



Indoor radon in a Spanish region with different gamma exposure levels

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Abstract

In the beginning of 1990s within the framework of a national radon survey of more than 1500 points, radon measurements were performed in more than 100 houses located in Galicia region, in the Northwest area of Spain. The houses were randomly selected only bearing in mind general geological aspects of the region. Subsequently, a nationwide project called MARNA dealt with external gamma radiation measurements in order to draw a Spanish natural radiation map. The comparison in Galicia between these estimations and the indoor radon levels previously obtained showed good agreement. With the purpose of getting a confirmation of this relationship and also of creating a radon map of the zone, a new set of measurements were carried out in 2005. A total of 300 external gamma radiation measurements were carried out as well as 300 measurements of ^{226}Ra , ^{232}Th and ^{40}K content in soil. Concerning radon, 300 1-m-depth radon measurements in soil were performed, and indoor radon concentration was determined in a total of 600 dwellings. Radon content in soil gave more accurate indoor radon predictions than external gamma radiation or ^{226}Ra concentration in soil.

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1. Introduction

The starting point of the Spanish experience in the study of High Background Radiation Areas is the development of a nationwide indoor radon survey carried out in 1988. This campaign, belonging to the first Spanish Radon Framework, consisted of more than 1500 indoor radon measurements which represented a valuable basis to face rigorously the radon issue in Spain (Quindós et al., 1991). In particular, radon measurements were performed in more than 100 houses located in Galicia region, in the Northwest area of Spain. The houses were randomly selected only bearing in mind general geological aspects of the region.

Subsequently, a nationwide project called MARNA (Suarez and Fernandez, 1997) dealt with external gamma radiation measurements in order to draw a Spanish natural radiation

map. The aim of this project was to estimate potential radon

emission from external gamma radiation measurements taking into consideration geological parameters and empirical correlations between outdoor external gamma dose rates and ^{226}Ra concentrations in soil. In the region of Galicia, the MARNA map distinguished between zones with high, medium and low levels of external gamma radiation exposure. The comparison between these estimations and the indoor radon levels previously obtained showed good agreement (Quindós et al., 2004).

With the purpose of getting a confirmation of this relationship and also of creating a radon map of Galicia, a new set of measurements were carried out in 2005. Together with 300 external gamma measurements and radiological characterisation of soils, indoor radon concentration was determined in a total of 600 dwellings, 200 for each of the abovementioned sub-zones. Fig. 1 shows a map of the region of Galicia with the low, medium and high external gamma exposition zones indicated as well as the randomly selected sampling points where radon measurements were performed. Additionally, a total of 300 radon concentration measurements at 1-m depth in soil were carried out, equally distributed between the three analysed areas.

