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Original

Indoor radon in Spanish workplaces. A pilot study before the introduction of the European Directive 2013/59/Euratom

Alberto Ruano-Ravina[a,b,c,*], Claudia Narocki[d], María José López-Jacob[d], Ana García Oliver[e], María de la Cruz Calle Tierno[e], Joaquín Peón-González[a,c], Juan Miguel Barros-Dios[a,b,c,f]

[a] Department of Preventive Medicine and Public Health, University of Santiago de Compostela, Santiago de Compostela (La Coruña), Spain
[b] CIBER de Epidemiología y Salud Pública (CIBERESP), Spain
[c] Galician Radon Laboratory, University of Santiago de Compostela, Santiago de Compostela (La Coruña), Spain
[d] Instituto Sindical de Trabajo, Ambiente y Salud (ISTAS), Comisiones Obreras, Madrid, Spain
[e] Secretaría de Salud Laboral, Comisiones Obreras, Madrid, Spain
[f] Service of Preventive Medicine, University Hospital of Santiago de Compostela, Santiago de Compostela (La Coruña), Spain

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A B S T R A C T

Objective: To explore whether there is a possible problem regarding indoor radon concentration surpassing the new European Directive 2013/59/Euratom threshold in Spanish workplaces. We also aim to find out whether radon concentration might be associated with certain characteristics of workplaces.
Method: We performed a cross-sectional study to measure indoor radon concentrations in Spanish workplaces including five different sectors (education, public administration, the health sector, the tourist sector and the private sector). To be measured, the workplace should be occupied permanently by at least one worker. Alpha-track type radon detectors were placed for at least three months and read at the Galician Radon Laboratory at the University of Santiago de Compostela. A descriptive analysis was performed on radon distribution by sector, building characteristics and number of workers affected.
Results: We faced enormous difficulties in finding volunteers for this study. Galicia and Madrid had the highest number of measurements. Of a total of 248 measurements, 27% had concentrations above 300 Bq/m^3. Median radon concentration was 251 Bq/m^3 in Galicia, followed by Madrid, with 61.5 Bq/m^3. Forty-six percent of the workplaces measured in Galicia had radon concentrations higher than 300 Bq/m^3 followed by 10.6% in Madrid. Nineteen percent of all workers were exposed to more than 300 Bq/m^3 and 6.3% were exposed to radon concentrations higher than 500 Bq/m^3.
Conclusion: Indoor radon exposure might be a relevant problem in Spanish workplaces and the number of affected workers could be high. The prevalence of workers exposed to high radon concentrations probably depends on the geographical area.

Radón interior en puestos de trabajo en España. Un estudio piloto antes de la introducción de la Directiva Europea 2013/59/Euratom

Palabras clave:
Radón
Cáncer de pulmón
Estudio transversal
Lugar de trabajo
España

R E S U M E N

Objetivo: Explorar si podría existir un problema en cuanto a la concentración de radón en los puestos de trabajo en España por superación del umbral propuesto por la nueva Directiva Europea 2013/59/Euratom. También se pretende conocer si la concentración de radón puede estar asociada a las características de los puestos de trabajo.
Método: Estudio transversal en seis regiones y diferentes sectores (educación, administración pública, sanitario, turístico y privado). El puesto de trabajo medido debía ser ocupado de manera permanente por al menos un trabajador. Los detectores de radón de tipo *alfa-track* estuvieron colocados al menos 3 meses y fueron revelados en el Laboratorio de Radón de Galicia, de la Universidad de Santiago de Compostela. Se realizó un análisis descriptivo de la concentración de radón por sector, por características de los edificios y por número de trabajadores afectados.
Resultados: Hubo dificultades para encontrar voluntarios para este estudio. Galicia y Madrid tuvieron el mayor número de mediciones. Se midieron 248 lugares de trabajo, con el 27% por encima de los 300 Bq/m^3. La concentración mediana fue de 251 Bq/m^3 en Galicia, seguida de Madrid con 61,5 Bq/m^3. El 46% de los puestos de trabajo en Galicia tenían concentraciones mayores de 300 Bq/m^3, y el 10,6% en Madrid. El 19% de los trabajadores estuvieron expuestos a más de 300 Bq/m^3 y el 6,3% a más de 500 Bq/m^3.

* Corresponding author.
E-mail address: alberto.ruano@usc.es (A. Ruano-Ravina).

