Understanding radon levels in houses

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Radon is the largest single source of radiation exposure to population

Radon goes through four stages until it reaches a living environment:

1) Its generation in the source media
2) Its migration in the source medium
3) Its entry into a dweling
4) Its accumulation indoors

Understanding these processes is useful to:

- Locate houses with high radon levels.
- Determine de most effective mitigation methods.
- Improve building design and practises to avoid high radon levels in new buildings

Modelling, together with experimental studies, generates understanding

- Relative importance of different parameters and processes.
- Exploration of different scenarios.
- Cost-effective powerful tool.

Many parameters of different origin take part at each stage, and most of them are time-dependent (real world).

Complexity! → Partial models and/or experimental studies

Review of radon models

Radon entry into houses from soil

Radon entry into houses from building materials

Indoor radon dynamics

Review of radon models

Radon entry into houses from soil

Gadgil. *Radiat. Prot. Dosim*. 45, 373-380 (1992)
Andersen. *Sci Total Environ*, 272, 33-42 (2001)

- Analytical models
- Lumped parameter models
- Numerical models

- **Idealised geometrical configuration**
- **Simplified boundary conditions**
- **Functional dependence of results on input parameters**

Review of radon models

Radon entry into houses from soil

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Andersen. *Sci Total Environ*, 272, 33-42 (2001)

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- Lumped parameter models
- Numerical models

- **Analogy of pressure-driven flow of soil gas to voltage difference driving a current in electrical circuit**
- **Discrete system of lumped parameters**

Review of radon models

Radon entry into houses from soil

Gadgil. *Radiat. Prot. Dosim*. 45, 373-380 (1992)
Andersen. *Sci Total Environ*, 272, 33-42 (2001)

- Analytical models
- Lumped parameter models
- Numerical models

- **Detailed transport of radon in soil (diffusion + advection).**
- **Discretisation of space (and sometimes also time).**
- **Finite difference, finite element and integrated finite difference models.**
- **Detailed knowledge of the soil-indoor interface required (cracks, gaps, holes).**
- **Common approach: homogeneous soil, constant soil gas-permeability and diffusivity.**

Review of radon models

Radon entry into houses from building materials

- Only steady-state diffusive exhalation is considered
- Aging (moisture), atmospheric pressure and covering materials

Indoor radon dynamics

- Constant entry rate from soil and/or building materials
- Ventilation rate + inter-zone flows
- Mass-balance equation

Summary

Reasonable good understanding of the main parameters and processes afecting indoor radon levels.

Most of the models are steady-state or site-specific

It is difficult to extrapolate partial model results to real inhabited houses

No integrated approach. Need of a “Global Dynamic Radon Model” more concerned with a global description, on which the knowledge acquired from partial models is collected.

