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A brief history of radon measurements and remediation in Spain

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Abstract

Indoor radon levels usually present highly spatial and temporal variations. Natural daily and seasonal cycles as well as other factors like geology, occupancy or weather conditions make the long term average radon level measurements the most suitable way to draw the radiological situation concerning radon in extensive areas. As the risk of lung cancer increases with the increasing radon exposure, this kind of measurements represents the first step to assess risks in exposed population. During the last 30 years the Medical Physics Group of the University of Cantabria (Spain) have carried out several national campaigns of indoor radon measurements which have provided radon values in more than 5000 dwellings.

Complementarily to the measurement campaigns, when high radon levels are found remedial actions have to be taken into consideration. The aim of radon remediation is not only to reduce indoor radon levels but to do so with minimal impact on the building structure and occupants. With regard to this important issue our Radon Group has been testing the effectiveness of several remediation systems in a model house located at a high background radiation area.

In this presentation, a summary of the different nationwide measurements is shown. Also some conclusions derived from the essays with different remediation techniques and last news about the future building code to be approved by the authorities during this year will be presented.

Introduction

Nowadays there is a wide scientific consensus about the role of residential radon as a lung cancer risk factor (Darby, 2004)(Krewski, 2005). Since more than thirty years ago, the interest in this main source of natural radiation have promoted the development of national surveys in order to evaluate the average radon levels in houses and locate the areas with a potential risk derived from radon and radon progeny inhalation.

In Spain, the first national radon measurement campaign began in 1988 (Quindós, 1991). The data coming from the 2000 measurements carried out in this survey represented the first step to rise the issue of radon in Spain. In addition since 1991 the Spanish Nuclear Safety Council, together with the National Uranium Company and some Universities have developed the so-called MARNA project (Suarez, 1997)(Quindós, 2004). This project is a nationwide study with the aim of estimating potential radon emission from external gamma dose rates and radium calculations taking into consideration geological parameters and empirical correlations found between outdoor external gamma dose rates and ^{226}Ra concentration in soil. As a main result, this project provides useful maps of the country where the zones with different gamma radiation levels are showed (Fig.1).

From the information obtained in these two studies, several regional surveys and another national one have been carried out until now. Surveys have usually included a broader approach to exposure to natural sources of radiation to people living in the studied areas by measuring external gamma dose rate and radioactivity in soils together with indoor radon.

Indoor radon measurements were performed by using track etched detectors CR-39 exposed for a six-month period in order to evaluate average radon concentration values. In all the measurements, a seasonal correction factor was assumed in order to mke the results obtained over a six month period representative of the actual mean annual indoor radon concentration (Miles, 2000).

Complementarily to the measurement campaigns, when high radon levels are found remedial actions have to be taken into consideration. The aim of radon remediation is not only to reduce indoor radon levels but to do so with minimal impact on the building structure and occupants. In existing houses, the methods to reduce radon concentration are based on dilution and/or pressure changes by means of a pressure modifying sump, often in conjunction with an extraction fan. On the other hand, for new build houses, the installation of radon proof membrane across the entire footprint of the house seems to be the most useful way to prevent radon entry (Scivyer, 2007). With regard to this important issue our Radon Group has been testing the effectiveness of several remediation systems in a model house located at a high background radiation area.

Brief description of surveyed areas and main results

Surroundings of the Spanish Nuclear Power Plants

During 1998 and 1999, financially supported by the Spanish Nuclear Safety Council, regional surveys were conducted to evaluate natural radiation exposure of the people living in the vicinity of the Spanish nuclear power stations. There are six facilities working in the country and the population of these regions is about 200000. In these surveys, indoor radon, external gamma dose rates outdoors and indoors, and radioactivity in soils were measured.

A remarkable result was found in the surroundings of Almaraz nuclear power plant in the province of Caceres where the highest mean annual effective dose to the population was found (Quindós, 2003). The estimated value, of 4.07 mSv y^{-1}, is 1.6 times higher than the national average value. The reason of this significant difference in dose value with the other nuclear power stations was the high radon concentrations found in homes. So, in order to perform a more accurate assessment of the dose coming from radon in this area, a new and more extensive survey on indoor radon was carried out in the named Campo Arañuelo region around the Almaraz nuclear power station.

Furthermore the increase of accuracy in dose assessment, this study revealed the presence of a high radon level area called La Vera in the northern side of the Campo Arañuelo region. It was found in La Vera a 9 % of houses with indoor radon concentrations higher than 400 Bq m^{-3}. In addition, the new dose assessment gave a value of 6 mSv per year in La Vera, with a maximum of 25 mSv per year estimated in Jarandilla, a town belonging to the former area where 30 % of houses had radon concentrations over 400 Bq m^{-3}.

