Radon Exhalation from Structural Walls in Heritage Buildings

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OVERVIEW

- **CONTEXT.** Radon contamination
- **RADON IN BUILDINGS**. Sources, Transport physics and accumulation
- Special case of **HISTORIC BUILDINGS**
- **RADIANT project**. Singular studies in heritage buildings. Approaches to mitigation proposals

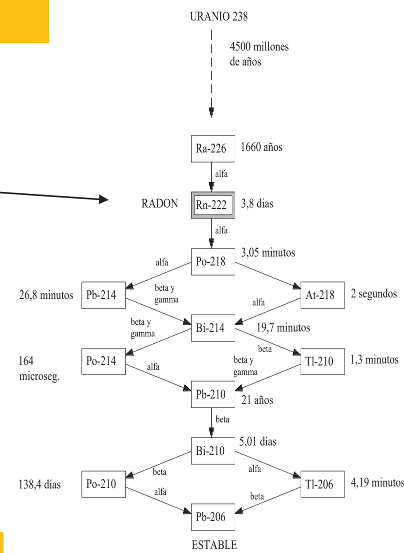
CONTEXT. Radon contamination

RADON: Radioactive Element. Isotope (Rn-222)

- Naturally occurring gas whose primary source is the ground (Earth's crust)
- Decay chain of U-238: *(Uranium → Radium → Radon)*

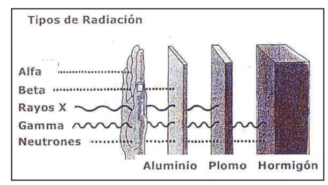
RADON: Chemical Element

- Inert gas: chemically stable
- Density: **9.73 kg/m³** (at 0 °C and 1 atmosphere) **heavier than air**
- Colourless, odourless, tasteless
- Soluble in water and other liquids

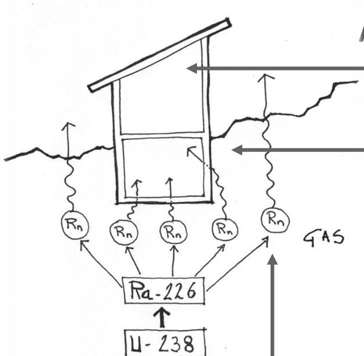


HEALTH: When inhaled, radon brings radiation closer to sensitive tissues

- Classified as a Group 1 carcinogen (WHO)
- Second leading cause of lung cancer, after tobacco smoking
- 15% of lung cancer cases worldwide are caused by radon
- Comparable to deaths from road traffic accidents



RADON IN BUILDINGS. Sources, transport physics and accumulation



Accumulation: increasing RISK > 300 Bq/m³

Transport physics

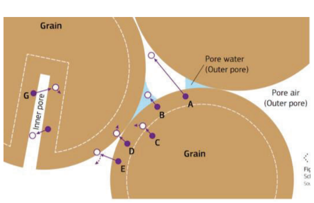
Diffusion: (C_{Soil}>C_{in})
De: Diffusion coefficient
(Through material/SLOW)

Advection : ($P_B > P_A$)
K: Permeability
(Through cracks, joints/FAST)

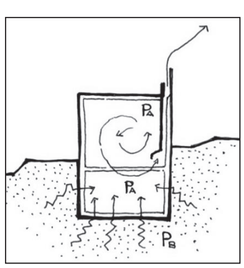
$$\frac{\partial \beta C}{\partial t} = \beta De \nabla^2 C + \frac{k}{\mu} \nabla C \nabla P + \varepsilon G - \lambda \varepsilon C$$

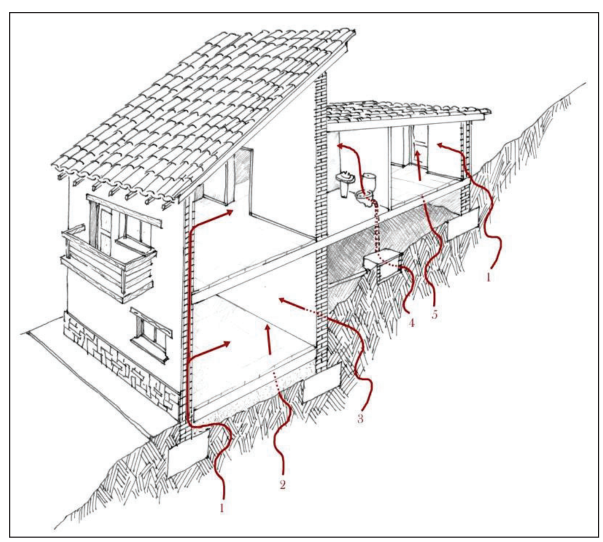
DIFUSIÓN — ADVECCIÓN — GENERACIÓN Y DESINTEGRACIÓN

Radon generation IN SOIL



European Atlas Natural Radiation





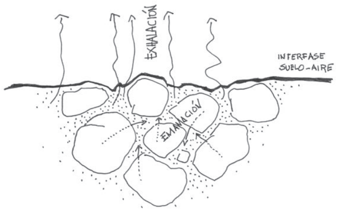
Common entry paths *(source: B. Frutos. European Atlas of Natural Radiation)*