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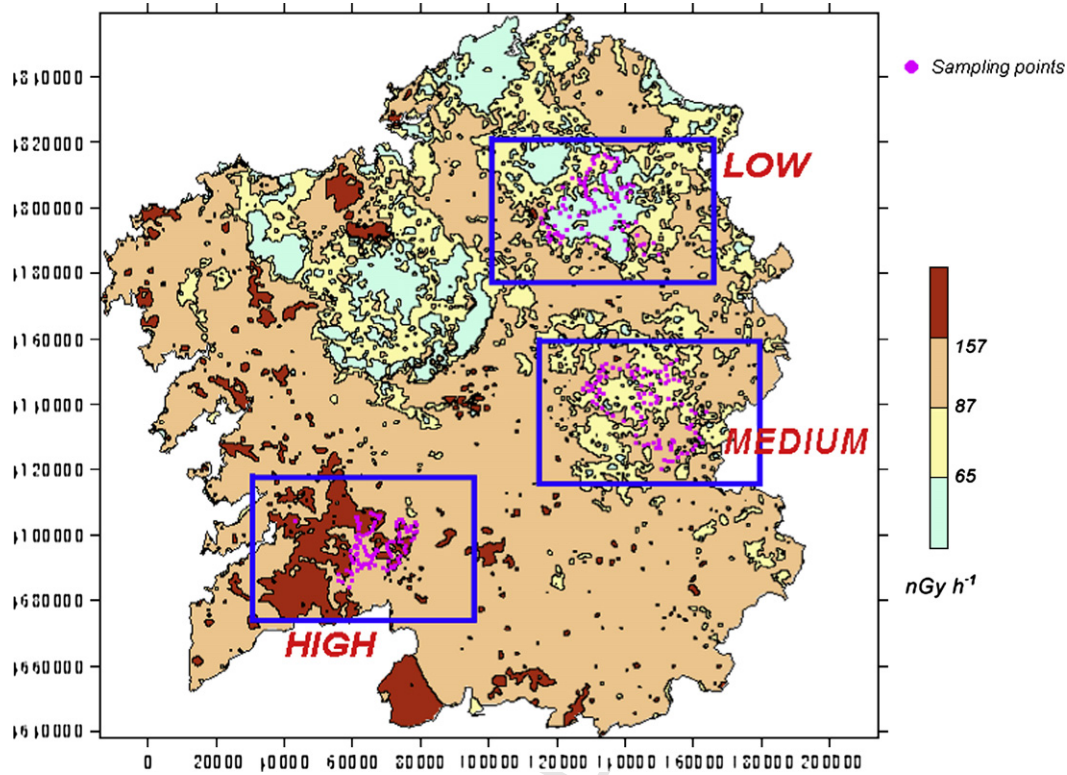


Fig. 1. External gamma radiation map of Galicia and the three analysed zones.

2. Material and methods

Each of the three analysed sub-zones was defined as a 25–30 km radius circle around a reference locality. The distinction between them was made according with mean MARNA's external gamma radiation exposure levels, which were lower than $87 \mu\text{Gy h}^{-1}$ for the low area, $87\text{--}130 \mu\text{Gy h}^{-1}$ for the medium level area and greater than $130 \mu\text{Gy h}^{-1}$ for the high level area.

External gamma measurements were performed by means of a Mini Instruments Environmental Monitor type 6-80 with an energy compensated Geiger-Müller tube MC-70, specially designed to measure environmental levels of gamma radiation, and a NaI(Tl) detector (Model GR-130, Exploranium Inc.). Both devices were calibrated at a national reference station called "Esmeralda" which belongs to the CIEMAT (National Centre for Energetic and Environmental Research and Technology). The GM tube showed a 20% variation in response to ^{60}Co photons relative to ^{137}Cs energy. On the other hand, the calibration factor used for the Na I (Tl) GR-130 device referred to the same relative variation was of 1.4. Combined standard uncertainty was on average 8% for external gamma exposures and ranged from 3% to 10% in gamma spectrometry measurements.

Table 1
Statistical summary of external gamma radiation measurements

(nSv h ⁻¹)		Arithmetic mean	Standard deviation	Geometric mean	DSG ^a	Interval
Low	UC	125.8	26.1	123.3	1.2	75.0–242.3
	MARNA	83.7	29.1	79.7	1.4	44.1–251.4
Medium	UC	127.2	19.4	125.7	1.2	68.1–171.7
	MARNA	88.4	19.4	86.4	1.2	47.7–143.1
High	UC	170.0	24.2	168.3	1.2	112.2–241.0
	MARNA	143.8	25.4	141.4	1.2	77.4–187.2

^a DSG is geometric standard deviation.

The measuring points were chosen in wide enclosures without near obstacles such as trees or buildings. At each point, devices were placed at 1-m height above the ground and the minimum counting interval was of 300 s.

At the same points, surface soil samples were collected for the radiological characterisation. Samples were weighed, air dried, and placed in an oven at 100 °C for 24 h. The sample was subsequently reweighed to determine the water content, sieved to remove stones and pebbles, and crushed to pass through a 1-mm mesh sieve. Finally, the prepared sample was packed in a sealable 250 ml PVC can and left for at least four weeks before counting by gamma spectrometry in order to ensure that radioactive equilibrium between ^{226}Ra , ^{222}Rn , and short-lived radon progeny was reached. Gamma spectrometry measurements were made using a low background HPGe detector with a relative efficiency of 20% and a resolution of 1.86 keV at 1.33 MeV.

