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Multi-approach assessment of radon risk in Spanish soils

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14th INTERNATIONAL WORKSHOP GARRM.
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Contents

Introduction

EU Directive 2013/59 (BSS) article 103:

"Member States shall ensure that appropriate measures are in place to ***prevent*** *radon ingress into* ***new*** *buildings. These measures may include specific requirements in national building codes."*

→ Risk assessment, but how?

Based on Radon maps or Radon risk maps	Radon-resistant new buildings in radon "priority" areas.
Based on *in-situ* measurements	Radon-resistant new buildings according to in-situ risk.

Soil-gas radon, soil gas-permeability

Exhalation rate, Radium Content, …

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Introduction

GOBIERNO DE ESPAÑA | MINISTERIO DE FOMENTO

CSIC

INSTITUTO EDUARDO TORROJA

CSN CONSEJO DE SEGURIDAD NUCLEAR

Explore the applicability of the Czech methodology

Use Spanish Radon risk map?

Radon risk assessment

- Low
- Medium
- High

New radon document for the Technical Building Code published by 2018/2019

The project for radon risk assessment - Objectives

Project funded by CSN. Nov. 2015 – July 2017.

4 university groups with experience on soil-gas radon measurements and radon metrology (UAB, UCAN, ULPGC, UPC)

Geologic assessment from Geomnia Natural Resources S.L.N.E. and collaboration from Geocisa.

Main goal: **Development and experimental validation of a methodology to obtain the soil-gas radon level representative of a piece of ground in Spain → radon risk assessment.**

Specific objectives

1. Establish a standard procedure to measure radon activity concentration in soil.
2. Provide guidelines for the determination of representative values of soil gas radon concentration and soil gas-permeability ("standard methodology")
3. Explore alternative methods when standard methodology cannot be used.
4. Explore applicability of radon-risk assessment based on in-situ measurements.
5. Provide recommendations on radon risk-assessment.

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The project for radon risk assessment - methodology

Activities structured in work-packages:

WP1: Management & coordination **Ll. Font (UAB), M. García-Talavera (CSN)**

WP2: Standard Procedure **Ll. Font (UAB)**

WP3: Quality Control **A. Vargas (UPC), V. Moreno (UAB)**

WP4: Representative value **J. Gª Rubiano and Héctor Alonso (ULPGC), and L. Quindós (UCAN)**

Both spatial and temporal variations taken into account.

WP5: Alternative methods

Rn exhalation. **V. Moreno (UAB)**
Ra content. **J. Garcia-Orellana (UAB), A. Vargas (UPC)**
Use of maps. **M. García-Talavera (CSN), C. Sainz (UCAN), C. Grossi (UPC)**

WP6: Surveys in selected sites **All participants.**

WP7: Geological studies **E. Sanz, A. Sánchez (Geomnia Natural Resources S.L.N.E)**

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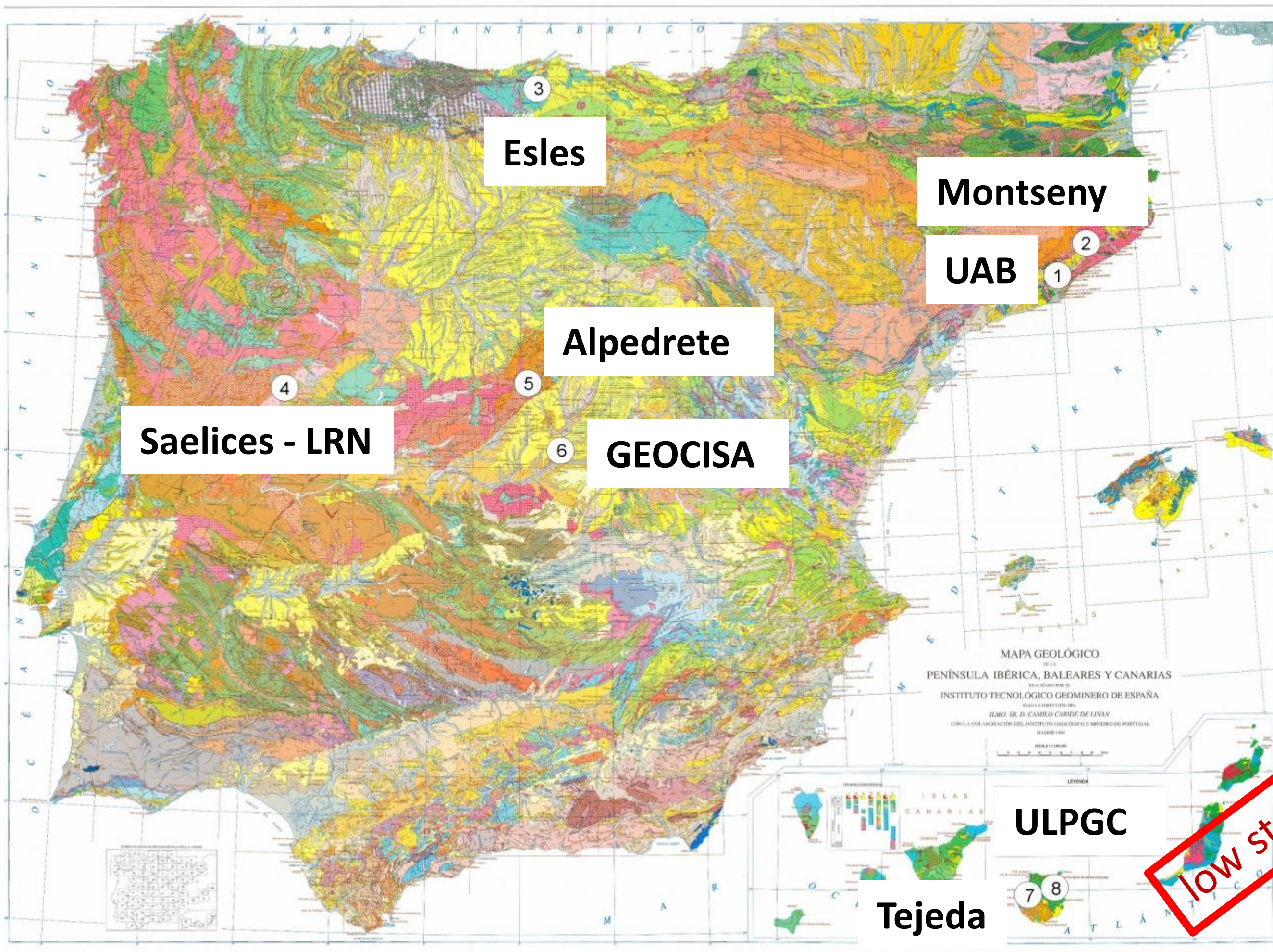
The project for radon risk assessment - methodology

Site selection

8 sites have been selected trying to cover a significant part of the Spanish geological characteristics, taking into account available budget and practical considerations.



Experimental sites located in soils derived from distinct lithologies:

- Tertiary sedimentary basins (1,6)
- Paleozoic slates and sandstones (2,4)
- Mesozoic carbonates (3)
- Granites (5)
- Volcanic and volcaniclastic rocks (7,8)

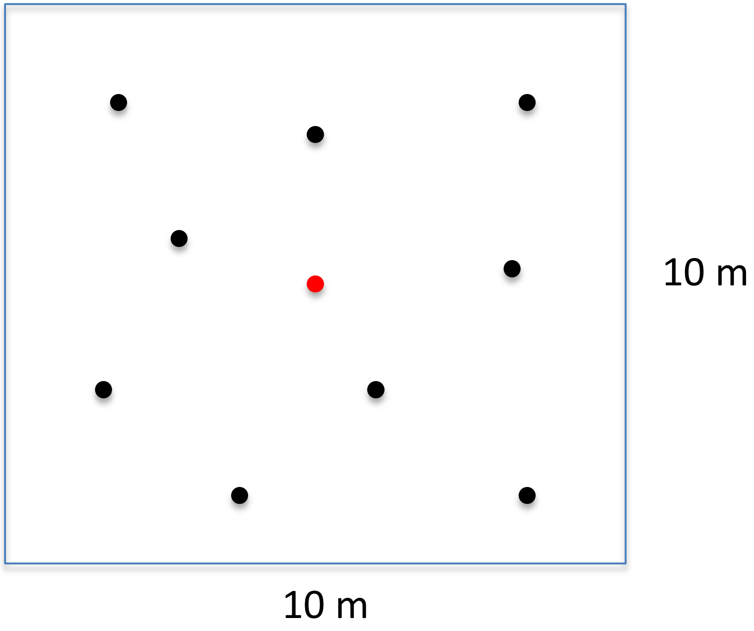
The project for radon risk assessment - methodology

Survey design

The same pattern in all sites (~100 m^2)

Soil-gas radon concentration:

- 9 measurement points that cover the site + 1 in the centre with a permanent steel rod.
- 1 measurement at all points per season.
- 1 measurement/month at the central point.



Radium content (Ra-226):

- Soil samples at different depths

Gamma-spectrometry, exposure rate

- One measurement per site

Exhalation rate

- One measurement/site/season in as many points as possible

Important remark:

- At each site the responsible group performs Rn measurements with its own detectors and procedure → quality control required.