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Conclusión: La exposición a radón podría ser un problema de salud relevante en los lugares de trabajo en España. El número de trabajadores expuestos parece elevado. La prevalencia de trabajadores afectados depende del área geográfica.

Introduction

Radon was declared a human carcinogen by the International Agency for Research on Cancer in 1988 and by the US Environmental Protection Agency in 1987.[1,2] Radon comes from the disintegration of Uranium 238, which is present in the rocks of the earth crust. It is an odourless, tasteless and colourless gas and it tends to accumulate indoors, particularly in areas where Uranium is present in high concentrations in rocks beneath closed spaces. There are various isotopes of radon and the most frequent and relevant from an epidemiological point of view is Radon-222. Its half-life is 3.8 days and therefore it is not risky by itself. The true risk is due to its short-life descendants Polonium-218 and Polonium-214. When they decay into other elements they release ionizing radiation in the form of alpha particles. Indoor radon exposure is the main source of ionizing radiation a human being will receive in lifetime.

In 2005, a pooling study on residential radon and lung cancer including 21,000 participants from 13 case-control studies[3] observed a linear and statistically significant association between residential radon and lung cancer, with lung cancer risk increasing by a 16% for each 100 Bq/m^3. Studies performed in Spain have also found an increased risk of lung cancer for residential radon exposure, both for ever[4,5] and never smokers,[6] and also a strong interaction between radon and tobacco consumption.[4,5]

In 2009, the World Health Organization (WHO) published a report establishing a recommended action level for residential radon of 100 Bq/m^3, with 300 Bq/m^3 as a radon concentration not to be surpassed in any case.[7] Indoor radon exposure may be high in dwellings, but also in workplaces. A Spanish by-law published in 2012 points out which workplaces have to measure indoor radon, i.e. underground workplaces and those workplaces settled in areas identified as radon-prone areas by the Nuclear Safety Council,[8] besides specific industries. In 2014, the European Union enacted a directive establishing 300 Bq/m^3 as a concentration threshold for both dwellings and workplaces. This directive should be enforced in February 2018 in all European Union countries.[9]

Despite these mandatory by-laws and scientific evidence, the available studies in Spanish (and European) workplaces are still scarce. They include mainly touristic caves and are usually limited to one region.[10,11] It is not known in detail which are the sectors or workplaces which may pose the highest indoor radon concentrations, and therefore have a higher potential of lung cancer risk. Given the lack of knowledge of radon concentrations in occupations not considered a priori to pose a radon-risk, we decided to measure radon exposure in such occupations.

The objective of this pilot study was to explore if there is a problem regarding indoor radon concentration in Spanish workplaces from different work sectors and describe if indoor radon may be associated with particular characteristics of those workplaces.

Methods

Design and setting

We designed a cross-sectional study where we selected workplaces located in six Spanish regions (Galicia, Castilla y León, Comunidad de Madrid, Baleares, Cataluña and Castilla-La Mancha). The sectors initially selected for measurements were education, healthcare, public transportation with underground premises, and touristic venues (hotels and spas) (Table 1). The total number of measurements, due to funding constraints, was limited to 250, so the number of workplaces was to be smaller as some workplaces had more than one measurement. We aimed to have workplaces in areas located at high, medium and low expected radon concentrations according to the theoretical radon exposure proposed by the Nuclear Safety Council in their province maps.[12] The study grant was awarded in 2015 and radon measurements took place between 2016 and 2017.

Contact with employers, selection of workplaces and information retrieved

Our initial strategy consisted in contacting with prevention services and responsibles from public institutions and private sector. A workplace was included for measurement only if we had permission to measure radon. In order to encourage participation, we prepared leaflets mentioning that the study was free of charge and absolutely confidential. The team presented the project and its objectives personally or through email or phone. Some companies were contacted through their prevention delegates with the help of regional federations of the union labour "Comisiones Obreras".

Once the recruitment of companies and administration started, we had to modify part of our strategy due to difficulties in recruiting premises or public institutions interested in taking part in the study. So, we proceeded to enlarge the recruitment criteria (including approximately 100 additional workplace measurements) in the following way: a) additional measurements were added to the sample from the hospitality sector in locations outside our first designed setting, as an industry group interested in taking part of the study asked for those measurements; b) we also collected measurements from office premises belonging to companies in any productive sector; and finally c) we used some measurements in workplaces made by the Galician Radon Laboratory in Galicia.

