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Natural gamma radiation map (MARNA) and indoor radon levels in Spain

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Abstract

During the last decade, the Department of Applied and Medical Physics has been involved in the development of a radiation protection programme. In the framework of this programme, measurements of indoor radon, principally, have been carried out nationwide. Geometric mean radon concentrations of 45 Bq m^{-3} in the whole country and 130 Bq m^{-3} in the high natural radiation area have been estimated. On the other hand, the so-called MARNA Project is developed into the framework of an agreement subscribed between the Spanish Nuclear Safety Council (CSN) and the National Uranium (ENUSA), the first phase of which has been the elaboration of the Natural Gamma Radiation Map of Spain on the scale of 1:1,000,000 using radiometric data generated in the 30 years of the lifetime of the ancient National Uranium Exploration and Investigation Plan mainly through airborne, carborne, and by foot surveys, within the MARNA Project itself. The lowest averaged dose rate from external gamma radiation (19.3 $nGyh^{-1}$) was found in carbonate bedrock and the highest (87.7 $nGyh^{-1}$) was found in granite and clay bedrock.

This paper summarizes the main results obtained from the measurements performed in both projects, with special interest in those concerning the correlation between the data reported in order to conclude about the potential benefit of the MARNA maps in the definition of affected areas in the country.

Keywords: Radiation; Gamma; Radon; Survey

1. Introduction

Spain consists of 50 provinces, which are amalgamated to form 17 different autonomous regions. Fifteen of these are located on the Iberian mainland while the other two, the Balearic and Canary Islands, are offshore. The North African cities of Ceuta and Melilla are administratively depending of the southern province of Malaga. It could be said that the Spanish Radon Programme began in 1988 with the development of a national survey in Spanish houses. At the present time, 12 years after, many activities performed by different institutions and universities have been developed and a good information about the Spanish radon problem has been achieved. Indoor radon measurements in over 5000 houses have been made, to date, by the following survey types: two local surveys, in the cities of Madrid and Barcelona; three regional surveys in the Canary Islands, Community of Valencia, and Cantabria; one nationwide survey in rural area dwellings; and two new, more specific surveys in the vicinity of the Spanish nuclear power stations and old uranium mine facilities of the country. The main results obtained from these surveys are shown in the references and from them it has been possible to define the actual status of radon in Spain as well as to organize the future in this field (Quindós et al., 1991, 1994, 1998; Gutierrez et al., 1992; Colgan, 1995).

The MARNA Project, being developed into the framework of an agreement subscribed between the Spanish Nuclear Safety Council (CSN) and the National Uranium Company (ENUSA), consists of four phases, with the first three having been already finished successfully in late December 2000. The final objective of this project was the elaboration of the natural gamma radiation map of Spain on the scale of 1:1,000,000 by using radiometric data generated in the 30 years of the lifetime of the ancient National Uranium Exploration and Investigation Plan, mainly through airborne, carborne, and foot surveys, and those

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obtained within the MARNA Project itself. At present, four other pilot maps on the scale of 1:50,000 accomplished for four radiometric zones of special interest and three more on the scale of 1:200,000 for the autonomous communities of Extremadura, Castilla-Leon, and Galicia are also available.

The research activities mentioned above have been carried out by two independent and different groups. In this paper, the main results and correlations have been selected from the whole data accumulated in order to improve the characterization of the affected areas in the country where a development of special programmes to minimize the exposure of the public to natural radiation sources is needed.

