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Original article

Radon mitigation in the workplace in Spain: a cross-sectional interview-based study

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ABSTRACT

Objective: To evaluate radon mitigation frequency and possible determinants for mitigation among employers in Spain, before the new regulation came into force. We also aimed to assess the reasons for not mitigating radon.
Method: In this cross-sectional study, participants were systematically identified from all employers in Spain who had previously measured occupational radon through the Galician Radon Laboratory from 2015 until 2022. Employers responsible for at least one workplace where radon levels exceeded 300 Bq/m^3 were included. Participants were interviewed via phone call by a trained interviewer. The information was recorded using an *ad hoc* questionnaire created as a result of a review. We analyzed mitigation frequency according to working sector, company size and maximum radon levels found. Reasons for not mitigating were ranked according to frequency.
Results: We interviewed 32 employers (response rate 91%). Overall mitigation frequency was 53%. Mitigation frequency increased with the company size. For workplaces ≥1000 Bq/m^3 mitigation frequency was 67%. Lack of perception of radon as a health risk was the main reason for not mitigating.
Conclusions: Enhancing radon mitigation frequency in the workplace is a major area of improvement. We are of the opinion that employers need guidance and availability of mitigation services to comply with the new regulatory requirements in Spain.

Mitigación de la exposición laboral a radón en España: un estudio transversal con entrevistas

Palabras clave:
Salud laboral
Directiva 2013/59/Euratom
Real Decreto 1029/2022
Cáncer de pulmón
Radiación ionizante

RESUMEN

Objetivo: Evaluar la frecuencia de mitigación de radón y sus determinantes en empleadores en España antes de la entrada en vigor de la nueva normativa, así como las razones para no mitigar el radón.
Método: Estudio transversal en el que los participantes fueron identificados sistemáticamente entre todos los empleadores que midieron el radón a través del Laboratorio de Radón de Galicia desde 2015 hasta 2022 y obtuvieron resultados que excedían el nivel de referencia. Fueron entrevistados telefónicamente por una entrevistadora capacitada usando un cuestionario *ad hoc* creado a partir de una revisión. Se analizó la frecuencia de mitigación según el sector, el tamaño de la empresa y los niveles de radón encontrados. Las razones para no mitigar se clasificaron según su frecuencia.
Resultados: Entrevistamos a 32 empleadores (tasa de respuesta del 91%). La frecuencia de mitigación general fue del 53%. La frecuencia de mitigación aumentó con el tamaño de la empresa. En lugares de trabajo con ≥1000 Bq/m^3, la frecuencia de mitigación fue del 67%. La principal razón para no mitigar fue la falta de percepción del radón como un riesgo para la salud.
Conclusiones: Mejorar la frecuencia de mitigación del radón en lugares de trabajo es una importante área de mejora. Los empleadores necesitan orientación y disponibilidad de servicios de mitigación para cumplir con los nuevos requisitos regulatorios.

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Introduction

Radon is a naturally occurring radioactive gas. It emanates from the rocks of the earth crust, and can make its way inside buildings through cracks, openings or poorly insulated foundations, and accumulate indoors.[1] Radon is classified as a group I carcinogen since 1988[2] and it is considered by the World Health Organization (WHO) as the second leading cause of lung cancer after smoking.[1] Radon exposure increases the risk of lung cancer following a linear dose-response trend.[3] From a public health perspective, the WHO recommends countries to stablish radon concentration reference levels of 100 Bq/m^3 at home or at work, unless this level cannot be implemented under the country-specific conditions.[1] EU Directive 2013/59/Euratom[4] mandates Member States to establish a national reference level between 100 and 300 Bq/m^3. The Euratom directive regulates exposure to ionizing radiation, including occupational radon exposure.

In Spain, occupational radon regulation was only recently updated to meet Euratom requirements.[5] This updated regulation published in December 2022, entered into force in Spain in June 2024 and it includes the obligation for employers to mitigate radon levels or exposure when annual average radon concentration in any occupied area of the workplace exceeds 300 Bq/m^3. To do so, it is usually necessary to undergo interventions in the building, such as installing a forced ventilation system, sealing cracks, or installing a radon sump under the foundations. Alternatively, employers can control radon exposure by reducing working hours at workplaces with excessive radon levels.[6] These mitigation systems require time, knowledge, planning, economic resources, and employer commitment.[7]

With radon mitigation employers can prevent workers future radon exposure, however past exposure cannot be prevented. For this reason, a recent revision from the Ministry of Health from Spain concluded the need for a health protocol to surveil those workers that have been exposed to excessive radon levels for years.[6]

Worldwide, most of the available studies on radon mitigation were related to home mitigation, but not to mitigation in the workplace.

