Two significant experiences related to radon in a high risk area in Spain

Carlos Sainz,
Jose-Luis Gutierrez-Villanueva,
Ismael Fuente,
Luis Quindos,
Jesús Soto,
Jose-Luis Arteche,
Luis S. Quindos Poncela

Abstract. Radon is a natural radioactive gas and it is currently accepted as being responsible for lung cancer in some cases. One of the most important sources of indoor radon is from the soil. The radium content of soil is also a very important factor to be taken into account. The natural radiation map of Spain (MARNA) classifies the country into three regions with different levels of natural gamma radiation. There are some areas in Spain with high levels of natural radiation one of those is the province of Salamanca. Western part of this province presents a population of 20 000 inhabitants and 7% of the houses have an indoor radon concentration above 400 $Bq \cdot m^{-3}$. In this high risk area, the village of Villar de la Yegua is of special interest: 11% of the houses in this village have an indoor radon level below 400 $Bq \cdot m^{-3}$, 89% have above 400 $Bq \cdot m^{-3}$ and 71% of the houses have a radon concentration above 1000 $Bq \cdot m^{-3}$. An old uranium mine site close to this village has been selected for the construction of an experimental pilot house. It is a two story house located in the place with a very high ^{226}Ra concentration in soil. Radon in soil at 1 m depth has an average level of 250 $kBq \cdot m^{-3}$. We present in this work the characteristics of the experimental unit located in this high risk area and we describe the zone where one of the Spanish villages with the highest radon concentration is located. This is a very interesting place for further research on indoor radon concentration and it is a unique opportunity of testing radon monitors, radon passive detectors and remedial actions for the mitigation of radon in real conditions. It is common to carry out intercomparison exercises under laboratory conditions. Nonetheless, it is not so common to develop these exercises in real conditions as we have in the experimental unit we present here. We offer in this work the possibility for other research groups of testing their equipments in this unit and we also show the evolution of the works carried out in the locality of Villar de la Yegua.

Key words: radon • workplace • mitigation • pilot house

C. Sainz, J.-L. Gutierrez-Villanueva✉, I. Fuente,
L. Quindos, J. Soto, L. S. Quindos Poncela
RADON Group,
Faculty of Medicine,
University of Cantabria,
c/Cardenal Herrera Oria s/n, 39011 Santander, Spain,
Tel.: +3494 220 2207, Fax: +3494 220 1903,
E-mail: gutierrezjl@unican.es

J.-L. Arteche
AEMET, State Meteorological Agency of Spain,
c/Ricardo Lorenzo s.n, 39012 Santander, Spain

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Introduction

It is widely known that radon gas is the main source of annual radiation dose. In the case of Spain, annual dose due to radon represents 47% of the total dose received by general population [5]. In 1991, a project to determine the estimation of the radon concentrations started. This was called the MARNA project and it concluded in 2004 [6]. The Radon Group at the University of Cantabria started to work on radon surveys in 1988. The Spanish Radon Programme started its activities at that time. The Radon Group carried out a series of radon surveys to get around 2000 values of radon concentration indoors. These results are a very useful tool in order to determine high background radiation areas (HBRA) in Spain [7]. The results of the MARNA project classifies Spain into different areas according to the different levels of gamma radiation. A map of MARNA project can be seen in Fig. 1.

From the results of MARNA project, we can identify very high levels of natural radiation in areas of the Iberian Peninsula. The highest levels are located in

