Comparison of a lumped-parameter and a distributed-parameter radon transport models adapted to an experimental radon accumulation chamber within the frame of the Spanish RADSIM project.

16th
GARRM

Lluís Font[1], B. Frutos[2], I. Sicilia[2], H. Alonso[3], J. García-Rubiano[3], M. García-Talavera[4], P. Martel[3], V. Moreno[1], L. Quindós[5], D. Rábago[5], C. Sainz[5], J. T. Santana[3], A. Tejera[3,6].

[1] Departament de Física. Universitat Autònoma de Barcelona. Spain
[2] Instituto de Ciencias de la Construcción Eduardo Torroja. Consejo Superior de Investigaciones Científicas. Spain
[3] Dpto. de Física. Universidad de Las Palmas de Gran Canaria. Spain.
[4] Consejo de Seguridad Nuclear. Spain.
[5]Grupo Radón, LaRUC. Universidad de Cantabria. Spain.
[6] Servicio de Laboratorios y Calidad de la Construcción del Gobierno de Canarias. Spain.

19 - 20 September 2023, Prague – Czech

Context

RADSIM modelling activities: WP7

See talk by J. G. Rubiano

Adaptation of a CFD model (using COMSOL Multiphysics) and the compartmental model RAGENA (using STELLA) to two experimental sites where data are taken.

Pilot house @ Saelices El Chico (Salamanca)

See talk by D. Rábago

Inhabited house @ Valsequillo (Gran Canaria)

See poster by J.T. Santana

First step: adapt both models to a simple case, a radon accumulation chamber that includes a “soil layer” + a concrete slab in which most of the parameters are known.

Goals:

1. Compare model outputs to experimental data.
2. Intercompare both models.

This talk.

Outline

The challenge of modelling indoor radon

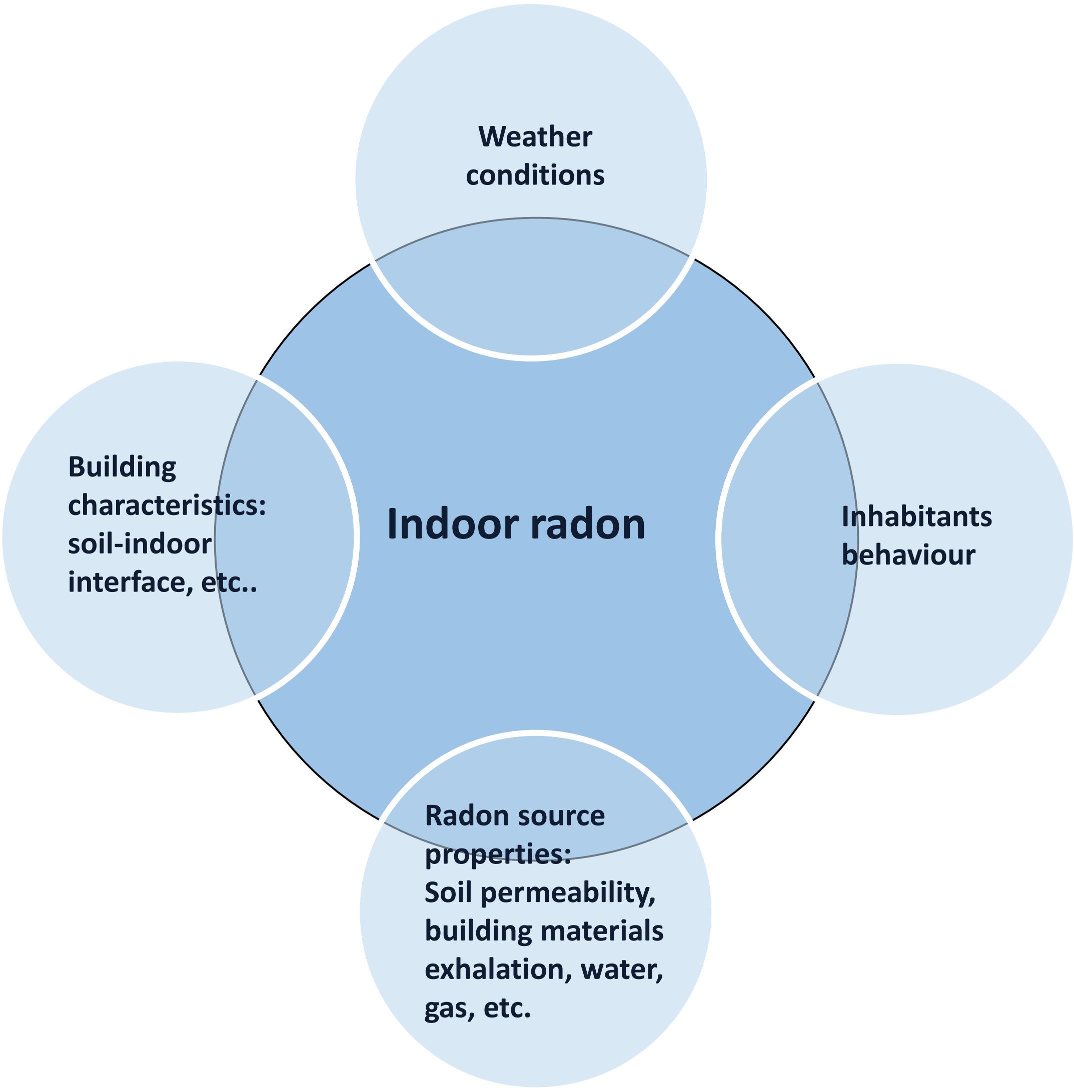
Distributed-parameter vs lumped-parameter approach

Experimental set up: a radon accumulation chamber with “soil” + concrete slab.

Comparison of the two modeling techniques performance

Conclusions

The challenge of modelling indoor radon



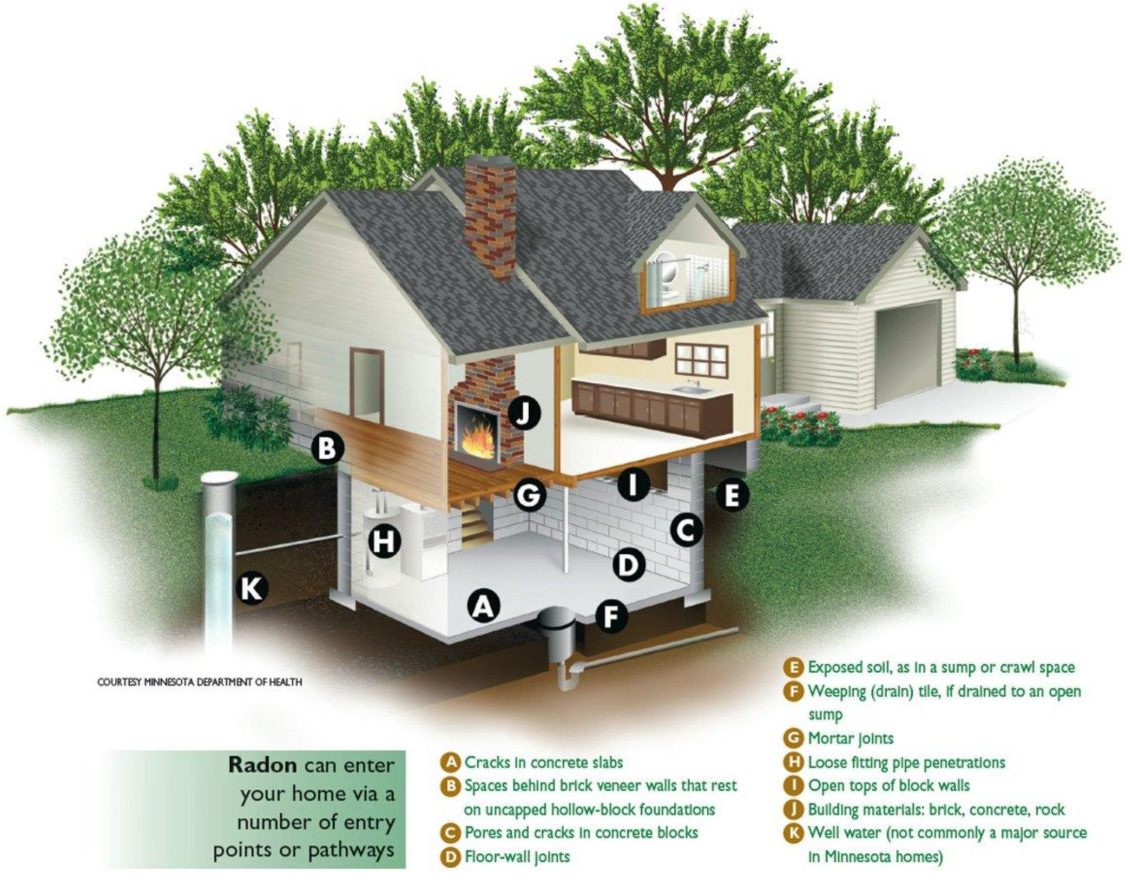
Weather conditions

Building characteristics: soil-indoor interface, etc..

Indoor radon

Inhabitants behaviour

Radon source properties: Soil permeability, building materials exhalation, water, gas, etc.

