Recent developments in the control of radon exposure in Spain

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Abstract

In this work, we provide an overview of the current Spanish legislative framework for the control of radon concentration with a focus on exposure in the workplace. The legislation is aligned with the recent epidemiological evidence and the ICRP's new approach to radon exposure. The concept of a reference level is applied, with an emphasis on optimisation below it, and values of 600 Bq m^{-3} and 300 Bq m^{-3} are established for, respectively, workplaces and dwellings. Furthermore, a key issue to reduce exposure nationwide is the identification of areas most at risk for high radon levels indoors. The methodology followed to delimit such areas is described.

1. Introduction

The concern about health hazards to population exposed to high radon levels has grown over the last several decades and it has recently been reinforced by new epidemiological evidence on residential exposure (Darby S. et *al.*, 2005; Lubin J.H. et *al.*, 2005; Krewski D. et *al.*, 2005) that highlights the need for protection even at radon levels as low as 100 Bq m^{-3}. International recommendations on radon (WHO, 2009; ICRP 2010, IAEA, 2011) have adapted to these new scientific findings, and many countries have now in place a variety of legal instruments and strategies for controlling radon concentration indoors both at home and at work.

In Spain, Royal Decree 783/2001 (transposing EC Directive 96/29/EURATOM) partly covered the problem by addressing the exposure of workers and public to increased radon levels due to work activities. But because of an unclear definition of the competent authorities who were to enforce the regulation, it was never set into practice except for a few situations of particular radiological concern. To unlock the situation, an amendment to Title VII of RD 783/2001 was passed in 2010, directly placing the obligation to conduct radiological risk studies on the employers, and further guidance has afterwards been issued by CSN, the Spanish regulatory authority, expanding on that matter.

For domestic exposure, a reference level of 300 Bq m^{-3} and a design level of 100 Bq m^{-3} for new construction developments have been recommended in 2012. However, the implementation of this reference level may vary across the country, as public health policy falls under the responsibility of the regional governments. On the other hand, efforts are being made to establish the design level nationwide by including protection measures against radon in the forthcoming revision of the Technical Building Code.

In this paper, we present several fundamental elements of the National Radon Programme focusing on the regulatory developments related to the control of radon exposure at the workplace. All the normative documents named below are downloadable at www.csn.es (only in Spanish).

2. Legislative framework

Protection against radon is based on the application of reference levels. These are defined in the 2007 Recommendations of the ICRP as the level of dose or risk above which planned exposure situations are considered inappropriate, and below which optimisation of protection should be implemented.

A reference level of 300 Bq m^{-3} applies to radon in homes (GS 11.02), whereas for workplaces 600 Bq m^{-3} is applicable (IS-33). For residential areas in workplaces, the reference level for dwellings holds, and a level of 300 Bq m^{-3} should be established at child-care centres and primary and secondary schools (IS-33).

Employers responsible for workplaces most at risk have the legal obligation to carry out studies on radon levels. These workplaces are (IS-33):

- Underground workplaces such as mines, subways, tunnels, stores or show caves.
- Facilities where water drawn from underground sources is treated, distributed or utilised, such as spas or ground-water treatment stations.
- All workplaces at identified radon-prone areas (the identification of such areas are discussed in Section 5).

The risk studies also ought to identify any engineering or administrative measures that may allow reducing exposures and, whenever possible at little cost, these should be implemented. If radon concentrations are found to be above the reference level, remedial measures aimed at reducing radon levels to below the action level should be taken. However, if all reasonable measures fail to reduce radon concentrations to below the action level, then the appropriate scheme of radiation protection measures should apply (GS 11.04).

Periodic retesting ought to be conducted every five years (IS-33), although subsequent studies do not need to be as detailed as the first characterisation survey.

3. Requirements for the competence of radon measurement laboratories

An effective national radon program needs to include provisions for ensuring the reliability of measurements. With that aim, CSN issued a Safety Guide (GS 11.01) establishing the fundamental requirements that all organisations involved in measuring radon concentrations in air, and especially measurement laboratories, should comply with.

The Guide refers to ISO/IEC 17025:2005 for general management requirements and further expands on technical requirements specific to radon measurement. It covers topics such as accommodation and environmental conditions, method validation, detector deployment, expression of results, internal quality control measures and external quality assessment. Its recommendations largely follow international guidelines (WHO, 2009) and other widely acknowledged references on the matter (as USEPA, 1997).