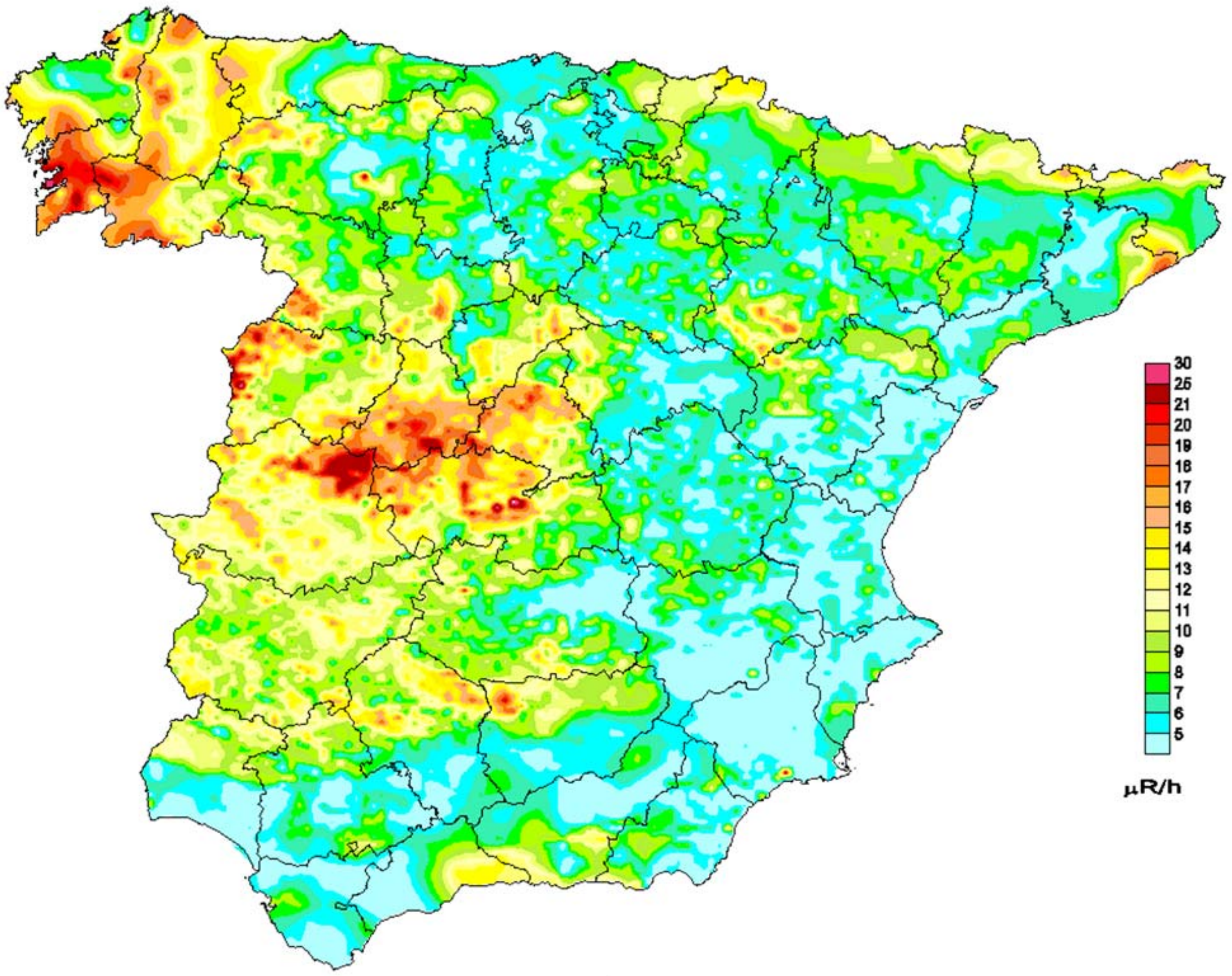

Fig. 1. Map of MARNA project in the Iberian Peninsula.

the northwest of the peninsula corresponding to Galicia. Other high levels are located in the centre of the peninsula and in two provinces on the border with Portugal. These areas are composed essentially of granitic rocks and there are also some uranium mine sites in the provinces with high levels in the Portuguese border. The highest indoor radon concentration ever found in Spain corresponds to a village located in one of these provinces named Villar de la Yegua. A value of 15 000 Bq·m^{-3} was found here [9]. If we take into account all the sources of natural radiation, a mean effective dose of 267 mSv per year was estimated in this village. According to the European recommended action level for old houses of 400 Bq·m^{-3} [1], 89% of the houses of this village present radon indoors concentrations above this action level.

