A new methodology for the evaluation of radon diffusion coefficients in anti-radon membranes

Ilaria Rocchetti [1], Manuela Portaro [1], Gianfranco Galli [2], Paola Tuccimei [1], Michele Soligo [1], Cristina Longoni [3], Dino Vasquez [3].

[1] Università "Roma Tre", Dipartimento di Scienze, Largo San Leonardo Murialdo 1, 00146 Roma, Italy

[2] Istituto Nazionale di Geofisica e Vulcanologia, Sezione Roma 1, Via di Vigna Murata 605, 00143 Roma, Italy

[3] .A, Waterproofing Line, Via Ca ro 22, 20158, Milano, Italy

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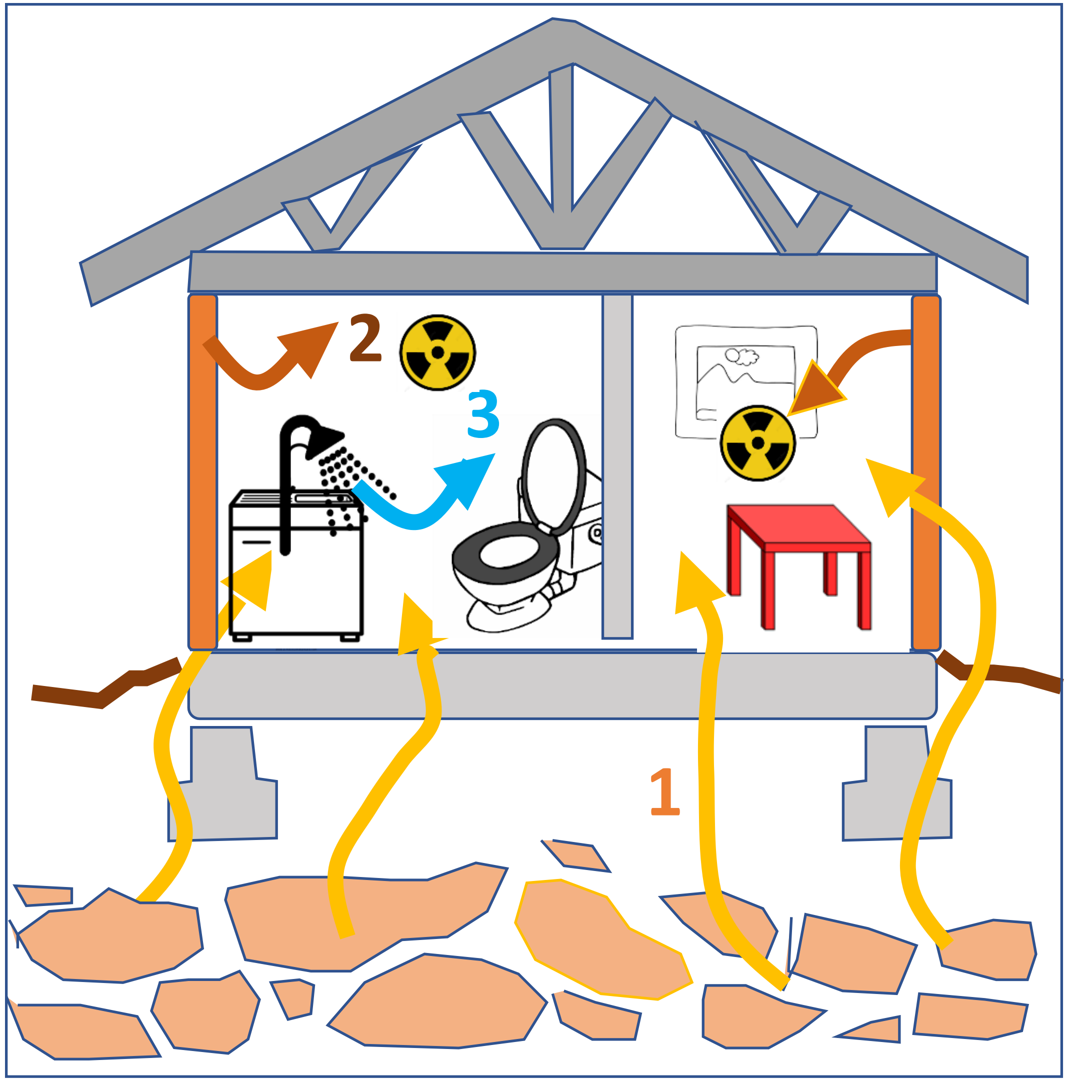
Presentation outline

- ❑ Indoor radon sources
- ❑ Mitigation and radon-barrier membranes
- ❑ Radon diffusion coefficient, diffusion length, resistance
- ❑ Testmat (setup, experiments, calculation)
- ❑ Validation
- ❑ Analyses
- ❑ Conclusions