4. Radon surveys in workplaces

The main objective of the studies required by regulation is to determine whether the radon gas concentration at the workplace exceeds the appropriate reference level. CSN Safety Guide GS 11.04 was issued to help employers ensure that surveys are designed and conducted in such a way that it is possible to statically demonstrate that radon concentration complies with national legislation. This section summarises the most relevant guidelines contained in this Safety Guide.

Measurements using nuclear etched-track detectors or electrets must be carried out over a minimum period of 3 months that, in general, should not include the summer season. Special care must be given to environmental conditions when selecting the most appropriate measuring device.

At the design phase of the survey, it is required that workplaces be divided into areas of homogeneous radon concentration *(*HZ*)* based on the characteristics of each area with regard to radon entry and transport (type of walls, foundations, soil and subsoil, ventilation type, temperature…).

At least one detector must be deployed per HZ, with a minimum of two detectors per workplace.[1] Large HZs may require placing several detectors (~1 detector per 200 m^2). Once the measurement results are available, a chi-square test on the internal (s_{int}) and external (s_{ext}) variance of the data may be performed to verify that the homogeneous zone has been defined properly:

$$\frac{s_{ex}^2}{s_{in}^2} = \frac{\chi^2}{(n-1)} = \chi_R^2 \quad (1)$$

The magnitude of χ_R^2, which is expected to be of the order of unity, allows conclusion on the quality of the data.

Radon concentration in every HZ must be expressed as an annual mean value. To demonstrate compliance with the reference level, this value should be compared with an upper limit for the mean at the 90% confidence level, calculated as follows:

$$LS_i = \overline{Rn}_i + t_{0.9,\, n-1}\, u_{c,i} \qquad \text{(one detector per HZ)}$$

$$LS_i = \overline{Rn}_i + t_{0.9,\, n-1}\, \frac{s_i}{\sqrt{n}} \qquad \text{(n detectors per HZ)}$$

If workers spend their time in different HZs, the upper limit should be obtained as the upper limit for the mean of the sum distribution.

Optionally, the following investigations can be undertaken to derive correction factors in order to improve the estimation of the annual dose. They are specially recommended when radon levels are close to or exceed the reference level, and in case of a), also when there are workers on a night shift:

a) Radon temporal variations: Radon concentration in a building is generally higher during the night hours. To correct for this effect, measurements may be carried out using a continuous radon monitors along at least five 8-h long-shifts at non-consecutive days.
b) Equilibrium factor (*F*): A 0.4 value for *F* is assumed by default in dose calculations. However, F can present significant variations at workplaces. F measurements may be long-term (see, for example, the methods described in Amgarou et al., 2003 or Yu et al., 2005) or short-term. In the latter case, the same conditions as in a) are required regarding measuring time.

[1] For multi-storey buildings, only the two lower occupied levels need to be characterised unless the survey results indicate that radon concentration exceeds the reference level. Workplaces for which water is the main source of radon should characterise all levels where water is utilised.

Note that the combined uncertainties associated with the correction factors should be also obtained. In these cases, it is usually necessary to apply a Monte Carlo-based method to obtain an upper limit for the final result.

5. Identification of radon-prone areas

There is no consensus definition of radon-prone area. The 2007 Recommendations of the ICRP define it as an area in which the concentration of radon in buildings is likely to be higher than the national average. In some countries, the definition of radon-prone area is based on a given fraction of the housing stock (as 10%) exceeding the reference level.

Although, because of random sampling variation, the sample of radon measurements in dwellings from a given town does not provide perfect information about the sampled population, it allows estimating a confidence interval for a parameter of the population. This interval can be claimed, with a specific degree of confidence, to contain the true value of the correspondent parameter characteristic. Since radon measurements usually conform to a lognormal distribution, a one-sided upper 100(1-α)% tolerance bound to exceed at least 100p% of the housing stock can be calculated as:

$$\tilde{T}_{0.90} = \exp(\bar{y} + g'_{(1-\alpha),0.90,n}\, s_y) = \exp(\bar{y})\exp(g'_{(1-\alpha),0.90,n}\, s_y) \quad (2)$$

where $\bar{y}$ and s_y are the mean and the standard deviation of the n transformed values $y_i = \ln x_i$ and $g'_{(.)}$ is given in Table 1 of Odeh and Owen (1980).