RADON SOURCES

SOIL

Emanation and exhalation process

- Uranium concentration in soil
- Soil permeability



ROCK	Content URANIO U^{238}
Basalts	1,0 (ppm)
Granite	5,0 (ppm)
Clays	3,7 (ppm)
Sand	0,5 (ppm)

Radón, un gas radiactivo de origen natural". CSN y Universidad de Cantabria

CONSTRUCTION MATERIAL

Exhalation rate:

$$J_W = R\cdot E\cdot \lambda\cdot \rho\cdot L\cdot \tanh(d/L)$$

R: Radio content;
E: Emanation fraction;
λ; Decay; ρ: Density;
L: Diffusion Length;
d: Thickness

Radium – 226 content	
Construction material	**[Bq/kg]**
Bricks	45.2 - 143
Concrete	21.1 - 192
Mortars	19.8 - 82
Ceramic Tiles	63.0 - 117
Sand	13.3 - 41
Clay	40.9 - 199
Cement	36.5 – 88
Gypsum	12.1 - 86

(The National Rad. Prot. Inst. (Rep. Checa)

Φ =Surface exhalation rate ($Bq/m^2.h$)		Reference
NATURALES SOILS		
Soils in France	3.6 – 360	ISO 11665-7:2016: Measurement of radioactivity in the environment — Air: radon-222 —Part 7: Accumulation method for estimating surface exhalation rate.
Mean in planet soils	72	
Natural soils	38.2– 102.6	Zhuo et al. 2006. Modeling Radon Flux Density from the Earth's Surface. Journal of Nuclear Science and Technology, 43(4), pp.479–482.
Natural soils	57.6	Neznal et al. 2000. Comparison of calculated and measured soil-gas radon concentration and radon exhalation rate. International workshop on the geological aspects of radon risk mapping. Prague (Czech Republic), pp. 16–26.
CONSTRUCTION MATERIALS		
Granite	2.3	Misdaq et al. 2000. "A new method for studying the transport of radon and thoron in various building materials using CR-39 and LR-115 solid state nuclear track detectors. Radioactivity Measurements. 32, 35e42.
Granite from E. Torroja Institute	3.5	Eduardo Torroja Institute
Brick wall	2.5	

Soil >> Materials (2 orders of magnitude)

Special case of **HISTORIC BUILDINGS**

Torre de Hércules. Coruña

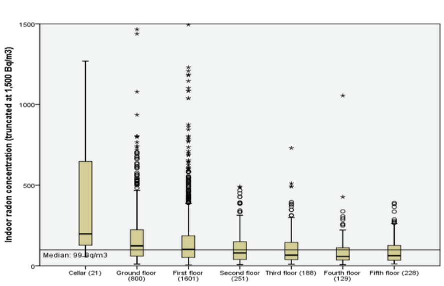
Level	High from the ground (m)	Mean Concentration (Bq/m^3)
Excavation	0	1178
Ground Storey	3.7	666
1st Storey	13.2	1196
2nd Storey	22.9	1429
3rd Storey	37.2	1200

Mean concentration (CR-39 detectors; 101 days. Gal RaD lab. U. Santiago de Compostela)

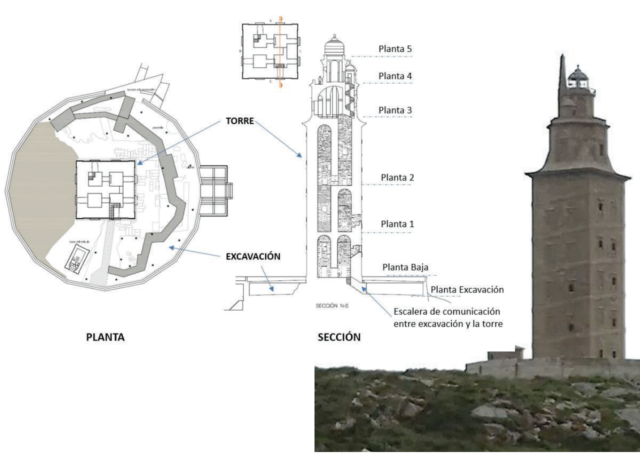
PROBLEM DETECTED

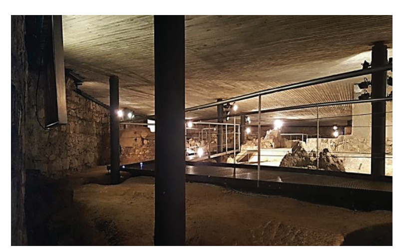
- High level of radon activity concentration
- Similar in all floors

No apparent dependence on the distance from the ground!