Indoor radon sources



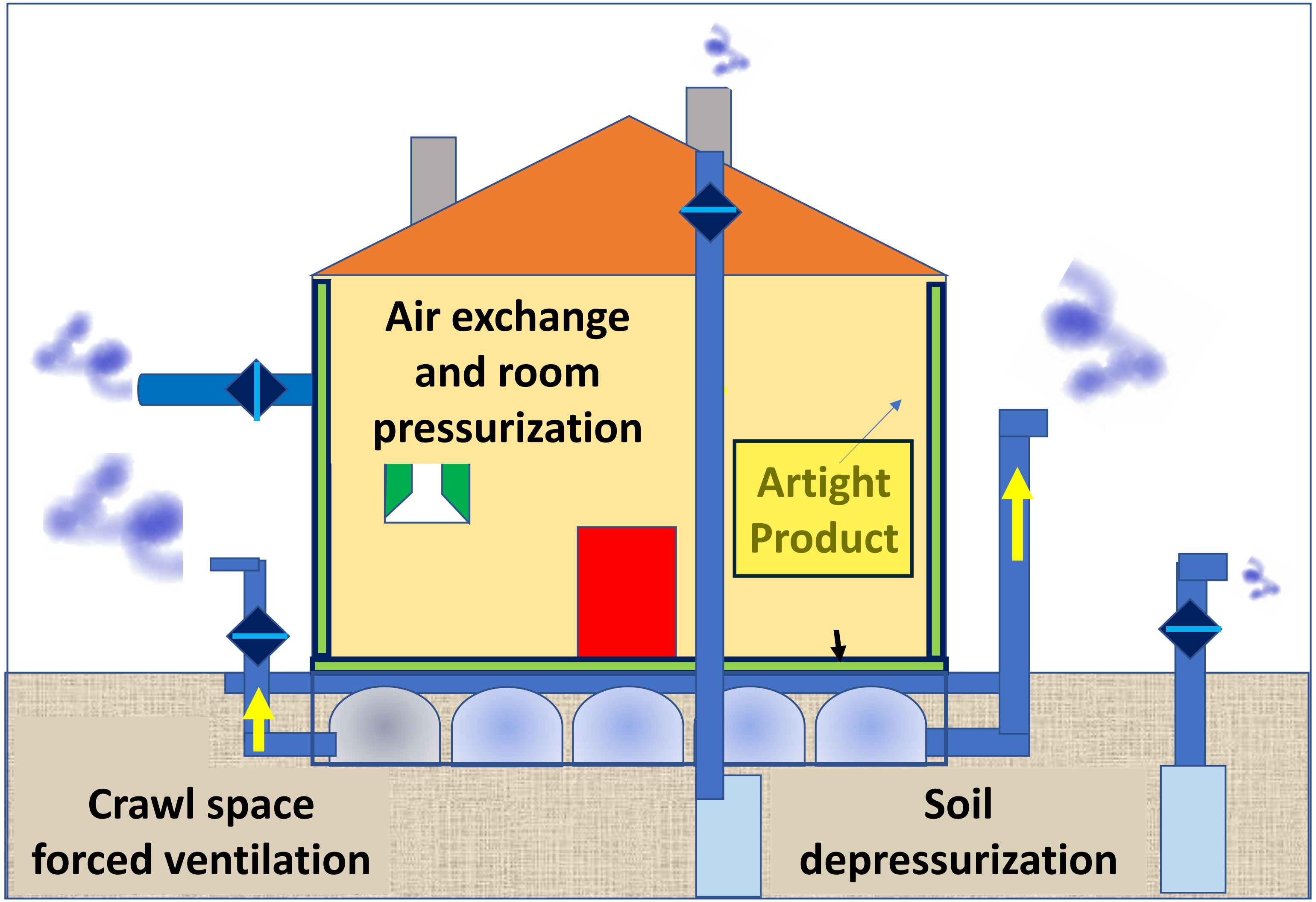
1 Geological bedrock
2 Building materials
3 Water for domestic use

Higher indoor temperatures, when compared to outdoor conditions, can create a pressure gradient that draws radon-rich soil gases into the building through the foundation and other pathways.

Risk Mitigation

In the case of buildings with high radon levels, proper mitigation actions must be taken.

Among then, airtight products



THE PROPERTIES OF AIRTIGHT MEMBRANES

- **Radon diffusion coefficients, D (m^2 s^{-1})**
- **Radon diffusion length, l (m)**
- **Radon resistance, R (s m^{-1})**

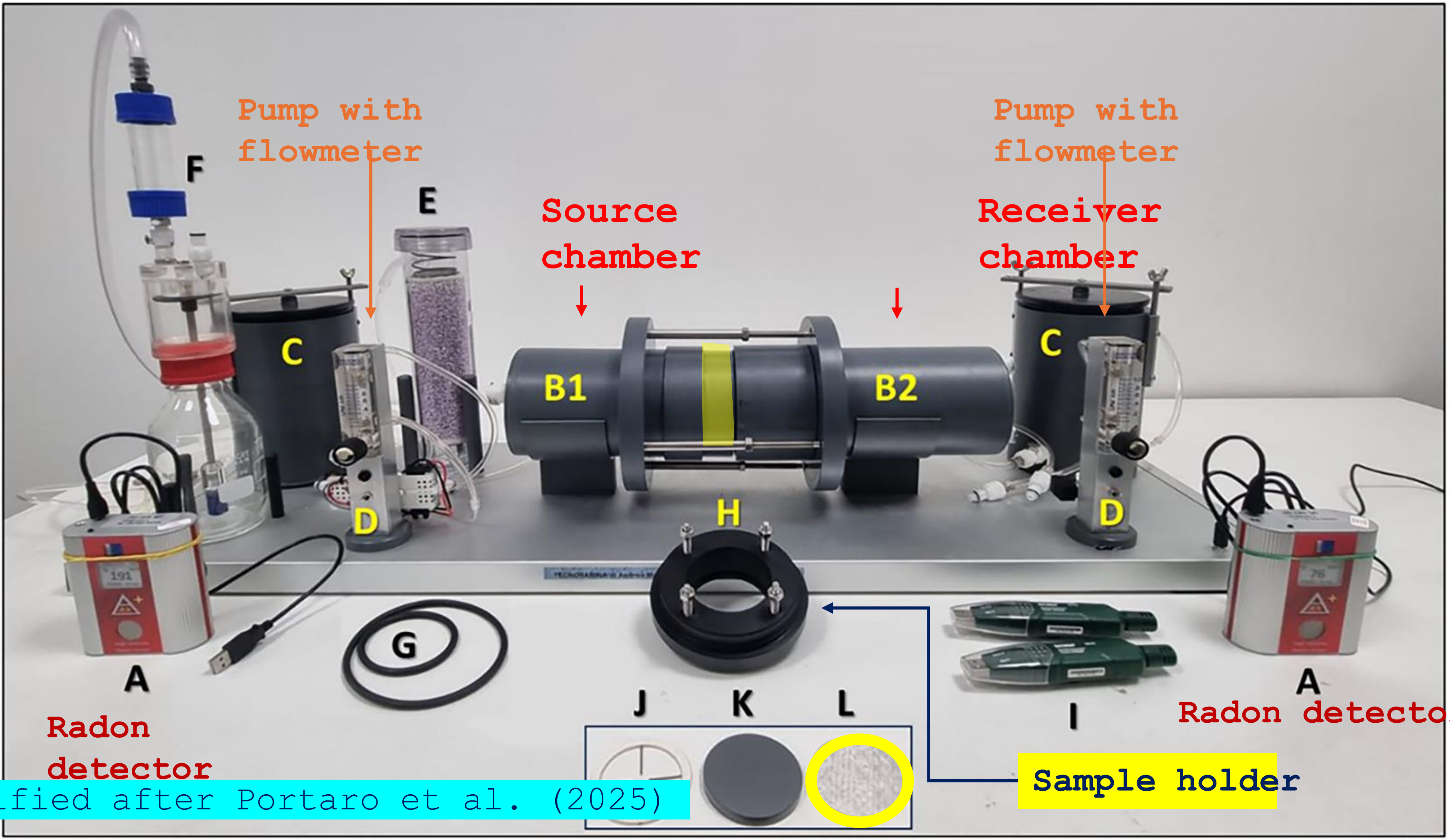
R_1 = d / D if the radon distribution in the membrane is linear → with d/l < 0.8

