Task 4.3.3: Estimation of **Rn priority areas** based on Rn extremes, with **case studies in France and Spain**

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Task 4.3.3: Identification of RPA

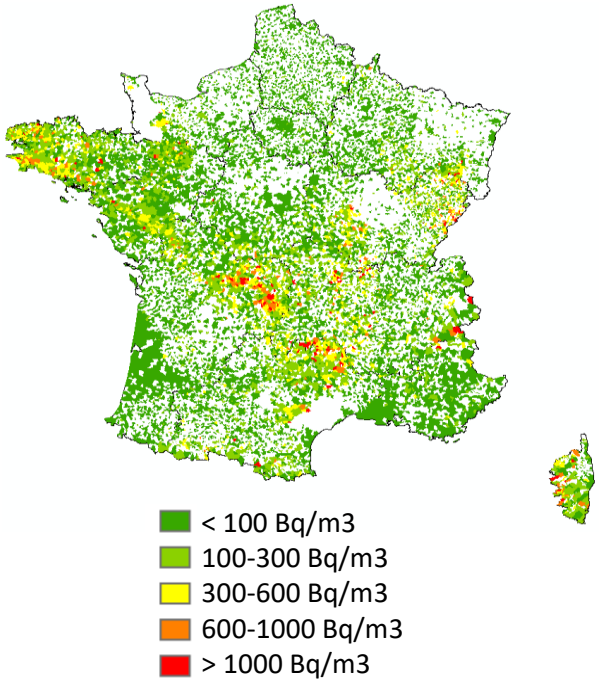
- Identification of areas that could be concerned by a significant proportion of dwellings with very high indoor radon concentrations of several thousands of Bq/m^3.
- Method tested in France and Spain, where such cases occur regionally.
- Based on the analysis of available quantities such as :
  - Geogenic radon potential,
  - Measurements of indoor radon concentration,
  - Other available data : dwellings characteristics, recent results of quantitative radon risk assessment etc.
- Such a method would allow targeting specific prevention and remediation actions in heavily affected regions to significantly reduce the exposure in buildings.

Case-studies in France – Methodology and data

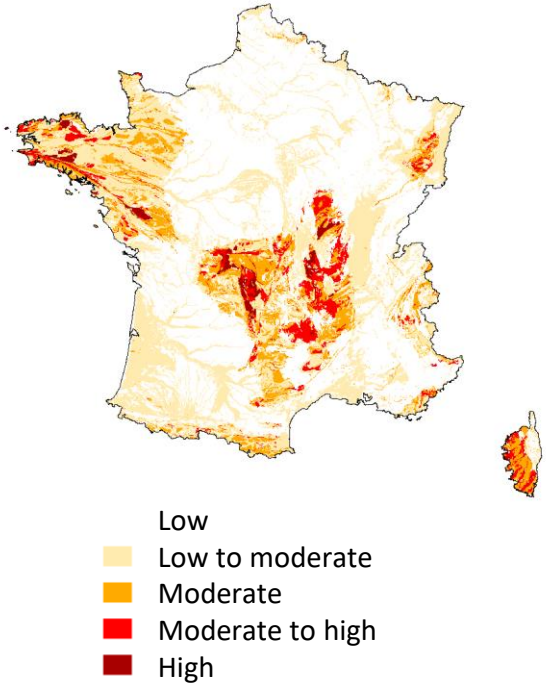
- Based on radon potential maps and all the indoor radon data available, **calculate the probability of exceeding 300 Bq/m³ and 1000 Bq/m³ in the different categories of radon potential**.
- **Hot spots identification** :
  - **Smaller sub-sectors will be delineated** (20x20 km cells). From the indoor radon data available, statistics could be produced on each of these sub-sectors → **identification of sub-sectors with the highest concentrations (= RPA)**.
  - For each RPA identified, a **detailed study of the local geology** could be carried out.
- **Outliers identification :**
  - Isolate all values **above 1000 Bq/m³**: for each value above the threshold but located in a low radon potential area according to the geogenic radon potential map, a check to see if it is associated with a particular geology will be made.
- Based on those different observations, a **list of geological features characterizing a RPA** can be realized. The presence of these geological features on a territory, even if few radon measurements are available indoor, could allow identifying the areas presenting a risk of high radon exposure. **Such a knowledge could guide specific prevention and remediation actions.**