The Global Dinamic Radon Model (GDRM) concept

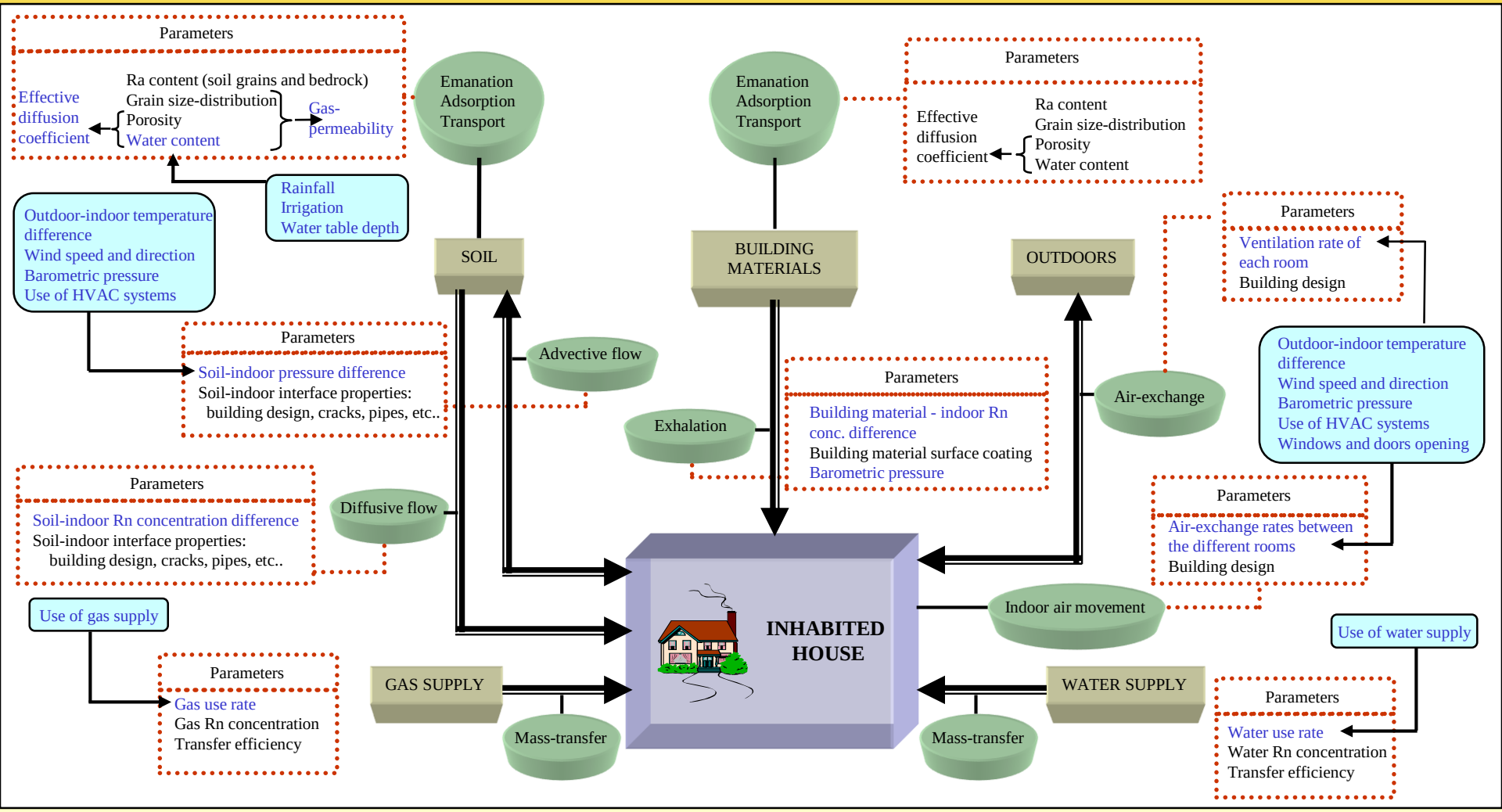


Diagram of the sources (brown square boxes), processes (green round boxes) and parameters that a Global Dynamic Radon Model has to consider. The time-dependent parameters are in blue.

A Global Dynamic Radon Model (GDRM) should:

1. Take into account all radon sources, processes and parameters affecting indoor radon levels
2. Describe the dynamics of the indoor radon levels
3. Be adaptable to different time-scales and have the possibility of incorporating time series experimental data.
4. Be applicable to different real sites, taking the advantage of the information available
5. Be able to simulate mitigation methods

The RAGENA (RAdon Generation, ENtry and Accumulation) model:

Dynamic. Time step can be fixed from seconds to years.

Structured in sectors. Compartmental model using “efective” values.

