# A REGIONAL SCALE RADON MONITORING NETWORK IN THE VOLCANIC ISLAND OF TENERIFE, CANARY ISLANDS (SPAIN)

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**Abstract**[1,2]

The emanation and transport of radon is being extensively studied in the volcanic island of Tenerife, Canary Islands (Spain). A radon monitoring network has been deployed in a series of boreholes that were drilled in areas of different geological and lithological settings. In this sense, the transport of radon might be studied from the topographic surface down to 30 meters depth. A large lithological database (more than 200 samples from volcanic rocks of the Canaries) has been built to study the likely relationship between radon concentration and geochemical and physical properties of the rock matrix. We also present examples of radon measurements at homes, where large concentrations exceeding the international safety limits were found.

## Introduction

In this work, we present an overview of our ongoing research on the spatial and temporal distributions of radon in the volcanic island of Tenerife, Canary Islands, Spain. In the past years, we have been implementing numerical models (Eff-Darwich et al. 2002, 2009), time-series analysis techniques (Viñas et al., 2007) and intercomparison exercises between different radon detectors (Viñas et al., 2004) in an

[1] This work has been funded by the Spanish Consejo de Seguridad Nuclear (CSN)
[2] The radon detectors were manufactured by SARAD (http://www.sarad.de)

attempt to understand the release, transport and concentration of radon in the island of Tenerife.

We realize that the geology of the island is a major factor affecting all aspects related to the transport and release of radon. Since Tenerife is a good example of island volcanism, we expect that our results could be helpful to other regions in the world with similar characteristics.

We will start with a brief description of the geology of Tenerife. Next, we introduce the Canarian lithological and radiological database and its potential as a proxy of radon prone areas. Finally, the problem of radon in low income houses will be illustrated with a real case.

## Geological Context

Tenerife is the largest island of the Canarian Archipelago and one of the largest volcanic islands in the world. It is located between latitudes 28-29◦N and longitudes 16-17◦W, 280 km distant from the African coast (see Fig. 1). The morphology of Tenerife is the result of a complex geological evolution: the emerged part of the island was originally constructed by fissural eruptions (the so called Old Basaltic Series) that occurred between 12 and 3.3 Ma and formed the massifs of Teno, Anaga and Roques del Conde, the remains of which are found in the NW, NE and S of Tenerife respectively. This volcanism produced basaltic shields, with few salic manifestations.

