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**RADON CONCENTRATIONS AND THEIR RELATION WITH
GEOLOGICAL MATERIALS: THE SUIDO RANGE
AND THE SANTIAGO DE COMPOSTELA CASES (NW OF THE IBERIAN PENINSULA)**

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ABSTRACT

Radon indoor concentrations and its relation with lung cancer has been an unknown problem for a long time. At present, because of the governmental agencies normatives, it has a place on public health agendas. There are several factors that influences in this problem, being the atmospheric pressure, the type of construction and, mainly, the geological substrate part of these factors. The target of the current work is establishing the relation of the harmful radon concentrations with the geologic substrate in the Northwest of the Iberian Peninsula. To achieve this, the Galicia Radon Laboratory (RADONGAL) has more than 4,000 measurements over one of the regions of the Northwest of the Iberian Peninsula, Galicia, which, combined with the geological shapefile can determinate, in an approximate way, this relation. Two cases with different geological setups, and different concentration values range, has been analysed to determinate which materials present the higher radon concentrations in the territory and which are the radon-prone areas where a priority actuation is required.

Keywords: Cartography, GIS, Human Health, Natural Hazards, Radon-prone areas

1. INTRODUCTION

The geological substrate of the earth's surface contains variable concentrations of radioactive elements, such as the Uranium (U), Thorium (Th) or Actinium (Ac); and similar; the disintegration of these elements produces alpha radiation emissions, which moves from the deeper parts of the planet to the surface, affecting the population settlements above them (Sainz Fernández et al., 2012). Radium (Ra) is a radioactive element descendant of the uranium family (U), in a solid form, and Radon (Rn) is the product of the Radium disintegration, with an average life of 3,8 days and a gaseous form, that facilitates its displacement to the surface. It is a risk for the human health because of its potential as carcinogenic due to the alpha radiation emission emitted for its descendant isotopes, the polonium (Po). Present in the air that the mankind beings breath, introduce alpha radiation in the human organisms, modifying the human cells, a process that can ends in a lung cancer (Barreiro Carracedo, 2012). Uranium is a chemical active element, with the capacity of move and associate with other elements, which implies that this element its findable in almost all geological substrates of the planet, on different proportions (Quindós Poncela, 1995), meaning that a big sector of the planet can be exposed to the Radon gas emissions. The true problem with the Radon element is related to the emissions that take place inside the buildings, because, depending of the type of the construction, the concentration can be higher or lower, affecting the population who are living or working on these buildings. The presence of Rn on the air inside the constructions has different origins, being the geological substrate materials where the building is located the main source (USGS, 1992). Not only the buildings characteristics have an influence on the Radon indoor concentrations. Other factors, like the atmospheric pressure, the temperature, the humidity or the type of soil where they are settled have an important role in the concentrations (Kulali et al., 2017). There are different concentration levels, and concentrations above certain limit are considered harmful for the human health, requiring actions to decrease them. The World Health Organization (WHO) establishes the non-harmful levels to human health below than 100 Bq/m³, the US Environmental Agency determi-

nate this limit on concentrations on 150 Bq/m³ and the European Union (EU), according to the EURATOM directive (EU, 2014) and the standard norm from 2018, fix the limit in 300 Bq/m³. Since there is no agreement between countries on put a universal concentration threshold, it is necessary to take measures (Ruano-Ravina et al., 2017). Most of the countries have the common idea that they need to take some actions to confront the harmful concentrations. However, if the Radon concentration is high, and the exposed population smoke, because tobacco still being the main cause of lung cancer, the probability of developing the disease is highest. Different studies shows that the combination of both factors get increase the lung cancer risk (Barros-Dios et al., 2002; Barros-Dios et al., 2012). Also, Radon is the leading cause of lung cancer in non-smokers (Lorenzo-González et al., 2019; Torres Duran et al., 2014). As noted above, buildings and environmental characteristics influence in Radon concentrations, so they are relevant when measures to decrease the concentrations are required.

The aim of the current work is to associate geological composition of the earth crust with the Radon concentrations measurements in two different areas used as an example located in the Northwest of the Iberian Peninsula.