One meter depth measurements in soil were performed by using the RTM 2010 radon monitor from SARAD GmbH. This system can pump air at different flow rates, uses semiconductor detector technology, is based upon alpha spectrometry of the radon progeny (^{218}Po and ^{214}Po) present inside the detector chamber, and covers a measurement range of radon concentrations from 10

Table 2
Statistical summary of radiological characterisation of soil samples

(Bq kg ⁻¹)		Arithmetic mean	Standard deviation	Interval
Low	^{226}Ra	34.1	20.9	11.3–137.7
	^{232}Th	50.6	27.6	16.4–159.3
	^{40}K	607	262	88–1335
Medium	^{226}Ra	35.6	18.8	5.0–149.7
	^{232}Th	55.7	20.5	8.2–142.1
	^{40}K	624	209	79–1265
High	^{226}Ra	82.2	32.1	22.7–184.3
	^{232}Th	71.0	43.0	15.5–212.9
	^{40}K	1022	243	76–1642

Table 3
Statistical summary of 1-m-depth radon measurements in soil

(Bq m ⁻³)	Arithmetic mean	Standard deviation	Geometric mean	DSG	Interval
Low	13 888	9125	11 522	1.9	2500–70 000
Medium	22 240	12 118	18 563	1.9	3000–70 000
High	61 703	43 101	45 844	2.3	7800–200 000

to 4×10^6 Bq m⁻³. Radon concentration can be recorded for different integration time intervals in a non-volatile memory. Individual uncertainty could be kept below 10% by using 1–10 min integration time intervals.

Finally, integrated measurements were made using two CR-39 track-etched detectors per randomly selected dwelling, placed at 1-m height on the ground floor (living room or bedroom) and exposed for a minimum of 6 months period in order to evaluate average indoor radon concentrations. The accuracy of this detection system has been checked with the successful participation in national intercomparison campaigns (CSN, 2004).

Every CR-39 detector was fastened under the cap of a cylindrical polypropylene container 55-mm high and 35-mm diameter with a small gap in its upper part which prevents radon decay products and also ²²⁰Rn from entering. Then, only alpha particles from radon that has diffused into the container and from the polonium produced inside can strike the detector. After the exposure time, an etching process is done, and radon concentration can be determined by counting the tracks in a given area. The overall individual uncertainty of radon measurements was estimated at less than 10%.

3. Results and discussion

Table 1 shows a summary of the 300 external gamma radiation values. The values obtained in this survey are systematically higher than those given by MARNA map. One reason is that University of Cantabria values took into account gamma exposure due to soil and cosmic radiation, whereas in MARNA values this latter contribution, 0.34 nSv h⁻¹ on average in the three areas surveyed (Quindós et al., 1993), was not well defined. On the other hand, since MARNA values were obtained from aerial measurements (Quindós et al., 2004), the differences with ground measurements must be taken into account.

In Table 2, the main statistical indicators of the radium, thorium and potassium content in soils are shown. As it can be seen, the comparison between values obtained in the low and medium areas shows no significant differences, as was observed with the external gamma values. This fact indicates that from the point of view of these two types of measurement, the low and medium regions could be considered as only one.

The statistical analysis of the distributions of 1-m-depth radon content in soil shows significant differences between the low and medium zones as well as between the medium and high areas (Table 3).

Table 4
Statistical summary of indoor radon measurements

(Bq m ⁻³)	Arithmetic mean	Standard deviation	Geometric mean	DSG	Interval
Low level zone	101.2	119.9	72.2	2.1	13–993
Medium level zone	168.2	202.7	105.9	2.4	20–1057
High level zone	348.4	243.5	280.3	2.0	49–1330