2. Materials and methods

The available radiometric data come from uranium deposit prospecting campaigns undertaken up to 1980 by the former Junta de Energía Nuclear and subsequently by ENUSA. As a whole, they provide information on more than 30 years of radioactive mineral prospecting from both ground and airborne measurements. The first includes data from regional and general prospecting campaigns carried out on grids covering between 200 and 1000 m, even less in some cases. The measurements correspond to exposure rate and are expressed in microroentgen per hour ($\mu R\ h^{-1}$). In addition to these measurements, there are others from self-supporting radiometric prospections in which the measuring equipment was installed on jeeps that took measurements on passable roads, obtaining a continuous data recording. All ground measurements covered the gamma energy spectrum from 0.4 to 2.7 MeV. Concerning aerial measurements, available data are referred to total radiation starting in 1968 and ending in 1975. To obtain these data, total count detectors that also covered the gamma energy band between 0.4 and 2.7 MeV were used. In both cases, background radiation influence was removed. Flights were made at an altitude of less than 120 m and the records were obtained in a continuous band and were corrected by flight altitude to reduce them to a standard altitude of 70 m (Suarez et al., 1995). These flights were made according to flight paths separated by 600–1000 m and covered an area of some 200,000 km^2. The equipment used was the Saphimo SRAT SPAT-2 and SPAT-3.

It is obvious that the exposure rate measured at 1 m above the ground does not coincide with that one obtained at 100 m above, since the first is from the point and the second includes radiation coming from a circle with a radius two times the flight altitude. It was considered that the latter measurement is the most representative one of the surroundings. In other words, for a standstill person, the ground measurement would be exact, but as this is not the case because a person moves around his surroundings, the aerial measurement is more representative. On the other hand, the cost of a map based on point measurements would be

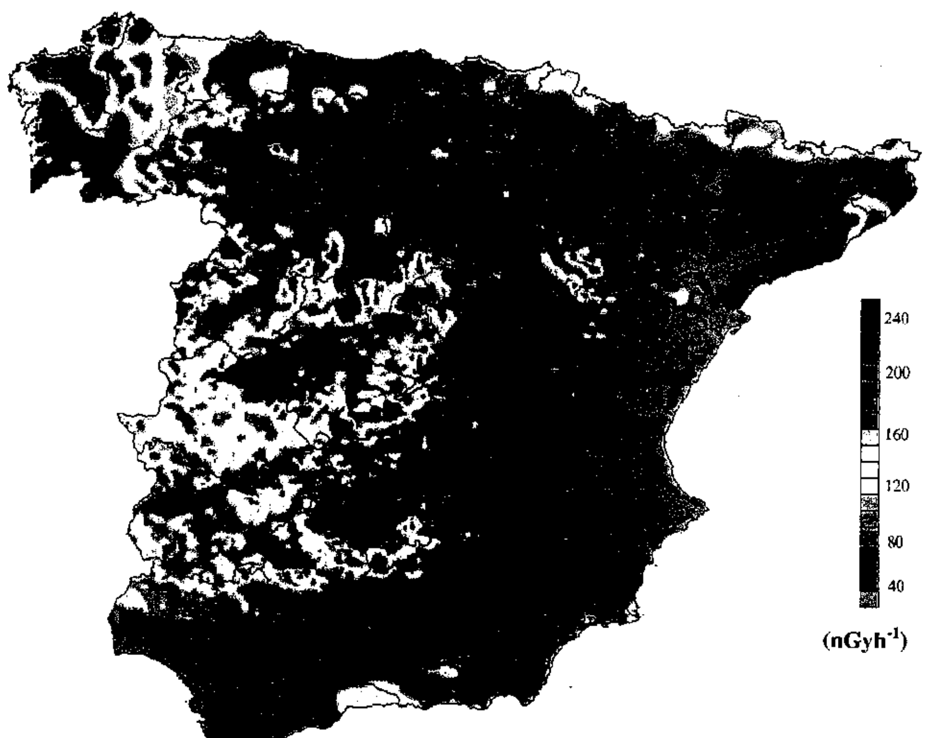

Fig. 1. Natural gamma radiation map of Spain.