2. STUDY AREA

The Northwest of the Iberian Peninsula is located between 41° N and 43° 45' N, and between 4°30' W and 9°19' W (Figure 1). In the Spanish case, the National Safety Council (CSN in Spanish) elaborated a potential Radon exposure cartography, where, between the areas with the higher concentrations, Galicia is listed (Figure 2). This is because of the geological materials you can find in Galicia are granites with an important uranium component (U⁹²), Radon predecessor (CSN, 2018). Two examples of this region were chosen to analyse the relation of the Radon concentrations with the geological substrates. Suido Range was selected because it is located on one of the high exposure areas and Santiago de Compostela municipality was selected because it is a contact point between different exposure areas, to compare the Ra-

don concentrations of different geological materials.



Figure 1. Study area and example cases location (pink stars). DEM provided by the USGS

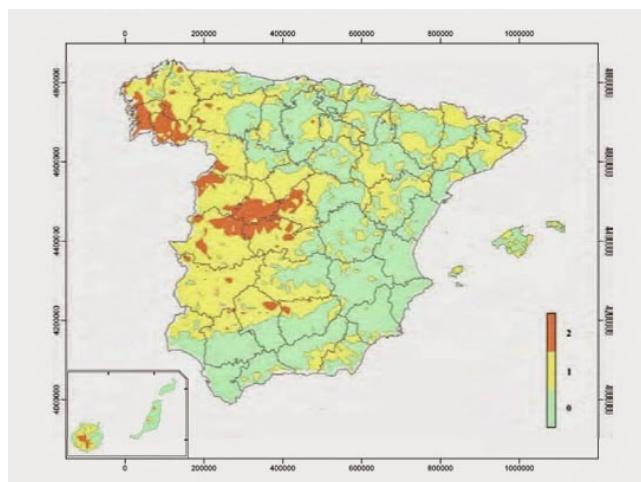


Figure 2. CSN Radon exposure map. The colours correspond to the radon potential exposure, being the red areas the ones with the higher exposition. Source: modified from CSN, 2018

3. METHODOLOGY AND OBJECTIVES

To elaborate this study, data were retrieved from the Radon Laboratory of Galicia (RADONGAL), institution that published the Galicia Radon map in 2017 (Lorenzo-González et al., 2017). These data were transferred onto the ArcGIS geographic information systems (GIS) in combination with the municipalities and census tracts shapefiles, with a created shapefile of the Radon concentrations measurements locations. A concentrations cartography in a census track level was developed, using the tracks geometric mean of the existing measurements as the representative value. Therefore, the regional geology shapefile, given by

the Spanish Geological and Mining Institute (IGME in Spanish), was introduced, and the layer of the study area measurements has been overlapped, in order to establish which kind of geology has the bigger relation with the Radon concentrations. Because of the granite is the dominant geological substrate, the tracks with this material and the higher Radon concentrations were selected to the study, like the case of the Suido Range. To compare the Radon concentrations in different geological substrates, Santiago de Compostela were selected, because it's a geological materials contact area between granite, schist, gneiss and metabasites, which makes easier the comparative between them.

In both cases the Radon gas concentrations in a census track level cartography was developed. Other cartography has also been developed based on the percentage of buildings that have concentrations above 300 Bq/m³, the EU threshold.

4. RESULTS AND DISCUSSION

In Suido Range, there are different geological substrates: schist, tonalite, quartzdiorite and the dominant one, the granite (IGME, 1994). There are 13 Radon measurements, being the higher concentrations on the granite sector. The lower one over this material is 153 Bq/m³, and the higher ones are over 500 Bq/m³, even reaching a 2,284 Bq/m³ measure, one of the highest of all the region. The measurements in other materials have lower values, with concentrations between 159 Bq/m³ and 299 Bq/m³, except one with a 559 Bq/m³ value, in the tonalites sector, similar value to the ones at the granitic area (Figure 3).