Due to the very high radon levels in this village, the Radon Group is continuing radon studies here. The high levels found in the village of Villar de la Yegua are particularly interesting, if we remember that according to recent studies radon gas is responsible for 13% of lung cancer [2].

Villar de la Yegua is located in Salamanca province, an area with special geological characteristics. From the geological point of view, Salamanca is a monotonous plateau in the Iberian Peninsula. This geological unit is split into four different parts: sedimentary rocks, schist rocks, granitic gneiss and porphyritic granite. For the two former units, associated soils are predominantly dystic cambisols with a great proportion of silt. Soils coming from schistose rocks are basically eutric cambisols containing mostly sands with a higher permeability. Another important fact is the existence of a uranium deposit in the Saelices el Chico locality. The deposit belongs to a complex of schists and grauwackes of the precambric superior-cambric inferior age, and it was deformed in NW-SE folds during the hercynian phase. The uranium minerals fill fault gaps and small veins without a predominant direction. Pitchblende, carbonates and iron sulphide form the most characteristic hydrothermal paragenesis. Many other secondary uranium minerals have been formed in the supergenic alteration of the deposit. The mine, with an average ore grade of 0.06%, was exploited over several years and was shut down in 2001.

Taking into account the potential radon mapping of Spain coming from MARNA project, the Radon Group decided to start a project in the old uranium mine site with the aim of building an experimental pilot house. This project was carried out in collaboration with Spanish Institute of Construction Science Eduardo Torroja and was funded by the Spanish Nuclear Security Council (CSN). The house was built on a site with very high radium concentration in soil. The radon levels found at 1 m depth present an average value of 250 kBq·m^{-3}. Another characteristics of the soil are the granulometry and permeability with a mean value of 10^{-12} m^{-2}.

In this paper we present the last results of the recent studies carried out at the village of Villar de la Yegua. We pay attention to the workplaces located in the village in order to apply the Spanish legislation for the protection of workers to sources of natural radiation [8]. We also give a description of the experimental pilot house. We have carried out different series of measurements in this house using a laboratory installed inside the house. We have also tested radon mitigation measures. The results of these activities are shown in this paper.

Description

Workplace

Apart from the measurement of indoor radon concentration in houses, we developed the measurement of this parameter for workplaces. There are some workplaces located in this village such as the medical consulting room, a social centre, church, the town hall and a tavern. These workplaces are spread over the whole village and special attention can be focused on the medical consulting room. This workplace shares the building with the school of the village which has not been included in this study. This building is located in a place where high levels of radium have been found in the surrounding soil.

Experimental pilot house

The design of the experimental module developed corresponds to the basic characteristics of detached house located in rural environment, without using modern constructive systems. It is a 2-floor house with 25 m^2 of surface in each floor. There is a semicellar buried 2 m free height and a ground floor 2.4 m of free height. A global view of the house can be seen in Fig. 2. The walls of the cellar have 1 feet of thickness and are made of crude bricks. The ground floor presents walls 0.5 feet of thickness and made of bricks. There is a polyvinyl chloride (PVC) pipe in the centre of the ground floor 120 mm of diameter. The joints of the PVC pipe are made of elastomeric fillers. Two windows, one at the front and another at the back are situated in the ground floor where it is also placed the main gate of the construction. The stairs 1 m wide are used to communicate

Fig. 2. Global view of experimental pilot house.

the ground floor and the semicellar. The steps of the stairs are 0.25 m wide. The house is lying on a base made of concrete 15 cm in thickness. The walls are composed not only of bricks but also of gypsum and polystyrene.

A small room attached to the house is used for storing the electrical suppliers. It consists of a diesel engine and 10 batteries placed in the ground floor. The engine is working when the batteries are discharged. This system provides continuous electricity to all of the devices in the house.