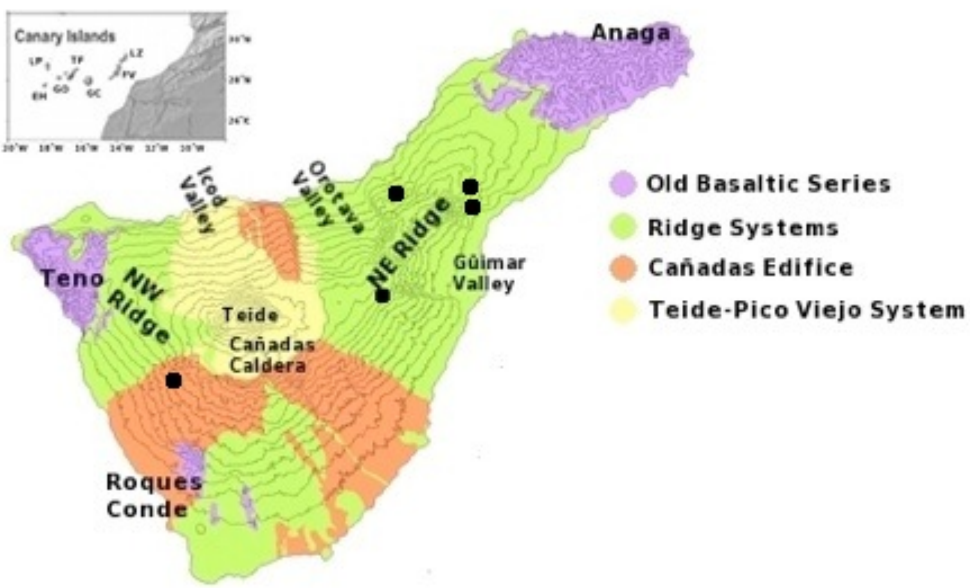


Figure 1. Geological map of Tenerife (modified after Laín et al., 2006), where the main volcanic edifices are shown in different colors (see text for details). A small map of the Canary Islands is also presented, with the locations of the seven main islands, namely Fuerteventura (FV), Lanzarote (LZ), Gran Canaria (GC), Tenerife (TF), La Gomera (GO), El Hierro (EH) and La Palma (LP). Black-filled circles indicate the location of the radon monitoring boreholes (see text for details).

Two well-differentiated eruptive styles occurred after shield building activity: ridges/effusive basaltic eruptions and Central Edifice/explosive eruptions, involving more silicic magmas. The basaltic lava continued to be erupted from vents concentrated preferentially along two volcano-tectonic axes: NE ± SW and NW± SE. These axes are aligned with two ridges which practically link the massifs of Teno and Anaga with the central area of the island, with the maximum eruptive activity of the ridges taking place around 0.8 Ma ago. Nevertheless, the crests of these ridges are formed by younger volcanism (less than 0.17 Ma), particularly the centers localized in the NW± SE ridge and also in the area of the NE ± SW ridge that is closer to the Central Edifice (Fig. 1). Recorded eruptive activity in Tenerife has consisted of six strombolian eruptions (Fig. 7), namely Siete Fuentes (1704), Fasnia (1705), Arafo (1705), Arenas Negras (1706), Chahorra (1798) and Chinyero (1909). The historical eruptions are similar in duration (few weeks) and low volume to those that occurred on other islands of the archipelago, excluding (due to its great duration, 5 years, and volume, 1 $km^3$) that of Timanfaya, on Lanzarote, which began in 1730. In this sense, total emitted volume and occupied area due to the historical eruptions in the NW ridge have been estimated in 0,13 $Km^3$ and 5,7 $Km^2$, respectively.

The position of the NE ± SW and NW± SE volcano- tectonic axes defines, in the centre of the island, an area where most eruptive events have taken place since the end of the volcanism that constructed the old massifs. Also, under this area there must have existed favourable conditions for the formation of magmatic chambers where basaltic magmas evolve to trachytic and phonolytic melts. It is the eruption of these salic lavas that gives the Central Edifice its singular features (lithological and geomorphological) which have formed over the last 3.5 Ma. In this great central volcano, it is possible to make out a basal part that is known as the Cañadas edifice, which culminates in a gigantic depression: The Caldera of Las Cañadas. This Caldera is an elliptical depression measuring 16x9 km, its base is at some 2000 m above sea level and is closed off by a huge wall, visible along the SW, SE, E and NE sectors, reaching 600 m at some points. A double stratovolcano has formed in the northern border of the Caldera over the last 0.15 Ma: the Teide-Pico Viejo system that includes some domes with explosive activity (Montaña Blanca and Los Gemelos, 2 ka old; Pico Cabras; Roques Blancos; etc.). The present activity is almost limited to fumaroles in the summit (3718 m) of Teide volcano. The last three eruptions in Tenerife have occurred at the NW ridge, the most active area of the island, together with El Teide-Pico Viejo complex, for the last 50,000 years.

## The Canarian Geochemical and Radiological Database

The quantification of naturally occurring radionuclides in the rock matrix, soil and building materials (including cements) has been carried out in many countries in order to assess the radiation dose affecting the public. The presence of natural radioactivity is partly due to primordial radionuclides contained within the Earth's crust, such as $^{40}K$, $^{238}U$, $^{232}Th$ and the products of their decay series. In this sense, the levels of gamma radiation (external radiation) in naturally occurring radioactive materials (NORMs) depend upon their contents of thorium, uranium and potassium, whereas the internal exposure occurs through the inhalation of radon gas, a decay product of $^{226}Ra$ (UNSCEAR, 2000).