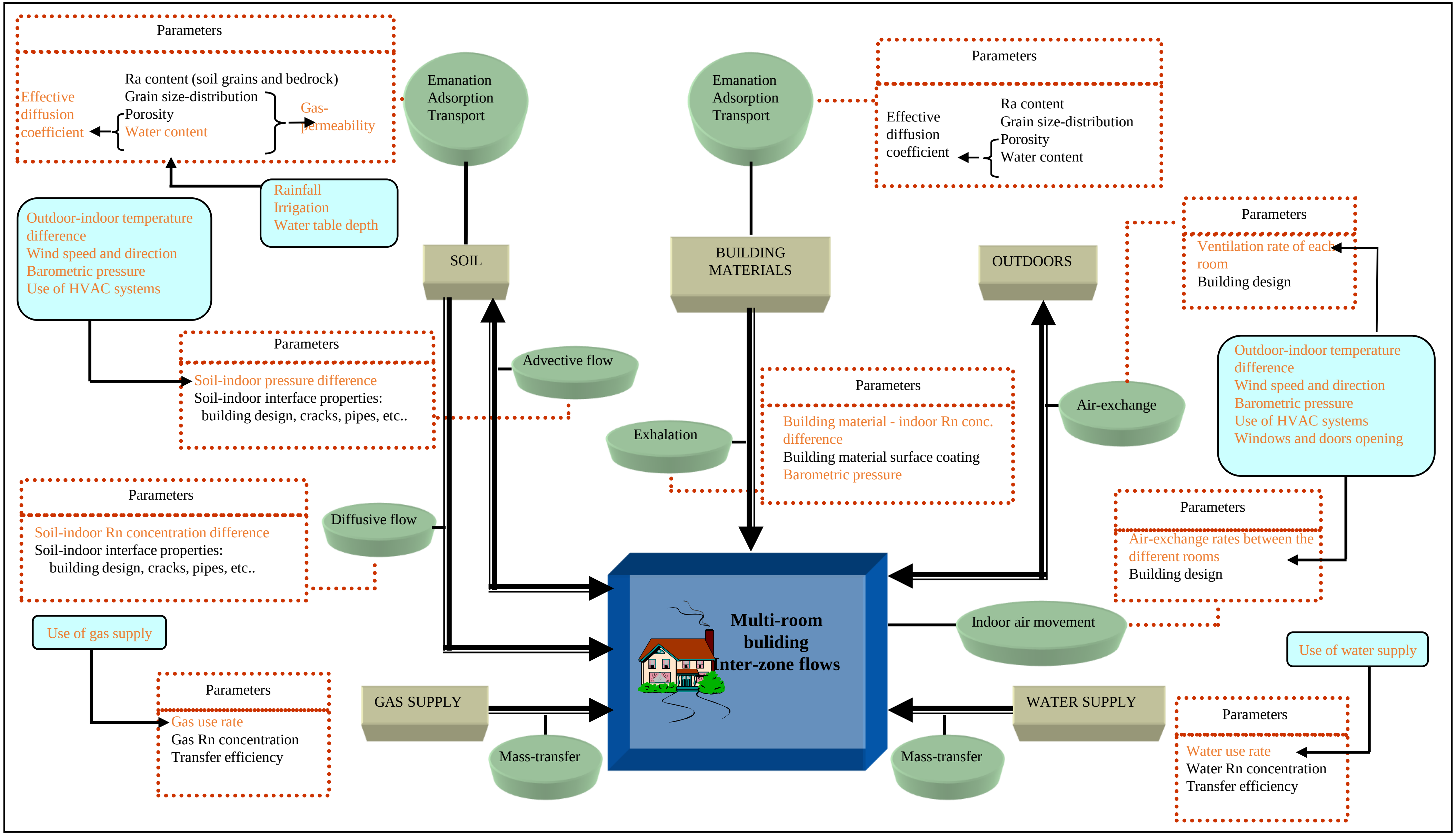


COURTESY MINNESOTA DEPARTMENT OF HEALTH

Radon can enter your home via a number of entry points or pathways

A Cracks in concrete slabs
B Spaces behind brick veneer walls that rest on uncapped hollow-block foundations
C Pores and cracks in concrete blocks
D Floor-wall joints
E Exposed soil, as in a sump or crawl space
F Weeping (drain) tile, if drained to an open sump
G Mortar joints
H Loose fitting pipe penetrations
I Open tops of block walls
J Building materials: brick, concrete, rock
K Well water (not commonly a major source in Minnesota homes)

The challenge of modelling indoor radon



Parameters

Ra content (soil grains and bedrock)
Grain size-distribution
Porosity
Water content

Effective diffusion coefficient

Gas-permeability

Rainfall
Irrigation
Water table depth

Emanation
Adsorption
Transport

SOIL

Emanation
Adsorption
Transport

BUILDING MATERIALS

Parameters

Ra content
Grain size-distribution
Porosity
Water content

Effective diffusion coefficient

OUTDOORS

Parameters

Ventilation rate of each room
Building design

Outdoor-indoor temperature difference
Wind speed and direction
Barometric pressure
Use of HVAC systems

Parameters

Soil-indoor pressure difference
Soil-indoor interface properties:
building design, cracks, pipes, etc..

Advective flow

Exhalation

Parameters

Building material - indoor Rn conc. difference
Building material surface coating
Barometric pressure

Air-exchange

Outdoor-indoor temperature difference
Wind speed and direction
Barometric pressure
Use of HVAC systems
Windows and doors opening

Parameters

Soil-indoor Rn concentration difference
Soil-indoor interface properties:
building design, cracks, pipes, etc..

Diffusive flow

Parameters

Air-exchange rates between the different rooms
Building design

Multi-room buliding Inter-zone flows

Indoor air movement

Use of gas supply

Parameters

Gas use rate
Gas Rn concentration
Transfer efficiency

GAS SUPPLY

Mass-transfer

WATER SUPPLY

Mass-transfer

Use of water supply

Parameters

Water use rate
Water Rn concentration
Transfer efficiency

Distributed-parameter vs lumped-parameter approach

Main features

Lumped-parameter model

- The dependent variables of interest are a function of time alone.
- The value of a certain variable is assumed to be constant within a certain volume (homogeneity, effective values)
- In general, this will mean solving a set of ordinary coupled differential equations (ODEs). Simplicity.
- Examples: compartmental models; analogy with an electrical circuit.

Distributed-parameter model

- The dependent variables of interest are a function of one or more space variables and can also be function of time.
- Variables can be indexed continuously or discretized both in space and time.
- In general, this will mean solving a set of partial differential equations (PDEs). Computing resources.
- Example: models based on Computational Fluid Dynamics (CFD).

Important remark: Modelling (always) implies making assumptions to simplify the system.

Distributed-parameter vs lumped-parameter approach

Lumped-parameter model		**Specially suitable for...**		Distributed-parameter model
Rn in source media (soil, basically) not uniform → Spatial resolution required. **Can an effective value be used instead? How to obtain it?**	✘	Radon entry from soil	✓	Radon transport equation in source media (soil, basically) solved (normally in a discretized space). **Detailed knowledge on source-building interface required.**
	✘	Radon entry from BM	✓	
Normally not considered, but easy to be included in mass-balance equations	✓	Radon entry from water and gas supplies	✓	Normally not considered, but it should not be an issue.
Mass-balance first order ODE describe inter-zone flows . Rn uniform within a room.	✓	Radon distribution among the rooms of the Building.	✘	Simulations require optimization of computing resources
Time-dependent parameters easily included. Almost not computing resources required.	✓	Rn dynamics (Inhab. habbits, weather, etc.)	✘	Simulations require optimization of computing resources. Most of radon entry from soil models to date are limited to the steady state.

Experimental set up

Radon accumulation chamber (methacrylate): 50 x 50 x 50 cm^3

Trapezoidal metal tray:

Top: 39 x 39 cm^2
Bottom: 37.1 x 37.1 cm^2
Heigth: 4.85 cm

Trapezoidal concrete slab with the same dimensions

Phonolitic gravel filling the metal tray used as a "soil"

Continuous radon mesuraments with SARAD monitor RTM

Experimental set up

Three diferent cases are considered:

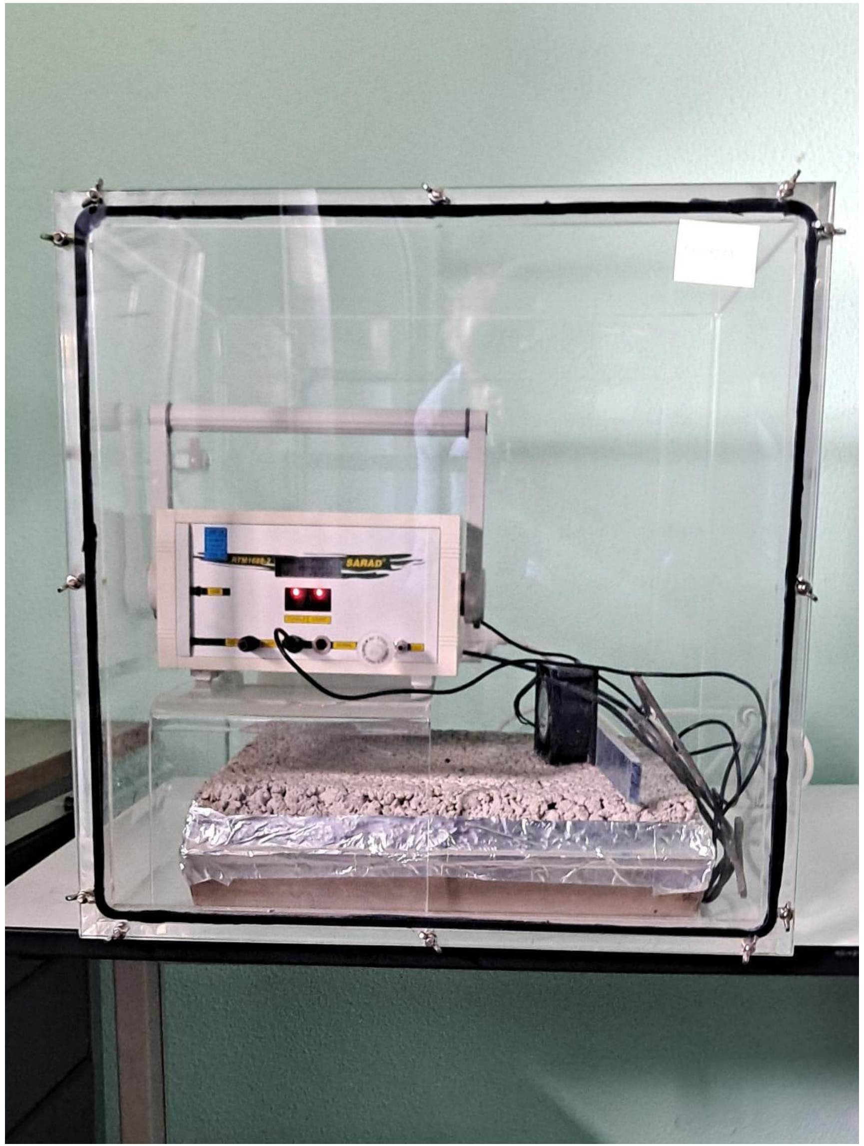
1.- The concrete slab is placed on top of the empty metalic tray.

2.- The concrete slab is placed on top of the metalic tray filled with the phonolitic gravel. The joint is not sealed, acting as a kind of “expansion joint”. Radon gas is assumed to migrate from phonolitic gravel to the accumuation chamber basically through the expansion joint.

Experimental set up

Three diferent cases are considered:

3.- The concrete slab is placed on top of the metalic tray filled with the phonolitic gravel. The joint is sealed with aluminium tape, forcing the radon gas from the phonolitic gravel to migrate through the concrete slab.



In all cases no pressure differences are generated.