Methods

Houses and workplaces

CR-39 track etched radon detectors were used for the determination of radon indoors in houses and workplaces at Villar de la Yegua. The exposure time was 3 months and the average radon concentrations during this time were evaluated. In the case of houses, selection was based on them being occupied the whole year. In these houses the detectors were placed usually in the living room and in bedrooms in some cases. A total number of 61 radon detectors were used. All the workplaces of the village were tested and the detectors were exposed from May to August. According to that, a seasonal correction factor of 1.45 was used to get the actual radon concentration in the whole year [3].

In order to estimate the annual effective dose, the model proposed by the International Commission on Radiological Protection (ICRP) [4] was used applying the expression shown in Eq. (1):

$$D = 1.5 \cdot 10^{-6} \times F \times C \times t \times \mathrm{DCF} \quad (1)$$

where D is the annual effective dose in mSv; F is the equilibrium factor; C is the radon concentration ($Bq \cdot m^{-3}$); t is the exposure time (h) and the DCF is the dose conversion factor. We used a dose conversion factor of 4 mSv per WLM (working level month) for houses and 5 mSv per WLM in the case of workplaces. We also consider occupancy of the places of 7000 h per year and 2000 h per year for houses and workplaces, respectively. An equilibrium factor of 0.4 was also considered. Finally, in the case of the medical consulting room and school, a radon monitor was used to control the radon concentration during 1 year period of time.

Experimental pilot house

Not only radon inside the house was measured, but also meteorological parameters were determined. With this aim, 8 different temperature sensors ($T1...T8$) and 4 pressure difference sensors ($P1 ... P4$) were placed in the house. It can be seen in Fig. 3 a schematic view of the placement of these sensors. Another meteorological parameters were also provided by a nearby station: mean wind velocity ($m \cdot s^{-1}$), maximum wind velocity ($m \cdot s^{-1}$), mean wind direction (°), mean air temperature (°C), maximum air temperature (°C), mean relative humidity (%), mean pressure (mbar), mean solar radiation ($W \cdot m^{-2}$), maximum solar radiation ($W \cdot m^{-2}$),

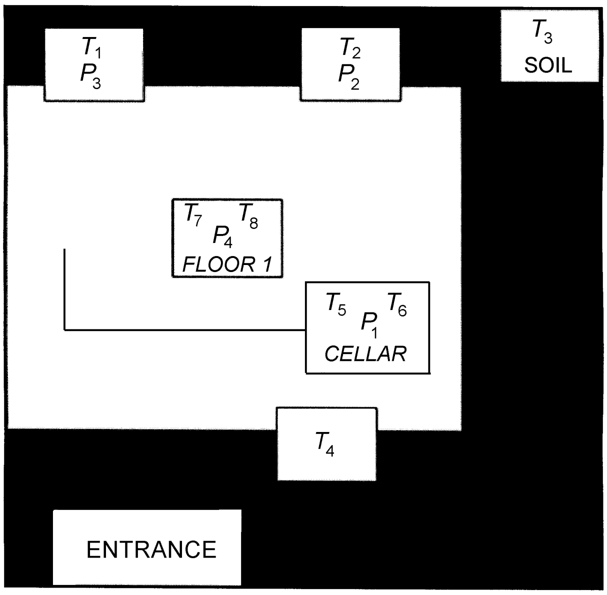

Fig. 3. Placement of meteorological sensors inside the experimental pilot house.

accumulated fall (mm), evaporation (mm) and battery state (V).

For the measurement of radon inside the house, several devices were used: 2 DOSEman and 2 Radon Scout from SARAD were employed for the continuous radon monitoring. COUNTER LUDLUM with an air flux pump and a Lucas cell modified with ZnS were also used.

We also tested several solutions for radon mitigation in the experimental house: central natural ventilation, lateral natural ventilation, central forced extraction, central pressurization, crossed ventilation and radon barrier.