The project for radon risk assessment - methodology

Geological characterization of each site

1. Data collected from Spanish Geological and Mining Institute: lithology, structural characterization, permeability, geochemical characterization.
2. Data from Spanish National Institute of Meteorology: climatology, weather data from the closest weather station.
3. Data from Spanish Geographic Institute: topography, orientation, slopes.
4. Trench 1 m in depth for soil profile description in selected sites.
5. Permeability test *in-situ*.
6. Collection of preserved (and non preserved) soil samples for determining in the laboratory.:
    1. Grain size distribution
    2. Humidity
    3. Density and porosity
    4. Permeability

7. Installation of soil moisture data logger for 1 year monitoring.

Main results

Standard procedure for the measurement of radon concentration in soil

- Based on the draft ISO 11665-11:2016 Radon-222 - Test method for soil gas.
- Restricted to grab sampling procedure only.
- It includes correction factors for a measurement at a depth different than 1 meter assuming typical soil Rn diffusive concentration profiles in homogeneous soils. Measurements referred to 1 m depth.

	l_d = 0,5 m		l_d = 0,75 m		l_d = 1 m		l_d = 1,25 m		l_d = 1,5 m		l_d = 1,75 m		l_d = 2 m	
z (m)	F_1	F_∞	F_1	F_∞	F_1	F_∞	F_1	F_∞	F_1	F_∞	F_1	F_∞	F_1	F_∞
0,1	4,8	5,5	5,9	8,0	6,6	10,5	7,2	13,0	7,5	15,5	7,8	18,0	8,1	20,5
0,2	2,6	3,0	3,1	4,3	3,5	5,5	3,7	6,8	3,9	8,0	4,0	9,3	4,1	10,5
0,3	1,9	2,2	2,2	3,0	2,4	3,9	2,6	4,7	2,7	5,5	2,8	6,3	2,8	7,2
0,4	1,6	1,8	1,8	2,4	1,9	3,0	2,0	3,7	2,1	4,3	2,1	4,9	2,2	5,5
0,5	1,4	1,6	1,5	2,1	1,6	2,5	1,7	3,0	1,7	3,5	1,8	4,0	1,8	4,5
0,6	1,2	1,4	1,3	1,8	1,4	2,2	1,4	2,6	1,5	3,0	1,5	3,4	1,5	3,9
0,7	1,1	1,3	1,2	1,6	1,3	2,0	1,3	2,3	1,3	2,7	1,3	3,0	1,3	3,4
0,8	1,1	1,3	1,1	1,5	1,1	1,8	1,2	2,1	1,2	2,4	1,2	2,7	1,2	3,0
0,9	1,0	1,2	1,1	1,4	1,1	1,7	1,1	1,9	1,1	2,2	1,1	2,5	1,1	2,8
1	1,0	1,2	1,0	1,4	1,0	1,6	1,0	1,8	1,0	2,1	1,0	2,3	1,0	2,5
1,1	1,0	1,1	1,0	1,3	0,9	1,5	0,9	1,7	0,9	1,9	0,9	2,1	0,9	2,4
1,2	1,0	1,1	0,9	1,3	0,9	1,4	0,9	1,6	0,9	1,8	0,9	2,0	0,9	2,2
1,3	0,9	1,1	0,9	1,2	0,9	1,4	0,9	1,5	0,8	1,7	0,8	1,9	0,8	2,1
1,4	0,9	1,1	0,9	1,2	0,8	1,3	0,8	1,5	0,8	1,6	0,8	1,8	0,8	2,0
1,5	0,9	1,1	0,9	1,2	0,8	1,3	0,8	1,4	0,8	1,6	0,8	1,7	0,7	1,9

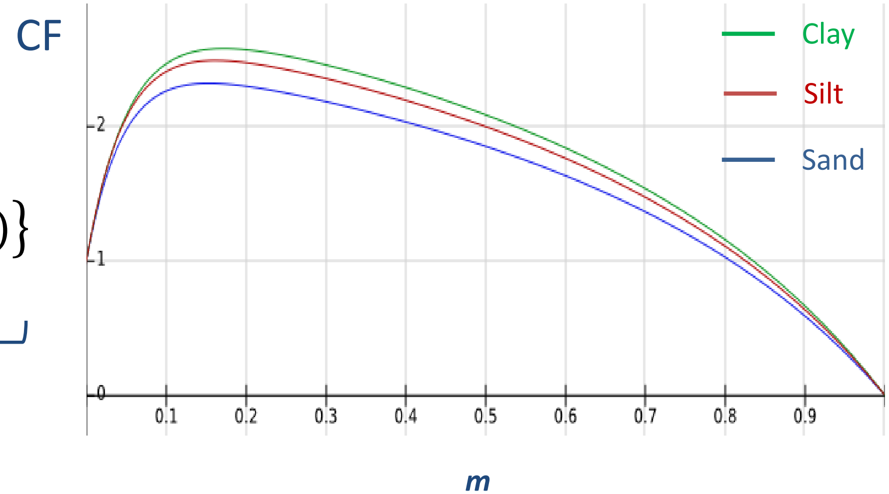
Main results

Standard procedure for the measurement of radon concentration in soil

- Based on the draft ISO 11665-11:2016 Radon-222 - Test method for soil gas.
- Restricted to grab sampling procedure only.
- It includes correction factors for a measurement at a depth different than 1 meter assuming typical soil Rn diffusive concentration profiles in homogeneous soils. Measurements referred to 1 m depth.
- It includes the dependence of soil radon concentration in equilibrium with radium (local radon potential or availability C_∞) with soil water saturation fraction (***m***), but no reference value of ***m*** is recommended.
- It does not include how to obtain a representative value of a certain plot of land.

$$C_{\infty,d} = C_{Ra-226} f_0(T) \rho_{gr} \frac{1-\varepsilon}{\varepsilon}$$

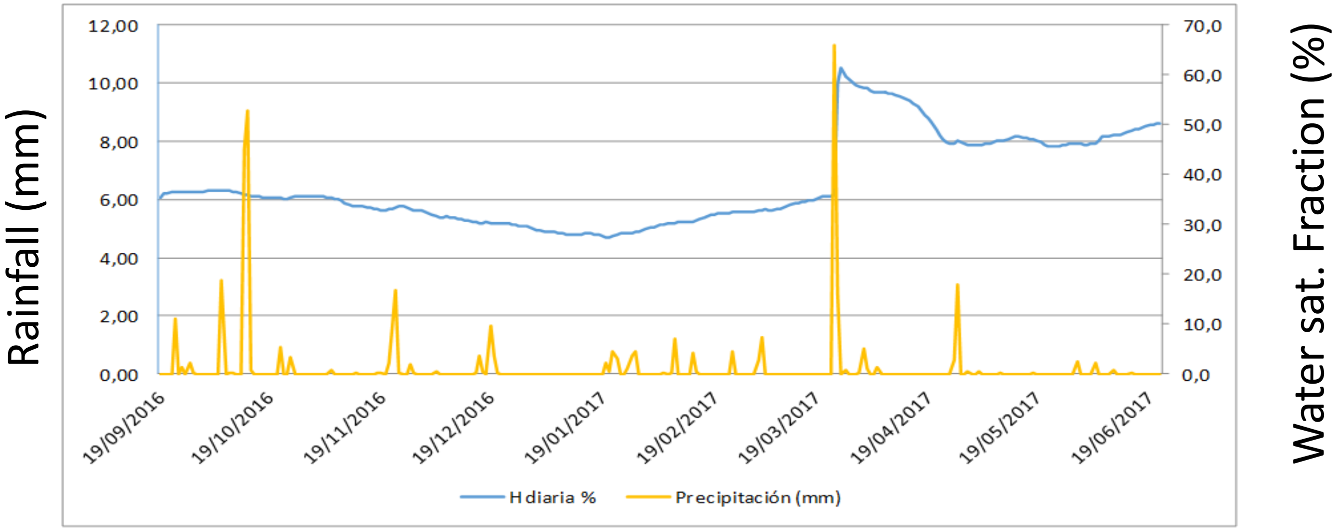
$$C_\infty = C_{\infty,d} \underbrace{\frac{1}{1+\frac{mL(T)}{1-m}} \left\{1 + a\left(1 - e^{-bm}\right)\right\}}_{CF}$$

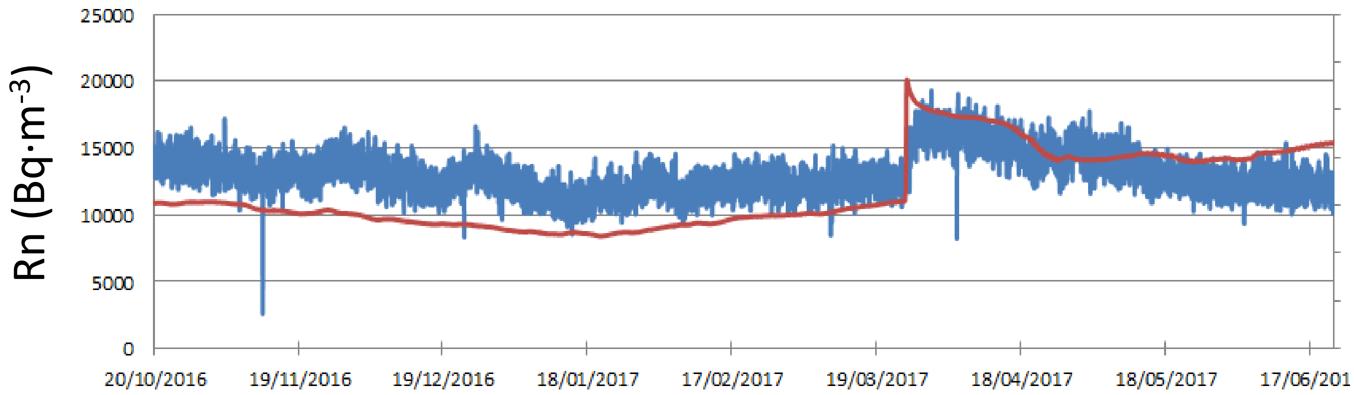


Font and Baixeras, 2003; Zhuo et al. 2006

Main results

Influence of rainfall on water saturation fraction and soil radon levels @ UAB





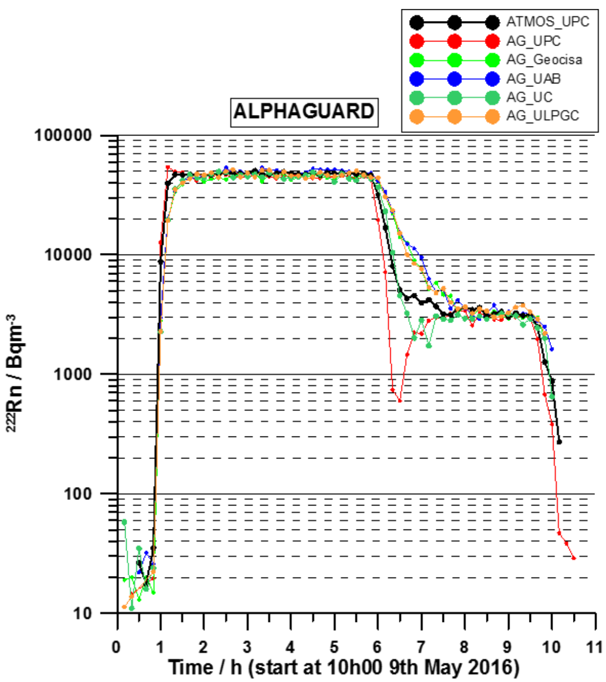
Modelling challenge: estimate water saturation fraction from rainfall in a specific soil