⬇

Only diffusive transport

Comparison of the two modelling tecniques performance

Input parameters

Parameter	**Gravel**	**Remarks**	**Slab**	**Remarks**
Radium content (A_{ra}) (Bq/kg)	46±2	Obtained exp.	26.5±1.5	weighted average of Ra content of components
Emanation coeficient (f)	0.25±0.05	From H. Alonso PhD thesis (2016)	0.24 ± 0.09	Obtained from accumulation curve fit.
Porosity (ε)	0.634	From grain (2619 kg/m^3) and bulk densities (958.2 kg/m^3)	**0.23**	From IET data on similar concretes. Range [0.15 – 0.35]
Effective diffusion coeficient (D_e) (m^2s^{-1})	6.98e-6	$D_e \sim D_0\varepsilon$ for dry soils $D_0 = 1.1e\text{-}5\ m^2s^{-1}$ (air)	**1e-7**	Estimated from bibliography [5e-6 – 1e-9]
Free exhalation (Bq/m^2h)	4.6 ± 0.8	Obtained from accumulation curve fit.	4.7 ± 0.9	Obtained from accumulation curve fit.

$$\lambda_{effective} = 0.0085\ h^{-1} \longrightarrow \lambda_{leakage} = \lambda_{effective} - \lambda_{Rn} = 0.000947\ h^{-1}$$

Adaptation of RAGENA model (with Stella software)

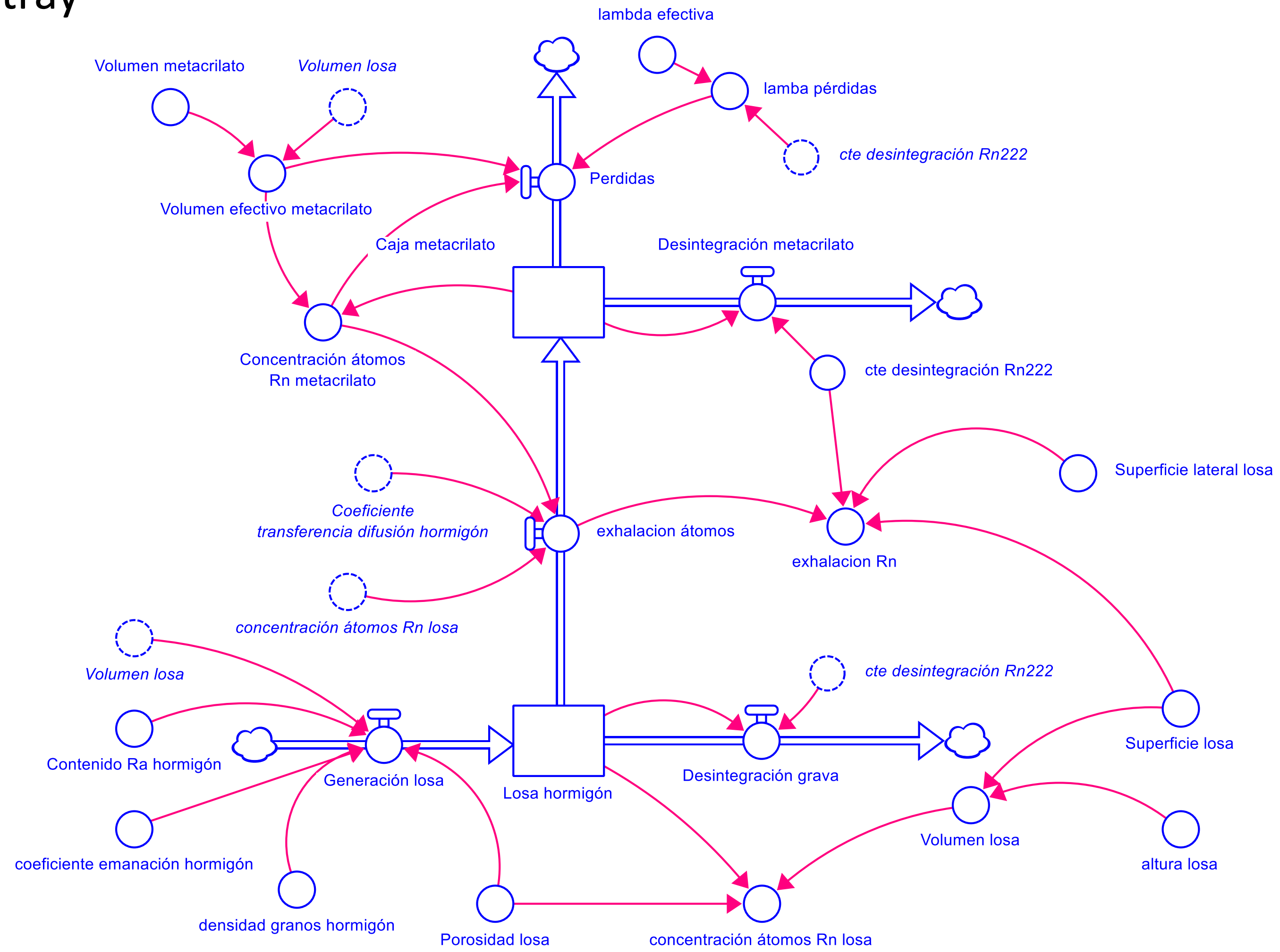
Case 1: Concrete slab on an empty metallic tray

$$\frac{dN_m}{dt} = \frac{k_{D,s}}{\lambda_{Rn}}(C_s - C_m) - \lambda_{Rn}N_m - \lambda_{leak.}N_m$$

$$C_s = \frac{N_s}{V_s\varepsilon} \qquad C_m = \frac{N_m}{V_m}$$

$$\frac{dN_s}{dt} = E_s - \frac{k_{D,s}}{\lambda_{Rn}}(C_s - C_m) - \lambda_{Rn}N_s$$

$$E_s = A_{Ra,s} f_s V_s (1 - \varepsilon)\rho_{gr}$$



The set of coupled ODEs is numerically solved by 4th order Runge-Kutta

Adaptation of RAGENA model (with Stella software)

Case 1: Concrete slab on an empty metallic tray

Exhalation from concrete surface (atoms/h)

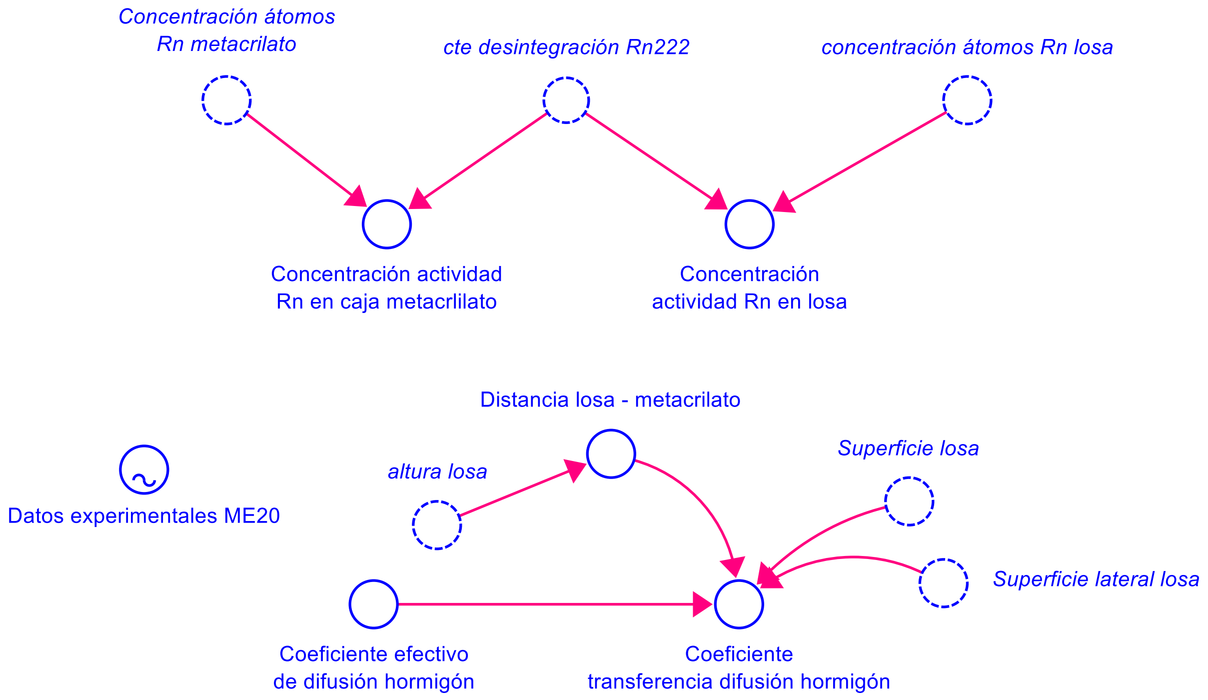
$$E_s = k_{D,s}(C_s - C_m)$$

Fick's law (atoms/m^{2}h)

$$\Phi_s = -D_{e,s}\nabla C_s$$

$$\nabla C_s \sim \frac{C_s - C_m}{d_{g-m}}$$

$$k_{D,s} = D_{e,s}\frac{2S_s}{d_{g-m}}$$


Concentración átomos Rn metacrilato

cte desintegración Rn222

concentración átomos Rn losa

Concentración actividad Rn en caja metacrlilato

Concentración actividad Rn en losa

Distancia losa - metacrilato

altura losa

Superficie losa

Datos experimentales ME20

Superficie lateral losa

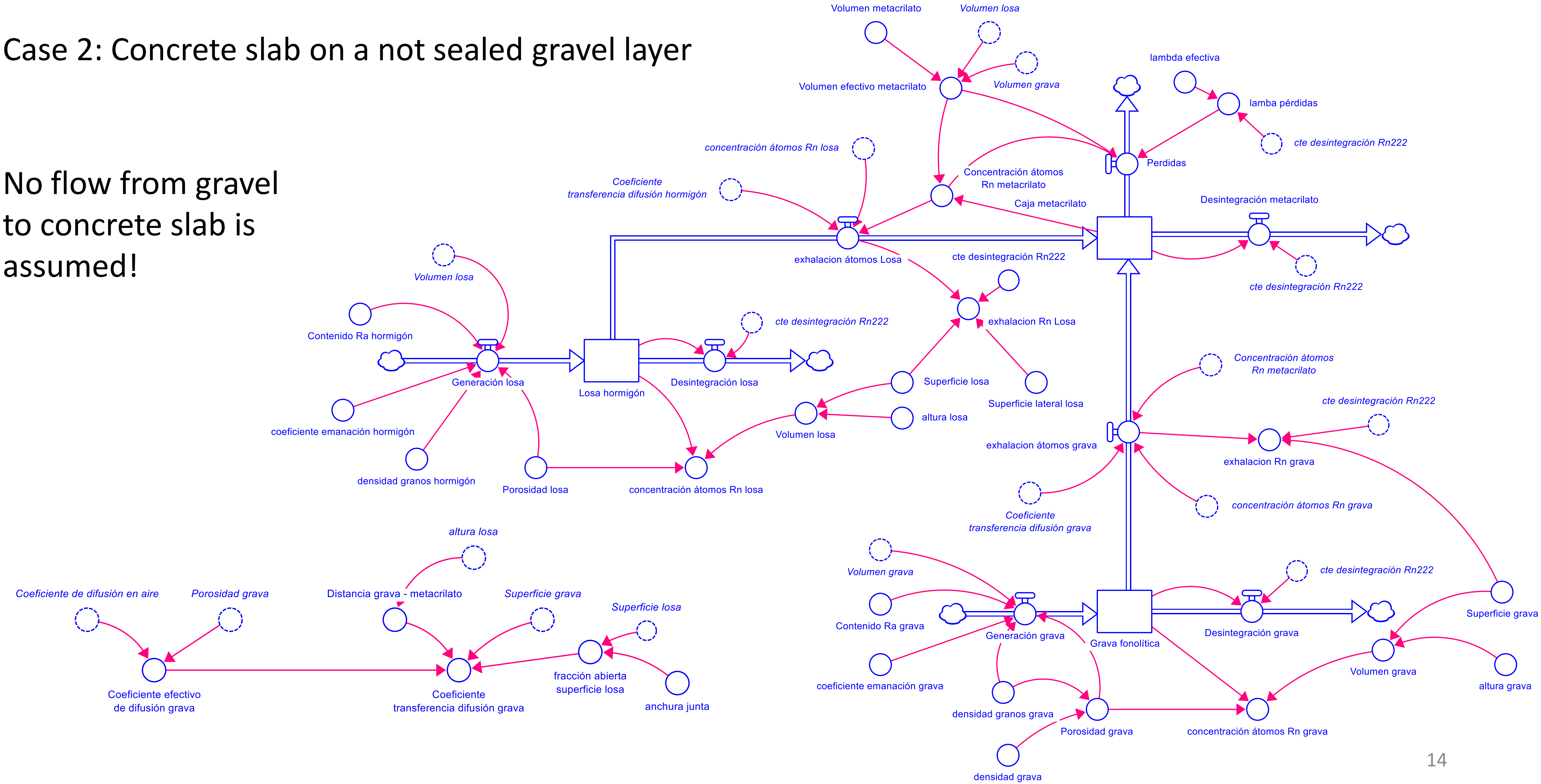
Coeficiente efectivo de difusión hormigón