Results

In Fig. 4 we can see the distribution of all the radon indoors measurements carried out in the houses of the village Villar de la Yegua. In the case of the workplaces studied, we found the next values summarized in Table 1: medical consulting room (55 830 Bq·m^{-3}), social centre (4921 Bq·m^{-3}), church (4253 Bq·m^{-3}), townhall

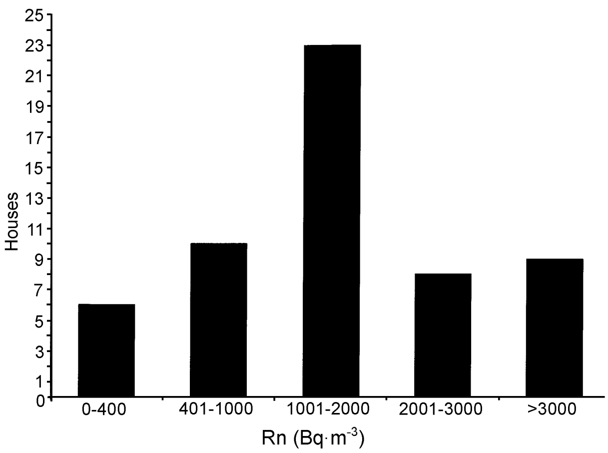

Fig. 4. Distribution of the radon indoors concentrations in the houses of Villar de la Yegua (Spain).

Table 1. Radon concentrations in homes and workplaces of Villar de la Yegua and pilot house. All values are expressed in Bq·m^{-3}

Place	Radon concentration
Medical consulting room	55 830
Social centre	4921
Church	4253
Townhall	429
Tavern	179
Average pilot house (cellar)	42 000
Maximum pilot house (cellar)	120 000
Average pilot house (cellar, using radon barrier)	1700
Average pilot house (ground floor)	7000
Maximum pilot house (ground floor)	40 000
Average pilot house (ground floor, using radon barrier)	500

(429 Bq·m^{-3}) and tavern (179 Bq·m^{-3}). The arithmetic and geometric means of the workplaces were respectively 3073 Bq·m^{-3} and 1551 Bq·m^{-3}. In the case of the houses, these parameters were 1851 Bq·m^{-3} arithmetic mean (AM) and 1453 Bq·m^{-3} geometric mean (GM). Figure 5 shows the radon variation found in the case of the building shared by the school and the medical consulting room of the village. Radon concentrations were measured every hour using a radon monitor. From these results we can obtain a mean annual effective dose of 33 mSv with a maximum value of 110 mSv.

In the case of the experimental pilot house, some initial measurements were carried out in order to get an idea of the initial conditions. With this aim the mean radon indoor concentrations obtained during a 4 month period of measurements were 42 000 Bq·m^{-3} and 7000 Bq·m^{-3} in the cellar and ground floor, respectively (see Table 1). The maximum value found in the cellar was 120 000 Bq·m^{-3} and 40 000 Bq·m^{-3} in the case of ground floor. It was also observed that the radon concentration increased after heavy rain and no significant influence of wind and temperature was detected. It was found and inverse correlation with radon concentration and atmospheric pressure variations.

Taking into account this situation, some remedial actions were proposed to be tested in the house. In Table 2 we can see the effectiveness of the remedial actions tested where central forced extraction was done using an electrical fan in the house. In Fig. 6 it can also be seen the effectiveness of the remedial actions we applied: natural ventilation, forced extraction, pressurization, crossed ventilation and radon barrier. The different curves correspond with measurements using radon monitors in the pilot house. Four of these measurements were done in the cellar and ground floor (marked as "sotano" and "Planta 1" in the legend of the graph, respectively) and the fifth measurement was done under forced extraction using the electrical fan (marked as "Ventiladores" in the legend of the graph). The last part in Fig. 6 corresponds to the use of the radon barrier and the high peak which can be observed is due to those measurements carried out in the cellar of the house. The radon barrier has the possibility of being taken out at any time and after the application