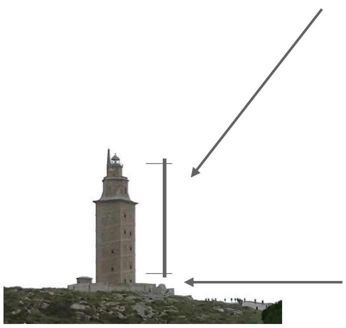


M Lorenzo-González et al (2017). Residential radon in Galicia: A cross-sectional study in a radon-prone area. Journal of Radiological Protection.





Internal spaces in the Tower



Basement. archaeological excavation

RADON SOURCES **IDENTIFICATION**

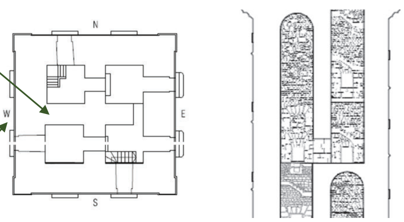
Examining materials and building systems

Tower **STRUCTURE**. Different Roman systems

Vault

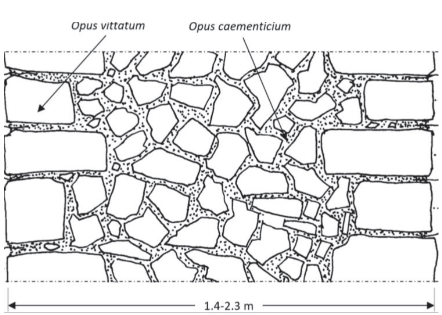
Internal walls 1.4 m thick

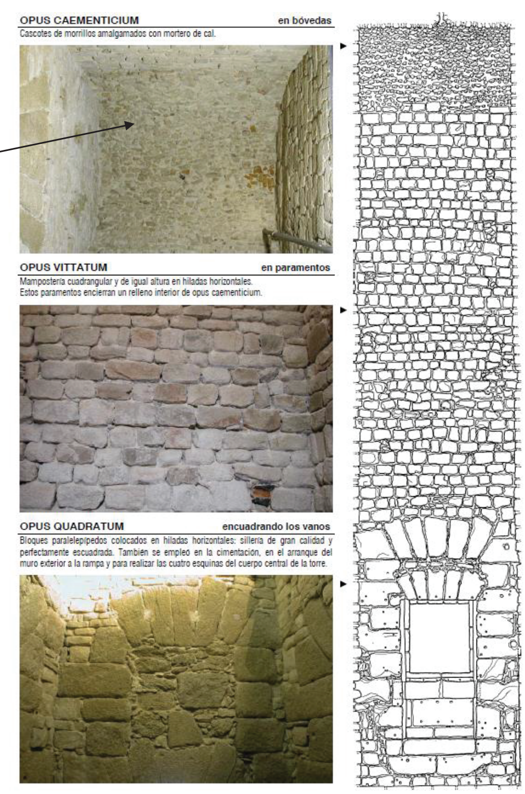
Façade walls 2.3 m thick



Plan and section

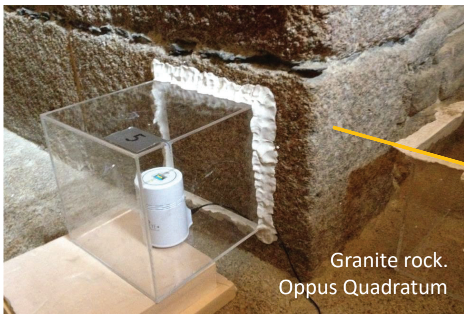
Granite Ashlar



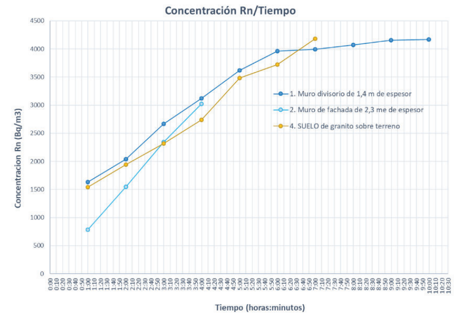


Source: administration and management of the tower of Hercules

Measuring the contribution of radon from building systems



Internal wall. 1.4m Opus Vittatum
And floors over vault;