For the buildings percentage with Radon concentrations above 300 Bq/m³ inside the census tracks, granites and tonalites sectors are the ones with the higher values. More of the 10% of the buildings have concentrations above 300 Bq/m³, which implies that they are sectors with high risk for the population. In the other sectors the risk is low, because of the lower values of the measurements or the absence of them (in this case the percentage is 0%). Due to this situation, more measurements are required for better accuracy, as well more are required in the 2,284 Bq/m³ value

area, to know if it is an isolated concentration or if really geological context of this point have this concentration.

In the Santiago de Compostela case there are 219 measurements. The geological substrates are granites, schist, metabasites, amphibolites and felsic gneisses (IGME, 1994). The measurements located at the schist area are above 100 Bq/m³, meanwhile, in the ones located at the granites area, the values are the highest. Metabasites and amphibolites are the materials, with higher concentrations, after the granites. In the urban core, settled over schists and felsic gneisses the majority of the concentrations values are lower than 100 Bq/m³, which implies that it's a place with low risk (Figure 4)

In all the geological areas, there are exceptionally high measurements, above 300 Bq/m³, being the maximum concentration on the schists 420 Bq/m³, on the metabasites 479 Bq/m³, and on the felsic gneisses 540 Bq/m³. The maximum concentration registered is 799 Bq/m³, on the granite section.

For the buildings percentage with Radon concentrations above 300 Bq/m³ inside the census tracks is above 10% in the granites, felsic gneisses and metabasites areas. As in the Suido case, more measurements are required to update the tracks without them.

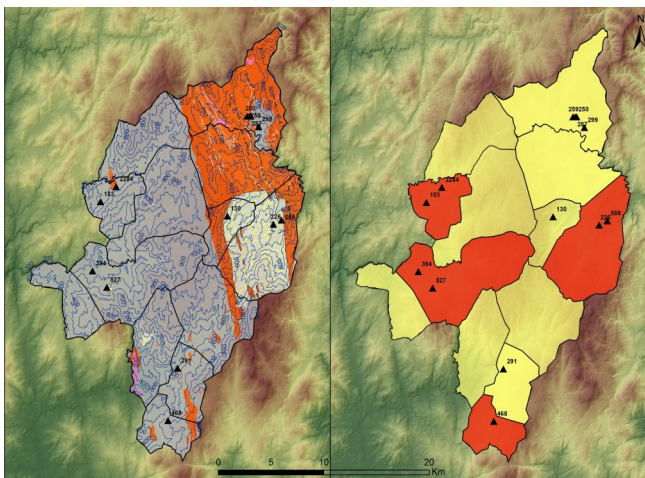


Figure 3. Suido Range main geological substrate, measurements values and locations, and Radon concentrations by census tracks. Left main geological

substrate: Grey = granite, Orange = schist, Gary & Yellow = tonalities. Right percentage of buildings with radon concentrations >300Bq/m³ divided by census tracks. DEM provided by the USGS.

