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Spanish experience on the design of radon surveys based on the use of geogenic information

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A B S T R A C T

One of the requirements of the recently approved EU-BSS (European Basic Safety Standards Directive, EURATOM, 2013) is the design and implementation of national radon action plans in the member states (Annex XVIII). Such plans require radon surveys. The analysis of indoor radon data is supported by the existing knowledge about geogenic radiation. With this aim, we used the terrestrial gamma dose rate data from the MARNA project. In addition, we considered other criterion regarding the surface of Spain, population, permeability of rocks, uranium and radium contain in soils because currently no data are available related to soil radon gas concentration and permeability in Spain. Given that, a Spanish radon map was produced which will be part of the European Indoor Radon Map and a component of the European Atlas of Natural Radiation. The map indicates geographical areas with high probability of finding high indoor radon concentrations. This information will support legislation regarding prevention of radon entry both in dwellings and workplaces. In addition, the map will serve as a tool for the development of strategies at all levels: individual dwellings, local, regional and national administration.

1. Introduction

The design of the Spanish indoor radon map is part of the framework of the Joint Research Centre (European Commission) plan for the elaboration of the European Indoor Radon map, as a part of the Atlas of Natural Radiation (Dubois et al., 2010; Tollefsen et al., 2011; Bossew et al., 2015; De Cort et al., 2011). This atlas will support policies in the field of public health, and it will contribute to increase the general public's awareness of the annual dose due to natural radioactivity.

A number of studies in various countries have proved that there is a clear correlation between exposure to radon inside buildings and the risk of developing lung cancer (ICRP, 2010, 2011). Radon gas is responsible for between 3 and 4 per cent of deaths caused by this illness in the first world (IAEA, 2011; WHO, 2009), being the main source of ionizing radiation (EURATOM, 1990, 1996, 2013; ICRP, 1994). Therefore, it is crucial to determine the areas where there is a greater probability of finding buildings with higher radon concentrations, as well as to analyse the variables which affect radon concentrations inside buildings.

Indoor radon concentration varies geographically. This is due to the large number of factors that affect radon appearance in buildings, such as the geology of the areas upon which buildings are constructed, soil permeability, specific rock characteristics, the meteorology and topography of the region, the proximity of active fault lines, the materials employed in construction, the design features of the buildings and the lifestyle habits of the occupants (García Talavera et al., 2013a). In our work we used a geographic information system (GIS) which enabled us to capture, store, create searches, analyse and visualize the statistical data we obtained. In order to adapt to the design of the European Indoor Radon map, Spain followed national (CSN, 2012a; CSN, 2012b) and international legislation (ICRP, 1993, 2009, 2014).

This paper aims to produce a radon map of the Spanish territory that shows the probability of finding areas with levels of radon indoors, and is related to the European legislation that has to be implemented in the member states before the end of 2018

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(EURATOM, 2013). This map will be a very useful instrument for applying the requirements of European legislation on the radon issue at all administrative levels: national, regional and local.

2. Methodology

2.1. Definition of the grid

The grid was generated using the programme ArcGIS where the extreme corners are defined by established coordinates in the European Datum 1950 UTM Zone 30N (ED50) projection system: Peninsular Spain NW (433193,87; 4834808,73) SE (692906,43; 3961069,60) Canary Islands NW (692915,11; 3320469,29) SE (698454,23; 2988008,14). These coordinates were converted to longitude-latitude ED50 (decimal degrees) to generate a 10 × 10 km^2 grid of the Spanish surface in Google Earth format (.kml). The ED50 system is an old geodetic reference system used in Europe and has been used in coexistence with the ETRS89 in Spain until 2015. The parameters of this system are defined in the ArcGIS.

In order to follow a similar scheme as other EU member countries, we began working with a continental level projection system (GISCO-Lambert Acimutal Equal Area) suggested by the Joint Research Centre of the European Commission (Dubois et al., 2010; Tollefsen et al., 2014). The Lambert Azimuthal Equal Area projection is a planar projection, which means that map data are projected onto a flat surface.

In this way, measurements between countries can homogenized and the so call border effect avoided. We took into account those parameters set by the Joint Research Centre to convert the coordinates ED50 to GISCO-LAEA. Therefore we obtain the following limits for 10 × 10 km^2 grid: Peninsular Spain NW (−1500000; −301000) SE (−351000; −1350000) Canary Islands NW (−2700000; −1900000) SE (−2150000; −1650000).