With regard to IS-33 implementation in workplaces, we established two types of radon-prone areas:

- Type-1 areas, where 10% of dwellings exceed 300 Bq m^{-3} (the reference level at long-permanence public buildings and schools).
- Type-2 areas, where 10% of dwellings exceed 600 Bq m^{-3} (the reference level at workplaces, in general).

Thus, for n=10 and a 90% confidence level, equation (2) gives estimates of approximately 300 Bq m^{-3} and 600 Bq m^{-3} for the 90th percentile upper limits of towns with geometric means (GM) of, respectively, 70 Bq m^{-3} and 120 Bq m^{-3}, (based on statistics on our data, it was assumed s_{70}=2.01 and s_{120}=2.17).

To identify radon-prone areas nationwide, we applied a combined mapping method using measurements in dwellings (taken at ground or first floors), geological information and the natural gamma radiation map of Spain (based on 1.500.000 plus measurements) – see Fig. 1.

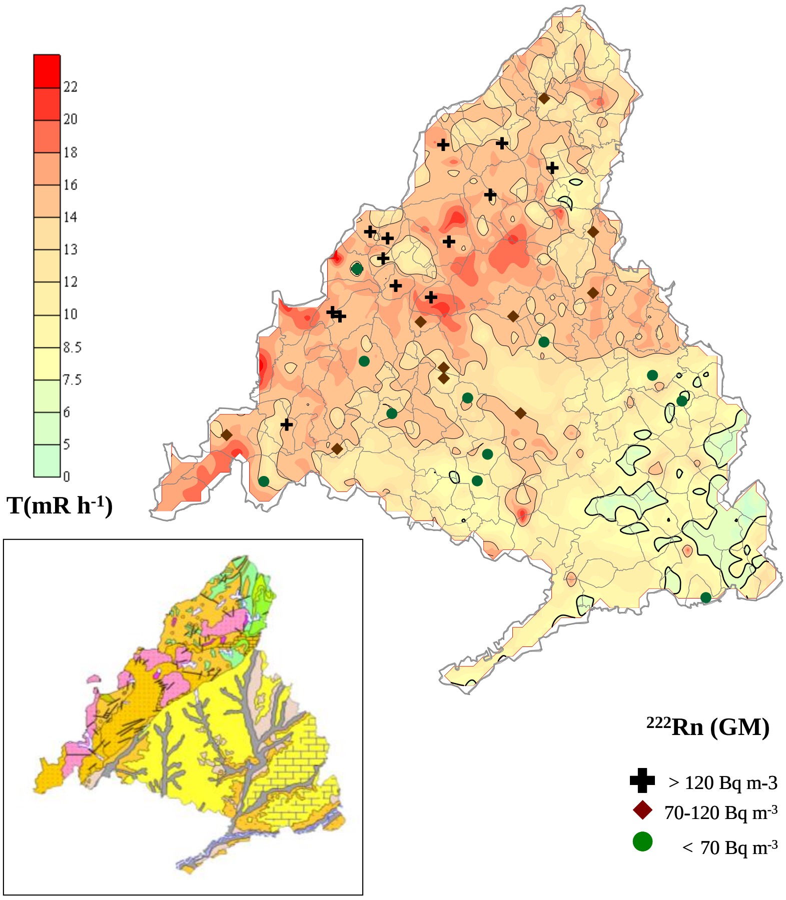

Fig. 1. Geological map and map of natural gamma radiation of the autonomous region of Madrid. Solid line in the latter mark the division between category 0, category 1 and category 2 areas. Symbols indicate towns or cities where radon measurements in dwellings have been made.

First, we produced a predictive radon-risk map using data from the natural gamma radiation map of Spain (Suarez et *al.*, 2000) as a surrogate,[2] and we defined three categories by the following ranges:

- <7.5 μR h^{-1} (category 0)
- 7.5-14 μR h^{-1} (category 1)
- >14 μR h^{-1} (category 2)

[2] As verified empirically from 656 data all around the country there is a linear relationship between the exposure rate due to gamma radiation from all emitters in the soil and the gamma exposure rate due to ^{226}Ra alone. This, in turn, is known to be related to ^{222}Rn concentration in soil.