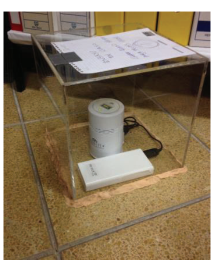
ISO 11665-7:2016: *Measurement of radioactivity in the environment — Air: radon-222. Part 7: Accumulation method for estimating **surface exhalation rate.***

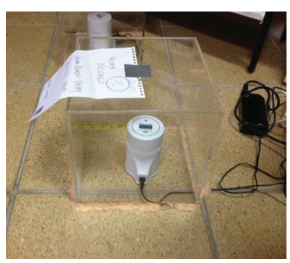
Constructive element	Φ =Surface exhalation rate (Bq/m².h)	Remarks on seals
Internal Wall. 1.4m thick. Opus Vittatum	120.0	With joint
Facade Wall. 2.3m thick. Opus Vittatum	180.6	With joint
Granite ashlar Opus Queadratum	13.0	**Without joint**
Granite floor over soil	117.0	With joint
Granite floor over vault	538.8	With joint

PAVEMENTS

Epoxi coating

0.2 Bq/m^2.h





Floor tiles, with and without joints, on ground

0,63 Bq/m^2.h (without joints) **17,28** Bq/m^2.h (Joint)

Comparison with common materials and building systems

WALLS

Brick + cement mortar

2,51 Bq/m^2.h

Concrete block

3,01 Bq/m^2.h

Brick

7.00 Bq/m^{2}h

Reinforced concrete

8.05 Bq/m^{2}h

Granite Ashlar

9.18 Bq/m^2.h

EXPLAINING ACUMULATION

HIPOTHESIS :

Relevant radon flows from **walls and vaults** could explain the high and homogeneous concentrations

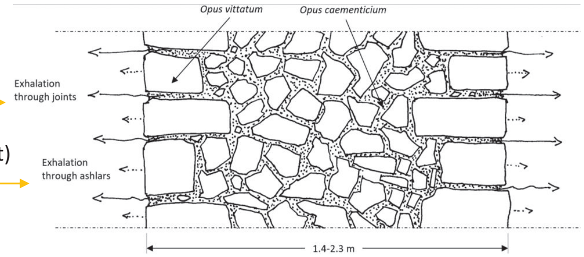
Estimated concentration is compared to measured

Soil + walls

$$C_{Rn} = \frac{\Phi}{(\lambda_{Rn}+\lambda_{ACH})\times V}$$

Though joints.
150 Bq/m²·h

Only Ashlar (without joint)
13 Bq/m²·h



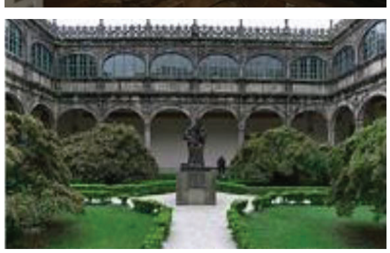
Inner wall filler must be responsible of the elevated exhalation rates through joints between ashlars

	Total exhalation rate	Vol.	ACH (ventilation + infiltration)	Radon decay rate	Estimated radon concentration C_{Rn} (est.)	Measured radon concentration C_{Rn} (meas.)
	Φ (Bq/s)	(m³)	λ_{ACH} (h⁻¹)	λ_{Rn} (h⁻¹)	(Bq/m³)	(Bq/m³)
Tower of Hercules	281	2800	0.38	0.00756	956.9	1133.8

84 % of concordance

High concentration **can only be explained if relevant sources are presented** in the whole tower, not only the soil

MORE EXAMPLES. Santiago de Compostela. University, church, and administrative buildings



1. WALL. Gneis Rock
128,19 Bq/m²h

2. WALL. Gneis Rock + mortar
25,54 Bq/m²h

3. WALL. Granite Rock
90,81 Bq/m²h

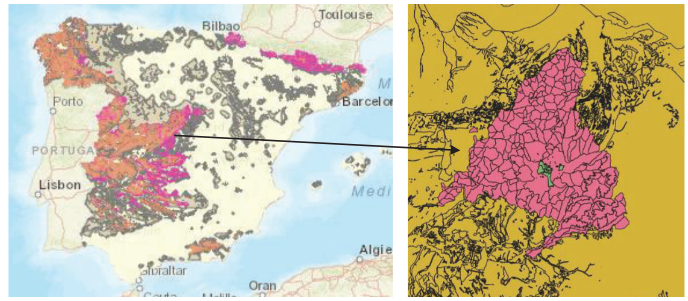
3. WALL. Granite Rock + mortar
79,64 Bq/m²h