Galicia has been previously classified as a radon-prone area[8] and many studies have linked residential radon exposure with lung cancer in smokers and never smokers.[9,10] Regarding radon exposure at work, a recent study analyzed radon concentration in 3140 Spanish workplaces, mostly located in Galicia. Of those 3140 workplaces measured, 20% (n = 623) exceeded 300 Bq/m^3. This study has the largest sample of occupational radon measurements available in Spain[11] and one of the most relevant in Europe.[5]

This study aimed to evaluate radon mitigation frequency and possible determinants for mitigation among employers in Spain. We also aimed to assess the reasons for not mitigating radon. This study corresponds to the situation prior to the adoption of the new regulation on radon at the workplace, so employers were under no legal obligation to remediate radon levels.

Method

Participants selection

In this cross-sectional study, participants were systematically included from all employers (companies and organizations) in Spain that had previously measured occupational radon through the Galician Radon Laboratory (GRL), described elsewhere.[11] Briefly, we collected all workplace radon measurements conducted from January 2015 until December 2022, obtaining a total of 3140 measurements in different workplaces which corresponded to 253 employers. We defined an employer as a private or public company, an institution, or a corporation. Within this initial sample, 623 workplaces, corresponding to 40 employers, exceeded 300 Bq/m^3. Employers responsible for at least one workplace where radon levels exceeded 300 Bq/m^3 were systematically contacted for participation in this mitigation study. Within each company/organization, we interviewed the person responsible for mitigation by using the contact provided for the initial radon measurement.

Questionnaire

The objective of the phone interviews was to identify whether radon mitigation was performed or not, and the reasons for not mitigating when applicable. To do this, we first performed a review of the available studies on radon mitigation and, secondly, we developed and piloted an *ad-hoc* questionnaire. This questionnaire was used to interview employers via phone.

The *ad-hoc* questionnaire was developed based on the review performed. The questionnaire was piloted and improved by experts; two health and safety technicians from two different private companies of more than 1000 workers, and a health and safety expert from a labor union. We also included questions about employer characteristics, namely number of workers. The definitive questionnaire used consisted of 11 open questions (see online Appendix. Supplementary data). In question 6 of the questionnaire, a list of 15 potential reasons for not mitigating was included to help registering the response. This list was not read out loud to the employers, instead it was used by the interviewer to better register employers' answer.

Table 1S in Appendix. Supplementary data includes further details of the 15 reasons for not mitigating preidentified, namely its source (from the literature review or during the questionnaire elaboration and piloting) and scope (type of location of the study source). Eleven of these reasons were directly obtained by grouping reasons found in the literature according to its content. For instance the reason "No risk perception" aroused from grouping the following reasons found in four different studies: "Not certain there is a serious risk", "No health risk", "I don't believe radon is a problem in my schools" and "I don't perceive that I am at risk". Four reasons were added during the questionnaire elaboration and piloting by the authors of this manuscript or by the reviewers.

Data acquisition

Phone interviews were scheduled and carried out by a trained interviewer (LMG). The final version of the questionnaire was used to guide and report on the phone interviews (see Appendix. Supplementary data). The interviewer collected and noted down all relevant information during and right after each phone interview. The interviewer confirmed that the information was provided by the right informants and performed several phone calls when required to reach out to the appropriate contact.

Data analysis

We analyzed the mitigation frequency within our set of participants, considering mitigation as any self-reported mitigation action. We also characterized mitigation frequency according to basic employer characteristics, namely according to ownership type (public or private), the working sector and number of workers. Working sector was assigned based on the following categories previously described elsewhere:[11] education (includes educational, science and sport facilities), culture (includes libraries, museums, socio cultural centers and institutions, churches, and media), financial services (banks), public services (public administration offices), utilities (power plants and water supply infrastructure), agricul-