Vicinity of the Spanish old Uranium Mines

From 2000 to 2001 and under the sponsorship of the Spanish Nuclear Safety Council the surveys in the six uranium-mining areas in the country were carried out. The mines are mainly located in the western part of Spain and their surface area shows prevalence of calcite carbonatite, gramodiorites and methmorphic slate rocks on its composition. The exploitation period ranged from 1950 to 1980, and between 1987 to 1996, a general decommissioning plan was carried out. One of the main objectives of the plan was to reduce and control radon flow and contamination of water. The population of these areas is over 400,000 inhabitants.

The highest geometric mean radon concentration and annual effective dose for natural sources, of 111 Bq m^{-3} and 5.1 mSv y^{-1} respectively, were found in the surroundings of Albala uranium mine (Quindos, 2004). Estimated mean annual effective doses for the six areas studied ranged between 3.2 to 5.1 mSv per year, which is between 1.2 and 2 times higher than the national average value. A 14 % of houses over 400 Bq m^{-3} were found in the vicinity of the Albala uranium mine.

Sierra de Guadarrama

The area called Sierra de Guadarrama situated in the North of the province of Madrid has been subject of another regional survey. The first national study showed high percentages of houses with radon concentrations higher than 200 and 400 Bq m^{-3} (European Union recommendation concerning radon concentrations in new and old houses, respectively)(EU, 1990). Due to the prevalence of granitic rocks in the soil composition of this area and the considerable residential growth (the population of this region has been increased from about 500,000 people in 1990 to 1.5 million in 2000) a regional survey is now ongoing from 2002.

Until now, the indoor radon measurements indicate that the 14 % of houses have levels above 400 Bq m^{-3} and 30 % above 200 Bq m^{-3}. Also, the geometric mean radon concentration is 180 Bq m^{-3} which is about 4 times higher than the national average value.

Villar de la Yegua town

Perhaps the most important high background radiation area in Spain is the Villar de la Yegua town where the highest indoor radon concentration, up to 25,000 Bq m^{-3}, have been found, and effective doses coming from natural sources as high as 40 mSv per year has been estimated. Several surveys have been carried out from 1988 to now, confirming Villar de la Yegua as a high radon level area (ICRP, 1994). The main results concerning radon concentration show a geometric mean of 818 Bq m^{-3}, 18.2 times higher than the national value, and percentages of houses with concentrations above 400 and 1000 Bq m^{-3} , of 75 % and 25 % respectively.

For these reasons it is clear the convenience of carrying out epidemiological studies in the health effects of natural radiation exposure to the population living in this town, even bearing in mind its small population, of about 500 people.

Effectiveness of different remediation techniques

In 2004 a two storied model house was built in a high background radiation area. Entry of radon into a dwelling from the soil gas is influenced by factors like radon concentration in the soil gas itself, ground permeability and meteorological conditions in the vicinity of the dwelling. For this reason, radioactivity in soil together with radon in soil and permeability were measured prior to construction of the house in order to characterize the radon source term.

Once the construction was finished, indoor radon concentration as well as meteorological parameters like wind velocity, temperature, pressure and pluviosity were continuously measured for more than one year. Along this measuring period, several remediation techniques were tested. Continuous radon monitoring was done with several devices of type DOSEman and RadonScout (SARAD GmbH, Germany) placed in the first floor and cellar of the building. On the other hand, wind speed and amount of precipitation were provided by a nearby meteorological station whereas temperature and pressure values where continuously recorded throughout a number of sensors placed at different locations inside the house.

In a first phase before the test of the remedial actions a study about the influence of meteorological parameters on indoor radon concentration was carried out. This study was done with the dwelling closed for four months. During this time, average radon concentrations were of 7000 Bq m^{-3} in the first floor and 42000 Bq m^{-3} in the cellar, reaching maximum values of 40000 and 120000 Bq m^{-3}, respectively. The major influence on radon concentrations was found to be the changes in atmospheric pressure and, in a lesser extent, pluviosity. Atmospheric pressure drops were observed to be inversely correlated with significant increases on indoor radon playing the ultimate role in determining the long-term trend in gas concentration. Pressure changes could be effective in inducing the flow of soil air into the building by leading to a significant difference in pressure between the indoor air and the pore air in the nearby soil. On the other hand, amount of precipitation had a shorter-term influence which could be explained because the permeability of the wet soil surrounding the house in considerably lower than that of the dry soil under the construction. Under the above conditions radon soil gas would be forced to enter the house.

In the second phase, the remediation techniques essayed were:

- Natural air extraction from soil with lateral or central pipe
- Forced air extraction from soil with lateral or central pipe
- Pressurization/depressurization of air within the soil with central pipe
- Crossed ventilation in cellar

- Insulation barrier (polyurethane product directly applied in floor and walls of the cellar)

Except soil gas depressurization and crossed ventilation, all the above techniques showed efficiency above 90 % in reducing radon concentration in cellar as well as in the first floor. Generally speaking, the applied actions were more efficient when applied in the central pipe rather than in the lateral one.