Radon devices were preferentially placed in ground floors and in cellars if those were used as a usual workplace for at least one worker. If the building had more floors, a radon device was placed if the number of workers upstairs was relevant (i.e. some education centres). In some cases, we also measured upper floors because responsibles were interested in having results there. To measure a workplace, a worker should be there during at least a 70% of the time of his/her daily work time.

For each measurement place, we collected relevant information such as floor of the building, presence of elevators, number of floors underneath, air conditioning, measurement period, and so on. A results letter with tailored recommendations based on radon results was sent confidentially to people previously designated in charge of the workplaces.

Indoor radon measurements

We used alpha-track radon devices, which are the most reliable for measuring radon exposure, as recommended by WHO[7] and the Nuclear Safety Council of Spain. Radon devices were placed

Table 1
Radon concentration brown down by work sector.

Work sector	Number of radon measurements (%)	Median concentration (Bq/m^3)	Radon measurements above 300 Bq/m^3, %
Tourist	29 (11.7)	47	6.9
Education	62 (25.0)	109	22.6
Public administration	107 (43.1)	60	23.5
Health	17 (6.9)	176	37.4
Others/private sector	22 (8.9)	129	22.7
Unknown	11 (4.4)	91	0
Total	248 (100.0)	129.5	27.4

Table 2
Radon concentration broken down by radon-prone area classification of Spanish Municipalities (based on the Nuclear Safety Council maps).

Radon-prone area	Number of radon measurements (%)[a]	Median concentration (Bq/m^3)	Radon measurements above 300 Bq/m^3, %
Low	56 (23.0)	80	7.1
Medium	125 (51.2)	210	44.8
High	63 (25.8)	126	9.5
Total	244 (100.0)	129.5	27.4

[a] For four radon measurements the municipality of placement could not be determined.

following the recommendations of the Nuclear Safety Council and WHO.[7,13] We have also demonstrated that alpha-track devices are more reliable than canister devices in a comparison study.[14] Alpha-track devices were placed for three months and afterwards were sent to the Galician Radon Laboratory where they were read. This Lab has measured more than 7000 radon devices, including dwellings and workplaces and uses high quality standards, including intercomparison exercises with excellent results.[15,16]

Statistical analysis

A descriptive analysis was performed using SPSS v20. Radon concentration was analysed broken down by geographic location, floor of the measurement, employment sector and building materials. We calculated p-values where convenient and statistical significance was considered when p-value was <0.05. Municipalities were classified according to the Nuclear Safety Council classification into low, medium or high radon potential.[12]

Results

The return rate of the detectors was 97% and we present the results of 248 radon measurements placed in six Autonomous Communities. The region with the highest number of radon devices was Galicia (51%), followed by Madrid (41.6%).

Median radon concentration was 123.5 Bq/m^3 (interquartilic range: 59-345 Bq/m^3), with a range of 16-3.039 Bq/m^3. Of all radon measurements, 27% (n = 67) were above 300 Bq/m^3, which is the radon threshold admitted by the new European Directive. Median radon concentration was 251 Bq/m^3 in Galicia (n = 126), followed by Madrid with 61.5 Bq/m^3 (n = 103). Of the workplaces measured in Galicia, 46% had radon concentrations higher than 300 Bq/m^3 (n = 58), followed by 10.6% in Madrid (n = 11).

A total of 640 workers had radon concentrations measured at the workplace. 19% were exposed to radon concentrations higher than 300 Bq/m^3 and 6.3% were exposed to radon concentrations higher than 500 Bq/m^3. Of workplaces, 89% were occupied 5 days per week. Mean time of personnel at workplace per day was 8.4 hours.

Radon distribution by sectors

Table 1 shows the number of measurements by sector and indoor radon characteristics. It can be observed that health sector is the one with the highest radon concentration, followed by public administration. The tourist sector is the one with the lowest radon concentrations. If we analyse these results by region, Galicia has the highest indoor radon concentrations in all sectors (data not shown).

Table 3
Radon concentration and floor of the workplace measured.

Floor[a]	Median concentration	Radon measurements above 300 Bq/m^3, %
Cellar-2 (n = 2)	125	0
Cellar-1 (n = 53)	151	28.3
Ground floor (n = 85)	91	23.5
First floor (n = 12)	405	75.0
Second floor (n = 8)	393.5	75.0
Third floor (n = 6)	362	66.6

[a] 82 measurements had this information missing.