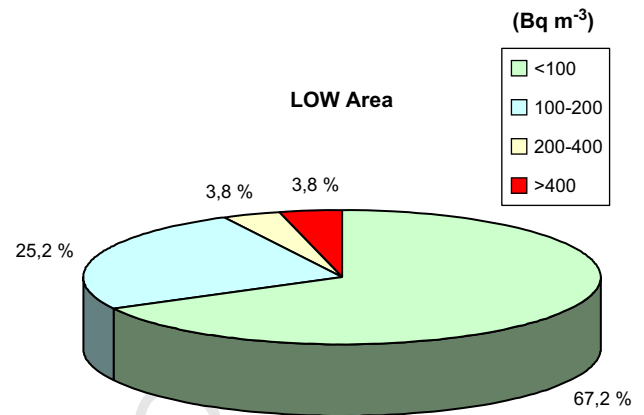


Fig. 2. Percentage of dwellings with radon concentrations in different ranges for the low external gamma radiation level zone.

Finally, Table 4 shows a summary of the indoor radon measurements in dwellings for each of the three external gamma exposure rate zones. These values confirm the clear distinction between the zones indicated above with the radon soil content measurements. More detailed information about the radon concentration distribution for each zone can be seen in Figs. 2–4. The percentage of houses with radon levels exceeding 200 Bq m⁻³ (EU recommendation concerning radon concentrations in new houses) (EU Council Directive, 1990) was of 7.6%, 21.9% and 68.5% for the low, medium and high areas, respectively.

Radon content in soil gave more accurate indoor radon predictions than external gamma radiation or ²²⁶Ra concentration in soil. The three studied areas show approximately the same ratio between the geometric mean values of indoor radon and radon concentration in soil (Tables 3 and 4). This fact looks reasonable if we take into account that some additional soil permeability measurements gave similar variation ranges for the three zones.

As a conclusion, exposure due to external gamma radiation can only be used as a qualitative indicator of high indoor radon

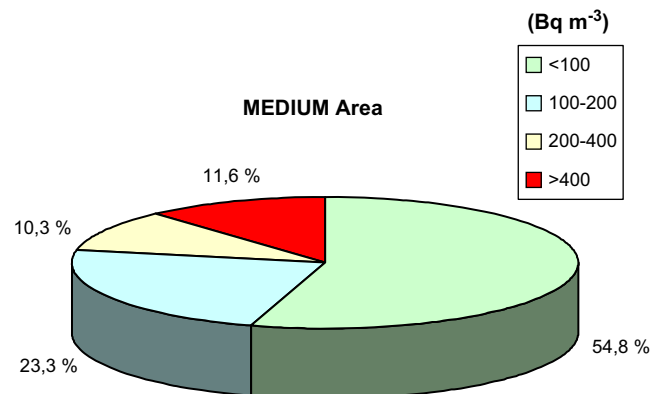


Fig. 3. Percentage of dwellings with radon concentrations in different ranges for the medium external gamma radiation level zone.

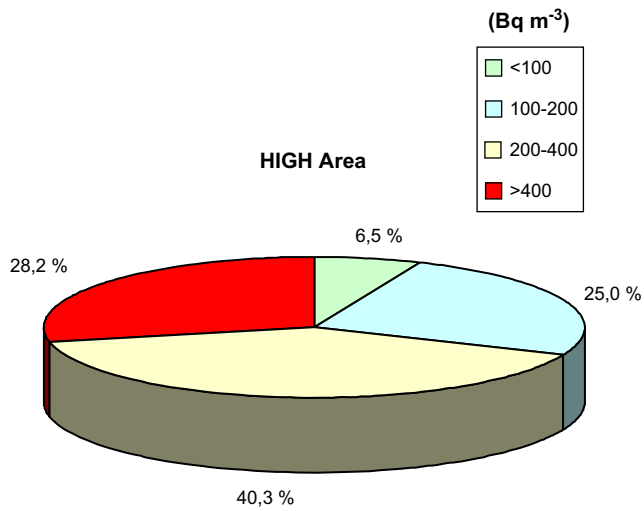


Fig. 4. Percentage of dwellings with radon concentrations in different ranges for the high external gamma radiation level zone.

concentrations when extensive areas are studied. For this reason, MARNA map can be useful for a great-scale radon

campaign set up. However, no quantitative indoor radon prediction can be calculated from it.

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