RADIANT PROJECT. Radon contamination in heritage buildings

Radon Assessment and monitoring using robotics, Digitization, and Artificial Intelligence techNologies in heriTage buildings

Studies:

- Non-destructive techniques for analyzing internal filler
- Characterization of radioactive isotopes in building material
- Radon concentration and exhalation monitoring
- Climatic monitoring and correlation with exhalation
- AI Data processing
- 3D Visualization
- Modeling behavior
- Final application: Mitigation techniques in protected buildings

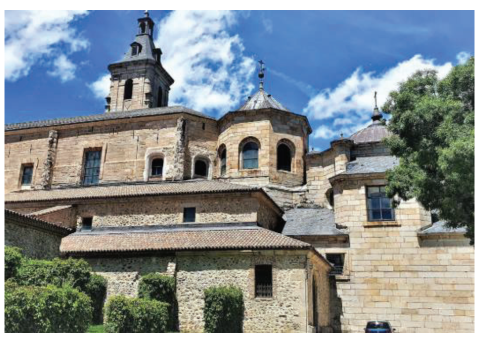


LABORATORY WALL
- Madrid

DEMONSTRATOR
- Madrid
- Santiago de Compostela

Some possible demonstrators

St Bernabe Church. El Escorial



El Paular

Monastery of Santa María de Valdeiglesias
Pelayos de la Presa

Monastery of El Escorial

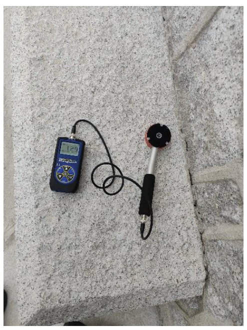
La Cartuja
Talamanca del Jarama

University of History and Geography.
Santiago de Compostela

Borja Frutos. Instituto de Ciencias de la Construcción Eduardo Torroja (CSIC) CSIC

FIRST STEPS: Characterization of radioactive isotopes in building material

Gamma radiation from isotopes in the uranium decay chain can be used as an **indirect indicator**



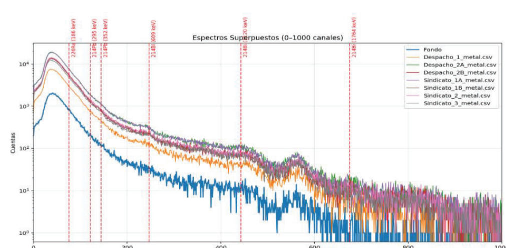
Ref	Material	Counts	Time	Counts/h
–	Exterior air cavity	3456	60	**3456**
M7	Gypsum board	743	15	**2972**
M10	Cement rubble	782	15	**3128**
M2	Porous cement paving block	786	15	**3144**
M9	Bamboo	803	15	**3212**
M8	Standard paving block type 1	811	15	**3244**
M6	Insulating glass 4/12/4	869	15	**3476**
M14	Vermiculite	989	15	**3956**
M3	Coated ceramic tile	1018	15	**4072**
M16	Standard paving block type 2	1042	15	**4168**
M17	Perlite	1149	15	**4596**
M1	Rammed earth	4621	60	**4621**
M15	Slate	1175	15	**4700**
M4	Grey clinker paving block	1189	15	**4756**
M5	Ceramic tile	1190	15	**4760**
M12	Unpolished granite countertop	1353	15	**5412**
M11	Polished granite countertop	1363	15	**5452**
M13	Natural granite paving block	1402	15	**5608**

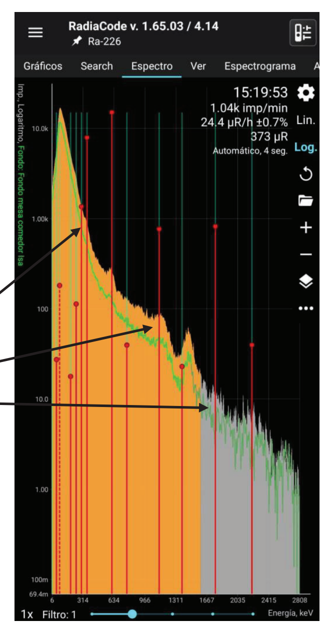
FIRST STEPS: Characterization of radioactive isotopes in building material

Spectrometry. Studies to determine radioactive isotopes **Pb214; Bi214 (R**adium progeny)

Isotopes	Energy (keV)	Canal
Ra-226 *	186.2	77
Pb-214	295	122
Pb-214	352	146
Bi-214	609	247
Bi-214	1120	434
Bi-214	1764	595

Peaks with energy patterns compatible with isotopes of the 226Ra decay chain (**Pb214; Bi214**)