Coeficiente transferencia difusión hormigón

Adaptation of RAGENA model (with Stella software)

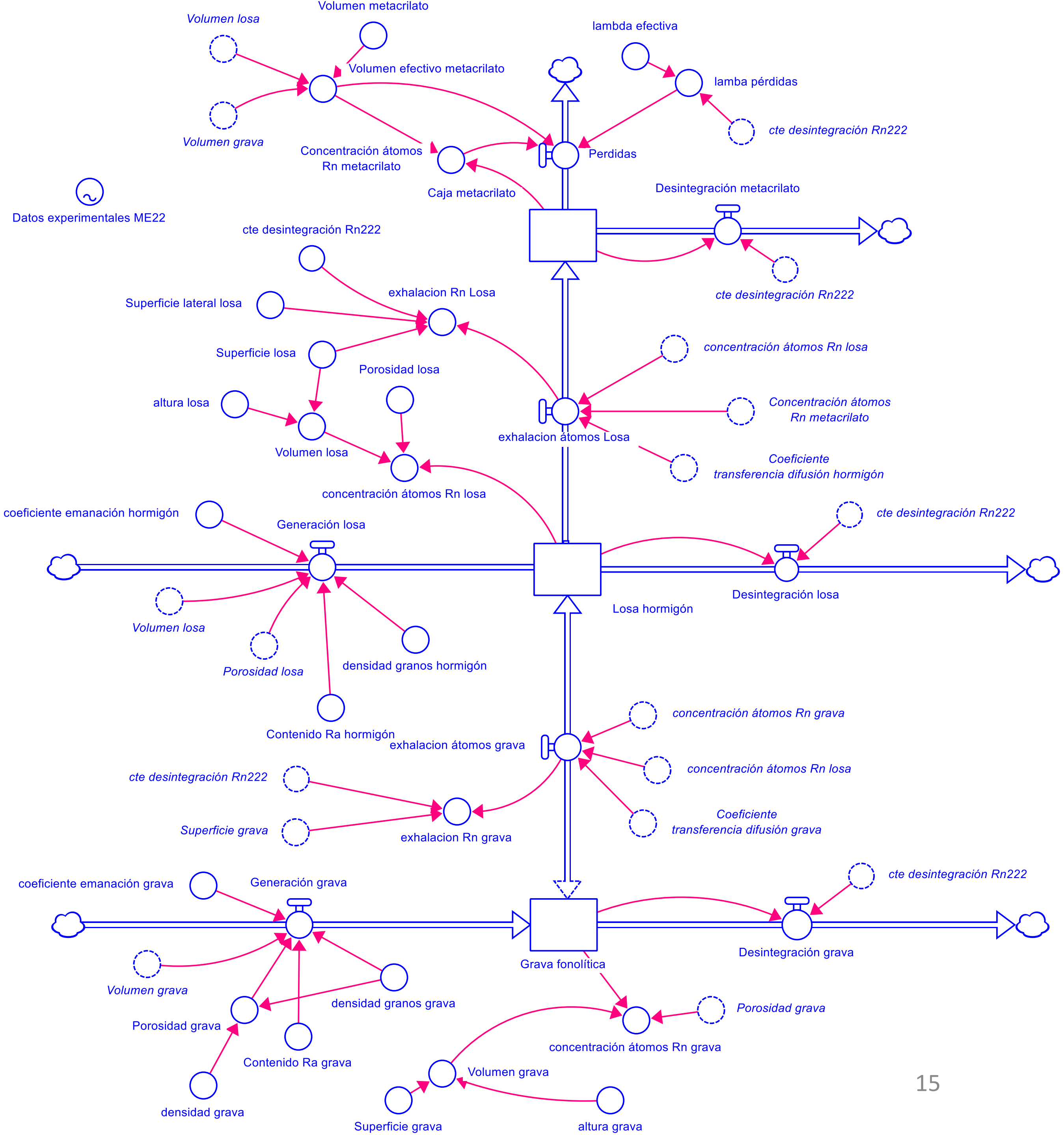
Case 2: Concrete slab on a not sealed gravel layer

No flow from gravel to concrete slab is assumed!



Adaptation of RAGENA model

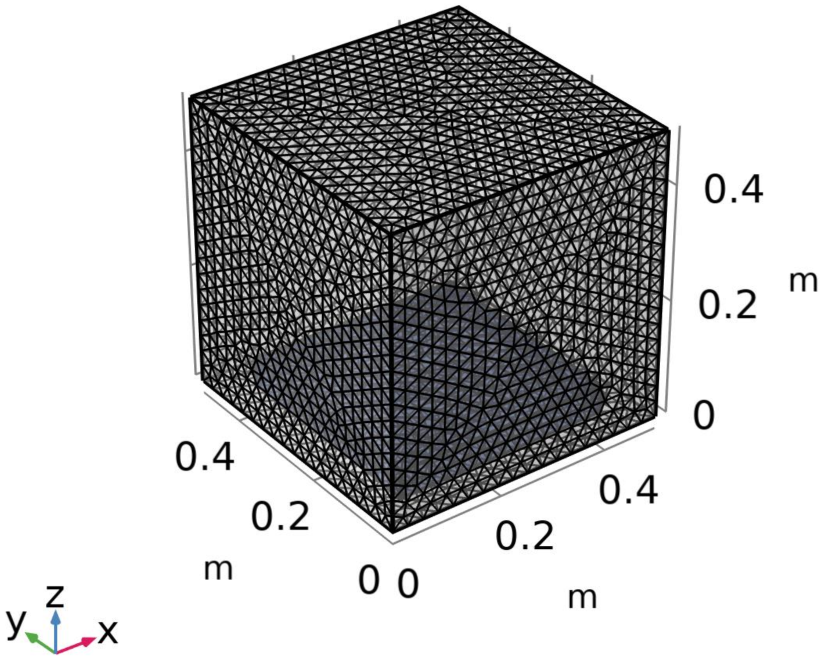
Case 3: Concrete slab on a sealed gravel layer

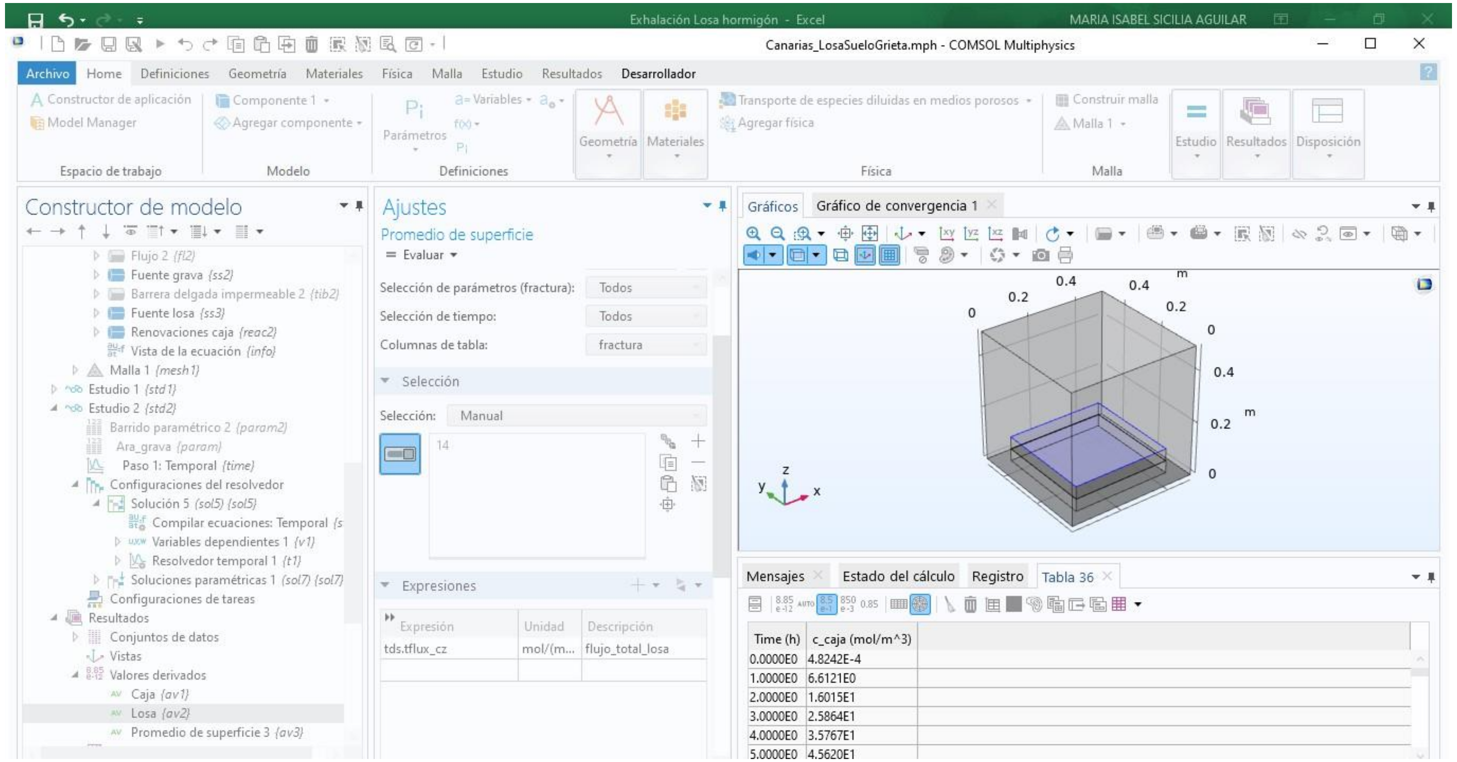


Adaptation of COMSOL-based model

Geometry of each case and all input parameters are included through the COMSOL user interface.