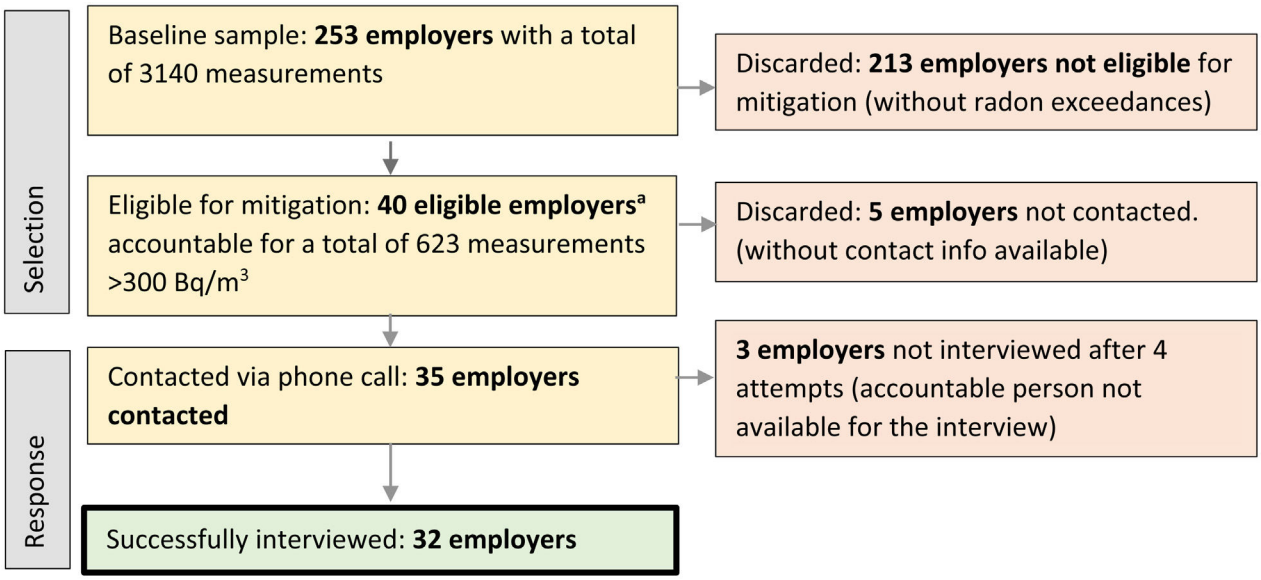

Figure 1. Workflow for participants selection and interview response. [a]Eligible employers: those responsible for at least one workplace exceeding 300 Bq/m^3.

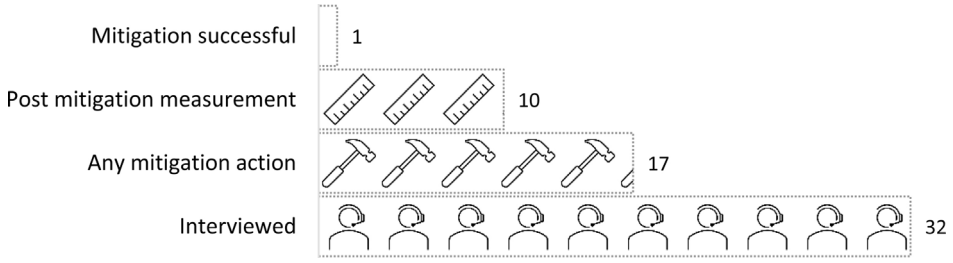

Figure 2. Mitigation actions reported.

ture, health services (includes adult day centers), mining, retail, technology (tech companies), tourism (hotels and spas) and transport. A descriptive analysis and visualization were performed using Excel. Reasons for not mitigating were ranked according to frequency.

Results

Response rate

A total of 40 out of 253 employers were eligible for interview, as they were responsible for at least one workplace exceeding 300 Bq/m^3 (annual average radon concentration). As shown in Figure 1, of those 40 employers, five were discarded because there was no direct contact available (only that of an intermediary contractor). We contacted 35 employers via phone, of which 32 agreed to respond to our interview (response rate of 91%) and three did not. Of those three, all responded to the phone call but could not carry out the interview after four attempts due to unavailability of the accountable person to respond at that time.

Main characteristics of the sample

All employers interviewed were responsible for workplaces located in radon prone areas. Most employers interviewed were public employers (72%). Sorted by specific working sectors, more than half of the participants (60%) were employers from the education and culture sectors. Regarding company size, most were small or medium size companies, and only seven exceeded 250 workers (Table 1).

Table 1
Characteristics of the sample.

Employer characteristics	n (%)
Ownership type	
Private	9 (28%)
Public	23 (72%)
Sector	
Education	14 (44%)
Culture	5 (16%)
Public service	6 (19%)
Others (health services, utilities, financial services)	7 (22%)
Size (workers)	
< 50	13 (41%)
50-250	12 (38%)
> 250	7 (22%)

Those interviewed had different responsibilities. In some cases, they were health and safety technicians, in others, they held positions with responsibility in human resources and, finally, others had different roles in the company (i.e. administrative staff reporting directly to direction).