We are interested in analyzing the relationships between geochemical, radiological and geotechnical characteristics of the main lythological units of the Canary Islands, in particular the island of Tenerife. At present, more than 250 samples of volcanic rocks have been studied and hence we carried out full geochemical analyses, as well as different physical parameters, namely porosity, density, permeability, thermal conductivity, geotechnical proxies, etc …. This large dataset constitutes the Canarian Geochemical and Radiological Database.

In order to limit the external gamma radiation dose from building materials to 1.5 mSv/y in practice a safety criterion, the external hazard index ($H_e$) has been proposed (Mujahid et al., 2008):

$$H_e = C_{Ra}/370 + C_{Th}/259 + C_K/4810 \qquad (1)$$

where $C_{Ra}$, $C_{Th}$ and $C_K$ are the specific activities of radium, thorium and potassium expressed in Bq/kg. In addition to the external hazard, radon and its short-lived products are also hazardous to the respiratory organs. To account for this threat the maximum permissible concentration for $^{226}$Ra must be half of the normal limit (185 Bq/kg). The internal exposure to carcinogenic radon and its short-lived progeny is quantified by the internal hazard index ($H_i$):

$$H_1 = C_{Ra}/185 + C_{Th}/259 + C_K/4810 \qquad (2)$$

The standard safety criterion requires that in both cases $H_e<1$ and $H_i<1$.

We found that the hazard indexes of our sample of rocks closely follow their corresponding rates of magmatic differentiation, as illustrated in Fig. 2. Both $H_e$ and $H_i$ are quite low at the mafic (more basaltic) end of the distribution and trend strongly upward at the felsic end, exceeding in some cases the safety criterion. The scatter of the data is also larger at the felsic end. If we analyze separately the concentration of potassium (Fig. 3), thorium (Fig. 4) and uranium (Fig. 5) as a function of the magmatic differentiation, the lowest values of these radioactive elements are found in the mafic (basaltic) end, whereas the largest are found in the felsic end. In the case of thorium and uranium, the scatter of data at the felsic end of the geo-chemical distribution is significantly larger. Felsic rocks (mostly phonolites and trachytes in the Canaries) contain significant amounts of tectosilicates (*e.g.* quartz and feldespats). The crystalline network of tectosilicates are large enough to accommodate elements such as thorium and uranium that have relative large ionic sizes. In this sense, felsic rocks contain more radionuclides than mafic rocks because felsic rocks contain more tectosilicates than mafic rocks.

The close relation between the content of radioactive elements and the geology of the island is illustrated in Fig. 6. The largest values of $H_i$ are found in the areas affected by the activity of the Cañadas and Teide-Pico Viejo Edifices, recalling that the lavas erupted by these volcanoes, that cover a good portion of the island, are generally felsic.