R_2 = $\overline{\text{sinh d / l}}$ if the radon distribution in the membrane is not linear → with d/l > 0.8

λ l

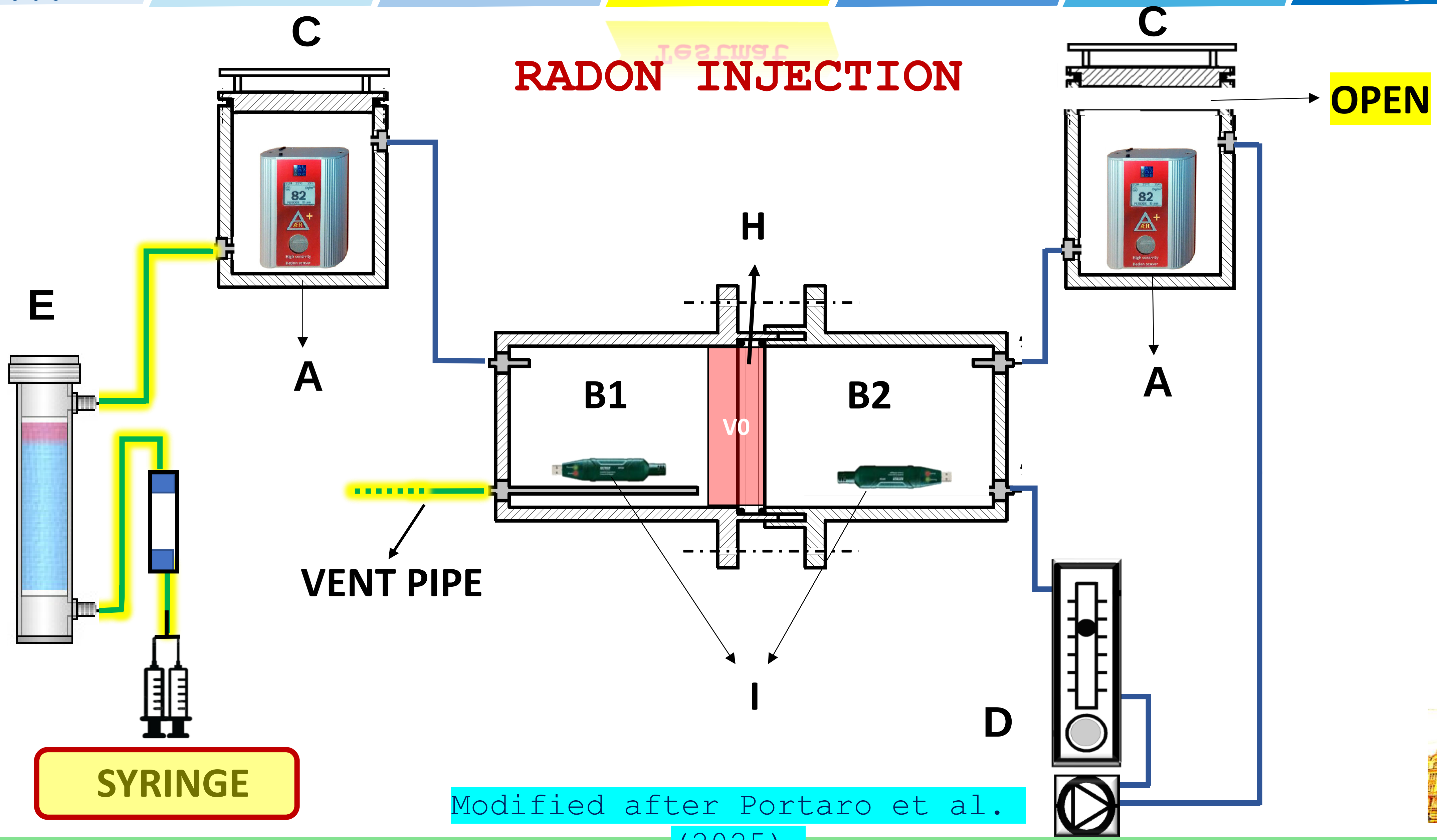
where:

d = tickness of



Modified after Portaro et al. (2025)