Table 1
External gamma radiation for different types of rocks

Rocks	Potassium[a] %	$nGyh^{-1}$	Thorium[a] ppm	$nGyh^{-1}$	Uranium[a] ppm	$nGyh^{-1}$	Total ($nGyh^{-1}$)
Basalt							
Average	0.8	10.5	4.0	10.5	1.0	5.3	26.3
Range	0.2–2.0	2.6–26.3	0.5–10	0.9–26.3	0.2–4.0	0.9–21.0	4.4–74.5
Granite							
Average	3.0	39.5	12.0	31.6	3.0	16.7	87.7
Range	2.0–6.0	26.3–79.0	1.0–25	2.6–67.5	1.0–7.0	5.3–39.5	35.1–184.2
Clay							
Average	2.7	36.0	12.0	31.6	3.7	20.2	87.7
Range	1.6–4.2	21.9–56.1	8.0–18.0	21.0–47.4	1.5–5.5	8.8–30.7	52.6–131.6
Sandstone							
Average	1.1	15.0	1.7	4.4	0.5	2.6	21.9
Range	0.7–3.8	8.8–50.9	0.7–2.0	1.8–5.3	0.2–0.6	0.9–8.8	8.8–61.4
Carbonate							
Average	0.3	3.5	1.7	4.4	2.2	11.4	19.3
Range	0.1–2.0	0.9–26.3	0.1–1.7	0.9–18.4	0.1–9.0	0.9–48.2	0.9–87.7

[a] 1% K = 310 $Bq\ kg^{-1}$; 1 ppm Th = 4 $Bq\ kg^{-1}$; 1 ppm U = 12.3 $Bq\ kg^{-1}$.

prohibitive and would have required many more measurements to achieve the representativity of an aeroradiometric map. There are more than 150,000 aerial measurements for 1:50,000 topographical sheets from the records originally available, which were reduced to one datum per square kilometer.

Fig. 2. Geological map of Spain.

To establish correlations between aerial and ground measurements, specific areas were studied to cover the entire radiometric range of geological backgrounds by using different equipment, car, and crossover measurements. Some 7000 ground measurements were taken in these specific areas and correlation coefficients exceeding 0.92 were obtained.

The data bank computerization was made using the Symphony, StatGraf, Surview, Golden, and Rtockware programs. To draw up the map to scale of 1:1,000,000, mean radiometric values, equivalent to 16,000 data corresponding to a grid measuring 7×5 km have been used. Their representativity was very good in the Extremadura, Castilla-Leon, and Galicia regions, and good in the zones where information was available from aerial and terrestrial prospections. In zones where no measurements were available, an estimate was made by geological extrapolation. Finally, all data regarding geographical coordinates were converted to standard UTM coordinates and radiometric data to adsorbed dose rate in nanogauss year per hour (1 μR $h^{-1} \cong 8.77$ $nGyh^{-1}$) in a generalized data base.

Time-integrating measurements of indoor radon concentrations in air were made for 80% of the total using solid state nuclear track detectors from Terradex (Tech/Ops Landauer, USA). The rest (20%) were made by using polycarbonate detectors and, in both cases, intercomparison exercises have been carried out to validate the results of these measurements (Miles et al., 1996). All of them were placed in ground floors (living room or bedroom) of rural dwellings using exposure periods of 1–6 months (Quindós et al., 1993).

3. Results and conclusions

The main results achieved from the MARNA Project are summarized in Fig. 1 and Table 1. The first shows the ground external gamma dose rate experimentally measured and the second the average values derived for different types of rocks throughout the country, basically corresponding with the geological map shown in Fig. 2. As predicted, a good relationship between both maps was found from a general point of view. Highest external