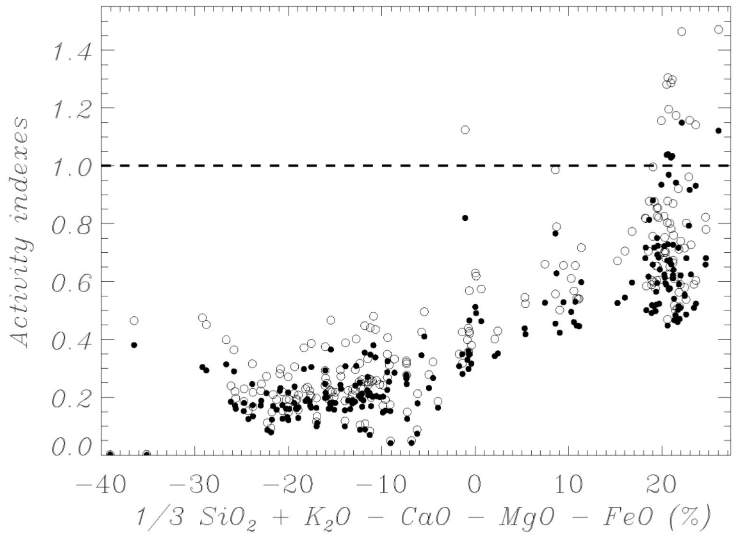


Figure 2. Geo-chemical variation diagram as a function of the external (solid circles) and internal (open circles) hazard indexes. Dashed lines indicate the upper safety limit of 1 for both activity indexes.

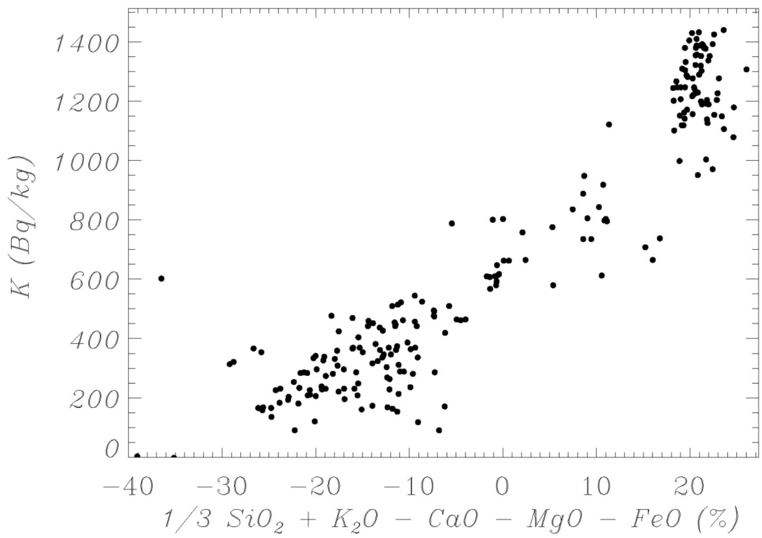


Figure 3. Geo-chemical variation diagram as a function of the potassium content.

The radiological analysis of the Canarian Database also contains the radon exhalation rates of the volcanic rocks. At present, the radon exhalation rate has been determined in a small sample of rocks. The first results (see Fig. 7) indicate that there is an increase of the radon exhalation rate as a function of magmatic differentiation, namely, the largest exhalation rates correspond to felsic rocks. This result should be taken with caution, since it is not yet statistically significant. However, if this trend is clearly defined, it could be possible to map radon prone areas through the analysis of $H_i$.

In this sense, we studied the relationship between $H_i$ and the easy-to-measure net dose rate, as illustrated in Figures 8 and 9. There is a significant correlation between $H_i$ and the net dose rate (Fig. 8), whereas both parameters follow similar spatial distributions (Fig. 9). If the results shown in Fig. 7 are confirmed with a statistically significant large sample, it may be possible to easily map radon prone areas through measurements of the net dose rate in the future.