Case-studies in France – Available data

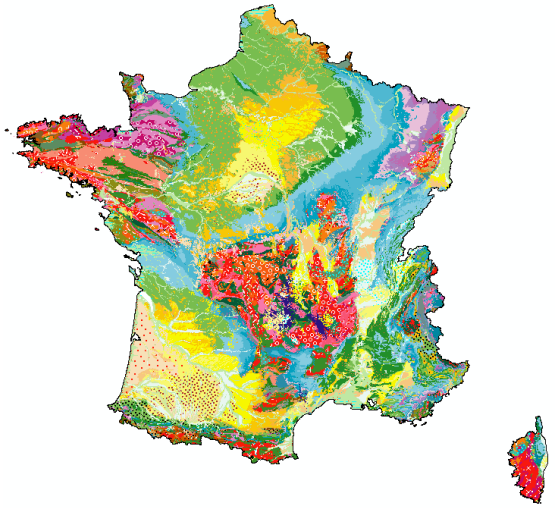
31,915 indoor measurements



French geogenic radon potential mapping (in 5 categories, scale: 1/1 000 000)



National geological map : 1/1 000 000



Case-studies in France – Available data

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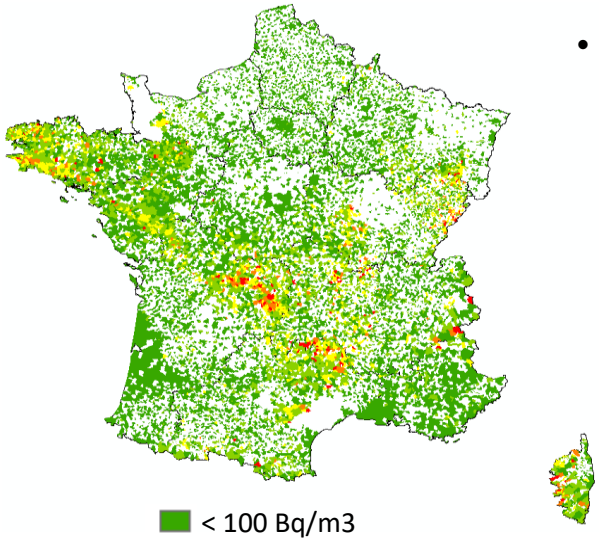


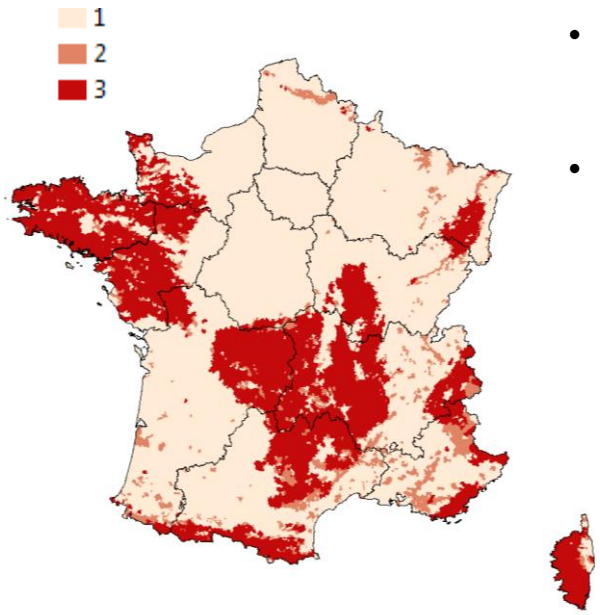
- **12,940 measurements** for the **national database** (IRSN-French Health Ministry) in dwellings over the period 1982-2002;
- **8,253 measurements** for some **public buildings** in the French regions most affected by radon risk (French Health Ministry database) acquired between 2014 and 2018;
- **10,722 measurements** acquired for **local measurement campaigns** in dwellings were also collected for this study (local Health Authorities databases).

	Number of data	Radon concentration (Bq.m^{-3})						
		Min	Max	Average (A.M)	S.D (A.M)	1st quartile	Median	3rd quartile
Total dataset	31,915	1	28,553	238	586	44	97	229
National campaign in dwellings	12,940	1	4,382	89	159	28	49	93

Global dataset overestimates indoor radon concentrations because regulatory measurements in public buildings and local measurements campaigns are rather carried out in high radon potential areas.