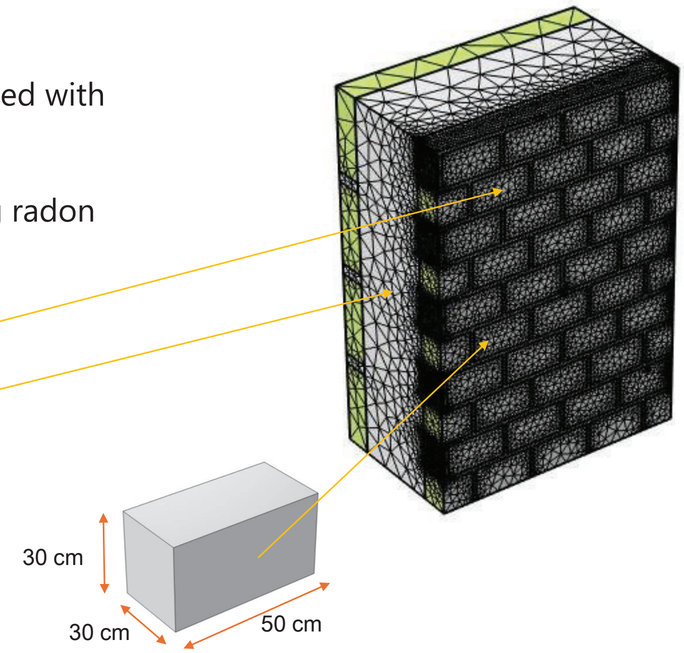


FIRST STEPS: **Laboratory-scale reproduction of a wall** (2 × 1.5 m^2 . 1 m thickness)

Will be used to:

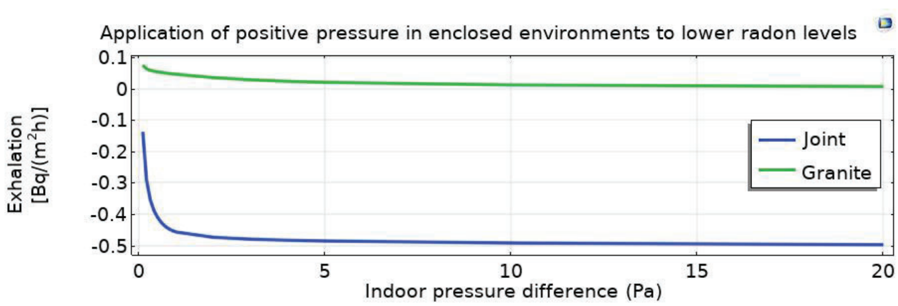
- **Studying radon dynamics exhalation** (correlated with atmospheric factors)
- **Calibrate a simulation model** aimed at studying radon exhalation behavior and mitigation techniques.

PARAMETERS	Granite	Opus Caementicium
Density [kg/m^3]	2650	2400
Permeability [m^2]	5.98697E-17	5E-8
Porosity	0.00685	0.4 / 0.2 (juntas)
Diffusion Coefficient [m^2/s]	5.6307E-10	2.4E-6
Radon Generation [Bq/(m^3·s)]	0.072616	0.06804

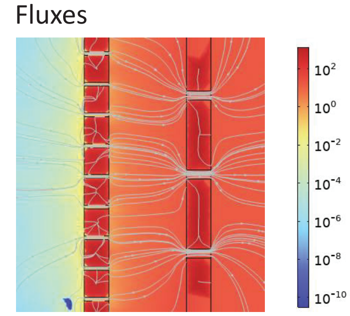


FIRST APPROACHES: CFD MODEL (Comsol Multiphysics)