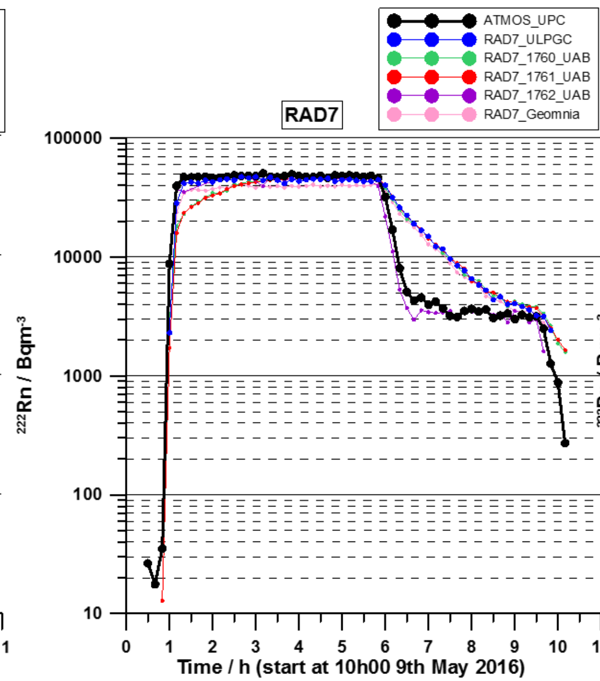
Main results

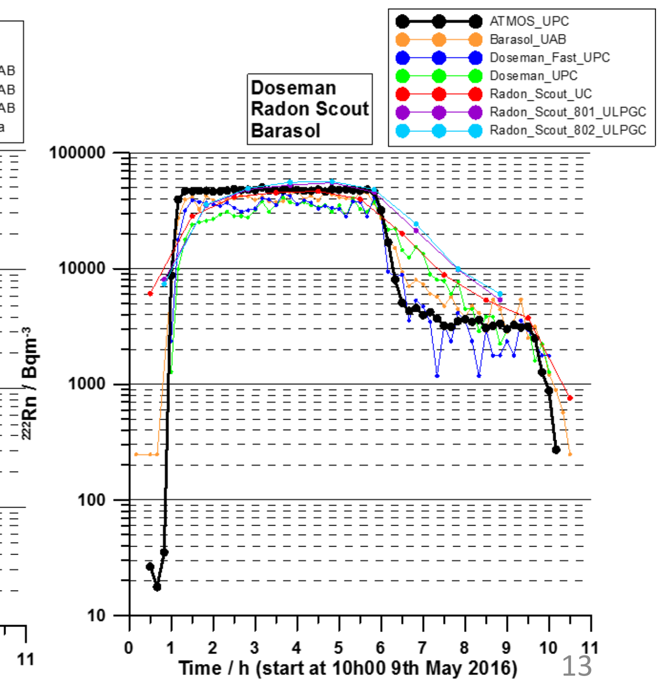
Quality control

Intercomparison exercise at the INTE(UPC) radon chamber

- For high Rn concentration values (~40 kBq/m^3) there is a good agreement between the different radon detectors used.
- For lower levels (~5 kBq/m^3) the instruments with small volumen of detection show higher scattering.
- Systems with a long response time are not suitable for fast Rn measurements (exhalation rate) and must be used with caution.







Main results

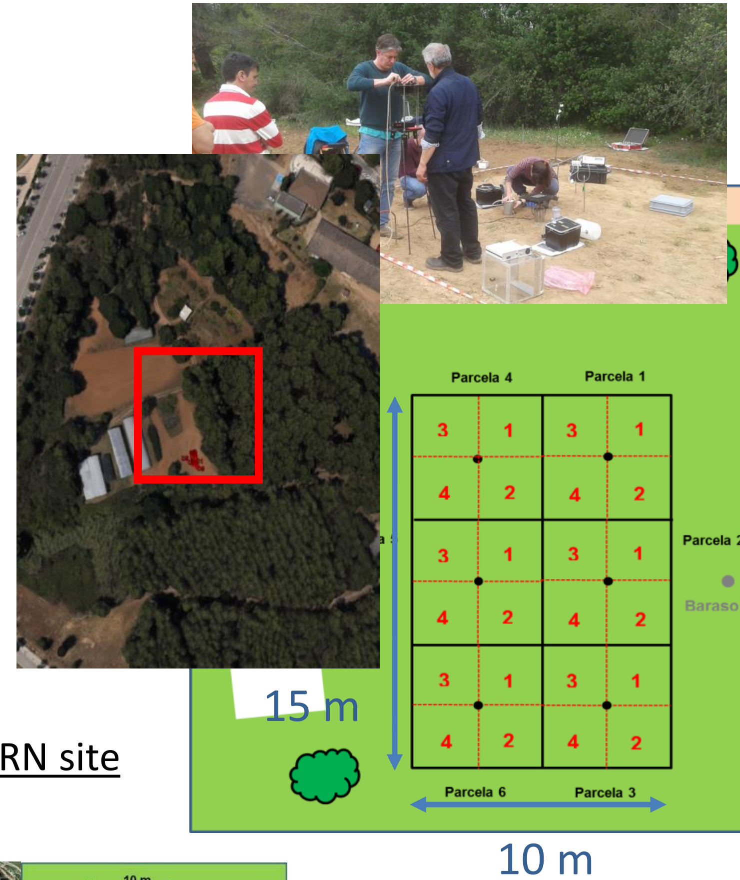
Quality control

Intercomparison exercises in the field

<u>Intercomparison 1 (May 10-11, 2016) @ UAB site</u>

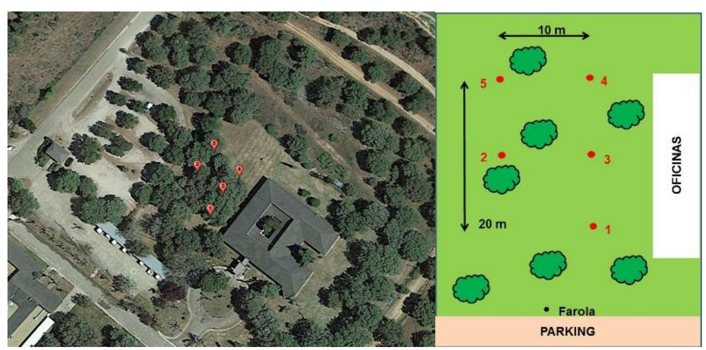
Soil-gas radon concentration measurement
- Test the effect of using different steel rods.
- Get the soil gas radon concentration profile.
- Test the influence of the volume collected from a single point.
- Test the influence of the air gap created for sampling.
- Compare with Barasol continuous measurement.

Radon exhalation measurement



<u>Intercomparison 2 (December 13, 2016) @ Saelices-LRN site</u>

Soil-gas radon concentration measurement
Radon exhalation measurement



Main results

Quality control

Intercomparison exercises in the field

Intercomparison 1 (May 10-11, 2016) @ UAB site

Soil-gas radon concentration measurement

- **Good agreement between different groups and continuous mesurement. “Homogeneous site with ~10 ±3 kBq·m^{-3}. CV = 30%”**

Sub-parcela	C_{Rn} (kBq·m^{-3})							
	Geocisa	Geomnia	UAB	UC	ULPGC	$\overline{x}_{sub\text{-}parcela}$	CV (%)	u_{test}
1	5.8 ± 0.4	7.5 ± 0.7	6.8 ± 0.4	11.9 ± 1.9	9.6 ± 2.0	8.3 ± 1.7	29	0.53
2	10.5 ± 2.8	11.4 ± 1.5	10.9 ± 0.6	13.9 ± 2.9	10.3 ± 1.6	11.4 ± 2.1	13	0.44
3	6.5 ± 2.2	-	7.9 ± 0.4	12.4 ± 2.7	7.2 ± 1.3	8.5 ± 2.4	31	0.41
4	12.2 ± 3.0	12.6 ± 1.6	11.6 ± 0.7	15.0 ± 2.3	13.2 ± 2.0	12.9 ± 2.1	10	0.90
5	-	3.1 ± 0.8	2.6 ± 0.2	11.2 ± 1.7	4.0 ± 0.9	5.2 ± 2.3	78	1.38
6	15.3 ± 3.0	14.8 ± 1.8	11.2 ± 2.8	11.9 ± 2.7	6.8 ± 2.1	12.0 ± 2.9	28	0.53
$\overline{x}_{grupo}$	10.1 ± 3.0	9.9 ± 2.5	8.5 ± 1.9	12.7 ± 2.5	8.5 ± 2.2			
CV (%)	39	47	41	11	38			
u_{test}	0.03	0.02	0.45	0.78	0.42			

$$CV = \frac{\sigma_x}{\overline{x}} \cdot 100$$

$$u_{test} = \frac{|x_i - \overline{x}|}{\sqrt{u_{x_i}^2 + u_{\overline{x}}^2}}$$

u-test limits commonly used.