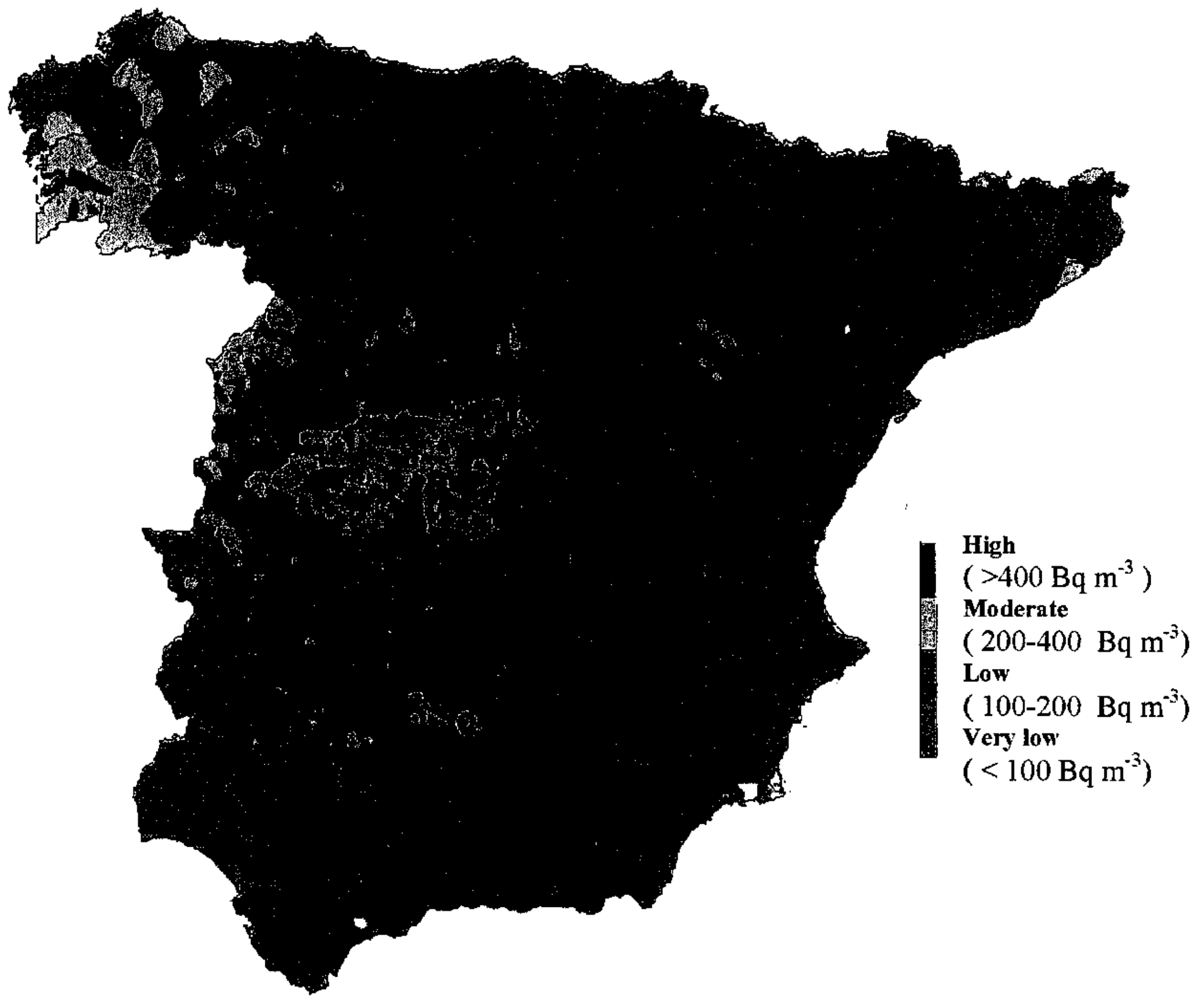

Fig. 3. Map of Spain based on indoor radon measurements.

Table 2
Indoor ^{222}Rn levels measured in nationwide and specific areas surveys of Spain

Surveys	Number of dwellings	Geometric mean (Bq m^{-3})	Geometric standard deviation	Percentage of houses with indoor ^{222}Rn>200 (Bq m^{-3})
Nationwide survey	4344	45	2.9	9
High indoor ^{222}Rn levels areas	620	130	2.1	25
Vicinity of the nuclear power stations	214	30	2.6	8
Vicinity of the old uranium mines	222	90	2.3	10

gamma radiation levels were found on granite bedrocks with an average of 87.7 $nGyh^{-1}$ and a range from 35 to 184 $nGyh^{-1}$. On the other hand, the lowest levels were found on carbonate bedrock with an average of 19.3 $nGyh^{-1}$, ranging from 0.9 to 87.7 $nGyh^{-1}$. Using these data obtained from aerial prospection, potential radon levels in the air can be roughly assessed by assuming that geological units present homogeneously distributed uranium and by taking into account factors such as radium content, density, emanation factor, porosity, and diffusion coefficient of the soils (Akerblom, 1995; Suarez et al., 1995). Using typical values for these factors appearing in the bibliography (Nazaroff et al., 1988), the potential radon map for the whole country shown in Fig. 3 has been built without taking into account other indoor parameters affecting radon entry, such as soil permeability or pressure differences.