RADON INJECTION



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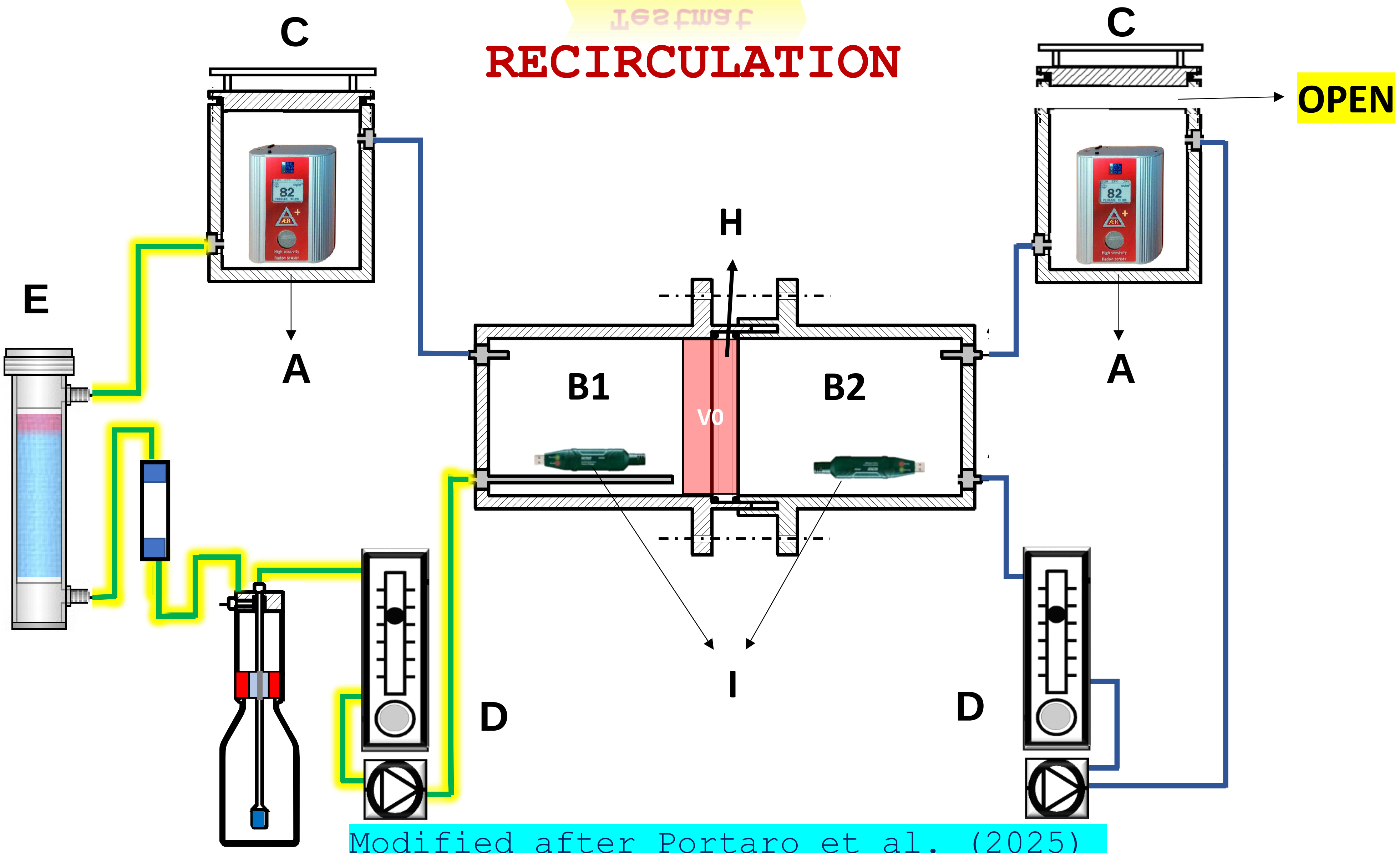
RECIRCULATION



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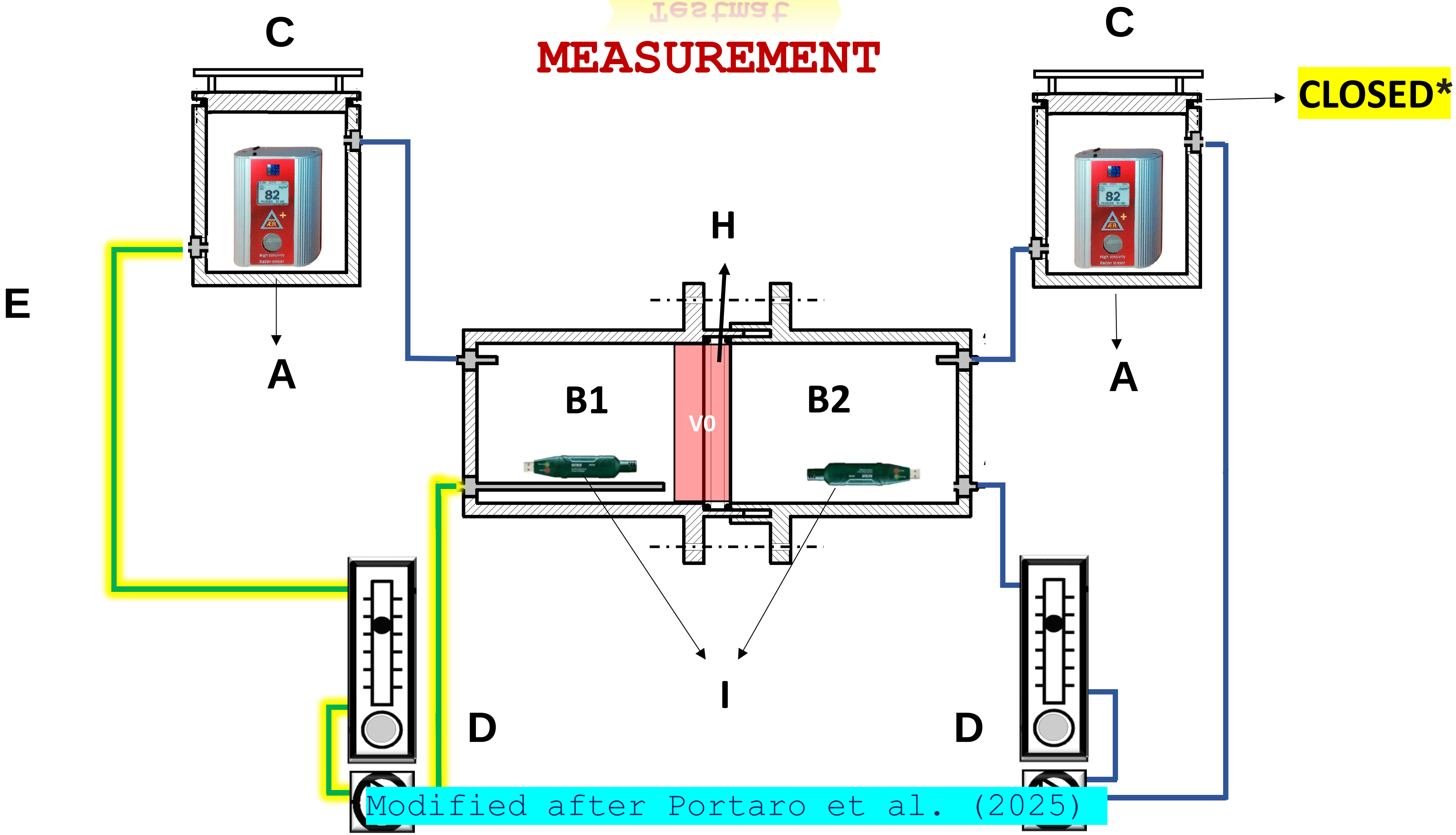
MEASUREMENT