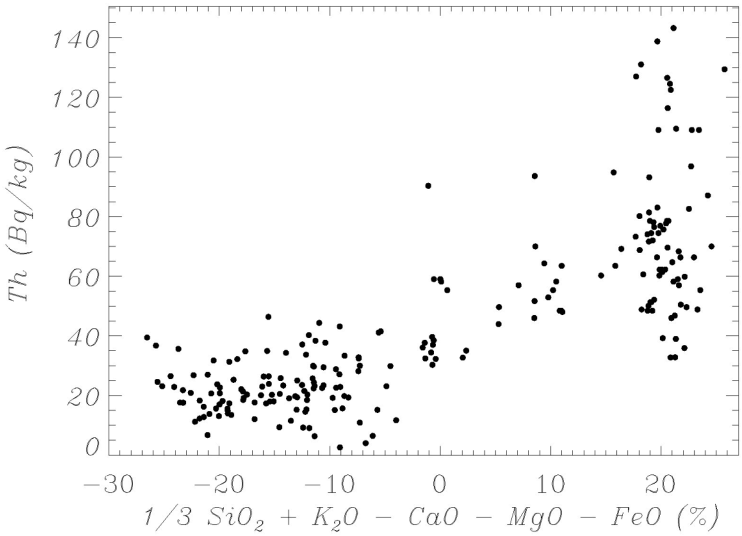


Figure 4. Geo-chemical variation diagram as a function of the thorium content.

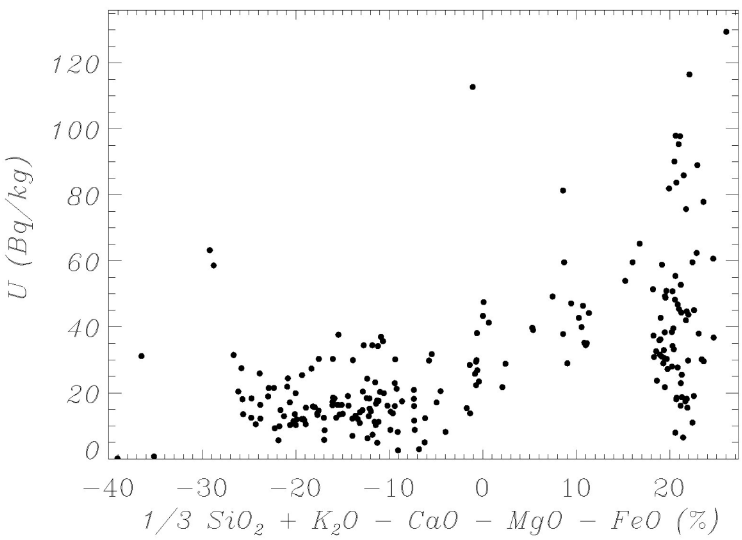


Figure 5. Geo-chemical variation diagram as a function of the uranium content.

**Radon at home**

Tenerife has a population of nearly 1 million inhabitants and a surface of less than 2500 km$^2$, hence it is one of the most densely populated islands in the world. During the 1950's to 1970's, the population grew considerably, as the result of the immigration from the other islands of the Canarian Archipelago. Due to the bad economical situation at that time, many houses were built with poor materials and foundations, as illustrated in Fig. 10. In this sense, there are many houses in Tenerife which are poorly sealed from the ground and hence, radon could be easily transported and released.

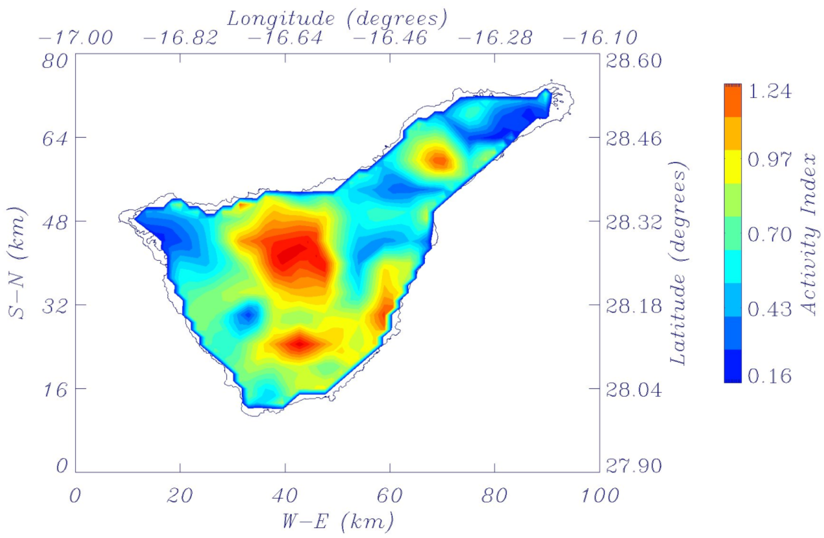


Figure 6. Spatial distribution of the internal activity index on the island of Tenerife.