	Condition
1	$1.64 > u_{test}$
2	$1.64 < u_{test} < 1.96$
3	$1.96 < u_{test} < 2.58$
4	$2.58 < u_{test} < 3.29$
5	$3.29 < u_{test}$

	Status
1	The reported result does not differ significantly from the expected value.
2	The reported result probably does not differ significantly from the expected value.
3	It is not clear whether the reported result differs significantly from the expected value.
4	The reported result is probably significantly different from the expected value.
5	The reported result is significantly different from the expected value.

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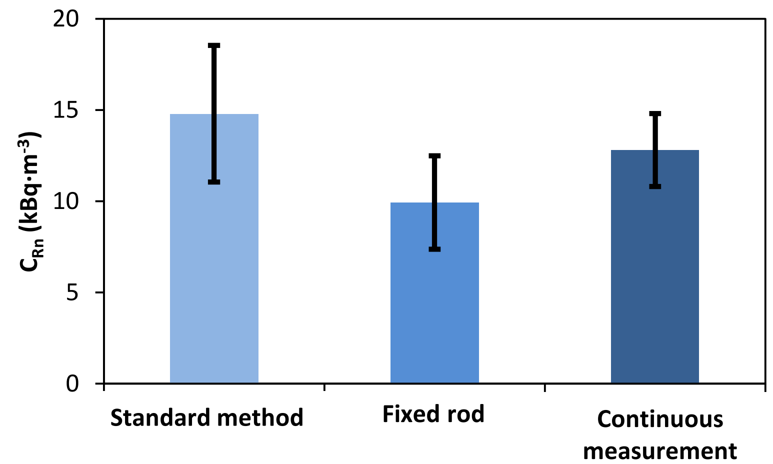
Main results

Quality control

Intercomparison exercises in the field

Intercomparison 1 (May 10-11, 2016) @ UAB site

Soil-gas radon concentration measurement
- **Good agreement between different groups and continuous measurement. "Homogeneous site with ~10 ±3 kBq·m^{-3}. CV=30%".**
- **No effect of using different steel rods.**
- Soil gas radon concentration profile consistent whith description obtained from the 1 m trench.
- No influence of the volume collected from sampling point.
- Influence of the air gap volumen not understood.



Radon exhalation measurement
- Results of the different groups are consistent.

Intercomparison 2 (December 13, 2016) @ Saelices-LRN site

Soil-gas radon concentration measurement
Radon exhalation measurement

Main results

Quality control

Intercomparison exercises in the field

Intercomparison 1 (May 10-11, 2016) @ UAB site

Soil-gas radon concentration measurement

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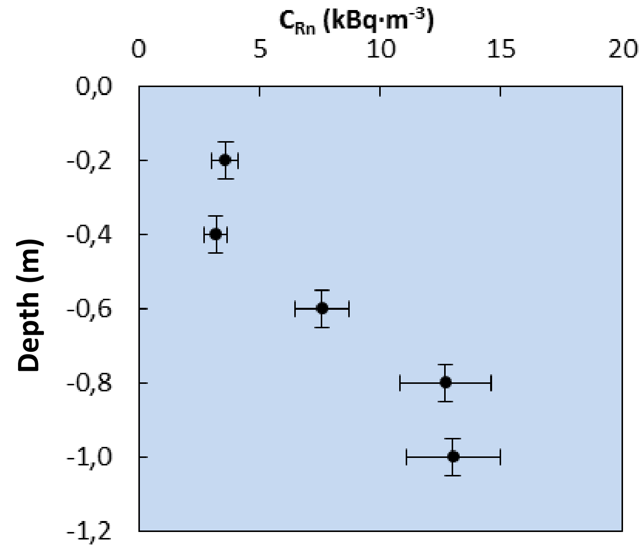

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Intercomparison 2 (December 13, 2016) @ Saelices-LRN site

Soil-gas radon concentration measurement
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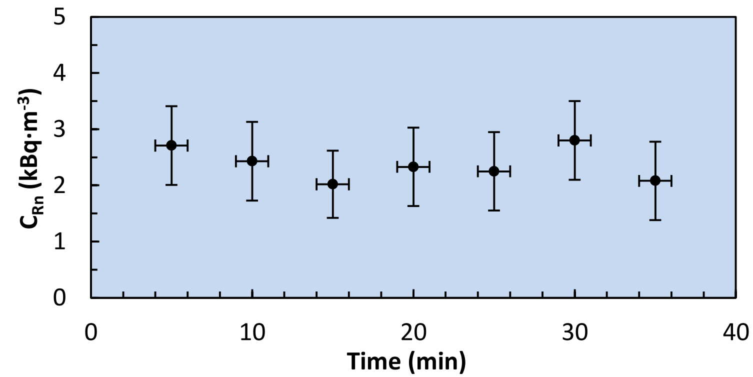

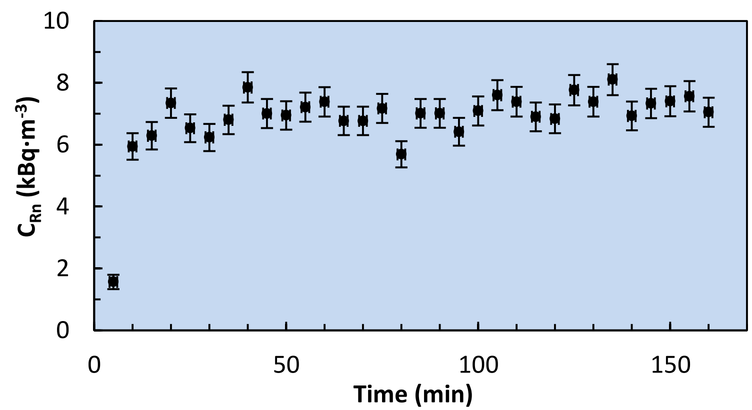

<u>Intercomparison 2 (December 13, 2016) @ Saelices-LRN site</u>

Soil-gas radon concentration measurement
Radon exhalation measurement

Main results

Quality control

Intercomparison exercises in the field

Intercomparison 1 (May 10-11, 2016) @ UAB site

Soil-gas radon concentration measurement

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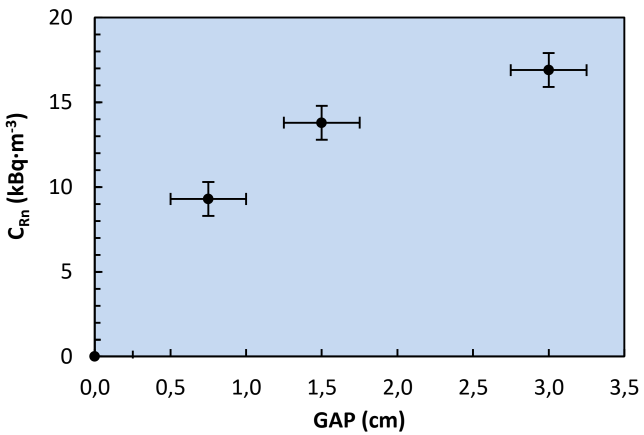
Radon exhalation measurement

- Results of the different groups are consistent.



Lost-tip rod. RM measurement with 1/2 GAP, 1 GAP and 2 GAP according to manufacturer.

Intercomparison 2 (December 13, 2016) @ Saelices-LRN site

Soil-gas radon concentration measurement
Radon exhalation measurement

Main results

Quality control

Intercomparison exercises in the field

Intercomparison 1 (May 10-11, 2016) @ UAB site

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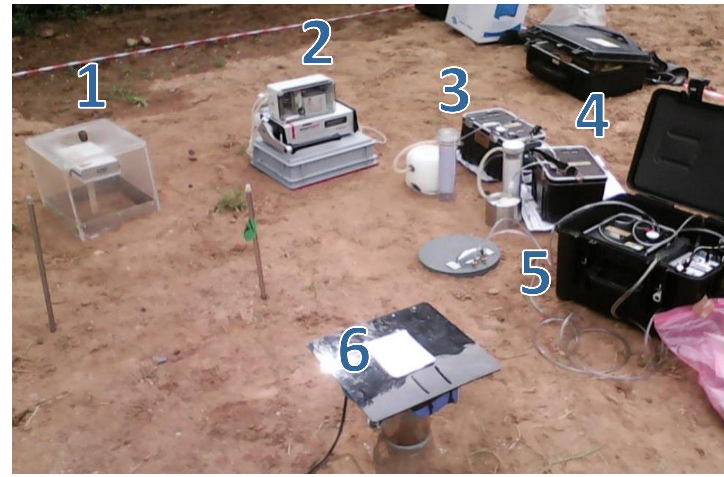

Radon exhalation measurement

- **Results of the different groups are consistent.**

Code	Group	Detector	Exhalation (Bq·m^{-2}·h^{-1})	Rel. Dif. (%)	u_{test}
1	UC	Radon Scout	< DL (30)	> 61	-
2	UPC	AlphaGUARD	88 ± 17	16	0.46
3	UAB	RAD 7	96 ± 14	26	0.79
4	UAB	RAD 7	97 ± 15	27	0.81
5	Geomnia	RAD 7	42 ± 20	45	1.21
6	UPC	Doseman	58 ± 20	24	0.64

- Mean: 76 ± 21 Bq·m^{-2}·h^{-1} [<30 – 97]
- u-test values < 1.64
- CV: 33 %

Main results

Quality control

Intercomparison exercises in the field

<u>Intercomparison 2 (December 13, 2016) @ Saelices-LRN site</u>

Confirmation of Intercomparison 1 results in a more hetereogenous soil

Sampling point	C_{Rn} ($kBq \cdot m^{-3}$)							
	Geocisa	Geomnia	UAB	UC	ULPGC		CV	u_{test}
1	9 ± 3	8 ± 14	7 ± 1	18 ± 4	17 ± 3	13 ± 2	41	2.31
2	107 ± 4	36 ± 7	-	93 ± 19	86 ± 13	66 ± 19	64	0.11
3	91 ± 4	-	96 ± 4	97 ± 17	105 ± 20	99 ± 3	7	0.92
4	105 ± 5	135 ± 6	133 ± 10	106 ± 21	101 ± 15	104 ± 14	32	1.10
5	94 ± 4	-	-	76 ± 15	69 ± 11	66 ± 14	43	0.10
group	81 ± 19	60 ± 39	79 ± 37	78 ± 20	76 ± 20			
CV	51	112	82	45	47			
u_{test}	0.38	0.22	0.20	0.27	0.19			

All groups:

77 ± 22 $kBq \cdot m^{-3}$

CV: 51%

Exhalation ($Bq \cdot m^{-2} \cdot h^{-1}$)							CV (%)
UAB	UPC	Geomnia	ULPGC	UC	Mean value	Interval	
201 ± 73	185 ± 91	113 ± 71	107 ± 20	207 ± 44	162 ± 68	107 - 201	30
u_{test}							
0.4	0.2	0.5	0.8	0.5			

Main results

Soil-gas Rn concentration representative values

See dedicated talk by J. García-Rubiano in this session.