Time-dependent radon transport equation is numerically solved in a 3-D mesh by finite elements.





Selección de parámetros (fractura): Todos
Selección de tiempo: Todos
Columnas de tabla: fractura

Selección

Selección: Manual

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Expresiones

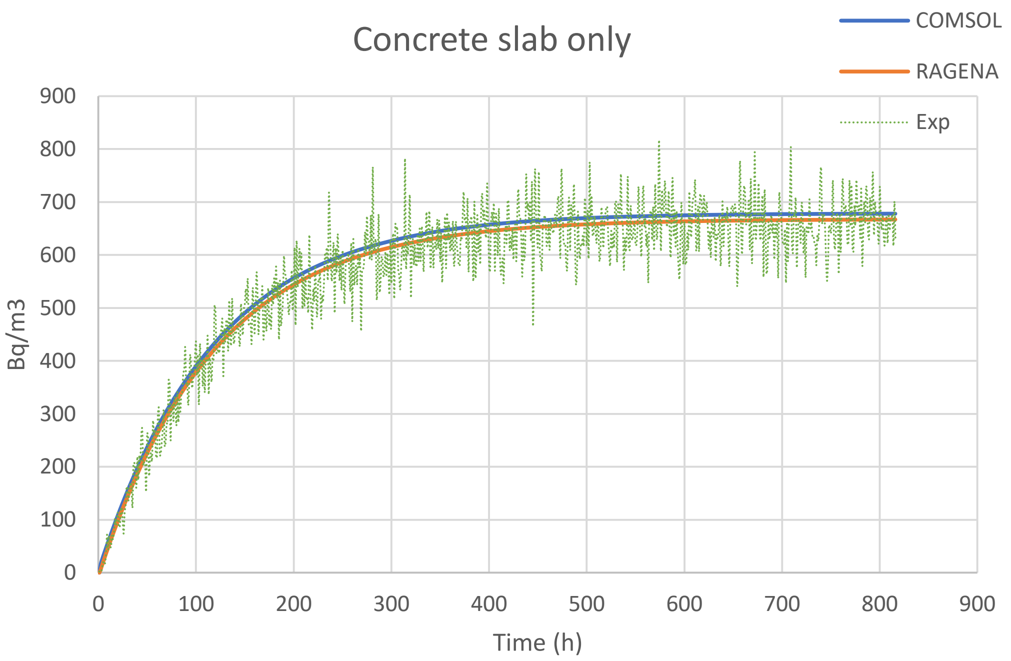
Expresión	Unidad	Descripción
tds.tflux_cz	mol/(m...	flujo_total_losa

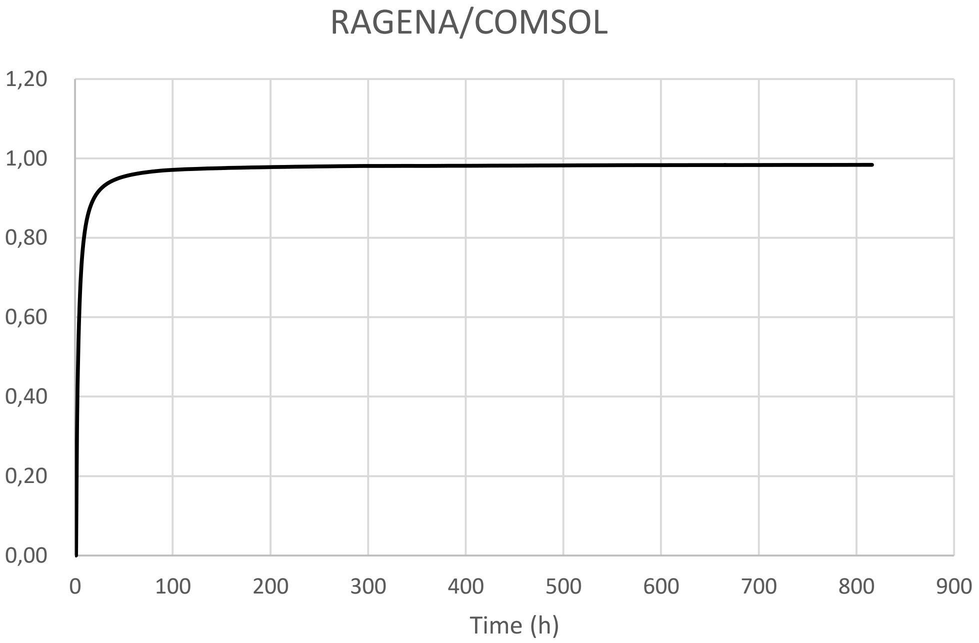
Time (h)	c_caja (mol/m^3)
0.0000E0	4.8242E-4
1.0000E0	6.6121E0
2.0000E0	1.6015E1
3.0000E0	2.5864E1
4.0000E0	3.5767E1
5.0000E0	4.5620E1

Case 2: the expansion joint is simulated by reducing the dimensions of the concrete slab accordingly

Model comparison results

Case 1: Concrete slab on an empty metallic tray



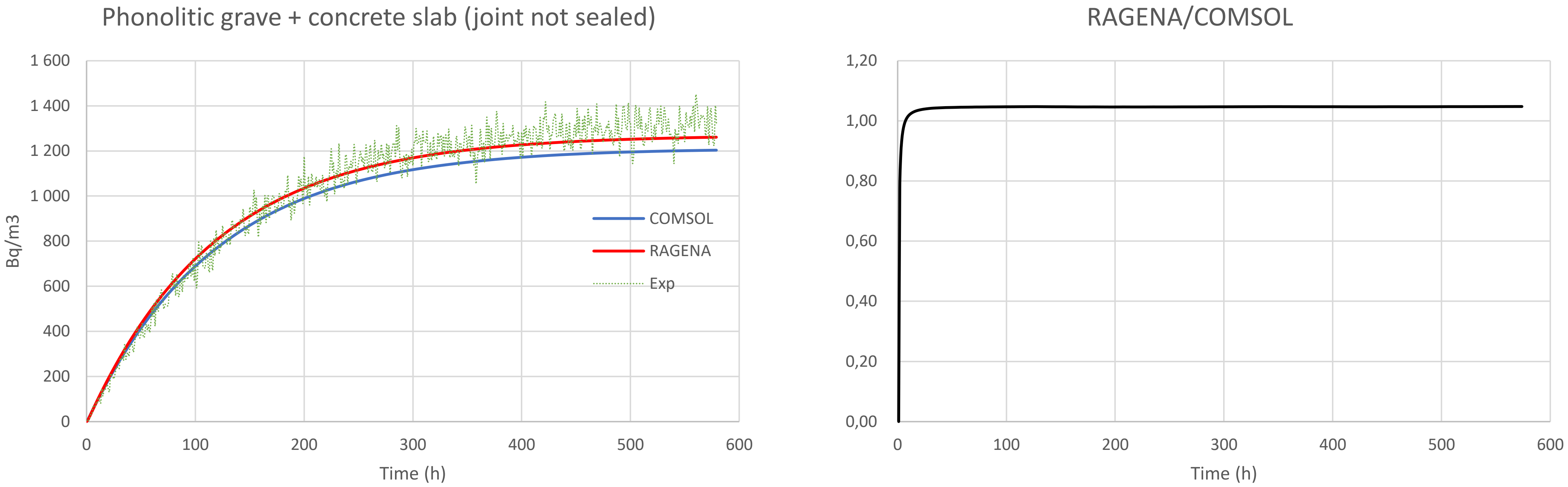


RAGENA/COMSOL = 0.984

Both steady-state and accumulation curve agree

Model comparison results

Case 2: Concrete slab on a not sealed gravel layer

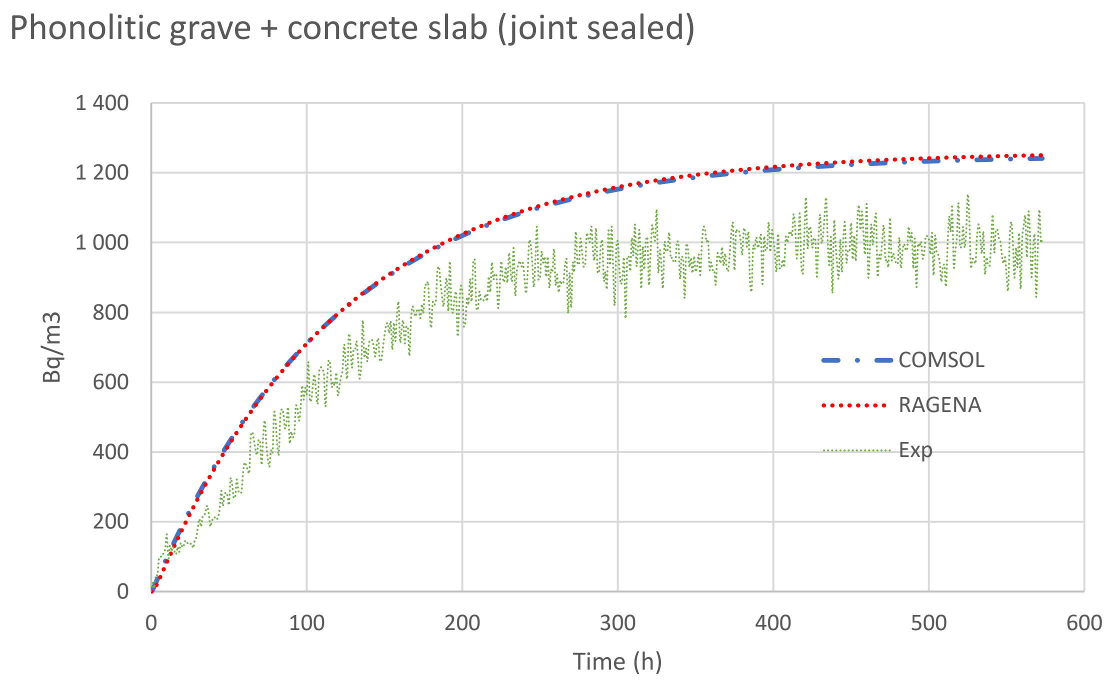


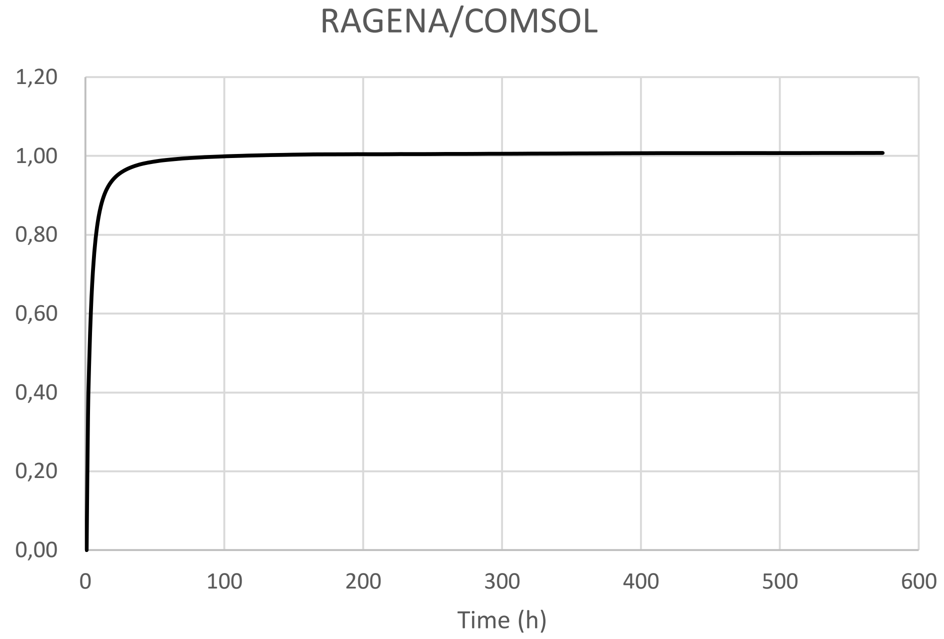
RAGENA/COMSOL = 1.048

Discrepance might be due to not considering flow from gravel to slab concrete in RAGENA