Case-studies in France – Probability of exceeding in the different categories of radon potential

Municipalities classification:



Municipalities classification based on French geogenic radon potential map :

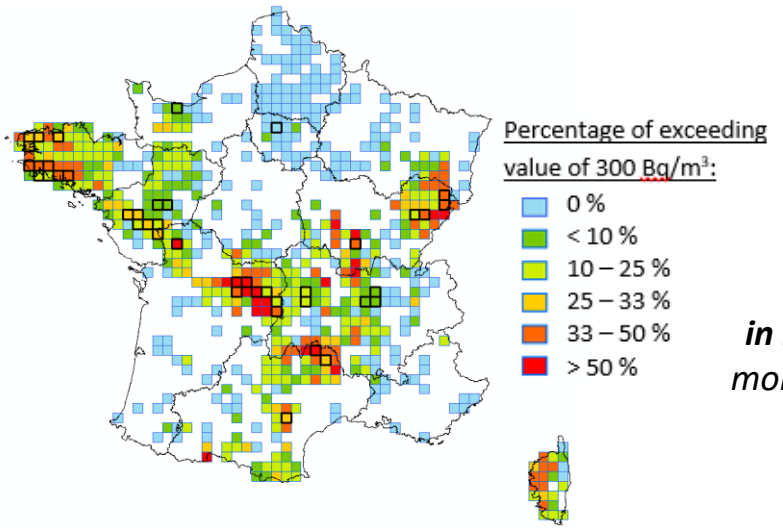
- **Category 1:** municipalities located entirely on geological formations with low uranium contents and with no factors that may facilitate the transfer of radon to the surface
- **Category 2:** municipalities also located on geological formations with low uranium contents, but a part of their surface is concerned by geological factors that can facilitate the transfer of radon to the surface
- **Category 3:** municipalities which present geological formations with higher uranium contents compared to the other formations, on at least a part of their surface. For this category, the presence of radon at high concentrations in buildings is most likely.

Category	Surface		Data Number		Average (A.M)	S.D (A.M)	> 300 Bq/m³	> 1,000 Bq/m³
	(km²)	(%)	-	(%)			(%)	(%)
Cat. 1	349,037	64.7	11,055	35	108	231	**6.9**	**1.0**
Cat. 2	35,187	6.5	1,743	5	144	232	**12.1**	**1.5**
Cat. 3	155,402	28.8	19,117	60	321	721	**26.8**	**5.6**
TOTAL	*539,627*	*100*	*31,915*	*100*	*238*	*586*	*19.1*	*3.8*

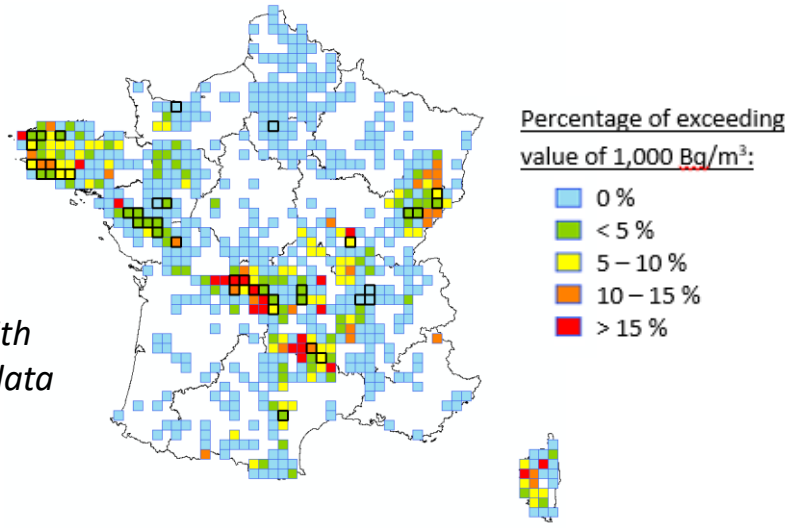
Good correlation observed between the three categories of municipalities and the results of indoor radon measurement

Case-studies in France – Hot spots identification

- The term *hot spot* refers to small regions where the indoor radon concentrations show anomalously high values
- French territory has been subdivided into regular sub-sections using a 20x20 km grid. Only cells with more than 10 measurements were used. The percentages of exceeding value of 300 Bq/m^3 and 1,000 Bq/m^3 were calculated for each cell.