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Esperiments

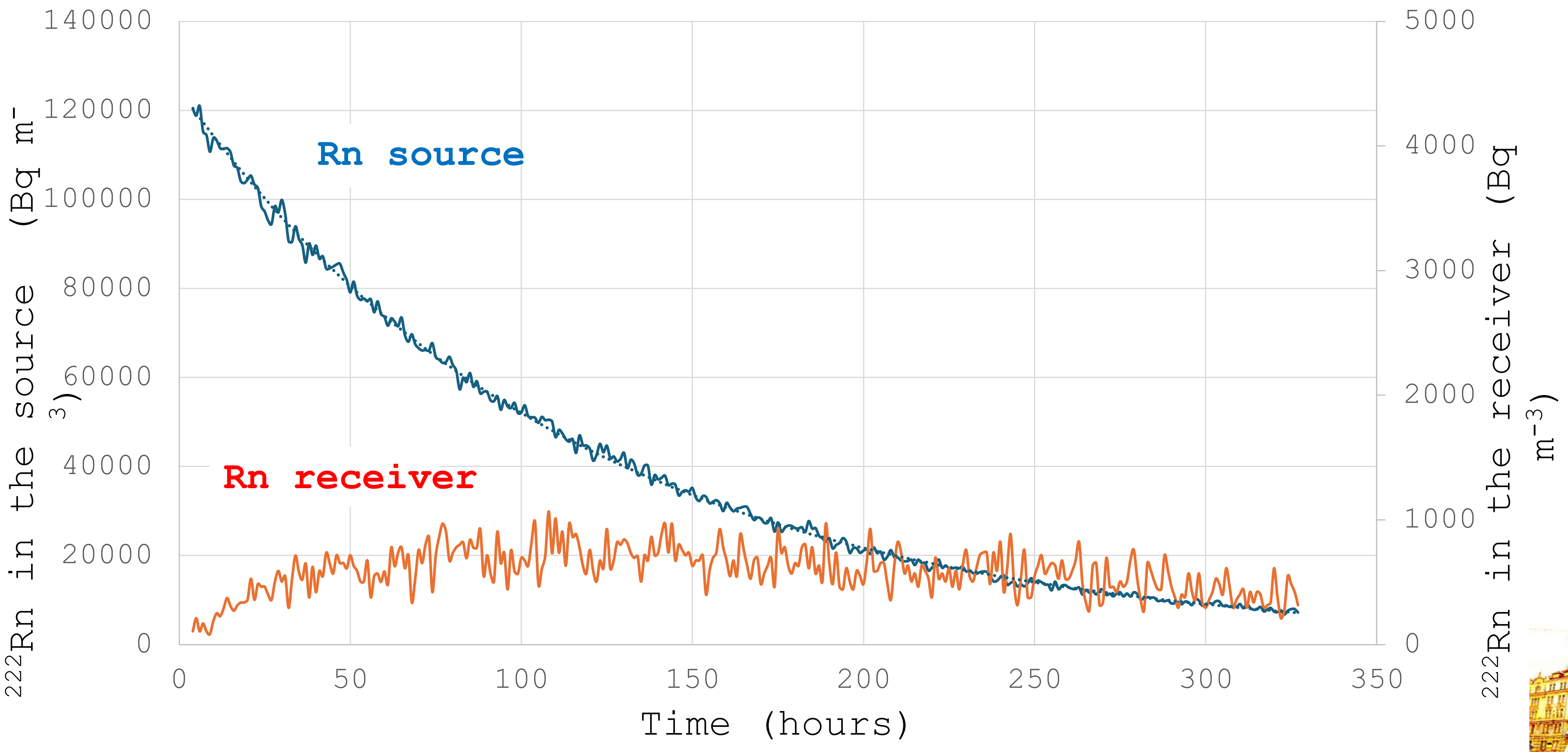
- The samples are circle-shaped with a diameter of 7 cm
- The samples thickness is measured with an analog caliper and the final value is the average of at least four determinations, according to the ISO standard (4 points per 0.05 m^2).
- Each test spans around two weeks