Model comparison results

Case 3: Concrete slab on a sealed gravel layer





RAGENA/COMSOL = 1.008

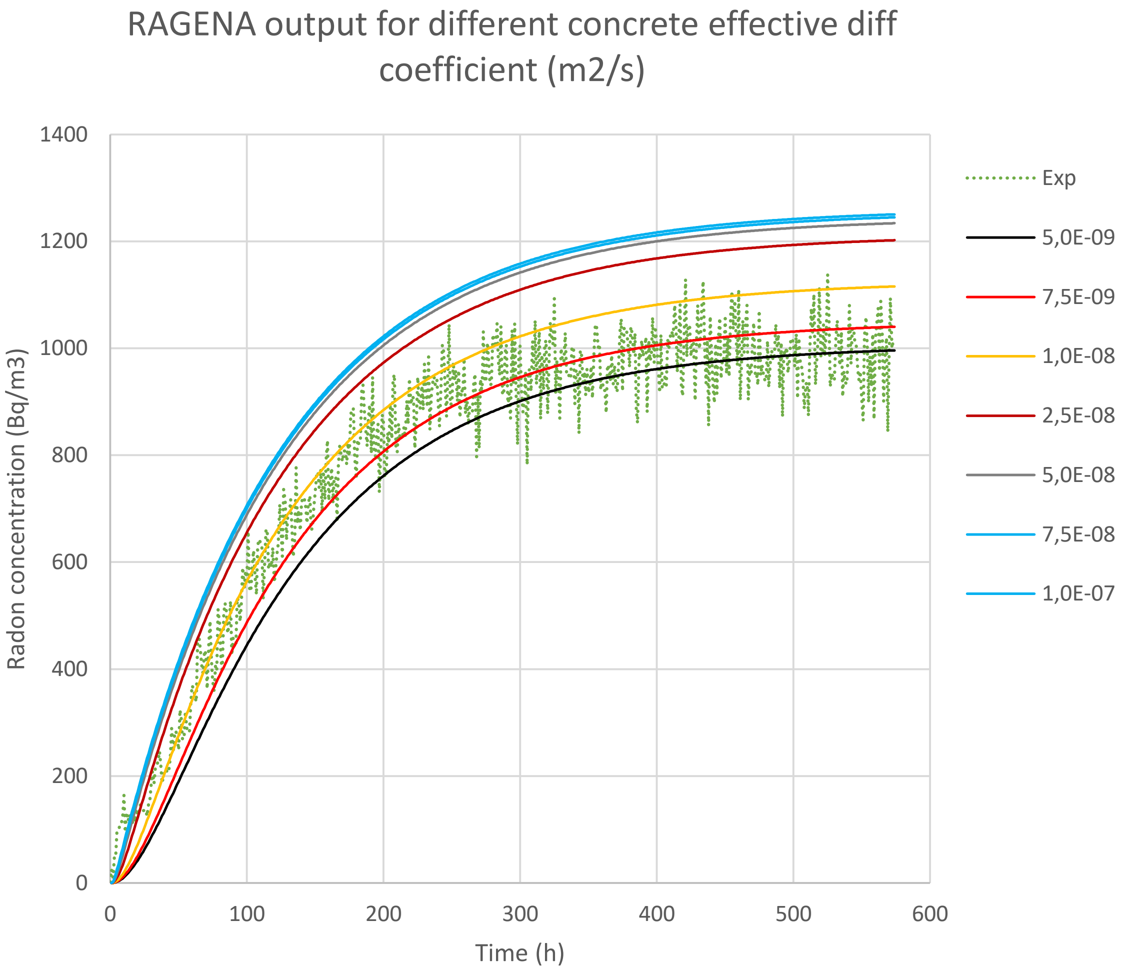
Excelent agreement between the two modelling methods, but disagreement with experimental data.

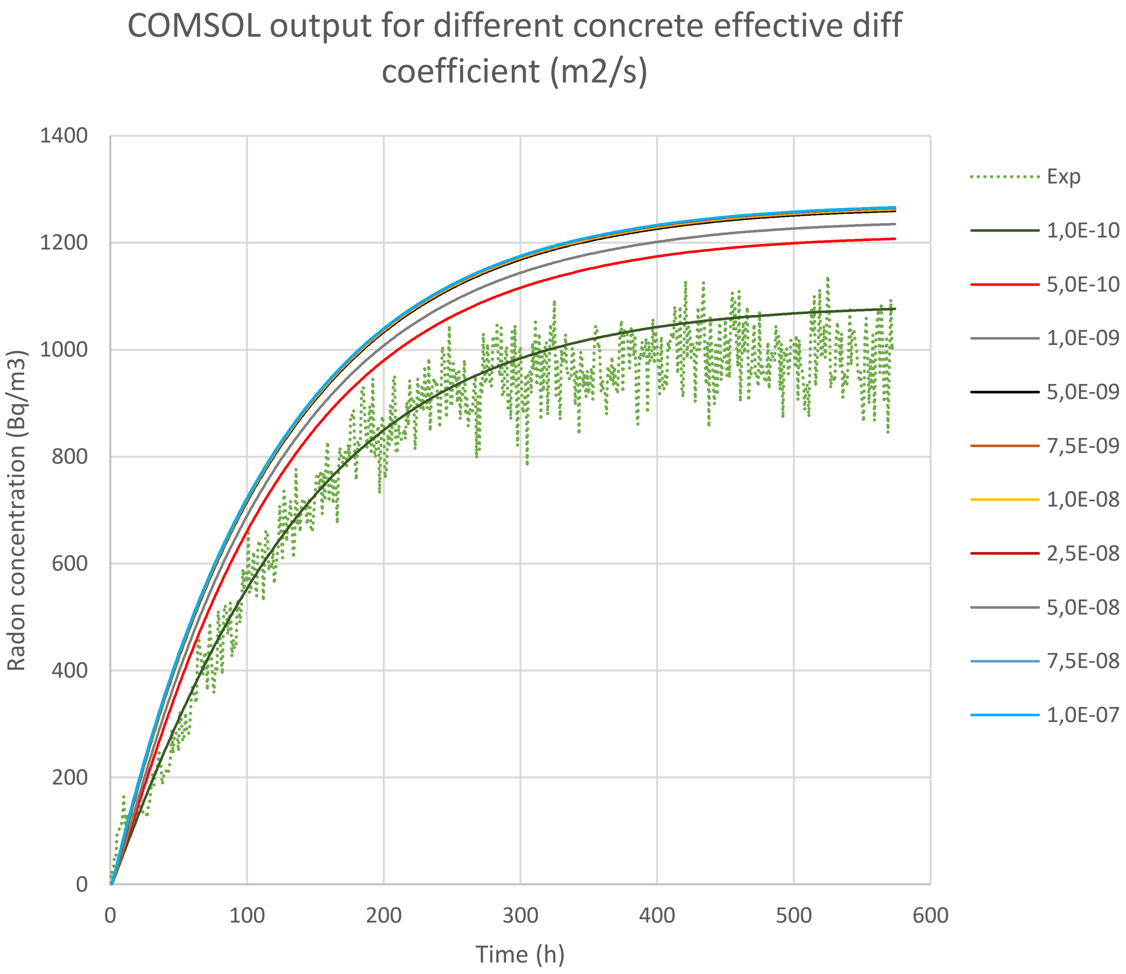
We explore concrete slab effective diffusion coefficient and porosity range.

Model comparison results

Case 3: Concrete slab on a sealed gravel layer

Sensitivity analysis: slab D_e





Model comparison results

Case 3: Concrete slab on a sealed gravel layer

Sensitivity analysis: slab D_e

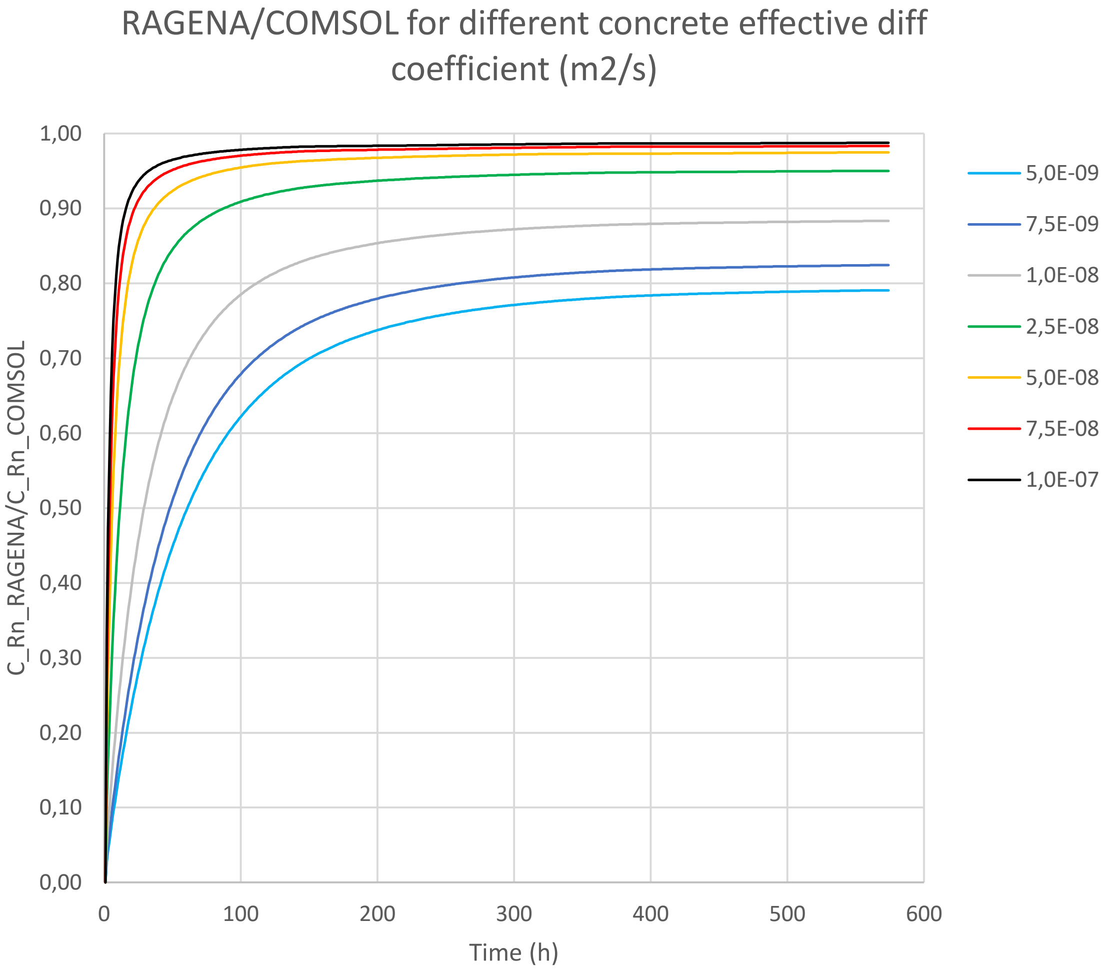
For large effective diffusion coefficient vaues (1e-7) both models agree.