Self-reported mitigation frequency

Out of 32 employers interviewed, 17 (53%) reported taking some type of action to reduce radon, from these, only 8 reported taking action on all its affected workplaces. Most commonly, to mitigate the workplace employers only improved natural ventilation (7 out of 17). As shown in Figure 2, of the 17 employers that reported any

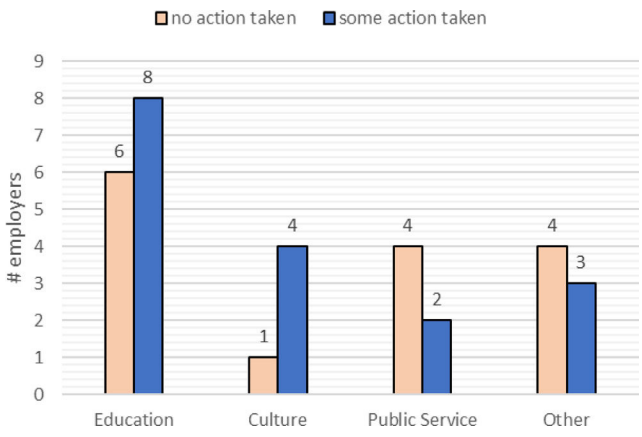

Figure 3. Mitigation frequency by working sector.

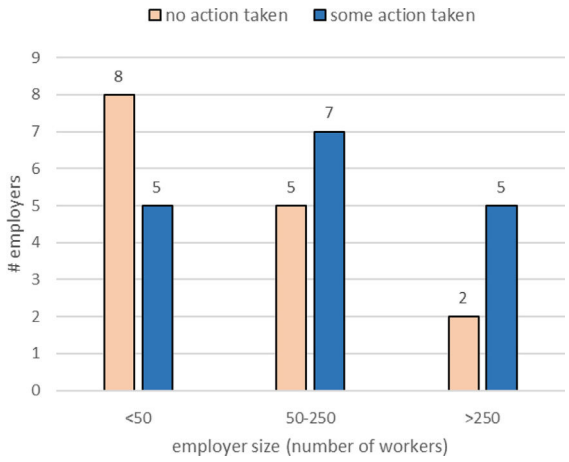

Figure 4. Mitigation frequency by employer size.

mitigation action, 10 declared that they had repeated the radon measurements after mitigation to verify its effectiveness. Only one employer confirmed that mitigation was successful through post-remediation measurements below 300 Bq/m^3.

Mitigation frequency was 56% among private employers and 52% among public ones. When analyzed by working sector, the mitigation frequency was 57%, 80%, 33% and 43% for the education, culture, public service sector and other sectors, respectively (Fig. 3).

When sorted by company size (Fig. 4), employers with less than 50 workers had a mitigation frequency of 38%, while those with 50 to 250 workers had a mitigation frequency of 58% and those with more than 250 workers had a mitigation frequency of 71%.

Finally, mitigation frequency varied according to employer maximum radon level (Fig. 5). For employers with one workplace or more above 1,000 Bq/m^3 (n = 18 employers), mitigation frequency was 67%, whereas for employers with at least one workplace between 600 and 1,000 Bq/m^3 (n = 3) it was 33%. To conclude, for employers with all workplaces below 600 Bq/m^3 (n = 11) mitigation frequency was 36%.

Reasons for not mitigating

Fifteen employers declared no mitigation action was taken to reduce radon levels in the workplace or workplaces affected. During the interview, insights about the reasons for not mitigating were collected. Some employers reported more than one reason. The most common reason for not mitigating was not perceiving radon

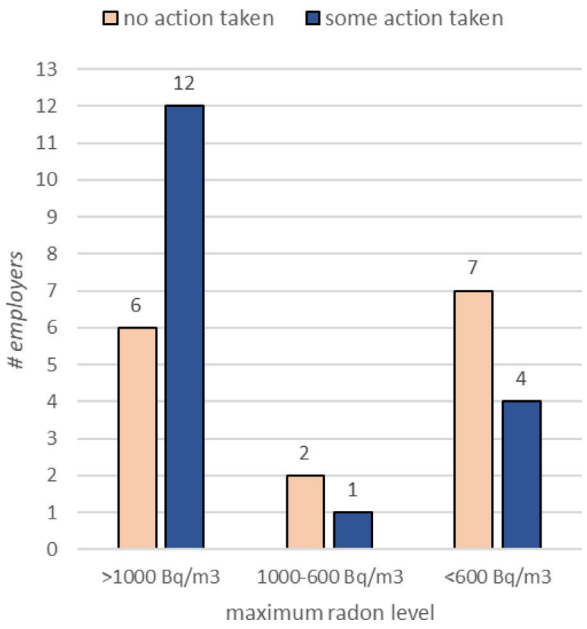

Figure 5. Employers mitigation frequency according to employer maximum radon levels.