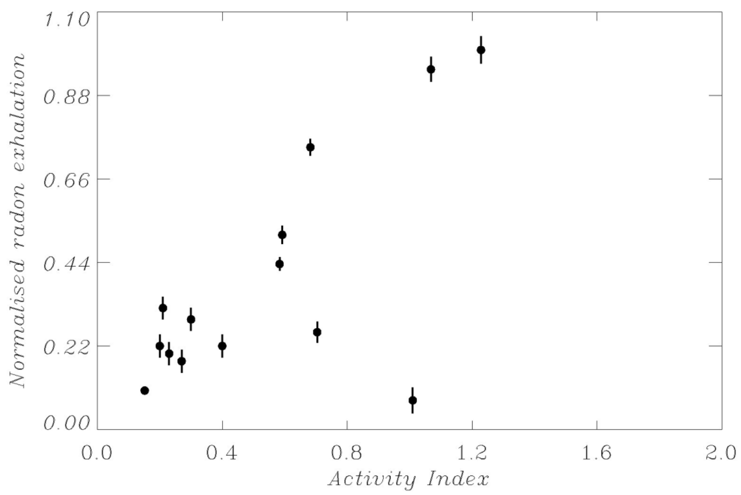


Figure 7. Normalised radon exhalation rate as a function of the internal activity index for a sample of rocks from the Canarian Database.

We are studying the distribution of radon in different rooms of a sample of low-income houses in Tenerife, as well as cheap remediation methods. Figure 11 shows the time distribution of radon (in black) in the main bedroom of a problem house. Radon concentration reaches in may cases up to 5000 bq/m$^3$, being these values significantly larger than the recommended safety limits. Similar values were found in other rooms of the house (red lines); however, the largest concentrations of radon were found in the wall that separates the house from a neighboring property (fruit tree plantation). Radon concentration in that wall reaches up to 30000 Bq/$m^3$. It is also important to note that radon reaches the maximum values in the wall approximately 1.5 days before it reaches maximum values in the bedroom. A closer inspection of the wall revealed cracks and very poor sealing from the ground. Radon moves from the ground of the neighboring property to the rooms of the house through the visible cracks in the wall. It takes radon approximately 1.5 days to move from the wall to the rooms and corridors of the house.

In periods of rainfall (see Fig. 12), the release and transport of radon from the ground is stopped and radon concentration in the house drops to negligible values.

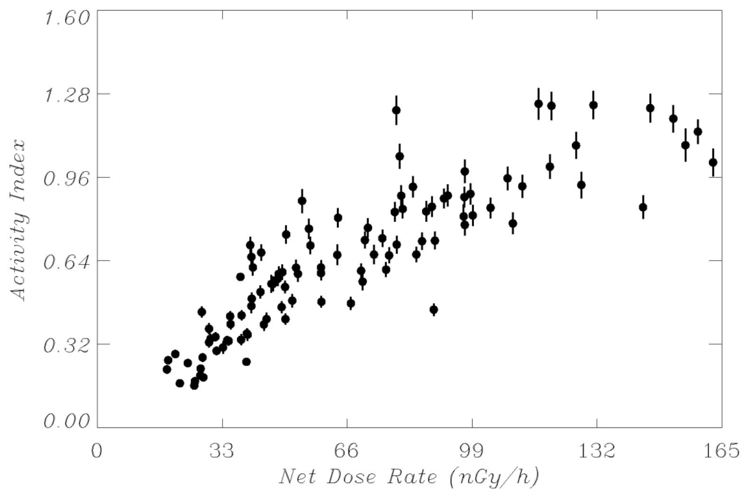


Figure 8. Internal activity index as a function of the net dose rate for a sample of the Canarian Database.