Sudying radon fluxes through **Ashlar and Joints vs. indoor pressure**

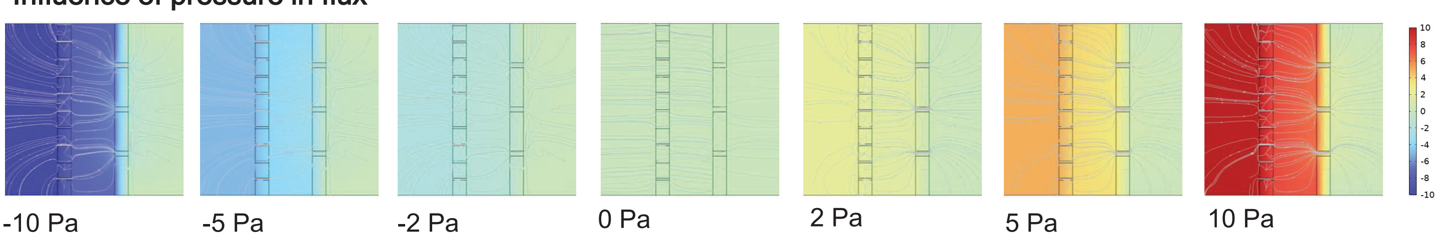


Fluxes

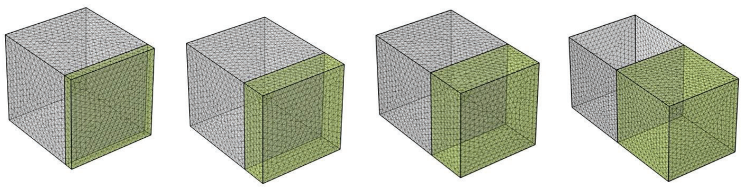


CONTRIBUTION		
	Granite Ashlar	**Joints**
Bq/m^2h	**17.68**	**169.8**

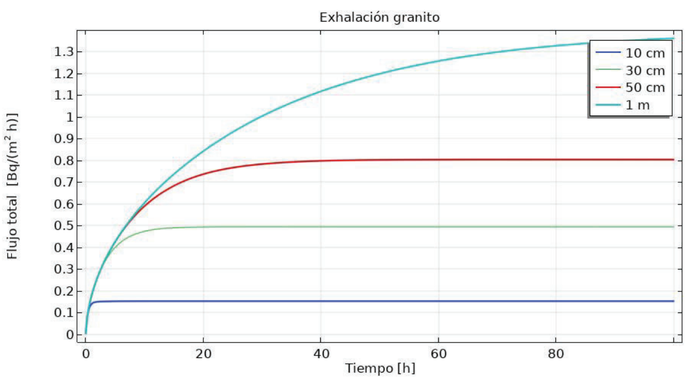
Influence of pressure in flux

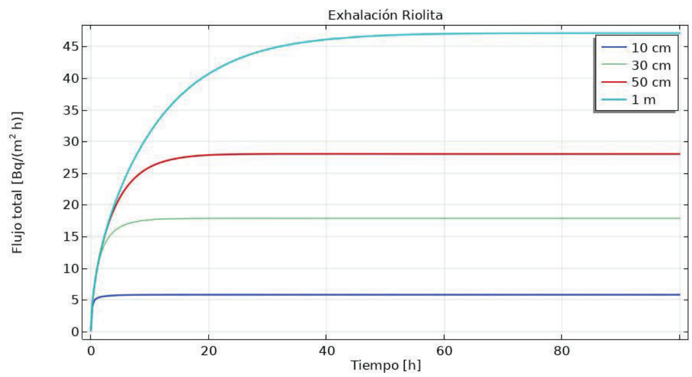


CFD MODEL. DIFFERENTS EXHALATION RATE FROM MATERIALS



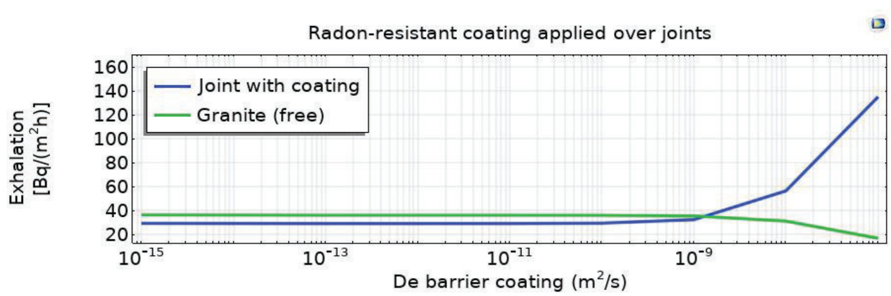
	Granito	Riolita
Contenido Ra	90 Bq/m^3	95 Bq/m^3
Permeabilidad	6E-17 m^2	1E-11 m^2
Porosidad	0.015	0.35
Densidad	2650 Kg/m^3	1500 Kg/m^3