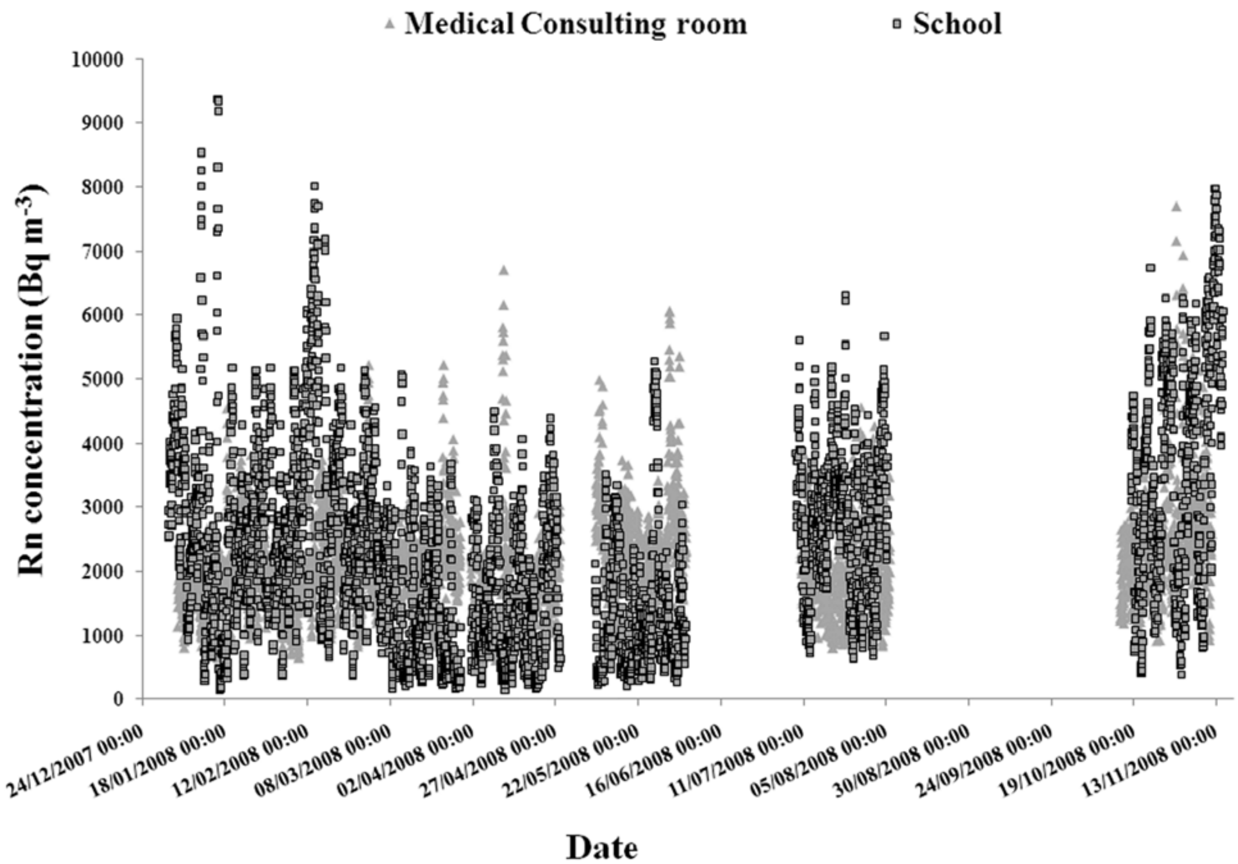

Fig. 5. Radon variation during 1 year in the building shared by the school and medical consulting room in the village Villar de la Yegua (Spain).