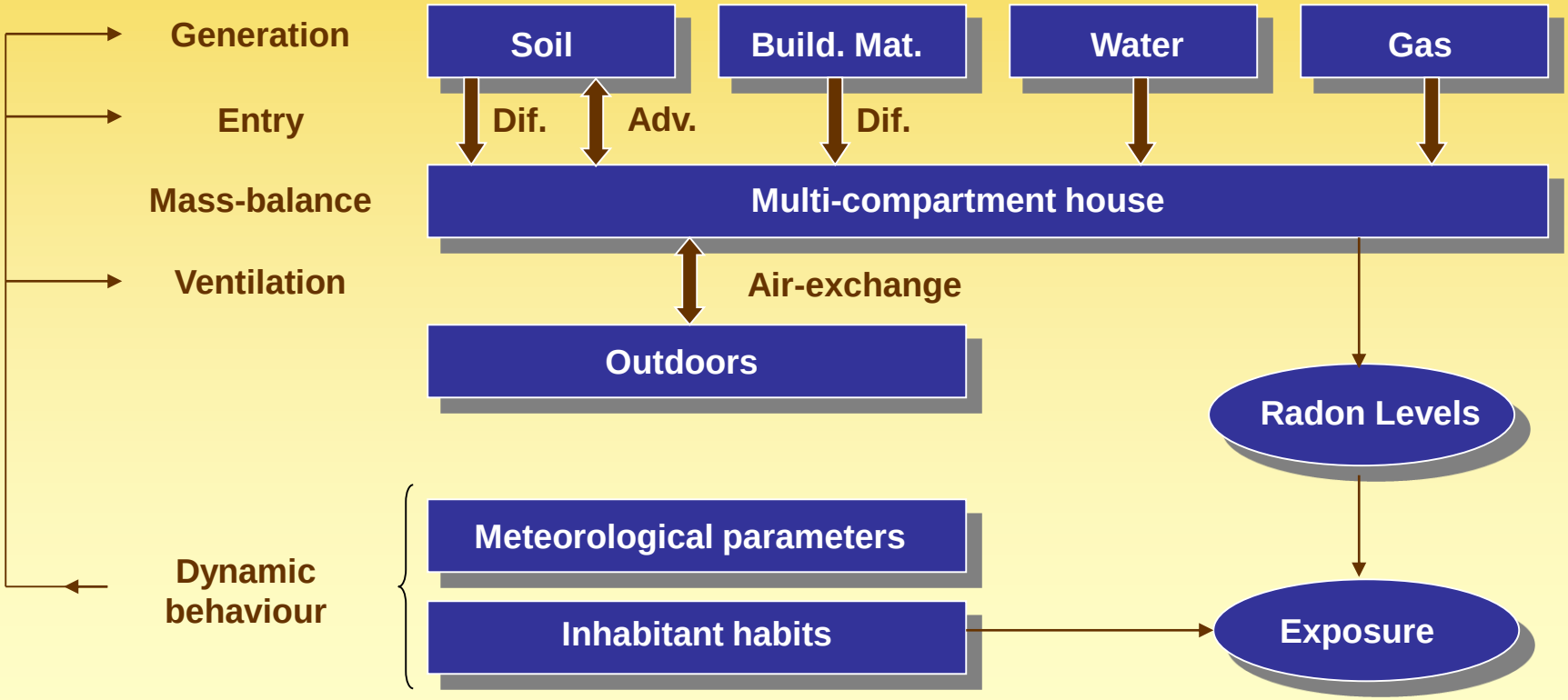
The set of coupled differential equations is solved by the 4th order Runge-Kutta numerical method.

Inputs: experimental time-series data, constant values, probability distributions

Outputs: C_{soil} (t), $C_{BM,i}$ (t), $C_{in,j}$ (t), ER(Bq/s) from each source

Font, Baixeras and Domingo. *Sci Total Environ*, 307, 55-69 (2003)
Font. *Radon Generation, Entry and Accumulation Indoors*. PhD dissertation (1997)

Diagram of the RAGENA model



Example: room *i*, build up with *n* different types of BM, exchanging air with outdoors and with *p* rooms

$$\frac{dN_i}{dt} = \frac{k_d}{\lambda_{Rn}}(C_{ds} - C_i) + \frac{k_a}{\lambda_{Rn}} C_{ds}\Delta P_{s-i} + \sum_{l=1}^{n} \frac{k_{d,bm}^{l}}{\lambda_{Rn}}(C_{bm}^{l} - C_i)$$

$$+ \frac{C_w U_w t_w}{\lambda_{Rn}} + \frac{C_g U_g t_g}{\lambda_{Rn}} - \sum_{j=0}^{p}\left(q_{ij}\frac{C_i}{\lambda_{Rn}} - q_{ji}\frac{C_j}{\lambda_{Rn}} \right) - \lambda_{Rn} N_i$$

The RAGENA model

Model behaviour → Reference configuration

Font and Baixeras. *Sci Total Environ*, 272, 25-31 (2001)

Variability analysis

- **Capability of the model to be adapted to different sites (not site-specific)**
- **Range of variation of each parameter**
- **Relative importance of each parameter (VI)**