Results by municipality

The number of radon measurements in municipalities classified by the Nuclear Safety Council regarding their radon potential classified as low, medium or high were 56, 126 and 63, respectively with their median radon concentrations being 80, 210 and 126 Bq/m^3. Measurements above 300 Bq/m^3 were 7.1% (n = 4), 44.8% (n = 56) and 9.5% (n = 6) following the radon potential ranking based on the Nuclear Safety Council classification (Table 2).

Construction materials and other characteristics of radon distribution

Radon concentration varied with the floor where it was measured (Table 3). It can be observed that radon concentration seems to increase with the height, reaching a maximum concentration in the first floor, where 75% of all measurements surpassed 300 Bq/m^3 (n = 12).

We observed differences in radon concentration regarding the inner construction materials employed in the buildings. Figure 1 shows a description of radon concentration regarding construction materials. If the building is built exclusively with inner brick walls, median radon concentration was 92 Bq/m^3 (n = 139), compared to 379 Bq/m^3 when stone was the inner construction material (n = 89) and 60 Bq/m^3 when the inner walls were made of other material (n = 14). Workplaces built only with brick had a radon concentration of 101 Bq/m^3 (n = 101), compared to 340 Bq/m^3 for stone buildings (n = 4).

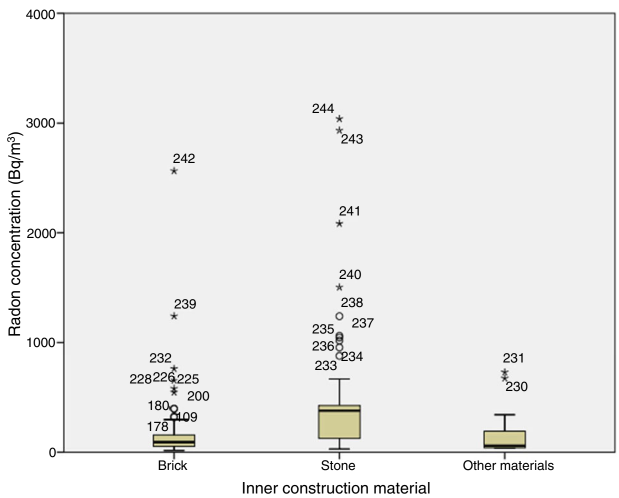

Figure 1. Radon concentration broken down by inner construction building. Stars and circles mean radon concentrations out of range-outliers.

Discussion

This study has shown that indoor radon might be a relevant problem in occupational settings, particularly in those located in radon-prone areas. It is also important to mention that high concentrations of indoor radon may be found also in workplaces settled in regions which are not characterized as radon-prone areas. Though this is a pilot study, it is the most relevant research of its kind performed in Spain. It is important to mention that studies such as the present one, which are focused in workplaces not usually classified as "high radon exposure", provide very useful evidence on prevention practices, and that an integral approach to radon risk assessment should be enforced in Spain, particularly when Spain does not have a National Radon Plan.

Indoor radon is a recognized human carcinogen but available studies analysing its concentrations in occupational settings are still scarce and have been mainly focused in workplaces where it is expected to find high concentrations such as touristic caves, old buildings, mines, cellars and so on.[11,17,18] Though radon concentrations observed in some of these studies are high, the number of workers exposed is usually low if we consider an overall workforce. England is one of the European countries with better by-laws regarding indoor radon (both residential and occupational). It is recommended to routinely test occupied basements for radon and there is a recent recommendation to include radon in risk assessments of basements of all workplace types, irrespective if they are or not in radon affected areas.[19] The yearly minimum occupation of a workplace to be measured should be 50 hours for radon affected areas and 250 hours in non-affected areas. In the present study we wanted to characterize workplaces and institutions with a high number of employees, such as public administration, education buildings and private sector, among others. In many of these places, radon devices were measuring radon exposure of many workers sharing the same office, something common in many occupations.

A study performed in workplaces of Extremadura (approximately 150 measurements) obtained a geometric mean of 130 Bq/m^3. Of workplaces, 31% had measurements over 200 Bq/m^3 and 13% had indoor radon concentrations above 400 Bq/m^3.[20] These figures are quite similar to the results obtained in the present study. The highest radon concentrations were observed in spas and in a touristic cave. In the present study, we have observed the highest radon concentrations in the public administration sector, which concentrates a high number of workers in Spain. We do not have any specific explanation for this finding, which perhaps could be related to the fact that some of the buildings measured are built of stone and are quite old. We have observed in previous studies in Galician dwellings that the age of the dwelling predicts a higher radon concentration.[21] The sector with the lowest radon concentrations is the tourist sector. Perhaps this is due because the tourist sector (hotels) is prone to more ventilated entry areas and presence of climatization with a regulated interchange of air. It is well known that buildings with proper climatization tend to have lower radon concentration.