As D_e values decrease, the models:

1. Increase their disagreement. To fit experimental data the disagreement on the "prediction" of the D_e reaches almost 2 orders of magnitude.

2. The models become more sensitive to D_e

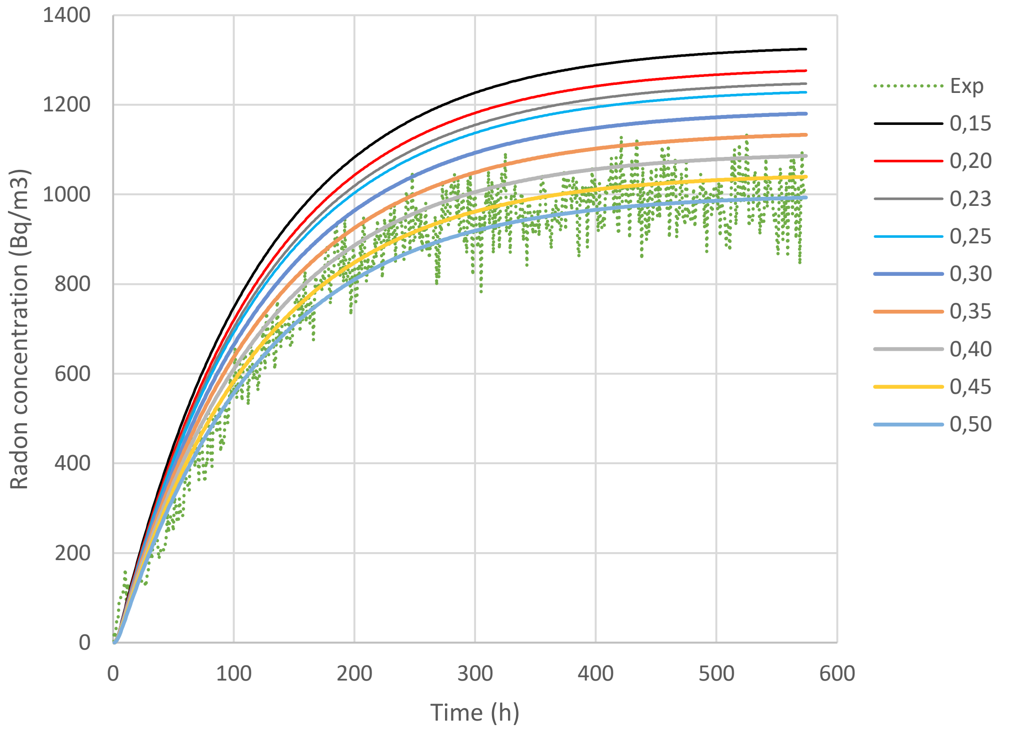
To be explored in detail!

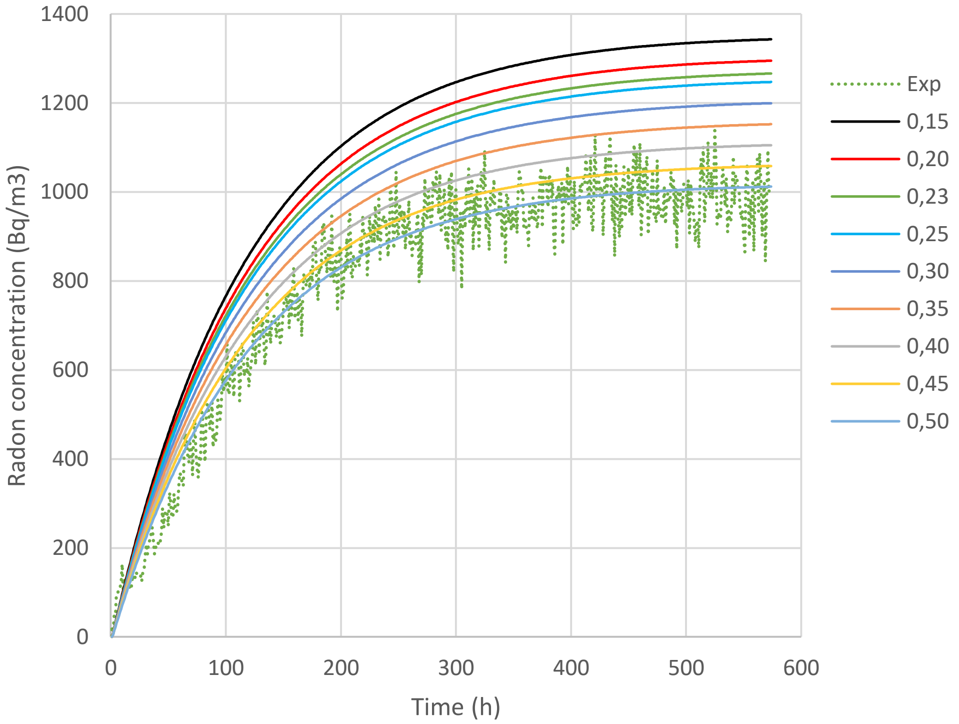


Model comparison results

Case 3: Concrete slab on a sealed gravel layer

Sensitivity analysis: slab porosity


RAGENA output for different concrete porosities


COMSOL output for different concrete porosities

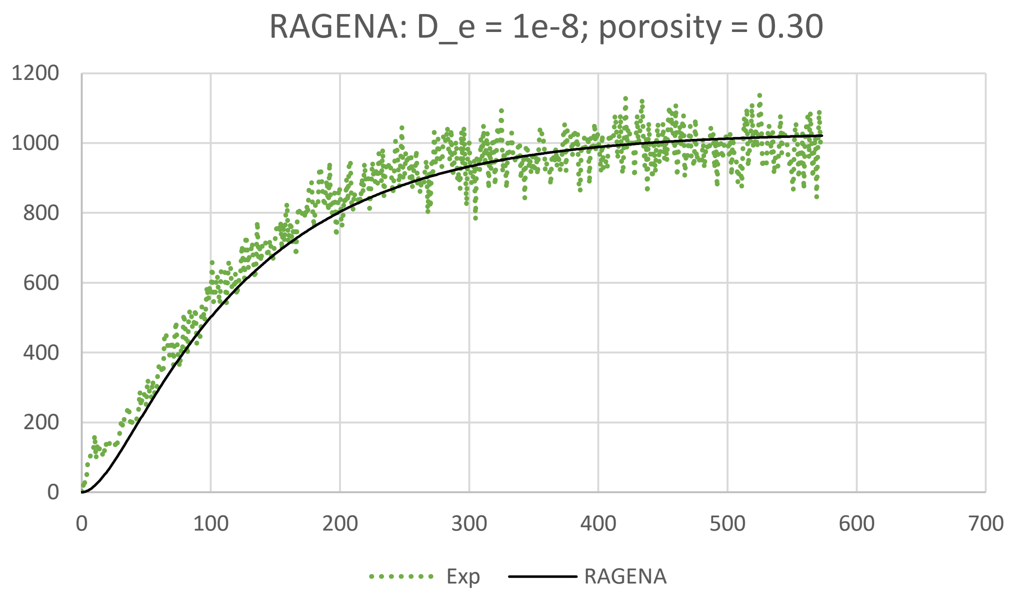
RAGENA/COMSOL ~ 1 (remember: D_e = 1e-7)

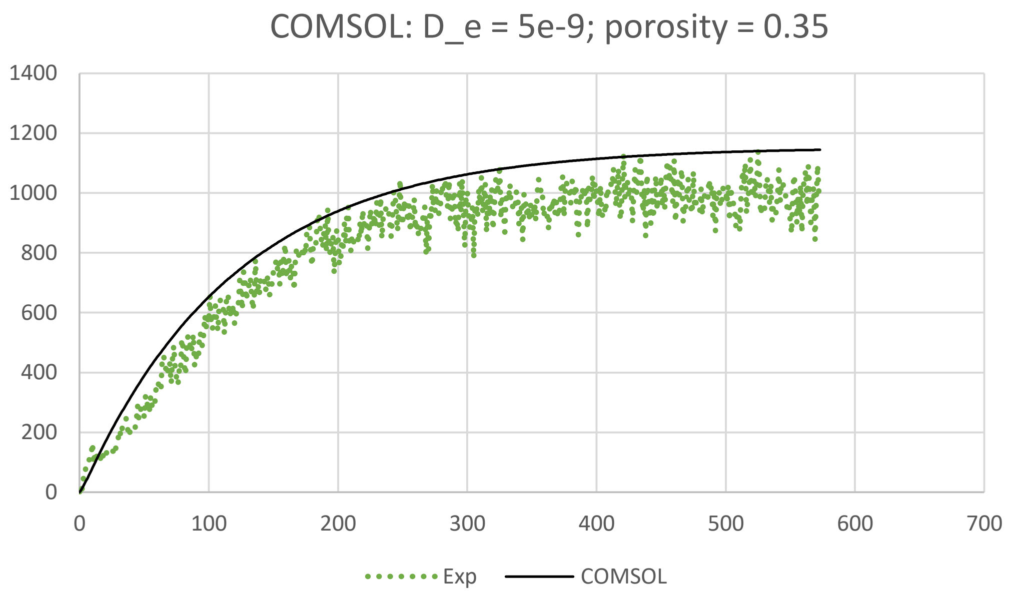
To fit experimental data the porosity of the concrete slab has to be higher than 0.23

Model comparison results

Case 3: Concrete slab on a sealed gravel layer

First try on an “optimum” [D_e, ε]





Both models could reproduce reasonably well experimental data assuming reasonable values of the two “free” parameters.

Experimental determination of D_e and porosity will better constrain the models.

Conclusions and next steps

In general, the agreement between models and experimental data is good in this simple case

Applying the models to this simple case has been shown as very useful: we have found out the problem with the relative discrepancy increasing as D_e decreases.

This has been the first time that such an excercise has been done (to our knowledge)

Next steps:

Try to understand the origin of the D_e problem

Better estimation (or measurement) of D_e and porosity of slab to constrain the models.