***in bold**: cells with more than 100 data*



Case-studies in France – Hot spots identification

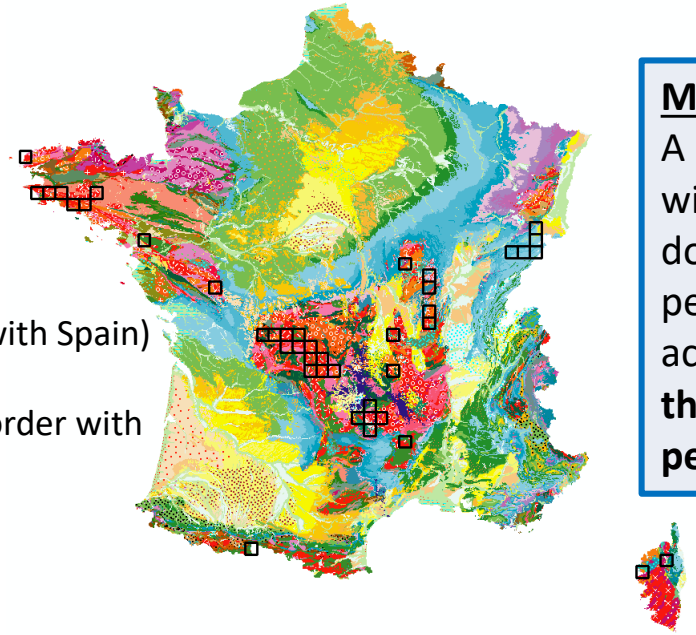
From these results, “hot spots” are defined as the cells having at least one of the following characteristics:

- Percentage exceeding 300 Bq/m^3 above 50%;
- Percentage exceeding 1,000 Bq/m^3 above 15%;
- Percentage exceeding 300 Bq/m^3 above 33% with more than 100 data in the cell.

According to these criteria, 42 cells can be considered as “hot spots”

Hot spots location :

- 9 in the Armorican Massif
- 25 in the Massif Central
- 1 in the Pyrenees (border with Spain)
- 2 in Corsica
- 5 in the Jura Mountains (border with Switzerland)



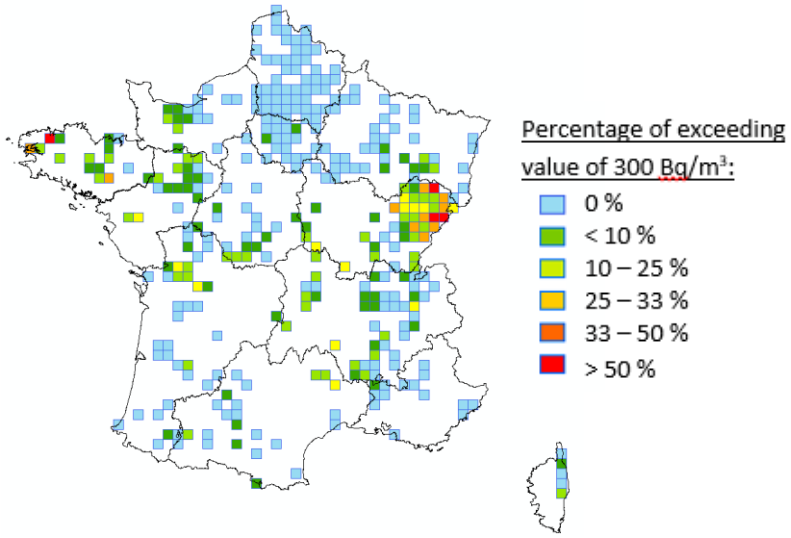
Main geological features :

A majority of hot spots are associated with some peculiar granites with a clear dominance of monzogranites and peraluminous leucogranites. Thus, according to the available indoor data, **this lithology appears to be the most penalizing for the radon issue in France**.