Concerning radon measurements, Table 2 compiles the average indoor radon levels measured in 5400 houses, including those developed in specific areas of the country. Fig. 4 shows the national distribution map of indoor radon concentration corresponding to these measurements.

As it can be seen from the analysis of Figs. 3 and 4, the predicted and measured average indoor radon concentrations show a good correlation. This correlation has been found on a national basis (scale of 1:1,000.000), showing the interest of maps as those from MARNA Project when data as shown are available, minimizing costs and efforts in the development of national radon programmes. However, in order to confirm these data for lower scales (1:50,000), both research groups, MARNA and RADON, are planning to carry out a pilot study on two geographical areas for which sufficient geological information exists and actual measurements of radon concentrations in the air will be available.

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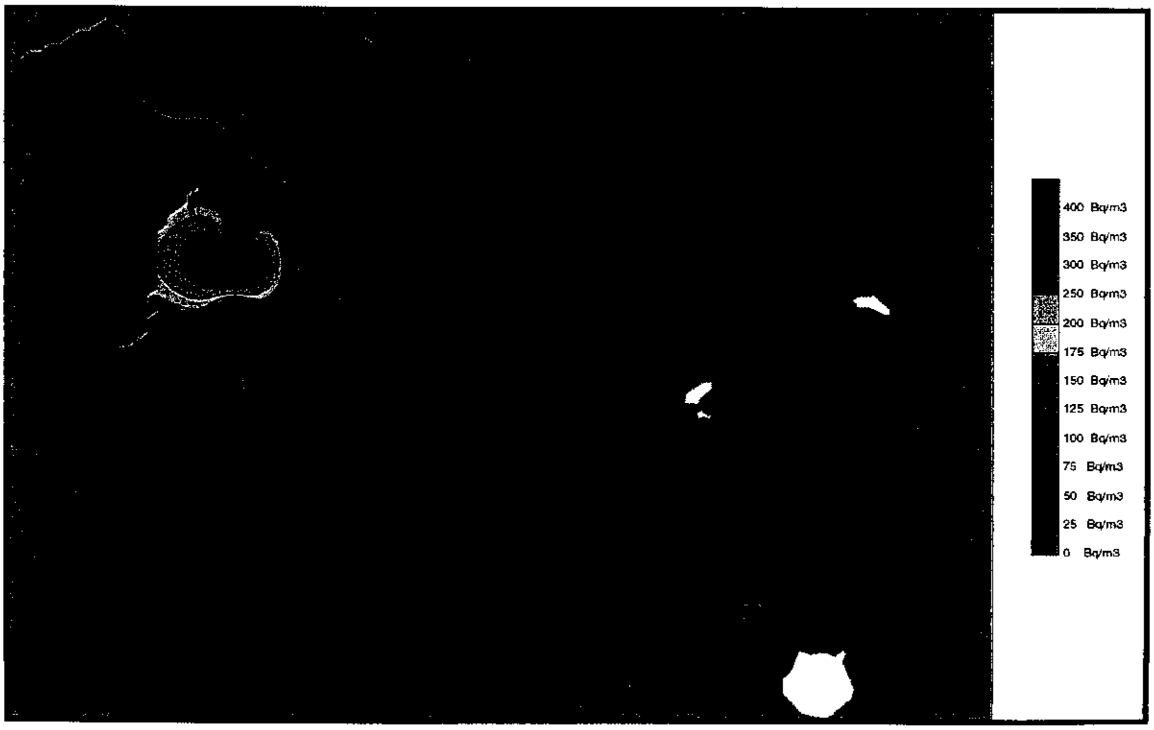

Fig. 4. Predicted map of potential indoor radon concentrations based on MARNA Project.

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