Full analysis in 6 sites.

- Q_3 chosen as a good indicator of the representative value.
- Temporal variations have not been found very relevant in all sites but in Montseny, which is also the site with highest heterogeneity in soil radon levels:
  - From 4.4 kBq·m^{-3} (June 2016) to 114.7 kBq·m^{-3} (May 2017) at the very same sampling point.
  - From 0.1 to 114.7 kBq·m^{-3} at different points in the very same day.
- Spatial variations are similar to temporal variations.

	CV(%)	Aritmetic mean (kBq·m^{-3})	GM (kBq·m^{-3})	Q_2 (kBq·m^{-3})	**Q_3 (kBq·m^{-3})**	Max. (kBq·m^{-3})
Campus ULPGC	16.3%	9.5	9.3	9.5	**10.5**	13.1
Tejeda	90.6%	42.2	18.6	32.0	**80.2**	111
Campus UAB	30.4%	12.3	12.2	11.6	**13.8**	27.3
Montseny	149.7%	14.4	2.1	3.3	**14.4**	125.9
Esles. UCAN	42.9%	85.7	75.3	80.7	**114**	138.8
GEOCISA	34.8%	9.0	8.3	8.4	**11.1**	18.6

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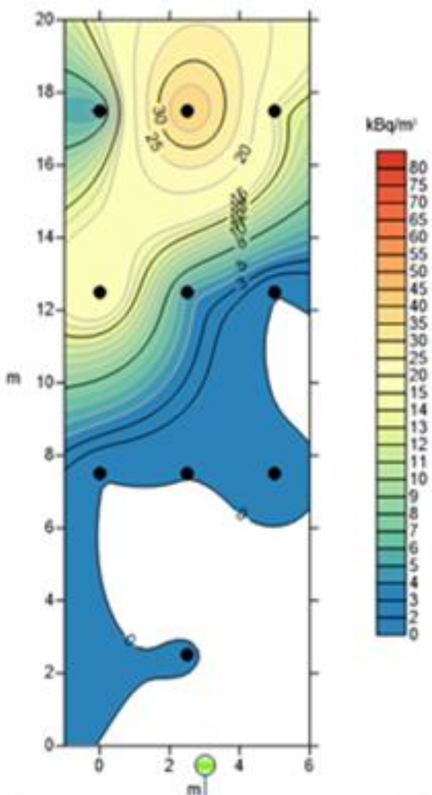
Main results

Soil-gas Rn concentration representative values

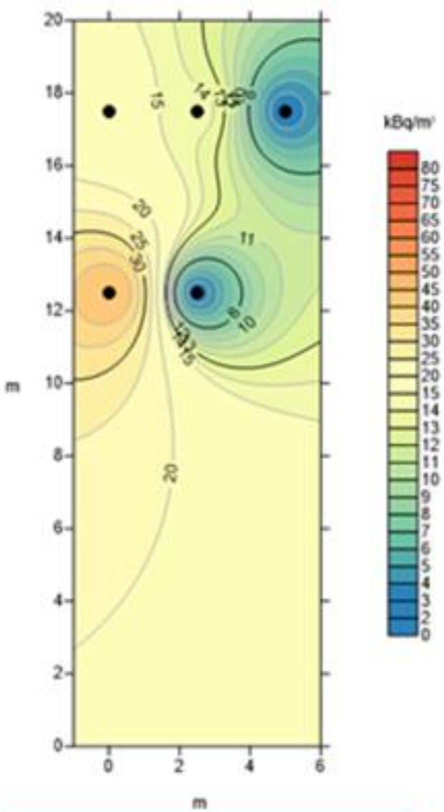
See dedicated talk by J. García-Rubiano in this session.

MONTSENY. June 2016



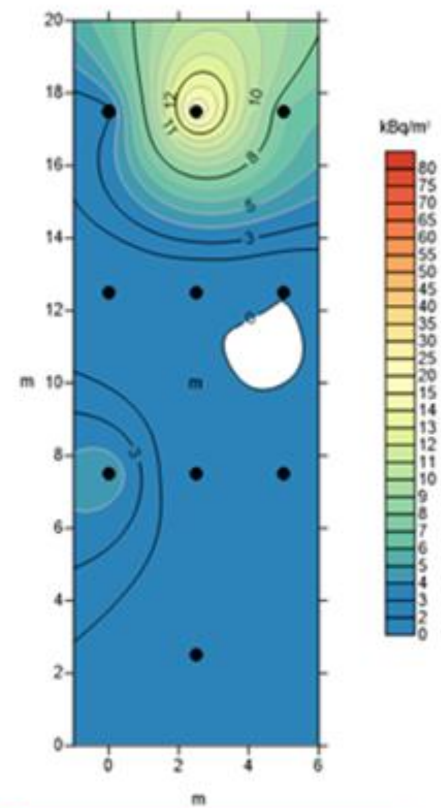
Mean= 8.6 kBq/m^3
CV =159.3%

MONTSENY. Sep. 2016



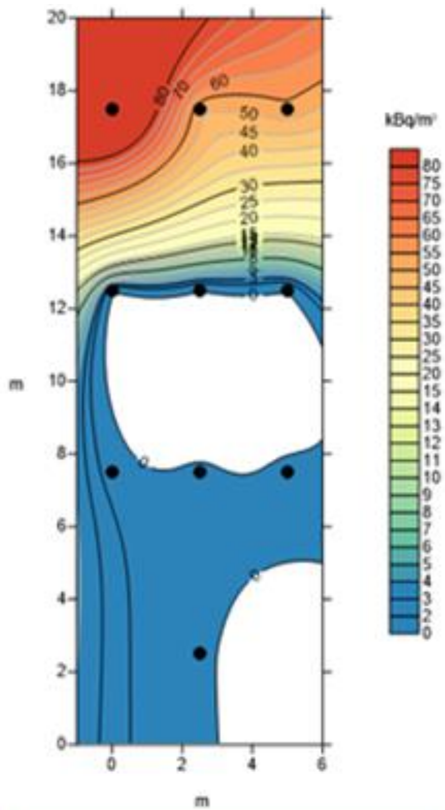
Mean= 16.5 kBq/m^3
CV =106.3%

MONTSENY. Feb. 2017



Mean= 5.8 kBq/m^3
CV =160.6%

MONTSENY. May 2017

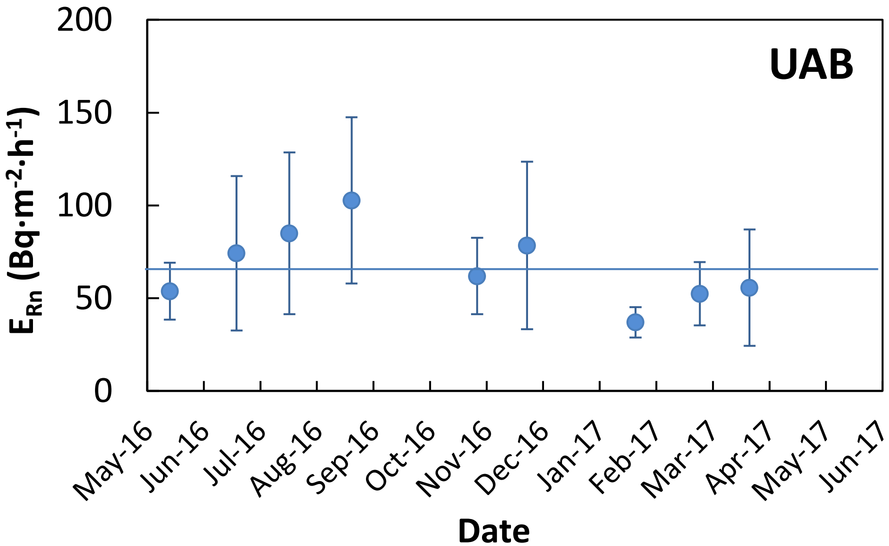


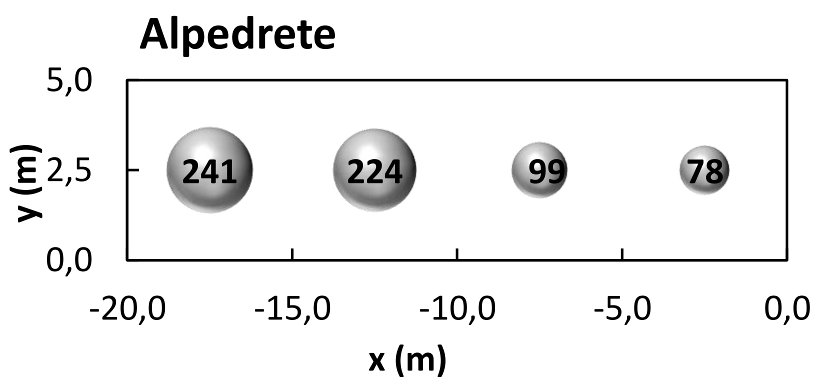
Mean= 22.3 kBq/m^3
CV =175.3%

Main results

Alternative methods: Rn exhalation rate

- Rn exhalation values are in the range [<40 – 7760] Bq·m^{-2}·h^{-1} and present CV from 24% to 52%. By far, highest values found in LRN, former uranium mine tailings.
- Significant spatial variations in each single site and temporal variations, with higher values in summer than in winter.
- Low correlation between mean Rn exhalation rates and Rn concentration values (Q_3).