For many of the participating institutions, employers, and persons in charge of health and safety management, this study gave the first information and awareness on indoor radon, showing the impressive lack of knowledge on radon exposure and its health risks in Spain. Furthermore, we faced important reluctance when trying to find employers willing to collaborate with us. In fact, while we initially intended to finish the study in one year, it had to be extended an additional year to achieve our objective of 250 indoor radon measurements.

The new EU Directive[9] was to be enforced in February 2018 in all EU countries. This directive will be particularly important in those countries with poor bylaws on indoor radon, which is the case of Spain. These results should be a heads-up for employers and workers and we expect an increase on radon awareness in those parties. Nevertheless, the Spanish Government has not transposed the directive in time and will be fined by the European Commission. Other countries have perfectly defined which workplaces should be measured, such as the Czech Republic, where workplaces built after radon regulation laws have to have effective radon mitigation structures.[22] Exposure to radon at work has to be added to a potential exposure to radon at home, particularly in radon-prone areas.

This research has certain limitations. The main one is that we have not performed a systematic approach to radon measurement in workplaces, established by workplace characteristics, sector or an a priori high radon risk. This was not our first intention but we can anticipate that it would have been a very difficult task to have this systematic approach due to the lack of collaboration we faced in many cases. Therefore, we have to define our sampling as opportunistic. Related to this sampling is the fact that we cannot consider our results as representative of the Spanish population. Nevertheless, the fact of having found high radon concentrations in unexpected areas is relevant and aligned with recent recommendations to measure cellars and ground workplaces released by Public Health England.[19]

This study has also some advantages, such as having used a reliable radon device such as an alpha-track type, which is the recommended for measuring radon exposure according to international guidelines.[7] The detectors were read at the Laboratorio de Radón de Galicia (www.radongal.com) at the University of Santiago de Compostela, which is a recognized facility in radon research[4,6] having measured 11 Spanish provinces for the residential radon map of Spain. Finally, the number of measurements is quite high given the lack of research on this field in Spain.

To conclude, we have found that radon concentration in Spanish workplaces might be high, particularly in radon-prone areas and old buildings. We have also observed that some workplaces have high radon concentrations in unexpected geographical locations. These results might have important implications and have served to one of the most important Spanish labour unions (Comisiones Obreras) to compose and distribute a radon information leaflet distributed to all representatives of the different regions.[23] With these results we have taken action at governmental level to increase radon awareness. There is currently a mandatory by-law where all regional public administrations should have and maintain a registry of workplaces where radon concentrations of workplaces in certain industries have to be communicated,[8] but we are aware that despite more than 6 years have elapsed since the enactment of that law, some regions do not even have such registry. There is a feeling of *déjà-vu* when checking an editorial published in this journal in 2014 where we advertised on the need of more action regarding radon exposure.[24] It is also important to raise concern among employers, who have the duty of protecting workers from a recognized human carcinogen such as indoor radon, workers, union labours and on risks prevention workers. Finally, the need to develop a National Radon Plan, which is present in many EU countries, should overcome many of the problems and difficulties faced in the present study.

¿What is known on the topic?

Indoor radon is a human lung carcinogen only surpassed by tobacco in magnitude. Some specific workplaces have high radon concentrations (mines, spas, underground workplaces) but studies are scarce in Spain. Radon concentration is mostly unknown in sectors employing a high number of workers.

What this study adds to the literature?

Of measured workplaces, 27% have shown to have radon concentrations above international thresholds (WHO, EU) and a remarkable percentage located in low-radon areas had high concentrations. We must raise concern among employers, workers, union labours and risk prevention workers. EU directive should be transposed as soon as possible to the Spanish by-laws and a National Radon Plan should be enforced.

Editor in charge

Juanjo Alguacil.

Transparency declaration

The corresponding author on behalf of the other authors guarantee the accuracy, transparency and honesty of the data and information contained in the study, that no relevant information has been omitted and that all discrepancies between authors have been adequately resolved and described.

Authorship contributions

All authors have contributed equally to the manuscript content.

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Conflicts of interest

None.

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