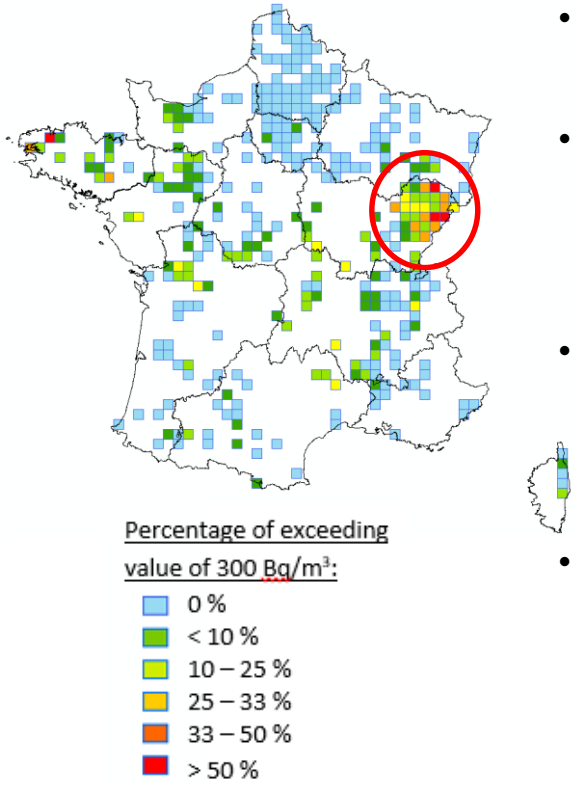
Case-studies in France – Outliers identification

- Outliers are values which **seem not to belong to a population**. For radon, outliers are the high values observed outside areas considered as high radon potential.
  → **Focus on the values measured in the municipalities classified in category 1 and 2**

- French territory has been subdivided into regular sub-sections using a 20x20 km grid considering only the indoor radon concentrations measured in municipalities in category 1 and 2. Only cells with more than 10 measurements were used. The percentages of exceeding value of 300 Bq/m^3 were calculated for each cell.



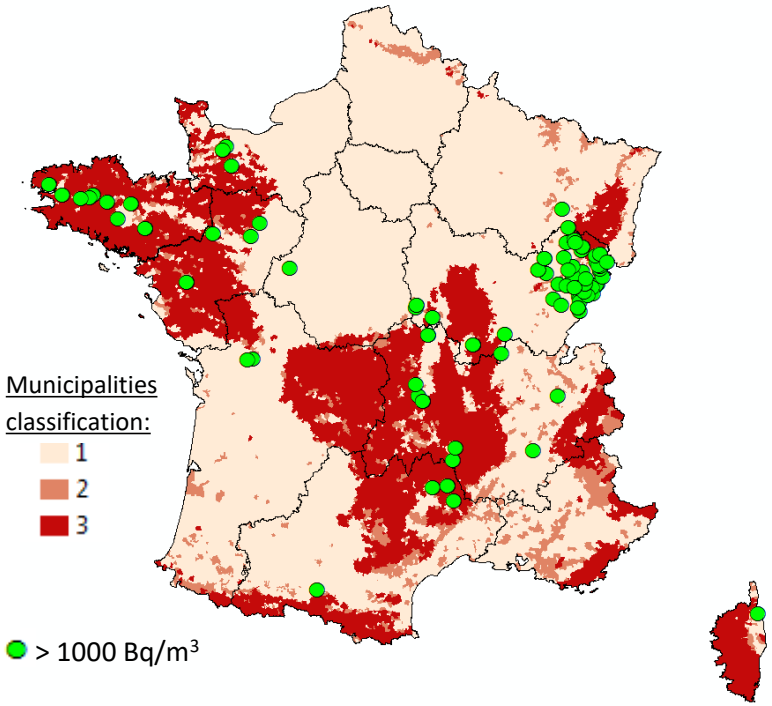
Case-studies in France – Outliers identification



- **Jura karstic area, at the border with Switzerland, stands out clearly**. Several cells in this sector were also defined as “hot spots”.
- Karstic systems are very complex and their impact on radon potential is not very well known. Indeed, the uranium content of karstic rocks (limestones) is low but karsts are very permeable geological environments that can facilitate the radon accumulation and/or the radon transport to the surface.
- IRSN performed a study to enhance knowledge on the influence of karstic structures on the radon production and migration in the French Jura Mountains. **This study confirmed that karstic environments could be the source of locally high radon contents in soils**.
- The data analysis and the modelling show that the **average levels of radon activity in soils are essentially the result of radium-226 emanation from the soil**. Indeed, on the study area, a relative enrichment of radium-226 was observed in soils due to the important dissolution of limestones in the past (karst formation) and the soil radium-226 contents was quite similar to those observed in some granitic regions.
- The study is still ongoing in other karstic regions in France before to be able to transpose these conclusions to the French geogenic radon potential map.