Main results

Alternative methods: Rn exhalation rate

- Rn exhalation values are in the range [<40 – 7760] $Bq \cdot m^{-2} \cdot h^{-1}$ and present CV from 24% to 52%. By far, highest values found in LRN, former uranium mine tailings.
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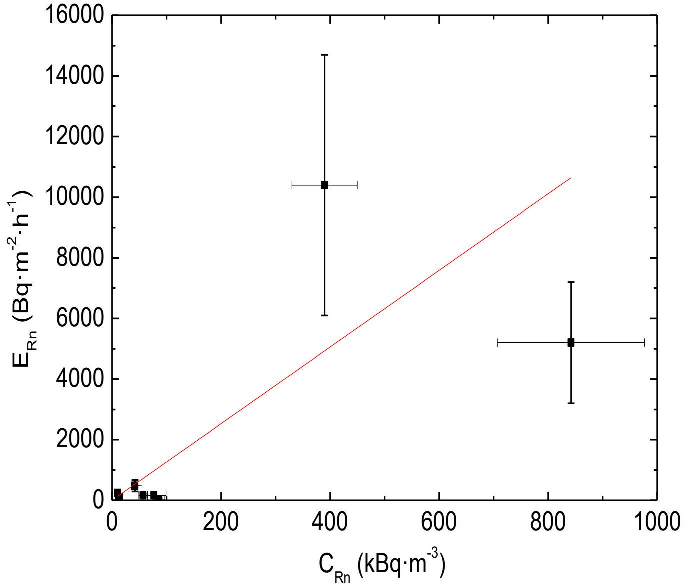
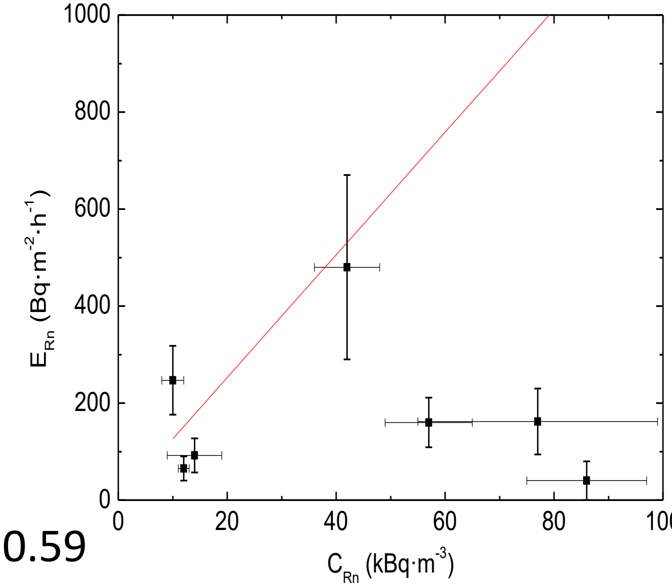


$r^2 = 0.59$



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Main results

Alternative methods: Ra content

- Common values, except in one LRN tailing (LRN_Cosma-Era), as expected.
- Remarkable good agreement between lab and in-situ measurements.

Site	A_{Ra-226} ($Bq \cdot kg^{-1}$)		
	Laboratory	Inspector	Rad-eye
UAB	20 ± 3	23.6 ± 1.4	23 ± 11
MONTSENY	46 ± 7	42 ± 2	28 ± 5
GEOCISA	37 ± 5		
ULPGC	37 ± 6		
TEJEDA	42 ± 3		
ESLES	46 ± 11		
LRN_Ballesteros	56		
LRN_Cosma-Era	6000		
SAELICES	49 ± 16	53 ± 11	57 ± 8

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Main results

Alternative methods:

- There is no way to use either Exhalation rate or Radium content as a proxy for soil radon concentration.

Low statistics

	Radon concentration ($kBq \cdot m^{-3}$)	Radium content ($Bq \cdot kg^{-1}$)	Exhalation rate ($Bq \cdot m^{-2} \cdot h^{-1}$)
Campus ULPGC	10.5	37 ± 6	261 ± 77
Tejeda	80.2	42 ± 3	$(0.48 \pm 0.19) \cdot 10^3$
Campus UAB	13.8	22 ± 1	65 ± 25
Montseny	14.4	46 ± 7	92 ± 35
Esles. UCAN	114	46 ± 11	< 40
GEOCISA	11.1	37 ± 5	

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Main results

The problem of soil-gas permeability (or intrinsic permeability, m^2) determination.

A key parameter of all risk estimation methods based on in-situ soil gas radon concentration measurement.

Do no miss round-table discussion on Thursday at 11:40!

Permeability (or water conductivity) (cm/s) $k = \frac{\beta \cdot m^2}{\lambda(1-m)} d^2$

m porosity
β = π/ 6 for spheres
d mean particle diameter (cm).
152 < **λ** < 207

Hazen

$k = c \cdot d_e^2$

$c = (\frac{m}{0,45})^6$

c ~100

Slichter

$k = c \cdot d_{10}^2 \cdot m^n$

n = 3.3

Bakhmeteff

$k = c \cdot d_{10}^2 \cdot m^{4/3}$

c = 710

Constant load method

In-situ Lefranc method

Conversion tables from permeability to intrinsic permeability required!

Intrinsic permeability (m^2)

Rogers and Nielson (1991)

$K = \left(\frac{p}{110}\right)^2 d^{4/3} \exp\left(-12 s^4\right)$

Nielson et al. (1994)

$K = 10^2 \left(\frac{\varepsilon}{500}\right)^2 d^{4/3} \exp(-12 m^4)$

Radon-JOK method

Main results

The problem of soil-gas permeability (or intrinsic permeability, m^2) determination

	Theory	LABORATORY MEASUREMENT						*IN-SITU*	
		Granulometry and porosity			Granulometry, porosity and humidity		Permeability meter		
		Hazen	Slichter	Bakhmeteff	Rogers-Nielson	Nielson	Constant load	Lefranc	Radon. jok
SAELICES	5.50E-14 to 5.50E-11	5.00E-10	1.04E-11	7.7E-10	1.06E-9	5.14E-9	7.24E-14		2E-12
ESLES 1	5.00E-15 to 5.00E-13	3.67E-12	2.05E-13	8.46E-12	4.01E-11	1.94E-10	1.12E-14		
ESLES 2	5.00E-15 to 5.00E-13	1.02E-11	5.21E-13	2.27E-11	4.62E-11	2.23E-10		5.54E-12	5E-12
UAB	5.00E-15 to 5.00E-13	3.67E-14	1.17E-15	6.76E-14	5.56E-12	2.69E-11	4.89E-14	1.1E-12	1E-12 to 1E-11
MONTSENY	5.00E-15 to 5.00E-13	3.67E-14	1.13E-15	6.66E-14	5.44E-12	2.63E-11	4.89E-14	1.38E-13	
ALPEDRETE	5.50E-14 to 5.50E-11	5.74E-12	1.46E-13	9.62E-12	3.26E-10	1.58E-9	5E-13		
ARGANDA	5.00E-15 to 5.00E-13	1.02E-13	1.92E-15	1.52E-13	2.15E-11	1.04E-10	4.39E-13	1.05E-12	5E-12
ULPGC	1.00E-15 to 5.00E-13	8.26E-14	7.19E-15	2.28E-13	3.96E-12	1.92E-11	1.22E-15		1.5E-11
TEJEDA	5.50E-14 to 5.50E-11	9.18E-13	2.88E-14	1.68E-12	2.92E-11	1.41E-10	1.02E-13		2E-13 a 5E-10

We have assumed as a representative value the average of *in-situ* and Rogers-Nielson and Nielson et al. values.

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Main results

Risk estimation

See dedicated talk by J. García-Rubiano in this session.

	Methods based on soil radon and gas-permeability				Spanish Rn risk map	Exhalation rate
	Germany	Czech Republic	Switzerland	Sweden	Percentil 90	This work
Campus ULPGC	Risk 3	RP Low-Medium	RAI =0.04 <0.2 $Bq \cdot m^{-2}$	Normal risk	> 400	Medium
Tejeda	Risk 4	RP Medium-High	RAI =0.19 <0.2 $Bq \cdot m^{-2}$	High risk	> 400	Medium-High
Campus UAB	Risk 3	RP Low-Medium	RAI =0.04 <0.2 $Bq \cdot m^{-2}$	Normal risk	201-300	Low
Montseny	Risk 3	RP Low-Medium	RAI =0.04 <0.2 $Bq \cdot m^{-2}$	Normal risk	< 100	Low-Medium
Esles. UCAN	Risk 5	RP High	RAI > 0.2 $Bq \cdot m^{-2}$	High risk	101-200	Low
GEOCISA	Risk 3	RP Low-Medium	RAI =0.04 <0.2 $Bq \cdot m^{-2}$	Normal risk	201-300	

Exhalation rate index ranges ($Bq \cdot m^{-2} \cdot h^{-1}$) (PRELIMINARY)	Risk
E ≤ 100	Low
100 > E > 500	Medium
500 ≤ E	High

Conclusions

Radon risk estimation based on in-situ measurements of soil radon and soil-gas permeability.