Sensitivity analysis

- **Site-specific.**
- **Step, pulses, sinwaves…**
- **Parameters that have to be measured with higher accuracy.**

Uncertainty analysis

- **Site-specific.**
- **Inputs: probability distributions**
- **Uncertainty with the model predictions**

The RAGENA model

Adaptation to an inhabited house

Procedure. Site description form

Spanish house

Font et al. *Radiat. Meas. 31, 277-282 (1999)*

Main source: building materials

Indoor radon levels are the balance between a steady entry from BM and a dynamic removal through ventilation, driven by indoor-outdoor pressure differences, by wind speed and by the opening and closing of windows and doors

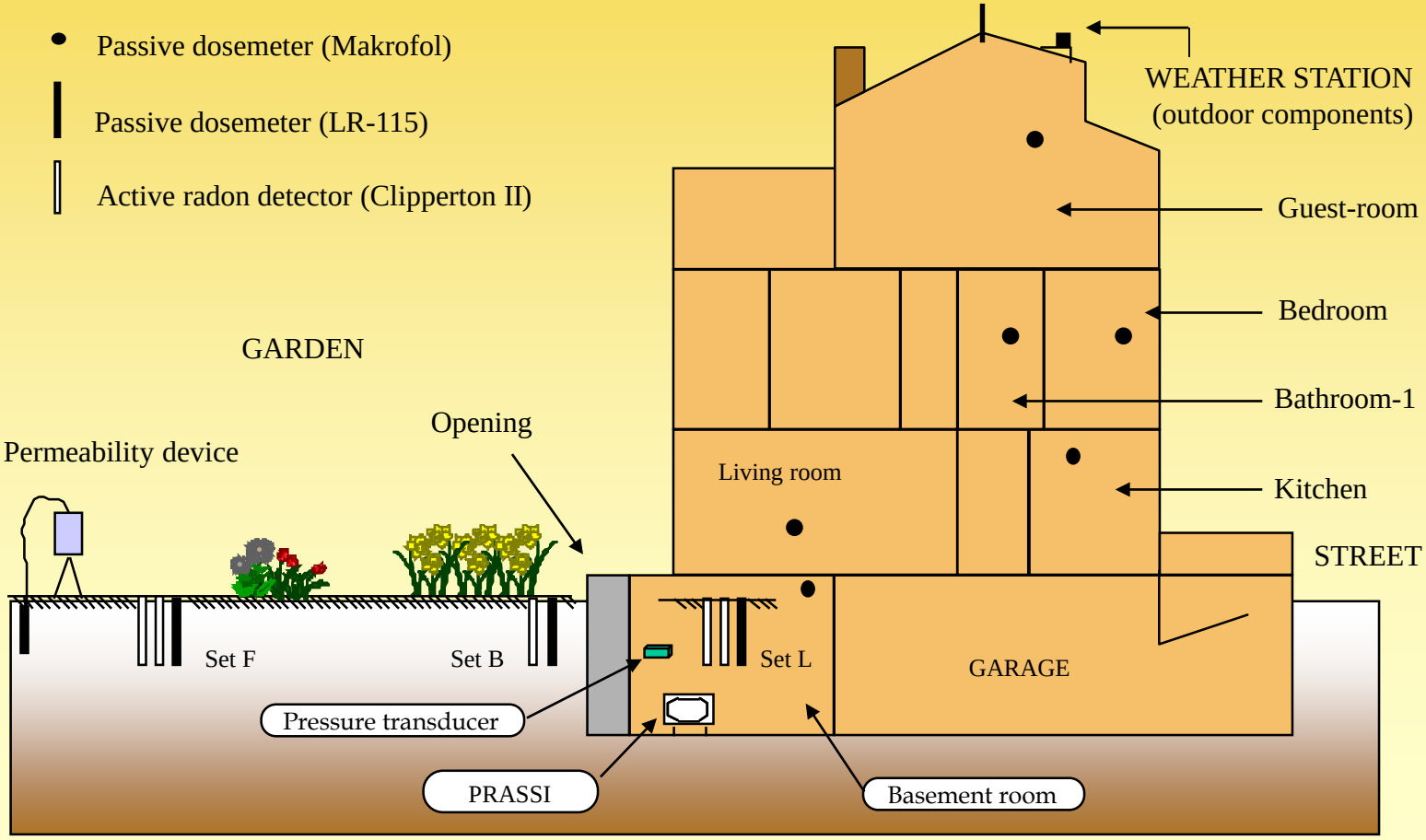
Swedish house

Main source: soil underneath

Main entry mechanism: advection

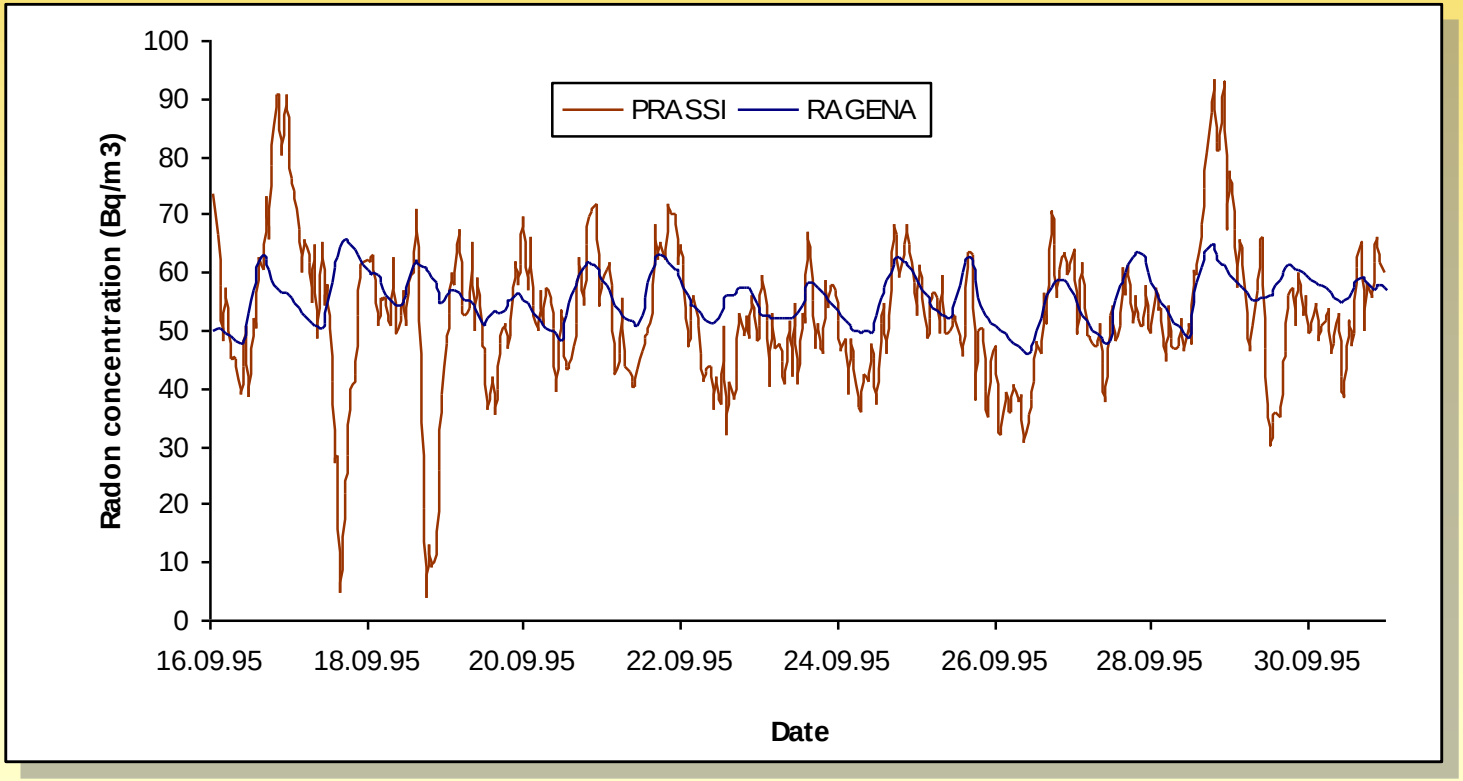
Font et al. *Radiat. Meas. 31, 359-362. (1999)*