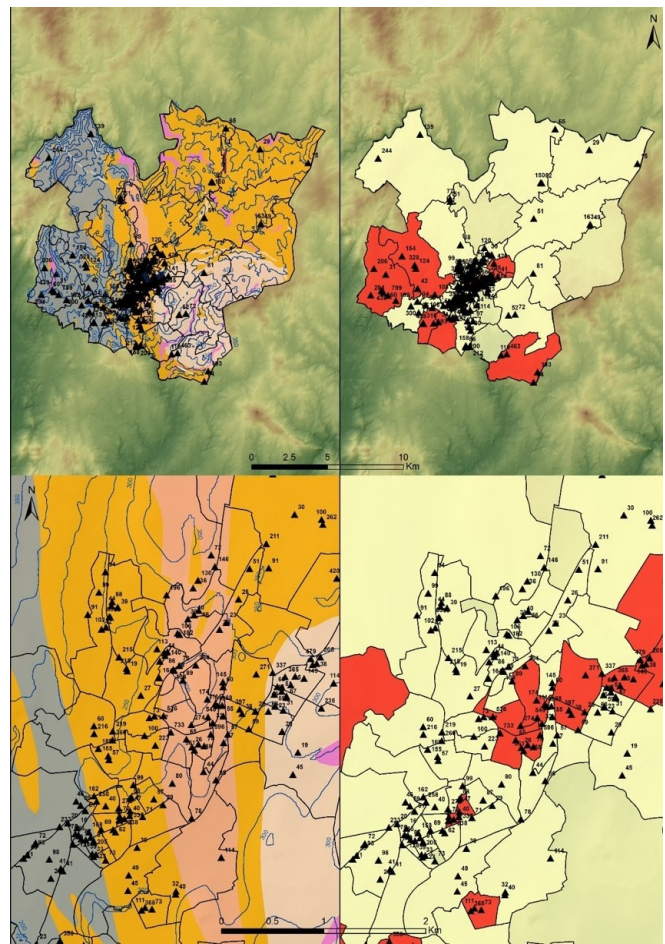


Figure 4. Santiago Compostela geological substrate, measurements values and locations, and Radon concentrations by census tracks. Left main geological substrate: grey = granite, Orange = schist, Pink = Quaternary, Light orange = felsic gneisses, Light yellow = amphibolites. Right percentage of buildings with radon concentrations >300Bq/m³ divided by census tracks. The lower part corresponds to a zoom to the most densely measured sector. DEM provided by the USGS

According to the current work, the construction type and the geological substrate on which its settled have an important relevance in the harmful Radon concentrations. The current constructions seek the hermeticity to obtain energy efficiency on these, which lead to most closed buildings, and this combination turns

difficult to ventilate the Radon inside them. Constructions with cracks in the basement will have higher concentrations, since they are routes of entrance of this gas. If the Radon concentrations are not far from the 300 Bq/m³ limit, an air conditioning system contributes to reduce the concentrations to non-harmful values (Frutos Vázquez, 2018), in constructions with higher concentrations, this is not possible, and some buildings modifications would be required.

In the analysed examples, granitic substrate areas are the ones with the higher concentrations. The application of mitigation measures is required in our example cases. There are some mitigation actions that it is possible to do: the soil on which the buildings are located can be depressurized, using ventilation systems such as a suction box, so that the Radon is attracted by the pressure differential and release it through an extractor, which goes through the interior of the infrastructure from basement to the roof, where the gas will be released into the atmosphere, similar dynamic to a chimney. The same action can be performed inversely, the external air is introduced through the extractor, this air reaches the ground and the Radon dissipates (Frutos Vázquez, 2018).

Another method to reduce the concentrations of this gas and prevent its entry are the barriers: the placement of Radon impermeable sheets or membranes with a high mechanical strength and durability at the base of the buildings; sheets made of plastic, PVC or rubber, among other materials (Frutos Vázquez, 2018) could perform this function. These sheets would have to be certified by a reference laboratory before its installation. This operation must be carried out with care, since the Radon would remain concentrated in the ground, but with no possibility to go through these membranes, meaning that in case of break, the gas would enter into the building. Finally, another type of solution would be the ventilation of the buildings, the diffusion of the gas by air exchange with the outside, introducing a flow of air inside the floors, which would make the Radon go outside. However, if the ventilation was high, and the gas values did not decrease, another measures will have to do.

The establishment of one measure or other varies depending on whether it is an existing building or if it is a project. In existing constructions, action from the inside can be done, through the placement of barriers or extractors, which may involve a high cost depending on the work. You could also act outside, using the sanitary forge, construing at the base of the buildings, creating an air chamber between the house and the soil that serves as thermal insulation and moisture, but its efficiency would be less, like its cost (Frutos Vázquez, 2018).

In the case of constructions in project would be simpler and cheaper, because due to the current regulation 2013/59 / EURATOM, it is mandatory to have mitigation systems for Radon concentrations, which could be composed with any of the previous actions. In this case, you could even make a combination of several measures to maximize the mitigation of gas entry onto the building, such combined barriers with an extraction system, for example, since it is easier to start a new construction than to modify an already completed.