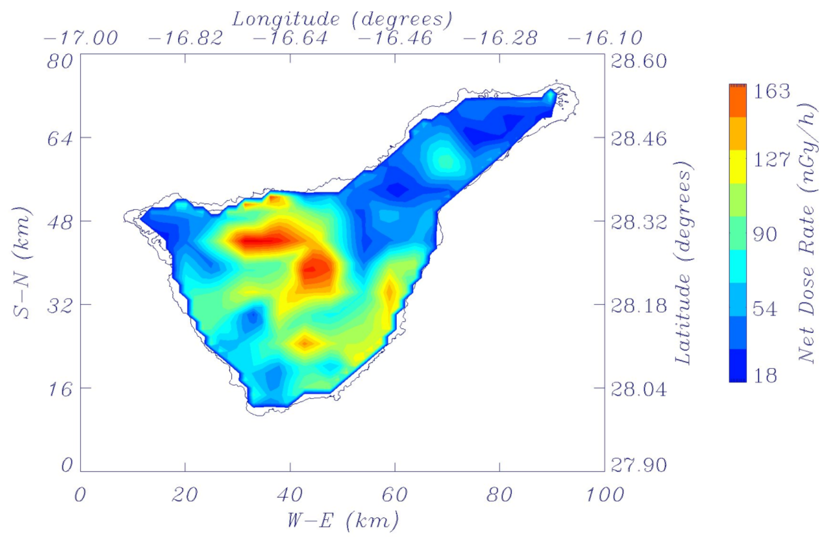


Figure 9. Spatial distribution of the Net Dose Rate on the island of Tenerife.

Figure 10. Photography of a house in Tenerife. The poor foundations and the different volcanic strata underneath  can be seen

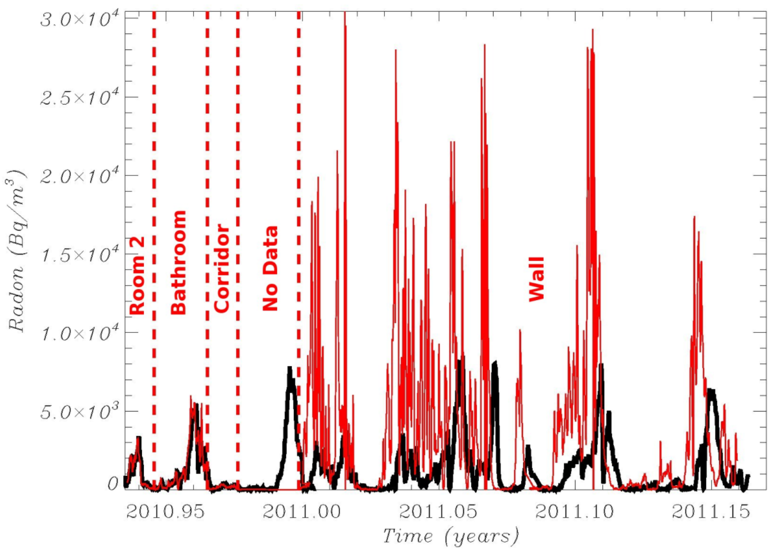


Figure 11. Radon concentration as a function of time in the main bedroom of a problem house (black line) and in different places of the house (red line). Vertical red dashed lines indicate the time period of evaluation of radon concentration in all the different places of the house, but the main bedroom.