Adapt the models to the 2 real cases.

Conclusions and next steps

We hope to show you the final project results in the 17th GARRM!

THANKS!

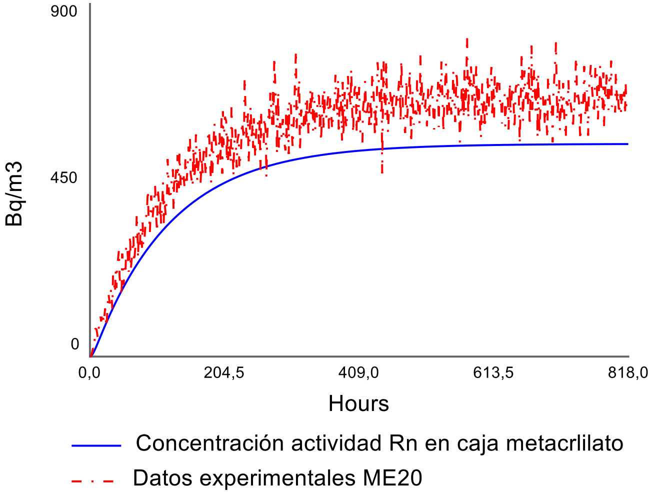
DĚKUJI!

BACKUP SLIDES

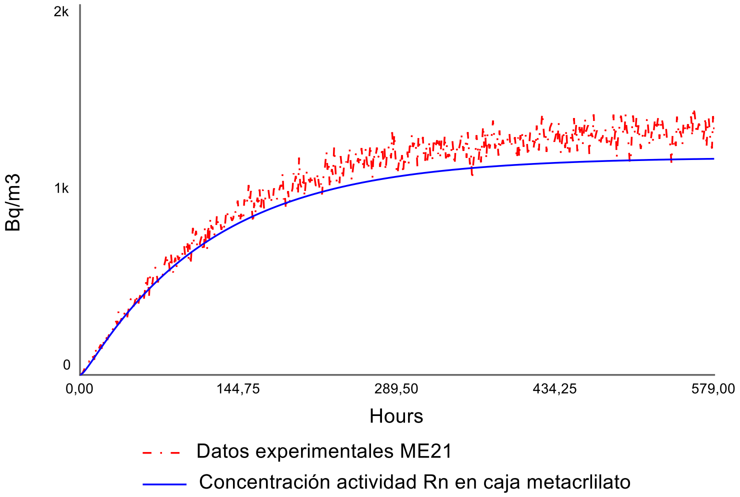
RAGENA

Results for **“optimum” [D_e, ε]**

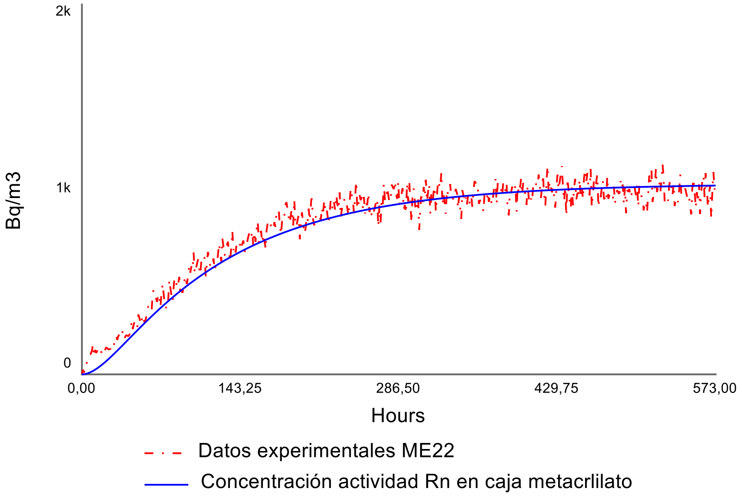
Case 1 slab alone



Case 2 slab+gravel not sealed



Case 3 slab+gravel sealed



The challenge of modelling indoor radon

(Some) Relevant facts:

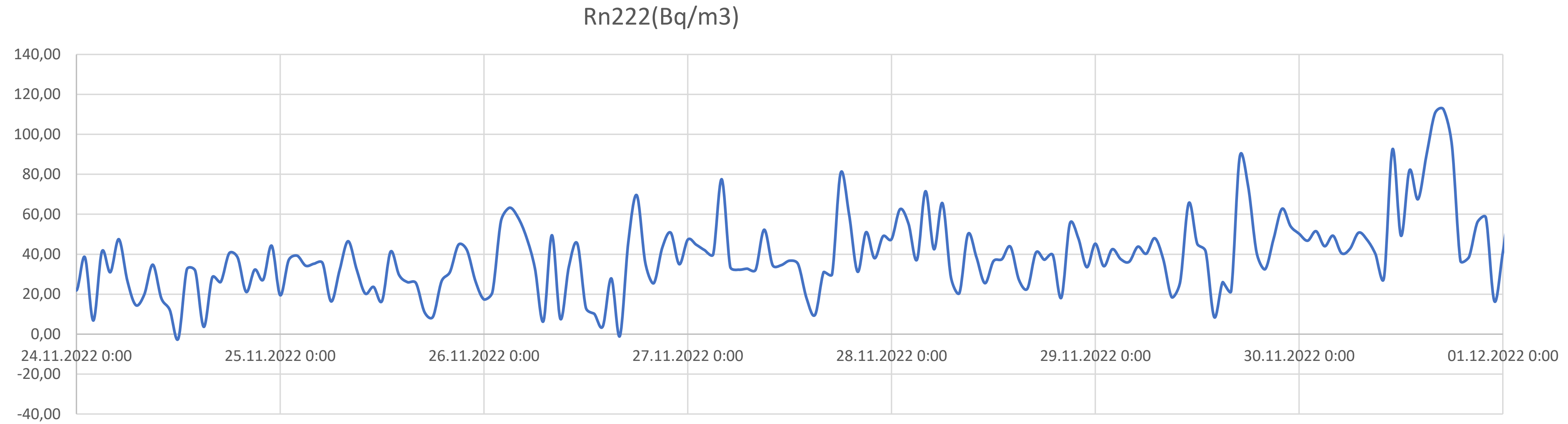
- In almost all regions there is a percentage of dwellings or workplaces with high annual-averaged indoor radon levels.

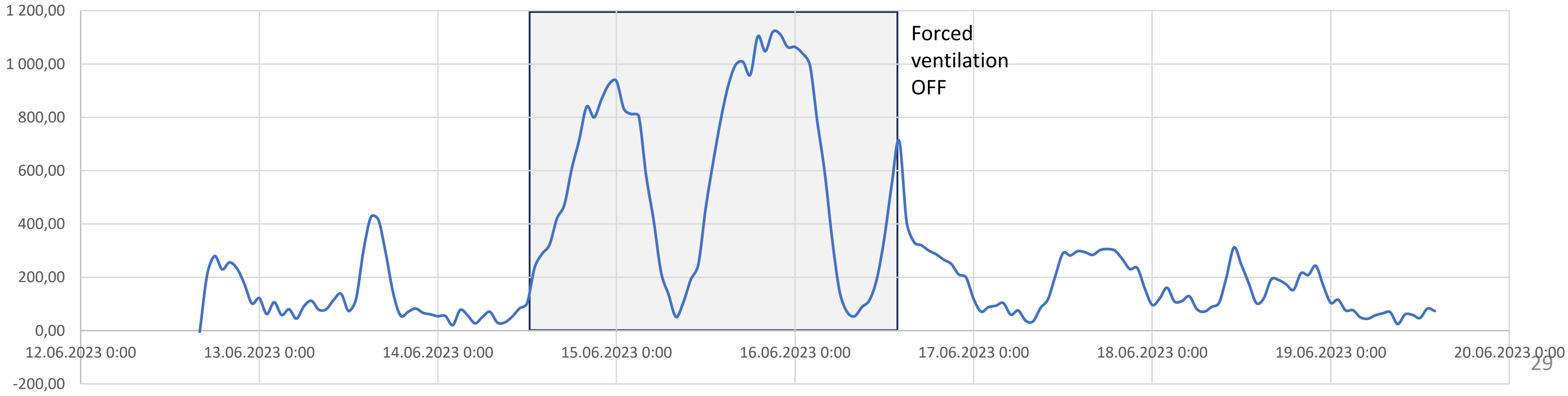
- There is a consensus that high indoor radon levels are mainly due to radon entering from the soil underneath the dwelling by advection. 5-10 Pa are enough.

- There is a market of radon mitigation methods that have been shown to be efficient in most cases.

- Both indoor radon temporal and spatial variations can be complicated.

The challenge of modelling indoor radon





The challenge of modelling indoor radon

(Some) Relevant facts:

- In almost all regions there is a percentage of dwellings or workplaces with high annual-averaged indoor radon levels.

- There is a consensus that high indoor radon levels are mainly due to radon entering from the soil underneath the dwelling by advection. 5-10 Pa are enough.

- There is an industry (background) of radon mitigation methods that have been shown to be efficient in most cases.
- Both indoor radon temporal and spatial variations can be complicated.

- We can certainly measure radon levels

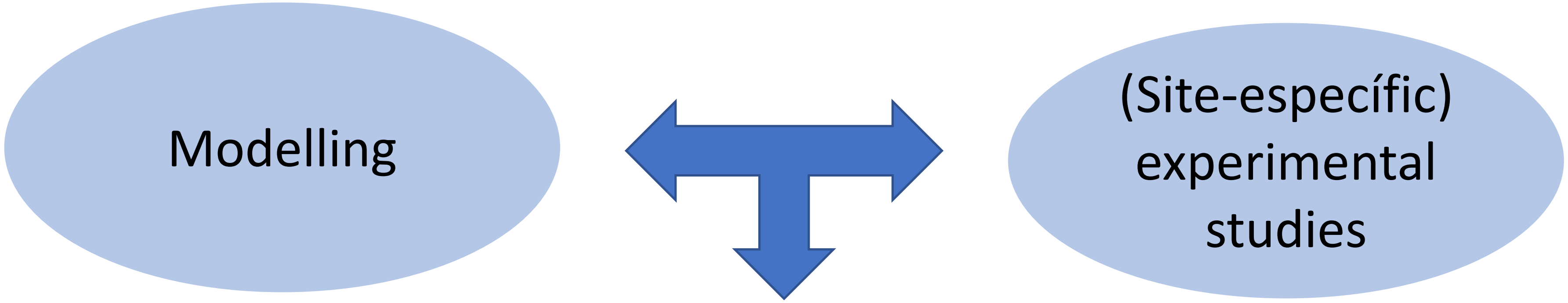
- We reasonably know how to mitigate them

- The (few) models have not really been successful (90’s).

→ Why should we model indoor radon?

The challenge of modelling indoor radon

Why should we model /simulate indoor radon?



Identification of entry pathways in a specific site

Identification of entry mechanisms (diffusion, advection)

Efficient mitigation methods

Providing descontamination guidelines in contaminated areas

It generates understanding