Pros:

1. High indoor radon levels are associated usually to either high soil radon levels or high permeability, being advection the main entrance mechanism.
2. In-situ measurements solve the problem of the spatial resolution of radon risk or indoor radon maps.
3. Soil radon concentration measurement does not show big problems, provided the standard method is used. There is room for improvement giving a reference water saturation fraction.
4. The average value obtained is representative of the piece of land if enough measurements are taken.
5. There is a reasonable agreement between the different methods from different countries based on these two parameters.

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Conclusions

Radon risk estimation based on in-situ measurements of soil radon and soil-gas permeability.

Cons:

1. The estimation of soil gas-permeability is an issue unless indications are given to follow certain methodology. We do not have any proof that the values we have assigned as representative for the terrain are the correct ones. In addition, there is the problem of spatial variability (dual probe methods?)
2. Temporal variations have not dramatically affected our determination of representative values, but this is in part because we had the four season values available. Additionally, from bibliography, we know that in some cases, like fractured systems, soils radon can present very high seasonal variations.
3. In Spain there are regions where soil radon concentration can not be determined following the standard procedure.
4. We have not found any good proxy for soil radon concentration measurement.
5. As far as we know, the radon risk estimation has not been validated experimentally.

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Conclusions

Comparison of different methods of radon risk estimation (**caution: low statistics!**)

1. The risk obtained from the Spanish risk map seems to overprotect with respect to the soil gas and permeability-based risk estimation.
2. The risk obtained from the exhalation rate seems similar to that obtained from the Spanish risk map. Further studies are required.

In view of our results:

1. We think the best indicator of radon risk is the map of indoor radon levels. It integrates all aspects affecting indoor radon levels.
2. A proper characterization of a piece of land may require a one-year study.

Recommendations for the implementation of Spanish National Plan against radon: Protection of new houses

1. Stablish a minimum level of protection in all new houses, and increase it as a function of the risk level estimated.
2. Estimate the risk from the radon risk map we have available in Spain, since it is the only one we have based on real indoor radon measurements. Use also the Czech methodology until the indoor radon database is big enough. Use it specially in large low density of population areas. If Czech methodology cannot be applied use only radon potential map. Use of exhalation rate?
3. Promote indoor radon surveys and establish a mechanism to incorporate new data in the radon risk map.
4. Establish a mechanism to validate experimentally any methodology implemented. This is the most important issue in our opinion.

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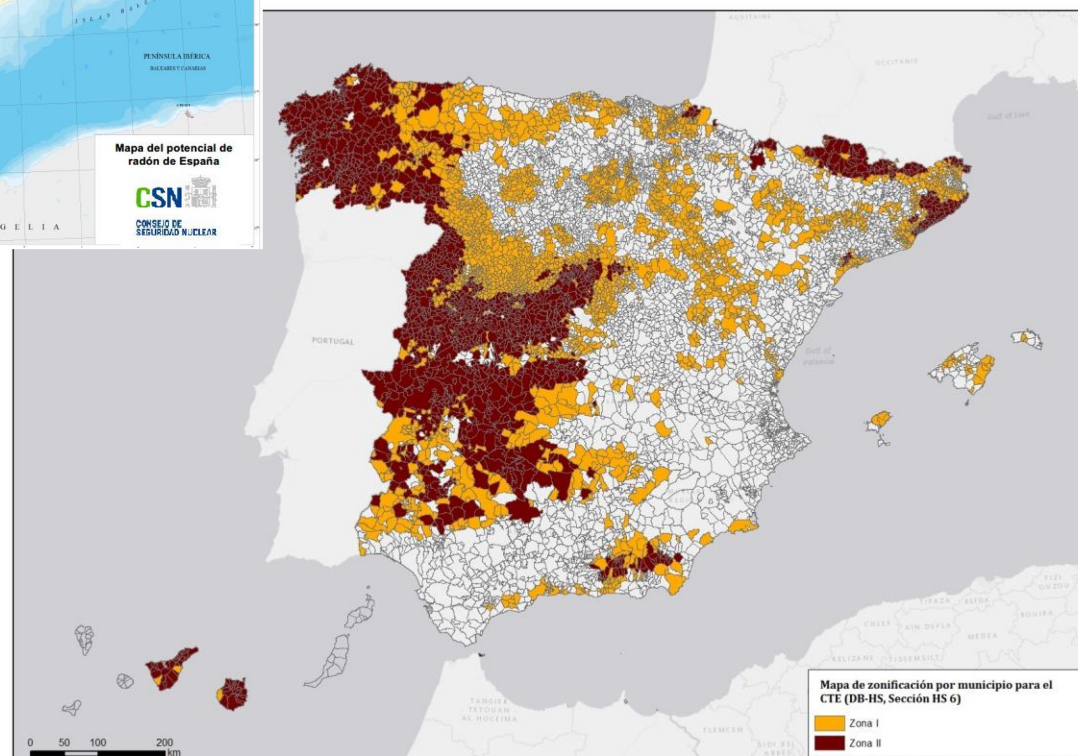
Spanish radon risk maps



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Díky moc!

Thanks a lot!

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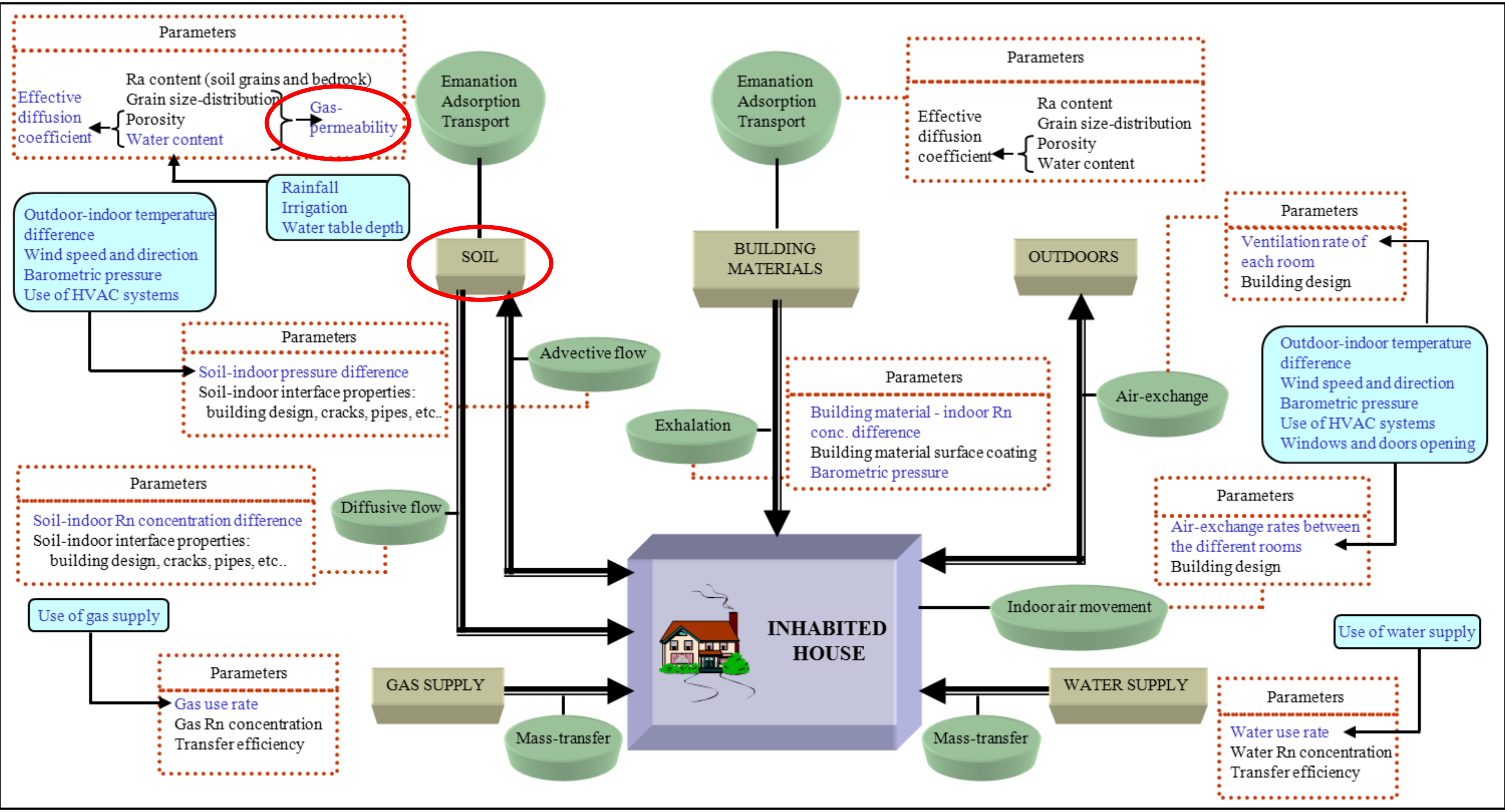
BACKUP