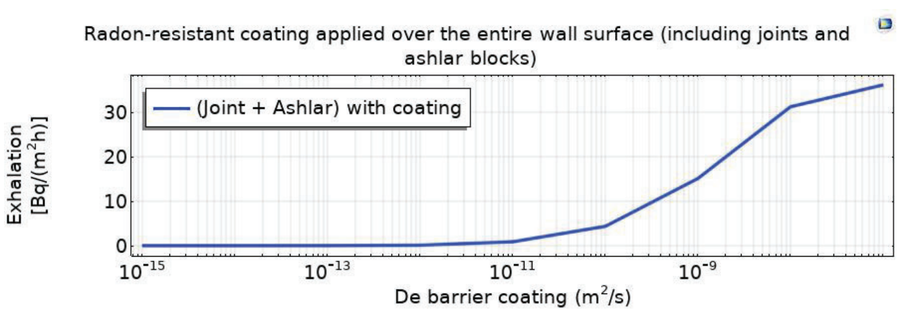


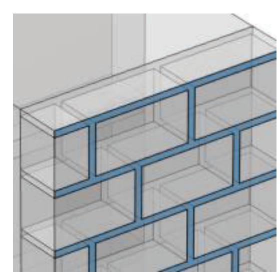


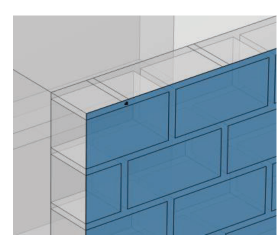
CFD MODEL. RADON MITIGATION APPROACHES

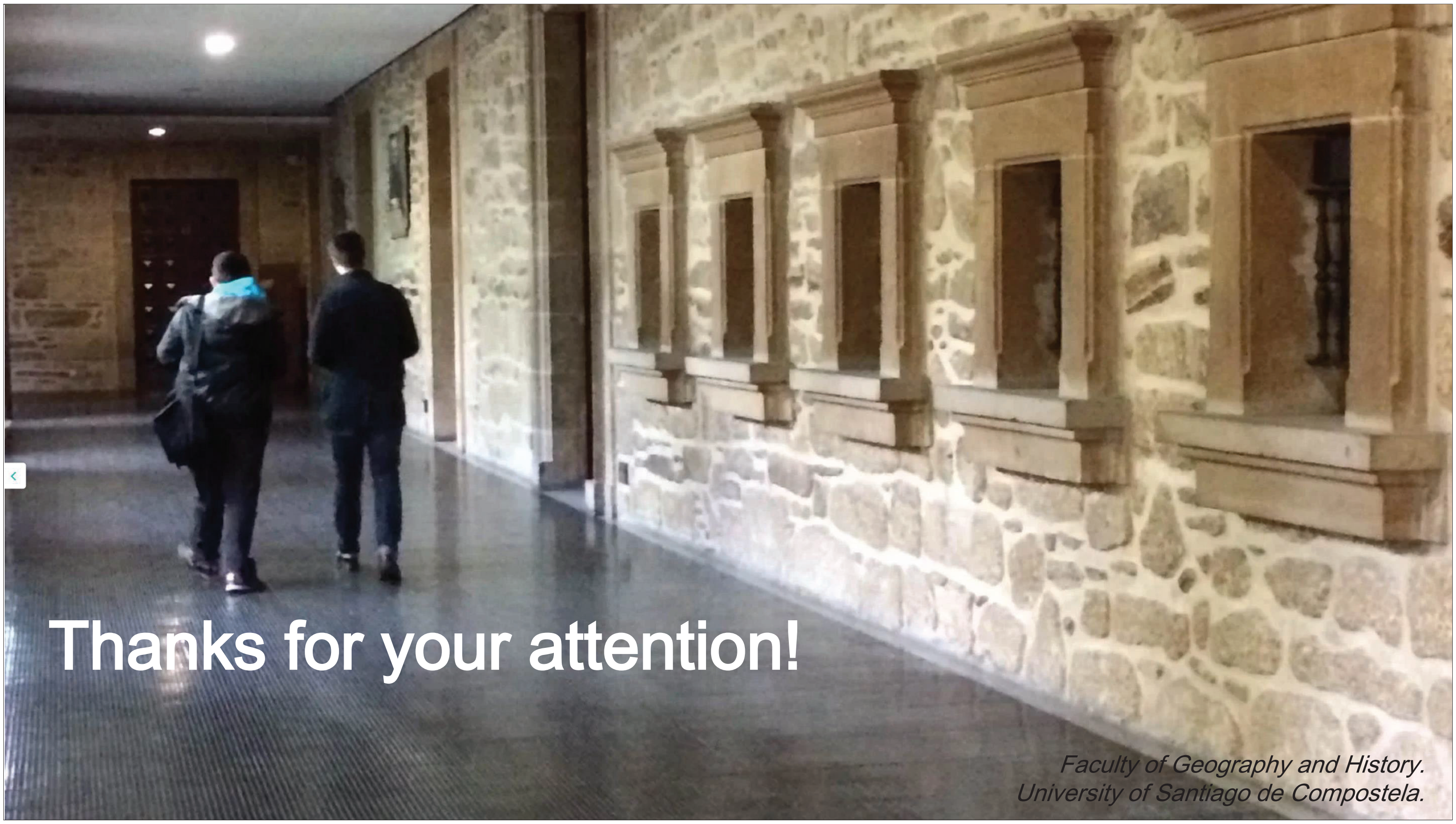
- **Sealing joints.**
- **Applying radon barrier coating**
  Compatible with heritage protection










Thanks for your attention!
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University of Santiago de Compostela.