Configurations

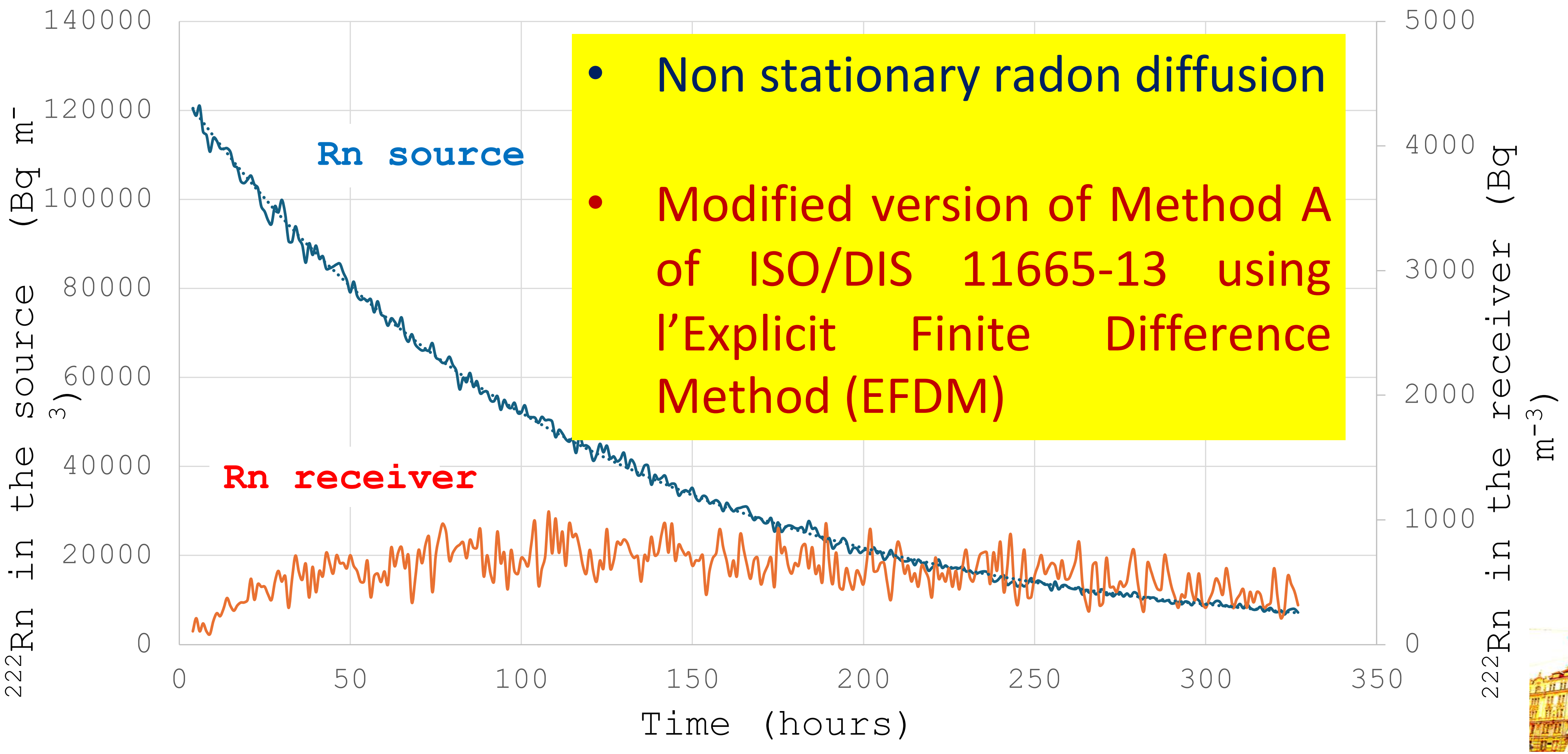
Configuration	Volume of the left circuit (L)	Volume of the right circuit (L)
1	2.951	2.840
2	2.951	1.394
3	1.499	1.394

with a progressive reduction in volumes and thus a gradual increase in radon concentration and minimum detectable value of D

Radon concentration in the source and receiver cha



Radon concentration in the source and receiver cha



- Non stationary radon diffusion
- Modified version of Method A of ISO/DIS 11665-13 using l'Explicit Finite Difference Method (EFDM)

Radon diffusion in a medium in which it is not produced

is described by the following differential equation:

$$\frac{\partial C(x,t)}{\partial t} = D\,\frac{\partial^2 C(x,t)}{\partial x^2} - \lambda C(x,t)$$

where C (x, t) is the radon concentration in the pore space of the medium (Bq m^{-3}) that depends on location x and time t

D is the radon diffusion coefficient ($m^2\ s^{-1}$)

λ is the radon decay constant (s^{-1}).

The solution of the diffusion equation through the membrane is provided using the explicit finite difference (EFDM) method:

$$C_j^D = C_{j-1}^D e^{-\Delta t/\tau} + D\,S\left(\frac{C_{d-\Delta x,j} - C_{d,j}}{\Delta x}\right)\Delta t \,/\, V^D$$

$$C_0^D = D\,S\left(\frac{C_{d-\Delta x,0} - C_{d,0}}{\Delta x}\right)\Delta t \,/\, V^D$$

C^D = radon concentration in the receiver chamber;

i and j = the discrete positions and times determined by step lengths Dx and Dt;

S = surface of the sample;

V^D= volume of the receiver chamber;