exposure as a health risk (8 out of 15), followed by practical difficulties (3 out of 15), lack of interest from the directive staff (4 out of 15), not being a priority (4 out of 15) and finally, not understanding measurement results (1 out of 15). Cost (including lack of funds) was not identified as a reason for not performing remediation by any of the interviewees.

Discussion

To our knowledge, this is the first published study showing mitigation activities in workplaces other than schools, therefore providing novel information on this topic. In absence of legally binding obligations, mitigation activities in Spanish workplaces seem to be neglected by an important percentage of employers. Almost half admitted not taking any action to mitigate worker radon exposure. This means that proactivity in measuring radon does not often translate into proactively mitigating radon, when advisable. More worryingly, the main reason for not mitigating is the lack of perception of radon as a health risk.

Previous studies on radon mitigation frequency

We have not found any previous studies reporting radon mitigation frequency in the workplace in Europe, and elsewhere only one in schools.[7] Our results are, nonetheless, in line with radon studies in dwellings where mitigation frequency and reasons for not mitigating were surveyed.[12,13] In Ireland and Switzerland, mitigation frequency were 25% and 46%, respectively, among residents that had excessive radon levels. In these countries the main reasons for not mitigating were the lack of perception of health risk and concern about cost. Outside Europe, a study in Wisconsin (USA) covering dwellings and schools, reported that only 8 out of 32 school districts with high radon levels took action to mitigate radon, and the main reason for not mitigating was concern about cost.[7] To this end, it is relevant to mention that the national action level in Ireland is 200 Bq/m^3, in the USA is 148 Bq/m^3, and in Switzerland it was 1000 Bq/m^3 at the time of the study. The mitigation frequency mentioned above refer to mitigation when pertinent national action levels were exceeded.

Reasons for not mitigating

The main reason for not mitigating was lack of risk perception. The complexity of radon risk perception has been previously studied,[19] and a recent review observed that several studies found an association between risk perception and intention to measure or mitigate radon.[14]

Nevertheless, in order to interpret the results of the present study, it is important to understand our set of participants. Most of them were employers from radon prone areas who proactively measured radon with the GRL before regulatory requirements to do so entered into force (by July 2024). Thus, we would expect our participants to have a higher radon risk awareness, but paradoxically the main reason not to mitigate is the lack of perception of health risk. We believe that, in radon prone areas the normalization of high radon levels could be an issue.

Noteworthy, even among those 17 employers who did undertake some mitigation action, only a single employer successfully completed the mitigation according to the new regulation (including the post-mitigation measurement < 300 Bq/m^3). Inadequate or insufficient mitigation could be attributed to the lack of guidance available.

In Spain, there is no clear guidance readily available on how to practically manage the mitigation process —for instance, how to select a contractor or solution, or how to determine the expected costs for workplace mitigation. There is a guide on radon mitigation for dwellings available at the National Building Code website,[15] a very specific site visited mainly by building professionals but unknown to most employers and the general population. This guide can help in selecting a solution but is not destined for workplaces, nor does it inform about how to choose the right contractors nor about the potential budget.

Furthermore, the Spanish National Radon Action Plan approved in January 2024[16] includes measures to disseminate radon mitigation guidelines among architects and contractors, but no specific actions are envisaged in this area targeting employers or the general population.

Mitigation frequency by sector, company size and maximum radon levels

Both public and private employers had similar self-reported mitigation frequency. However, when sorted by specific sector, the public service sector had the lowest mitigation frequency with only two out of six employers taking any mitigation actions.

More remarkably, the mitigation frequency seemed to increase with company size, from a mitigation frequency of 38% (n = 13) for companies with less than 50 workers, to a mitigation frequency of 71% (n = 7) for companies with more than 250 workers. This finding is consistent with a well-known phenomenon in risk prevention: small and medium-sized enterprises usually suffer from poorer safety and health management.[17]

Finally, understandably those employers with radon levels above 1000 Bq/m^3 mitigated more often than the rest as the health risk was greater in such workplaces.