Case-studies in France – Outliers identification

- In order to more specifically identify outliers, **all the exceedances of the value of 1,000 Bq/m³ measured in categories 1 and 2 municipalities were selected** → 132 measurement results (out of 31,915 initial measurements, i.e. 0.4%)



- Most outliers thus identified are located **in the vicinity of category 3 municipalities** (high geogenic radon potential), in the Massif Central and in the Armorican Massif.
- Numerous outliers are also identified in the Jura karstic area, already mentioned.
- Finally, some outliers appear isolated in areas with low geogenic radon potential.

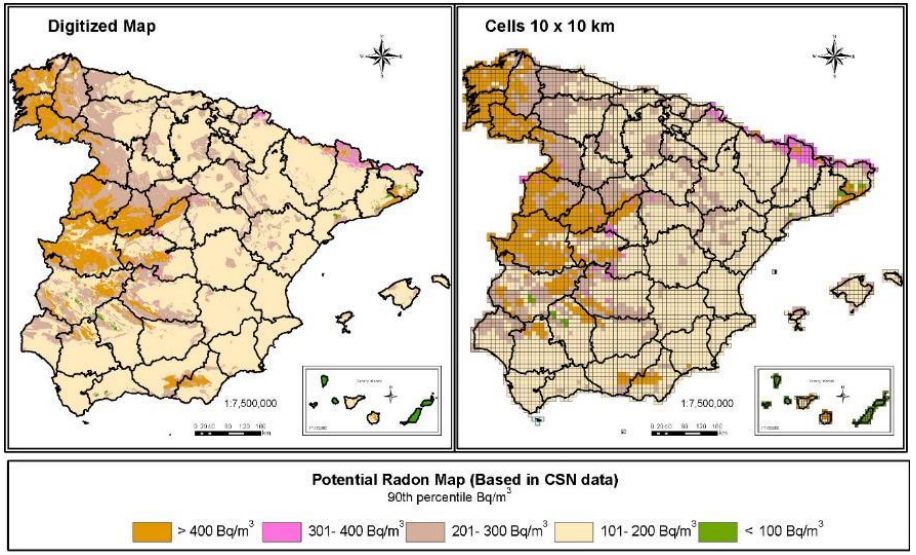
Case-studies in Spain – Available data

- The national radon database in dwellings by the Nuclear Safety Council (CSN) has 12,000 measurements made in different sampling campaigns. The University of Cantabria (UC) contributed until 2014 with 9,211 measurements.
- Sampling in Spain was not random. The CSN defined a sampling criteria that intensified the number of measurements in an area previously selected. This sampling was adjusted to a 10 x 10 km cells system.

No. of data	Radon concentration (Bq/m^3)									Skewmess	Kurtosiss
	Min	Max	Average (A.M)	S.d A.M	Average (G.M)	S.d G.M	1st Quartile	Median	3rd Quartile		
9,211	10	15,403	95	270.57	55	2.61	28	54	103	33.1	1,539