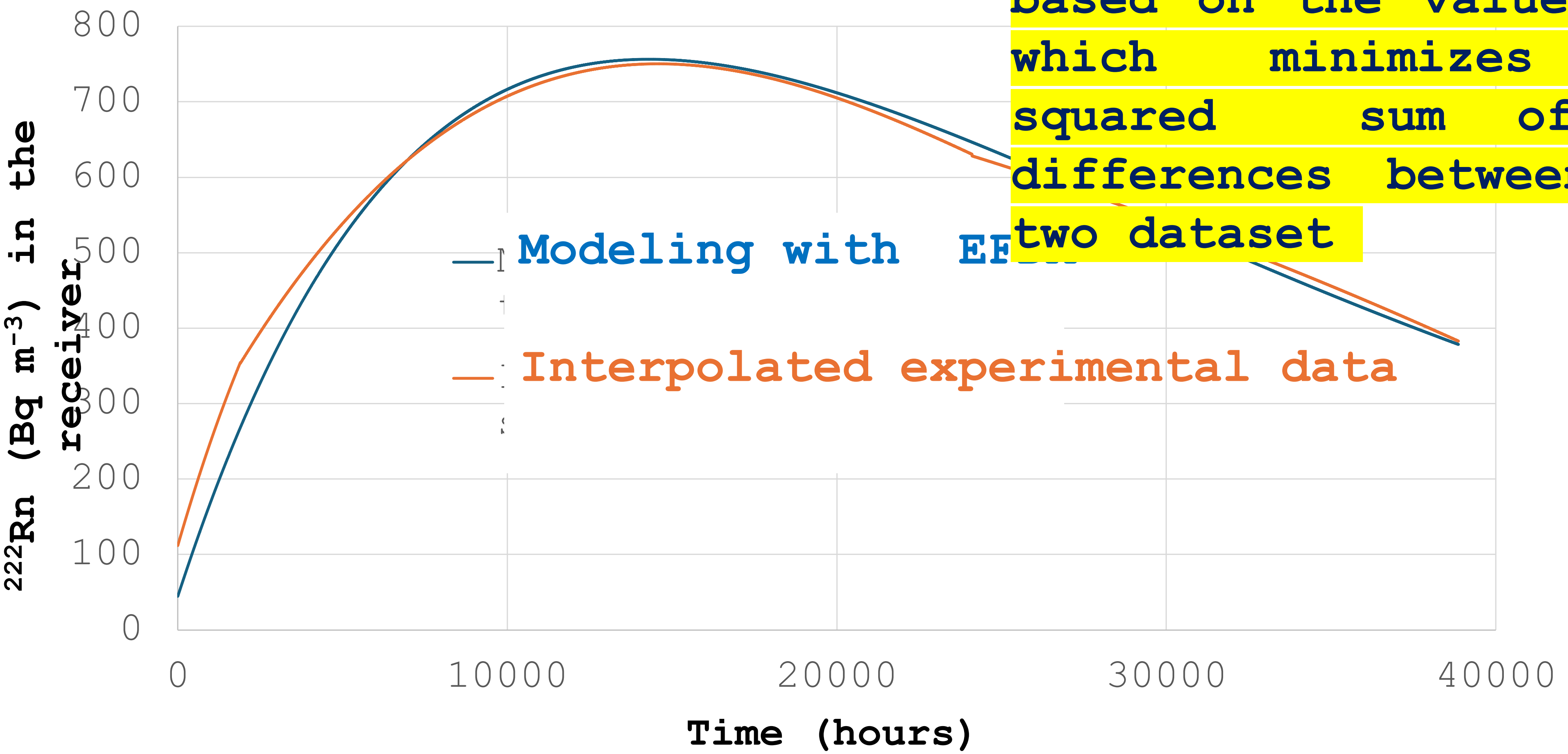
D = radon diffusion coefficient

τ = radon average life

Gradient of radon concentration in the membrane at time j and zero.

CHECKING THE MODELING THROUGH CURVE OVERLAYING

Iterative procedure based on the value of D which minimizes the squared sum of the differences between the two dataset