Strengths and limitations

This study is the first to provide an approximation of radon mitigation frequency in Spain, and the first worldwide to provide it for workplaces other than schools. Each participant was carefully interviewed, paying attention to each participant need to be able to answer the questions. Our sample size was limited (32 participants), constituting a great limitation for this study. This small sample size prevented us from analyzing potential significant differences in mitigation frequency between employees based on their characteristics. Of note, other radon mitigation surveys do not have a larger sample size and share this common limitation. The largest is the Swiss national radon mitigation study (for dwellings only) with 199 participants and a response rate of 65%. Though limited in size, the strength of our set of participants is that it was obtained systematically (Fig. 1), with a response rate of 91% covering different public and private sectors.

This study has a number of additional limitations. First, all participants had radon measurements carried out by the GRL. Therefore, the present study could be showing the mitigation frequency of GRL customers rather than the mitigation frequency of Spanish employers. Even if the latter was truth, the GRL is one of the laboratories performing the largest number of measurements in Spain, thus the results would still be relevant.

Public health implications and future studies

Radon mitigation frequency in the workplace remains unknown or unpublished in most countries.

HERCA (Association of European Radiation Protection Authorities) advices to use mitigation statistics as key performance indicator (KPI) of National Radon Action Plans; namely remediation frequency.[18] Nevertheless, few countries have implemented this recommendation. The use of KPI specifically to workplace mitigation is even more uncommon; to our knowledge, only the Portuguese National Radon Plan includes such indicator.

Spain's Radon Action Plan should foster such support measures, and include indicators based on the number of workplaces mitigated and reasons for not undertaking remediation. Data for these indicators could be obtained on a yearly basis through cross-sectional studies with a randomize sampling. A questionnaire such as the one proposed in our study could be used for that purpose.

In Spain, the new regulation, should radically increase workplace mitigation frequency. Future studies should include larger sample sizes allowing for a comprehensive characterization analysis. Furthermore, longitudinal studies where employers could be followed up through time could better assess the impact of different initiatives on the employers' decisions related to mitigation.

We expect an intense work ahead for employers and competent authorities to ensure compliance with what will soon be a legal requirement subjected to inspection. Nevertheless, we are of the opinion that enforcement through inspection will not be enough to meet regulatory standards. Employers need guidance, reference of good practices, tools, and availability of recognized/authorised radon mitigation services to become compliant with the new regulation.

Conclusions

The main reason for not acting against occupational radon in Spain is lack of risk perception. To this end, specific radon risk awareness campaigns targeting employers and workers are needed. Mitigation guidance for employers and inspection efforts from competent authorities are needed to grant radon regulation compliance, as half of the employers admitted not taking any action against radon exposure and, finally, large companies mitigate radon more often than smaller ones; therefore, it is important to have a special focus on smaller companies that require further support to address radon risks.

What is known about the topic?

A recent study revealed that one out of five workplaces located in radon priority areas surpassed 300 Bq/m^3. Employers must measure radon and mitigate when its concentration exceeds 300 Bq/m^3 to comply with the applicable regulation. There are not available studies on radon mitigation frequency among employers.

What does this study add to the literature?

This is the first study to quantify radon mitigation frequency in Spain, furthermore it provides a novel questionnaire to assess radon mitigation in a systematic way.

What are the implications of the results?

The results show that improving radon risk awareness among employers and supporting smaller companies is needed for an effective and compliant radon mitigation in workplaces in Spain.

Availability of databases and material for replication

The data that support the findings of this study are not openly available due to reasons of sensitivity and are available from the corresponding author upon reasonable request. Data are located in controlled access data storage at University of Santiago de Compostela.

Editor in charge

Alberto Lana.

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

L. Martín-Gisbert: Writing original draft, visualization, investigation, methodology, conceptualization and funding acquisition. A. Ruano-Ravina: writing, review and editing, investigation, conceptualization, methodology and funding acquisition. M. García-Talavera: writing, review and editing, and methodology. C. Candal-Pedreira: writing, review and editing, and resources. G. García: writing, review and editing, and visualization. L. Varela Lema: writing, review and editing. M. Pérez Ríos: writing, review and editing, and methodology. J. Rey-Brandariz: writing, review and editing, investigation and methodology.

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Conflicts of interest

None.

Appendix A. Supplementary data

Supplementary data associated with this article can be found in the online version available at https://doi.org/10.1016/j.gaceta.2024.102440.

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