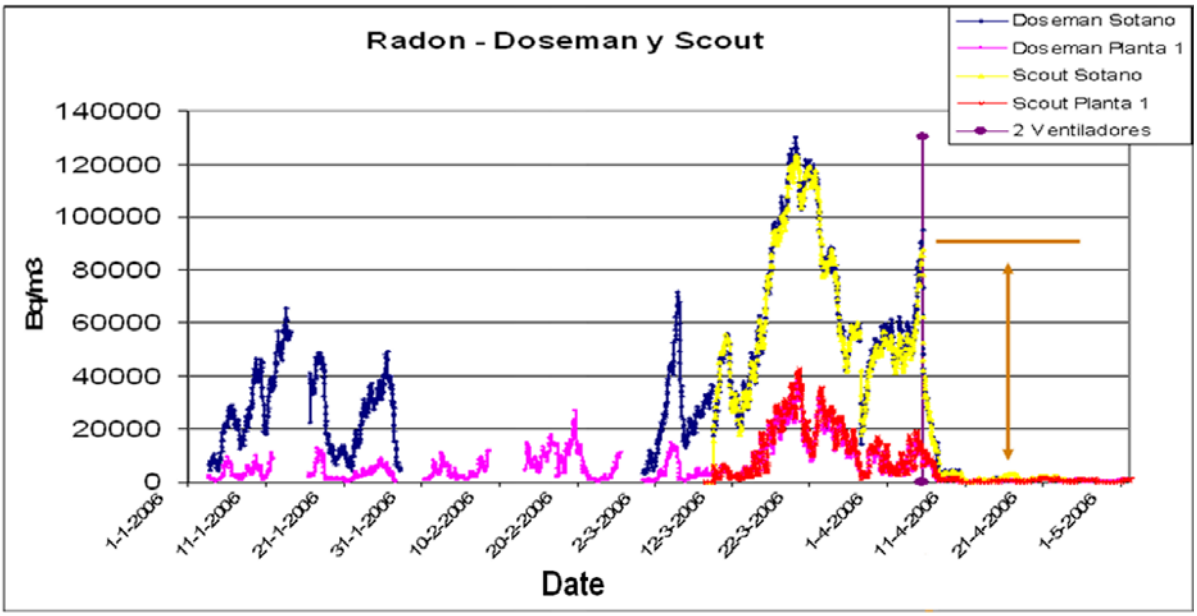

Fig. 6. Effectiveness of the remedial actions tested. The last part of the graph shows the results obtained using the radon barrier.

of this remedial action, the mean radon concentration reached was 1700 Bq·m^{-3} for the case of the cellar, and 500 Bq·m^{-3} in the case of the ground floor.

Conclusions

The very high levels of radon indoors found in the houses and workplaces of Villar de la Yegua can be summarized as follows: 11% of the houses in this village have an indoor radon level below 400 Bq·m^{-3}, 89% are above 400 Bq·m^{-3} and 71% of the houses have a radon concentration above 1000 Bq·m^{-3}. Also, the average external gamma dose rate found was 300 nGy·h^{-1}. All these values are due to the fact of very high levels of radium found in the soil of this village. From these results, the village of Villar de la Yegua can be classified as a radon prone area according to the recommendations of the

Table 2. Effectiveness of the remedial actions tested in the experimental pilot house. The values represent the mean lowest radon level reached being expressed in $Bq \cdot m^{-3}$

Action	First floor	Cellar
Central natural ventilation	600	1700
Lateral natural ventilation	2300	16 000
Central forced extraction	250	400
Lateral forced extraction	700	1300
Central pressurization	400	300
Crossed ventilation	500	7200
Radon barrier	500	1700

ICRP. Due to the link between radon and lung cancer, remedial actions should be undertaken in this village in order to reduce the radon levels found.

In the case of the experimental pilot house, we have measured the radon variation over a long period of time. The remedial actions tested show that it is possible to reduce the radon concentration inside a house. From all the mitigation strategies, the use of radon barriers is the most effective remedial action. After using a barrier, the radon levels, both in the cellar and the ground floor, were drastically reduced.

The privilege location of the experimental house offers a unique possibility for the use of this house to carry out a wide number of experiments inside. Special attention should be paid to the intercomparison exercises which can be done inside. It is a very interesting option to test the different radon measurement systems under real conditions. We can also measure the variations in the temperature and pressure inside the house. This is a complementary tool for the intercomparison exercises carried out under laboratory conditions.

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