Factors affecting indoor radon levels and its dynamics



Soil radon seasonal variations

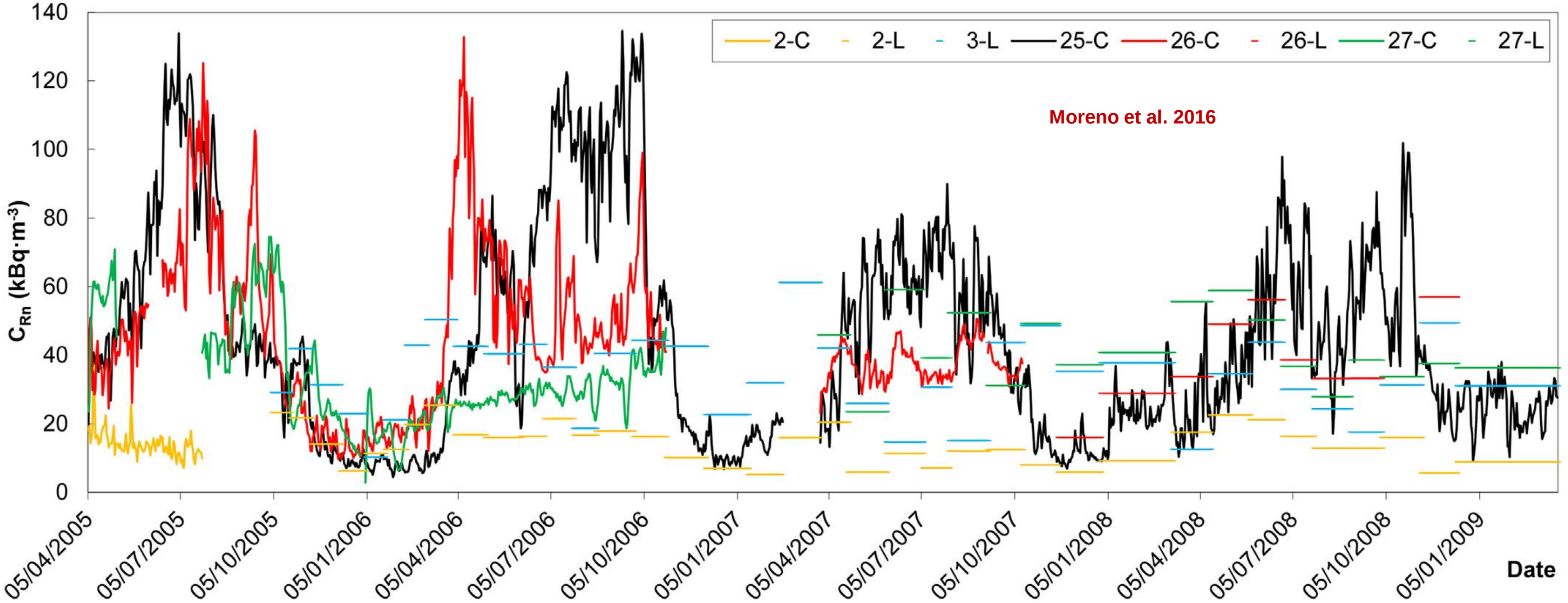


Fig. 5. Soil radon concentration temporal variation obtained along profile L3, with Clipperton probes (-C, daily mean values) and LR115 (-L, integrated values from 3 to 5 weeks). Data of the first 16 months of continuous measurements with Clipperton probes in points 25, 26 and 27 were already published in Font et al. (2008).

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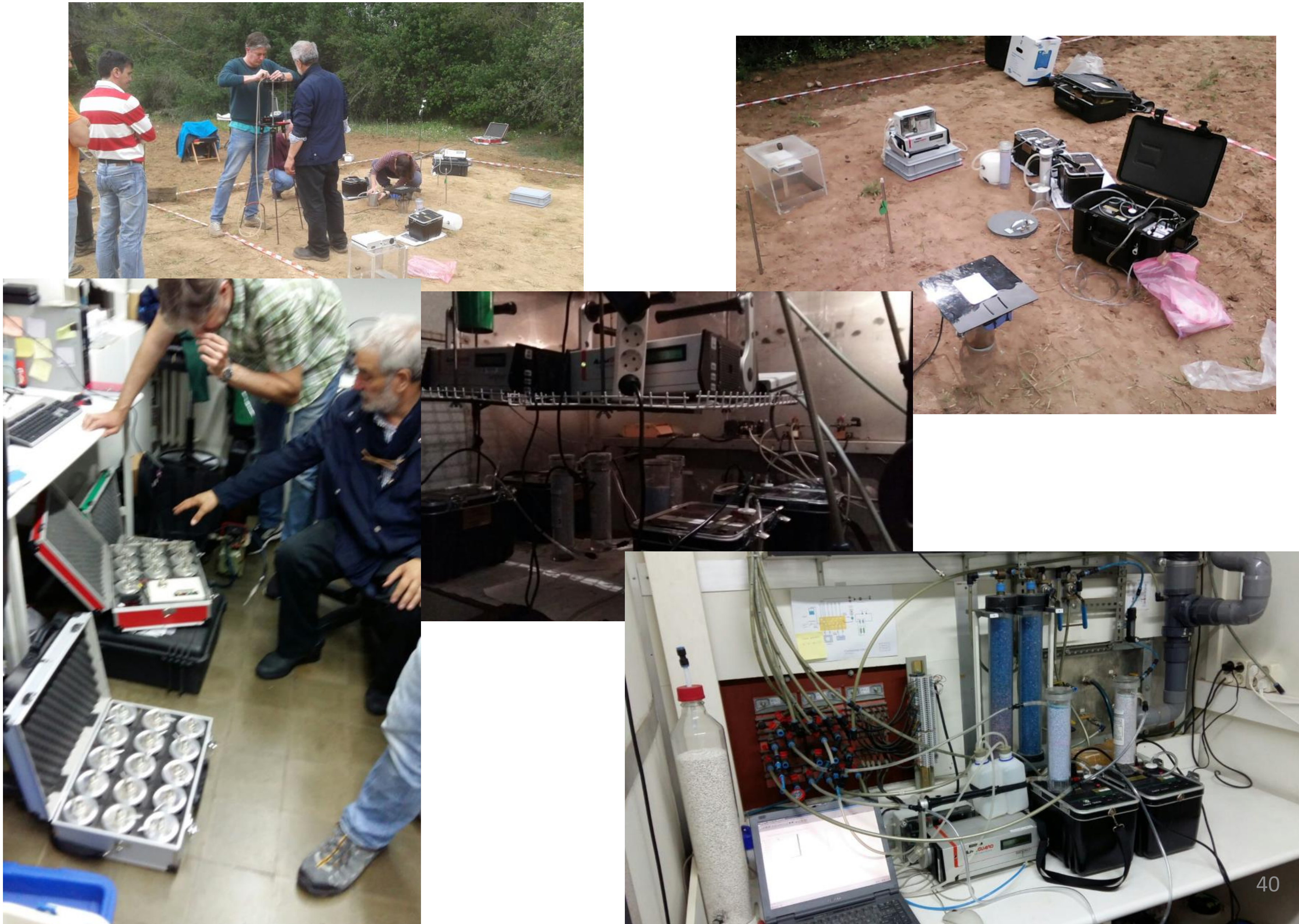
Status of the project

13th GARRM



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Concluding remarks

13th GARRM

1. There are serious concerns about the applicability of the Czech methodology in general and in Spain in particular:

- Spatial variations of soil radon activity.
- Soil radon levels in a diffusive profile might not be representative of radon entry potential by advection.
- Temporal variations of soil radon activity. Seasonal variations might be huge if radon source is not local (fractured systems).
- In some cases the standard method might not be possible:
    - Shallow soil depth (Canary Islands, semi-arid Mediterranean regions)
    - Shallow water table

2.- However, the other alternative methods (exhalation rate, Ra content, ...) might present also similar or additional problems leading in any case to a complicate radon risk estimation.

3.- Radon maps, or radon risk-maps may be efficient as an average, provided the map has been well elaborated, but it has to be taken also into consideration that in a specific site the soil might be very different than that obtained from the maps.

Concluding remarks

4. In case of doubt, or being in the frontier between two risk categories, we should overprotect.

5. Radon generation in the source media, transport, entry and accumulation indoors is a complicated process.

6. We will do our best to try to find the best possible methodology:

- Independently of the methodology used, the fact that a certain percentage of new houses will be radon-resistant can only, in principle, reduce the dose.

- To optimise the investment, any methodology should be long-term checked to find its effectiveness.

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The project for radon risk assessment - methodology

WP1: Management — Ll. Font (UAB), M. García-Talavera (CSN)

Coordination of the project and elaboration of follow-up and final reports

WP2: Standard Procedure — Ll. Font (UAB)

Definition of standard procedure to obtain soil-gas radon activity concentration in a single point, restricted to active sampling

WP3: Quality Control — A. Vargas (UPC), V. Moreno (UAB)

Definition of quality control requirements for soil-gas radon measurements.

Calibration exercise in a radon chamber (INTE- UPC)

Intercomparison exercise in a piece of ground @ UAB campus (including radon exhalation measurements)

The project for radon risk assessment - methodology

WP4: Representative value

WP4.1 : Spatial variations

J. Gª Rubiano and Héctor Alonso (ULPGC),

Study of sources for both horizontal and vertical variations in selected sites.

Criteria to obtain a statistically significant representative value.

WP4.2 : Temporal variations

L. Quindós (UCAN)

Characterization of temporal variations in selected sites.

Influence of **climatology** in selected sites.

Identification of areas in Spain with potentially high soil radon time-fluctuations.

Criteria to obtain a statistically significant annual-averaged value from a punctual measurement.

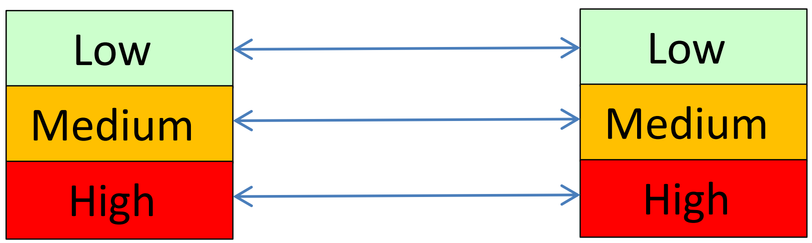
The project for radon risk assessment - methodology

WP5: Alternative methods

"The hope is in the coarse binning"

Establishment of 3 categories that best fit with standard procedure in selected terrains. Under which conditions, or for which types of soil the percentage of the correlation is higher?

Alternative method "value" is — Soil radon level (or **risk**) is



<u>WP5.1 : Radon exhalation</u> V. Moreno (UAB)

<u>WP5.2 : Ra-226 content. γ- spectrometry</u> J. Garcia-Orellana (UAB), A. Vargas (UPC)

<u>WP5.3 : Use of maps and climatology</u> M. García-Talavera (CSN), C. Sainz (UCAN), C. Grossi (UPC)

Radon and radon risk maps

Geological maps