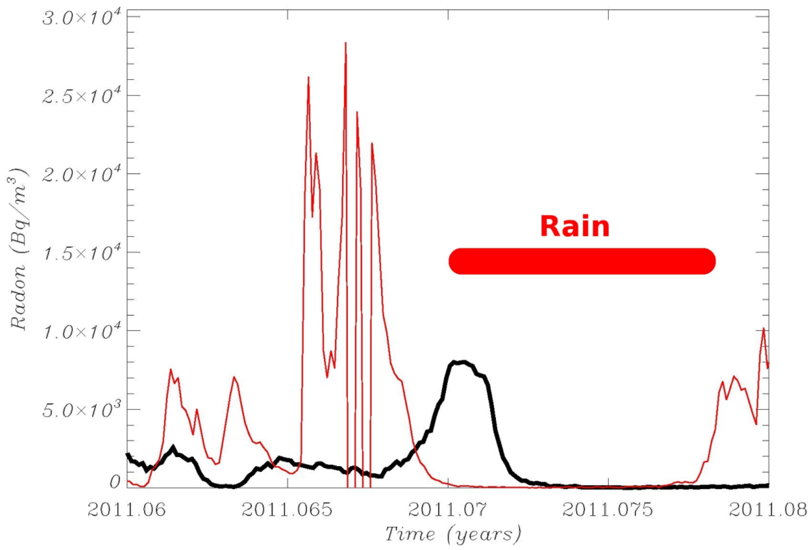


Figure 12. Radon concentration as a function of time in the main bedroom of a problem house (black line) and in a poor-isolated wall of the house (red line). The thick horizontal red line indicates the time period with rain.

### Radon transport in the subsurface

We are building a network of boreholes (approximately 30 meters depth) to study the transport of radon in different geological settings of the island of Tenerife (see Fig. 1). Eff-Darwich et al. (2002) already studied the effect of changes in the permeability and porosity of rocks in the concentration of radon in underground tunnels in Tenerife. At present, 5 boreholes have been drilled. All of them are equipped with temperature sensors, every 8 meters and a radon detector at the top of the borehole. These sites are also monitored in an attempt to find a relationship between temporal and spatial variations in radon concentration as the result of an increase in the geological/volcanic activity in the island.

The first results obtained from the network of boreholes (see Fig. 14) indicate that the transport of radon significantly differ from one site to the other, indicating the effect of the different geological settings. In some instances, the barometric pressure is the main parameters affecting radon concentration, whereas there are some boreholes, where temperature rather than pressure is the parameter controlling radon concentration. We need to finish deploying the network of boreholes and we also need longer time-series to establish the factors controlling the transport of radon in the subsurface and its release into houses or other residential infrastructures.

Figure 13. Drilling of one of the boreholes devoted to study the transport of radon under different geological settings.

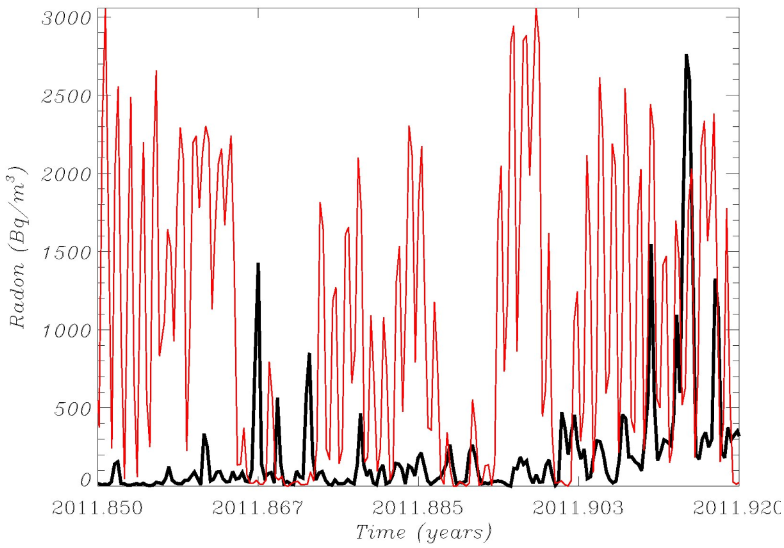


Figure 14. Radon concentration as a function of time for two of the boreholes drilled in Tenerife to study the transport of radon under different geological settings.

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