Concerning the suitability, the application of a polyurethane compound directly projected to the floor and walls in the cellar would be the best option avoiding the necessity of forced ventilation systems. By this way, radon concentration was reduced until 300 Bq m^{-3} in the first floor and 1700 Bq m^{-3} in the cellar. Although inverse correlation could still be appreciated between radon concentration and atmospheric pressure, the thermal insulating effect of the polyurethane barrier could smooth indoor pressure changes thus collaborating to prevent the entry of radon via pressure difference. Finally, the application of radon proof barriers to the walls could also reduce the baseline level defined by emanation from the structure of the building itself, which can be relatively high depending on the type of materials used in construction.

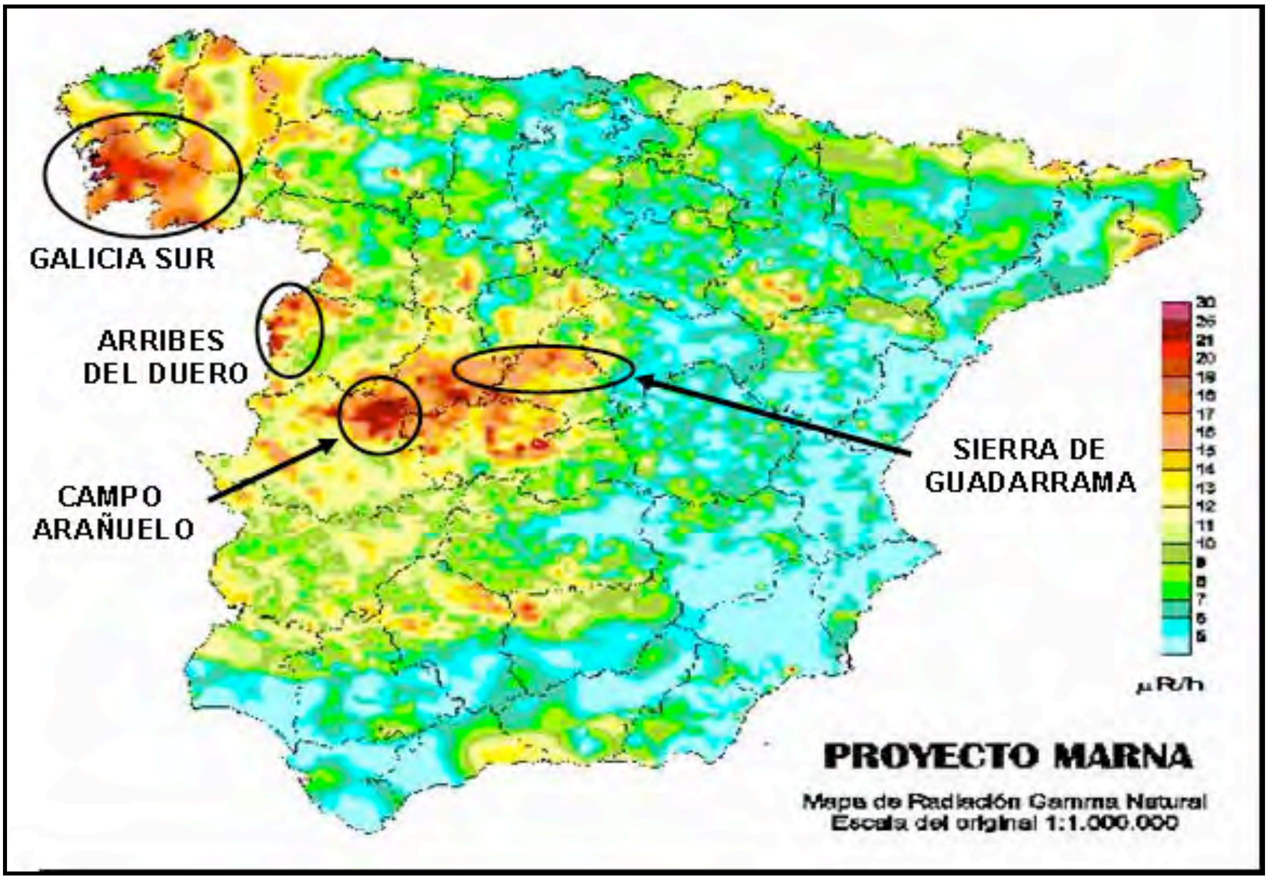

Fig. 1: External gamma radiation map of Spain with the radon prone areas found from the national and regional surveys carried out in the country

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