To define the working area, we used the administrative boundaries provided by the National Geographic Institute (IGN, 2014). Thus we generated a total number of 5478 cells of 10 × 10 km^2 surface. For each cell, an identifying code was created and its centroid in meters ("x" and "y" coordinates) calculated. The statistical data obtained from the measurements were georeferenced to the centroid.

2.2. The measurement campaigns

The Spanish indoor radon map comprises, to date, 9211 measurements, obtained over successive sampling campaigns (Fig. 1). In each campaign, a series of measurements for each cell was defined, taking into account superficial, population, external gamma dose (MARNA Project) (Sainz Fernández et al., 2014; Suarez Mahou and Fernandez, 1997, Suárez Mahou et al., 2000; Quindos et al., 2004; Quindós et al., 2008) and lithostratigraphic criteria. To decide the number of measurements per cell, it was essential to prioritise objectives and establish criteria. The decision on which criteria to use was made taking into account the objectives behind the European Radon map.

1. Surface criterion: The whole Spanish territory had to be covered by, at least one measurement per 10 × 10 km grid cell. 478 cells out of 5478 total number of cells are inhabited and no data were collected. Thus, the lowest number of possible measurements was done over 5000 cells.
2. Population criterion: In the first measurement campaign, an extra measurement was done for each town with a population exceeding 50,000 inhabitants, based on the Spanish National Statistics Institute (INE, 2014). Hence, an additional 1000 measurements had to be made according to this criterion. In the second campaign this criterion was expanded to require a minimum of 6 measurements in cells including towns with populations larger than 200,000. A further 123 measurements were taken to meet this criterion.
3. MARNA criterion: Considering the importance of the geological factor it was decided to increase the number of measurements in areas with high radon potential. The starting point was the MARNA project (Suárez Mahou et al., 2000). MARNA determines potential radon emissions by taking into account the correlation between ^{226}Ra concentration in the soil and outdoor gamma dose levels.

This criterion is based from 7400 locations where measurements were performed to determine the potential for radon emission. These locations were linked to the 10 × 10 km^2 cells, so-called MARNA cells. The different levels of exposure assigned to each cell correspond to the town with the higher dose. During the first campaign, additional measurements were taken in each cell identified in the MARNA project with a gamma exposure level over 35 nGy/h [4 μR/h]. 2 additional measurements were added for each location that exceeded 35 nGy/h [4 μR/h].

By doing so, 2000 additional measurements were made (Sainz Fernández et al., 2014). Throughout the second campaign, measurements focused on towns with a gamma exposure level between 65 and 122 nGy/h [7.5 and 14 μR/h] (median risk) and

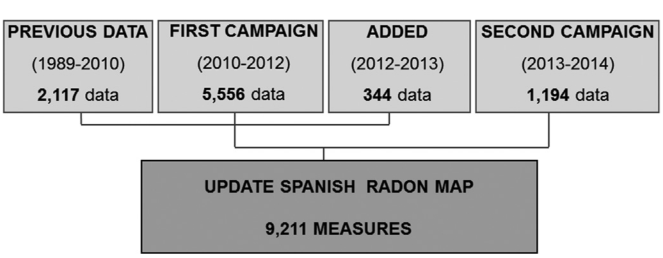

Fig. 1. Description of the sampling campaigns carried out towards the development of the Spanish indoor radon map.

Table 1
Description of the spatial units of interest as used in this work and their lithostratigraphical definition.

Lithostratigraphic unit code (IGME)	Lithostratigraphy definition
130	Limestones, calcoschists and whiteboards
131	Micaschists, gneises, phyllites, quartzites and plasters
133	Micaschists, quartz and gneises
79	Slates, sandstone and quartzite. Series of los Cabos
85	Slates, sandstones and microconglomerates. Slates from Lancea
86	Quartzites, shales and rocks volcanocl. and volcanised. Quartzite from Barrios and FM Oville
91	Slates and sandstones. Huergas slates
104	Quartzites, slates, sandstones, shales, limestones and dolomites. Paleozoic Iberian Aragon
117	Quartzites and slates
369	Shales with interbedded carbonate and gypsum
7	Plutonic basic Hercynian rocks (gabbros, dioritas, tonalite, ultramafic rocks)
2	Acid rocks metamorphic (Otogneises,migmatitas). Gn. gland., metarriolitas (Ollo Sapo).
127	Phyllites, schists, quartzites, limestones, slates and corneal (metamorphic)
152	Sandstones, sands, sandy limestones, marls, clay and loamy
153	Sandstones, shales and marls
173	Limestone reef, rudistas, bioclastic limestones, dolomites and marl
174	Marl, limestone, clay and dolomites