf/10.1177/ANIB_43_3.

Martín, M. J. L. Concentraciones de radón en viviendas españolas. Otros estudios de radiación natural. Colección Informes Técnicos. Madrid, Consejo de Seguridad Nuclear, 2004. Disponible en: https://www.csn.es/documents/10182/27786/INT-04-09%20Concentraciones%20de%20rad%C3%B3n%20en%20viviendas%20e spa%C3%B1olas.%20Otros%20estudios%20de%20radiaci%C3%B3n%20natural.

Righi, S. & Bruzzi L. Natural radioactivity and radon exhalation in building materials used in Italian dwellings. *J. Environ. Radioact., 88(2)*:158-70, 2006.

Ruano-Ravina, A.; Fernández-Villar, A. & Barrios-Dios, J. Residential Radon and Risk of Lung Cancer in Never-Smokers. *Arch. Bronconeumol., 53(9)*:475-6, 2017.

Sainz, C.; Dinu, A.; Dicu, T.; Szacsvai, K.; Cosma, C. & Quindós, L. S. Comparative risk assessment of residential radon exposures in two radon-prone areas, Stei (Romania) and Torrelodones (Spain). *Sci. Total Environ., 407(15)*:4452-60, 2009.

Vázquez, B. F.; Adán, M. O.; Quindós Poncela, L. S.; Fernández, C. S. & Merino I.F. Experimental study of effectiveness of four radon mitigation solutions, based on underground depressurization, tested in prototype housing built in a high radon area in Spain. *J. Environ. Radioact., 102(4)*:378-85, 2011.

Corresponding author:
Rafael Ruiz Cruces
Faculty of Medicine
Medical Health Research Center
University of Málaga
Málaga
SPAIN

E.mail: rrcmf@uma.es

Received: 28-06-2018
Accepted: 06-02-2019