Apart from the technical measures, actions related to make the population aware of the problem are required because it's a matter that has been ignored for years. The non-mandatory nature of measuring at homes and work centres until 2018, and its limited dissemination by the media to the present, have contributed to the fact that it goes unnoticed in a significant sector of the population. In addition, despite its important influence on lung cancer, it is difficult to attribute an exact number of deaths, since the deaths in which it is involved is usually attributed to other causes such as smoking. Another fact that influences this issue, is that it is not distributed homogeneously in the territory. For example, if we take two adjoining houses at the same area with the same geological substrate, both houses will have different concentrations. Government authorities can collaborate in the integration of the population to reduce the risk of Radon gas emissions. The creation of programs to raise public awareness, as well as greater dissemination of the media, with a clear and direct language, to cover a large sector of the audience, would be necessary for

the population to begin to understand the problem. In fact, most of the measurements are voluntary, on the part of the population that had been informed about the subject, with what it is necessary to favour that more people choose to measure their homes and work centres. In other countries, they have specific plans to confront it, such as Ireland or the United Kingdom, apart from accessible, clear and public cartographies, so that the population know why they are on risk, and when.

In the analysed examples we have only voluntary measurements, for the time being, and only a few research centres have been concerned in preparing studies and cartographies, and making public the Radon concentrations problem. If general people understands the problem, it will be easier to integrate it into the solution and decide to measure its buildings, which will make it easier to determine the Radon-prone areas of the territory and deal with its emissions.

5. CONCLUSIONS

There is a before and after to the 2013/59 / EURATOM regulation: it has gone from a context in which the Radon is the great unknown and treated by few, beyond research, to a growing concern for it, and to assume which is a risk to human health, in which the population begins to take an interest and the institutions are obligated to fight it, and although there is still much to be done, this regulation brings the necessary guidelines for the affected population to face it.

Galicia has many areas with high concentrations, which implies that a large number of studies will be required throughout the territory to reduce the risk to the citizens. With the approval of the European regulations, the existence of this phenomenon has begun to be known among the population, due to the obligation that now exists a real threat, to treat high concentrations, and has begun to concern normal people and every day more and more people are getting conscious about this underlying problem. However, the lack of dissemination prior to the application of the regulations implies that a large part of the population

remains to be informed and concienciated.

In the analysed examples a large part of the measurements exceeds the threshold of 300 Bq/m^3 determined by the EU, and in some cases, with great differences, such as the measurements of the Suido Range, location where the unusual values are those that do not exceed that threshold. In the case of Santiago, the dynamic is different, most of the values do not reach the limit, but despite this, there are places that need intervention. The previous examples are locations with different geological compositions. The measurements taken in the Suido Range, predominantly granite massif, have high concentrations, of 13 measurements, only 2 do not reach 200 Bq/m^3 , and although most of the data were obtained in the dominant material, those obtained from the others materials also have high concentrations. In fact, it is an area that has one of the highest concentrations in the entire territory, $2,284 \text{ Bq/m}^3$. In the case of Santiago, contact zone between granite, shale, gneisses felsic and metabasite, the values collected are lower, compared to the other example. It presents local differences, the granitic materials have the highest concentrations, but the gneisses or the metabasites also present relatively high measures, although all these would be smaller than those established in the Suido Range. In both case, for greater precision in the study, it is necessary to take more measures, since in both cases there were census sections without any, fact that in the official cartography are reflected without risk, when the reality could be different.

If the concentrations of Radon exceed the limit of 300 Bq/m^3 , as already mentioned, the solution is simple, but the real problem is in those buildings that exceed 400 Bq/m^3 , 500 Bq/m^3 , $1,000 \text{ Bq/m}^3$ or even more, which require urgent interventions and imply a cost that is not possible to pay for all of the owners. The institutions have not dealt with the issue before, and the mandate of the EU has forced them to update quickly without being prepared for this new context, which translates into lack of planning, measures and involvement on the part of these agencies. The same applies to certain companies, since, although there are mainly housing, the work centres

are also governed by this rule, which have begun to take measures this year.

It would also happen in the population, since until this year the interest in Radon has been minimal, and many homes have high concentrations, without knowing it, which does not imply that they inhale the alpha radiation from the transformation of the gas in their descendants, and are exposed to its effects. Radon concentrations is a common problem to all the sectors of the society, so the implication of all the population is required in order to mitigate this risk.

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