Subsequently, we analysed data on the geometric means (GM) for the radon distributions measured at 427 municipalities (with at least six available measurements) in relation to the predictive radon-risk map.[3] Correspondence analysis of these data revealed that, as shown in Fig. 2, the three categories in the predictive radon-risk map corresponded well with the following groups of radon concentration:

- GM<70 Bq m^{-3} (~low radon)
- 70<GM<120 Bq m^{-3} (~medium radon)
- GM>120 Bq m^{-3} (~high radon)

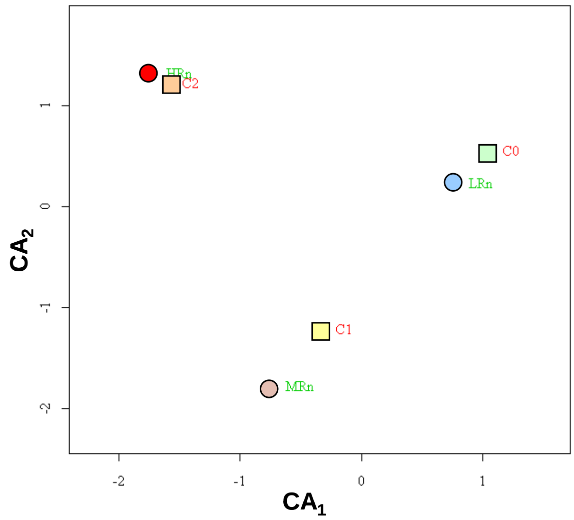

Fig. 2. 2D Correspondence analysis plot of categorical variables "predicted radon-risk" (category 0, category 1, category 2) and "radon in dwellings GM" (low, medium, high).

Only 11% of category 0 municipalities have radon GMs in excess of 70 Bq m^{-3} (whereas the corresponding figures for category 1 and category 2 areas are 53.6% and 76.5%, respectively). Category-0 might therefore be identified with low radon areas with a good classification rate. Furthermore, considering variables such as geology, geographical distance or soil permeability, no consistent pattern was identified in the misclassified values. Hence, all category 0 areas were directly rated as low radon areas.

For category 1 and category 2 areas, we used the lithostratigraphic map of Spain at scale 1:200,000 to improve prediction accuracy (at some points, more detailed geological maps at scale 1:50,000 were also consulted). A Moran's I test for spatial autocorrelation was performed

[3] These *GM*s should not be considered representative for population exposure, since measurements have been confined to the two lower floors, while most of the population lives in multi-storey buildings.

on the GMs of all municipalities within the same lithoestratigraphic unit. In absence of correlation, all individual measurements were combined in order to obtain an estimate for the weighted GM and a prediction on an upper limit for the 90th percentile. According to these values, the unit was classified as type-1 or type-2 radon-prone area. When not enough data were available for a lihtoestratographic unit, the unit was classified as a type-1 radon-prone area if it was majorly associated to category 2 radon-risk, or as low-radon area if it was associated to category 1.

The lithostratigraphic map was also used to refine the definition of area boundaries from the natural gamma radiation map. Geological-based boundaries are more appropriate since ambient γ dose rates do not always exactly reflect the characteristics of the soil beneath. For example, measurements are distorted by the influence of factors such as large water bodies, topographic effects (since portable gamma ray spectrometers are calibrated for a 2π surface geometry), or – in large cities – construction materials.

Identification of radon-prone areas according to the methodology described above is still in progress. Results will be published by CSN as a list of the municipalities concerned. Radon-prone area classification will be revised in 5 years in view of new information available. With that aim, CSN will soon be launching a new project to characterise all major lithological units in category 2 radon-risk areas and complete sampling at all cities and towns with a population of more than 200,000 inhabitants. In addition, any valuable radon data from other sources will be gathered.

6. Conclusions

While radon protection is still a pending issue in Spain, a number of significant steps either have been taken in the past few years or are going to be taken soon that will bring a substantial improvement in the short-term:

- Radon exposure control has been included in labour law.
- Children are given special protection, because all schools in areas where more than 10% of dwellings are likely to exceed 300 Bq m^{-3} must be measured and, when necessary, their radon levels must be remediated.
- Specific measures against radon are expected to be incorporated shortly into the Spanish Technical Building Code.
- Guidance to ensure the quality of measurements and surveys has been issued.

However, many efforts still need to be made, such as improving and maintaining a national database with any available radon-related measurements; accordingly, updating the map of radon-prone areas and revising the methodology used to produce it, and; creating radon education programmes, since public awareness towards radon is currently almost non-existent.

7. References

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