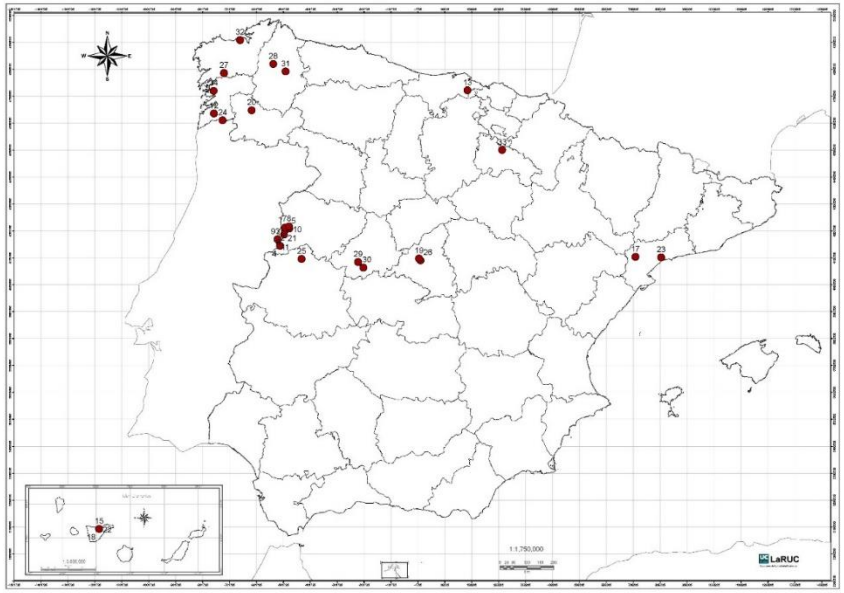
Case-studies in Spain – Hot spots identification

- The Spanish radon potential map was transfer to a 10x10 km cells system and the value of the category P90 with more area in each cell was assigned
- Focus on category 1 and 2
- The geologies associated with the cells defined as category 1 (<400 Bq/m^3) in Peninsula and Canary Islands, just as those in category 2 (between 301 and 400 Bq/m^3) were analyzed in base on the number of measurements made within the each cell
- The most representative lithologies at 1:1,500,000 are:
  - the "**Biotitic Granitoids**" (192 Bq/m^3) with 1,404 samples taken in these cells, where 12 % of the data exceeds 300 Bq/m^3
  - the "**Serpentinites, metabasites and meta-vulcanites acids**" (184 Bq/m^3) where 15 % of the data exceeds 300 Bq/m^3
  - the "**Acid rocks metamorphosed as peraluminous granitoids**" (151 Bq/m^3) where 12% of the data exceeds 300 Bq/m^3
  - the "**Slates, sandstones, quartzites, limestones or vulcanoclastic rocks**" (146 Bq/m^3) where 8 % of the data exceeds 300 Bq/m^3



Case-studies in Spa in – Outliers identification

- There are 34 point data of radon measurements in dwellings in which the 1,000 Bq/m^3 of annual average concentration is exceeded
- Regarding the lithostratigraphies at 1: 1,000,000 it is verified that :
  - 26 % of the samples were taken on "Biotitic Granitoids",
  - 26 % on "Slates, sandstones, quartzites, limestones or vulcanoclastic rocks“
  - 24 % on"Sandstones, slates, quartzites or limestones and conglomerates”
- There are 5 data on karstic formations: Three samples were taken in Canary Islands on "wind sands subordinates" (calcoalkaline volcanic rocks) and the other two in moderately karstified carbonate formations on "sandstones, slate, quartzite or limestone and conglomerates".
- The faults proximity analysis shows that 12 of the sampled points of more than 1,000 Bq/m^3 are less than 2 km from these structures.



Case-studies in France and Spain – Discussion and perspectives

- For France and Spain, both arithmetic means of indoor radon measurements are quite close and around **90 Bq/m3**.
- In France, the highest indoor radon concentrations are located in the Armorican Massif, the Massif Central, the Pyrenees at the border with Spain, in Corsica and in the Jura Mountains at the border with Switzerland. The main high values are associated with some **peculiar granites** with a clear dominance of **monzogranites, peraluminous leucogranites or peralkaline granites**. The high values identified in the Jura Mountains are located in **karstic areas**.
- In Spain, the highest indoor radon concentrations are associated with "Biotitic Granitoids", "Slates, sandstones, quartzites, limestones or vulcanoclastic rocks, Sandstones, slates, quartzites or limestones and conglomerates ". Some high values have also been observed in certain karst formations. Finally, the faults proximity analysis shows that 35% of the sampled points of more than 1,000 Bq/m^3 are less than 2 km from these structures.
- The results provide **first elements** to target areas where more precise studies are needed to acquire more indoor radon data precisely located and the characteristics of buildings associated with the measurements. An analysis of both geological features and building characteristics (mainly the interface between the soil and the building, the building materials, ventilation systems etc.) need to be realized to identify the best indicators of highest indoor radon values.