The Spanish inhabited house experimental study



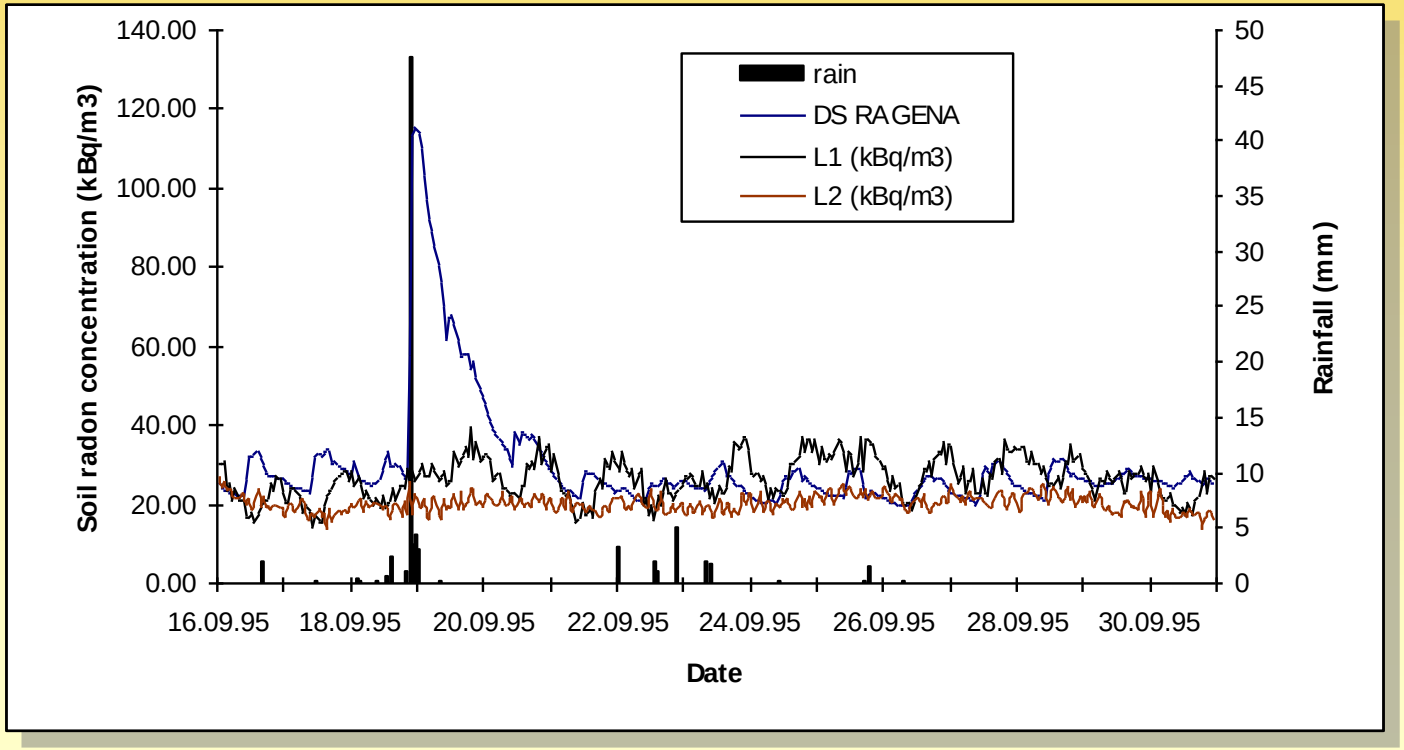
Some dynamic results

Comparison model - experimental results indoors



Some dynamic results

Comparison model - experimental results in soil



Perspectives

A lot of work to do!

To improve the knowledge on any partial model, specially from a dynamic point of view:

- Relationship between water saturation fraction in soil and rainfall, water table depth and irrigation (in houses).
- Ventilation rate in each room of the house.
- Effect of barometric pressure changes on the soil-indoor transient pressure differences.
- Effect of bioporosity on transport parameters.
- Effect of barometric pressure changes on radon exhalation from building materials.
- Model outdoor radon concentration dynamics.