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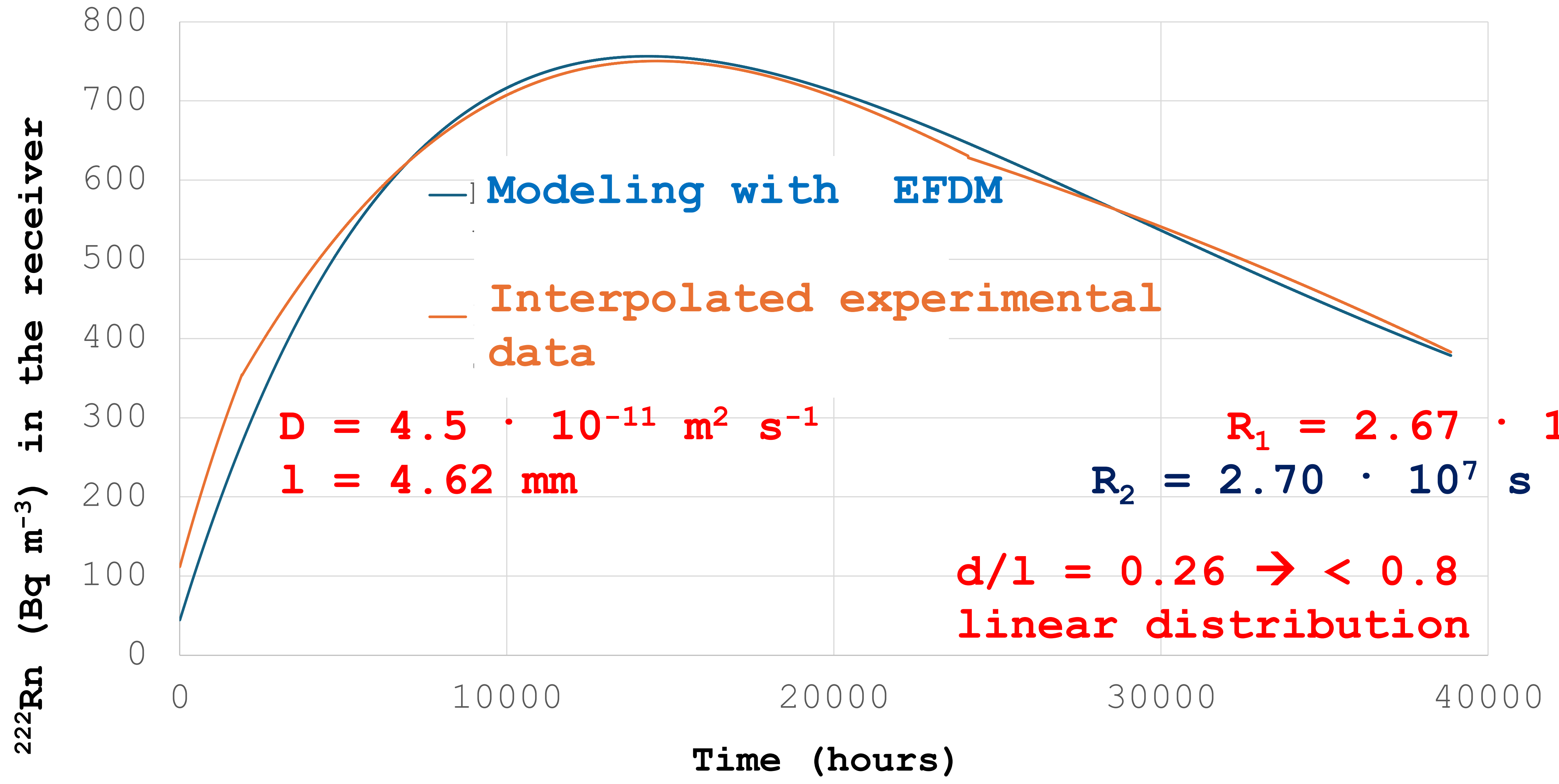
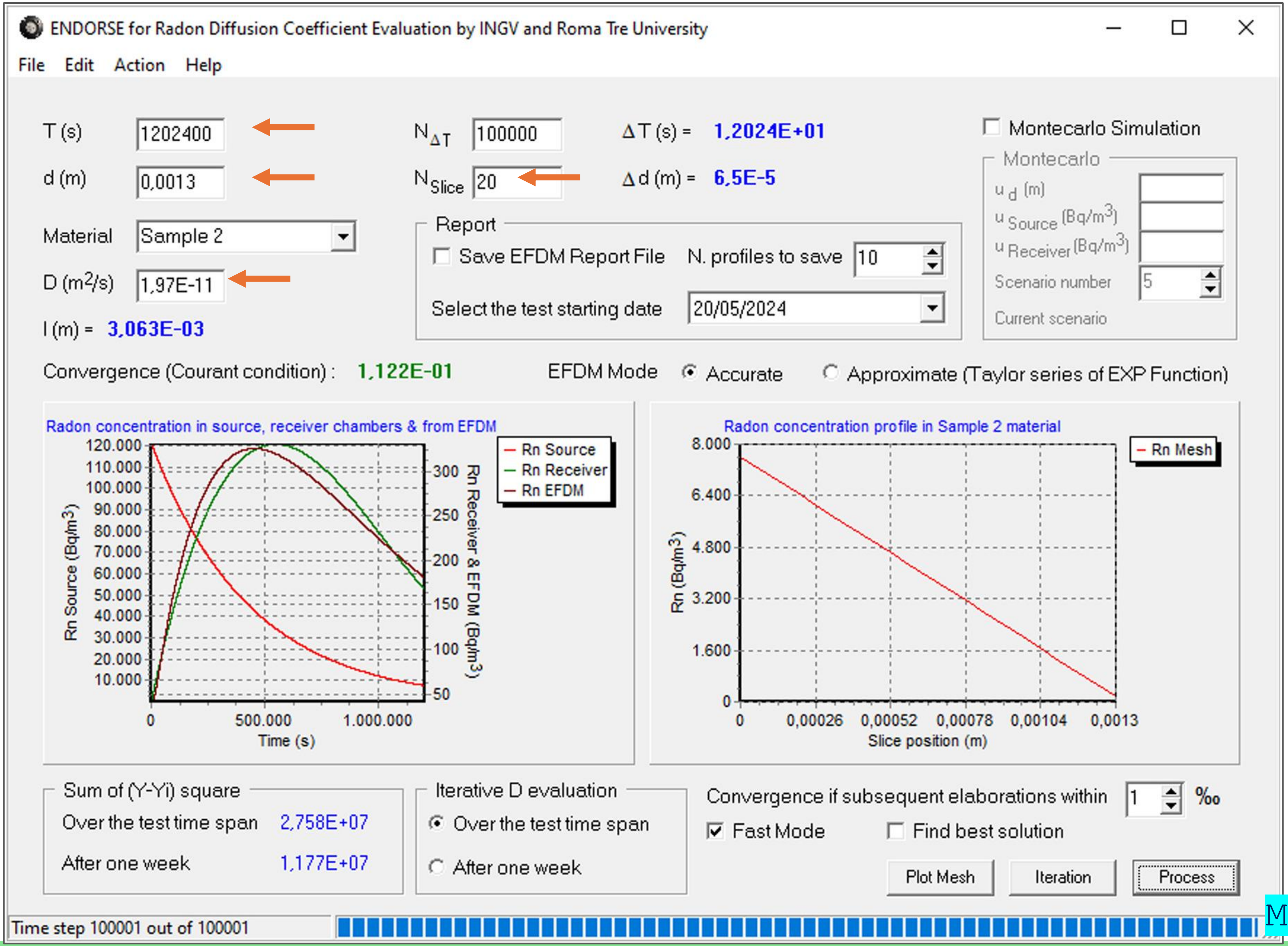




SOFTWARE FOR RADON DIFFUSION COEFFICIENT

ENDORSE

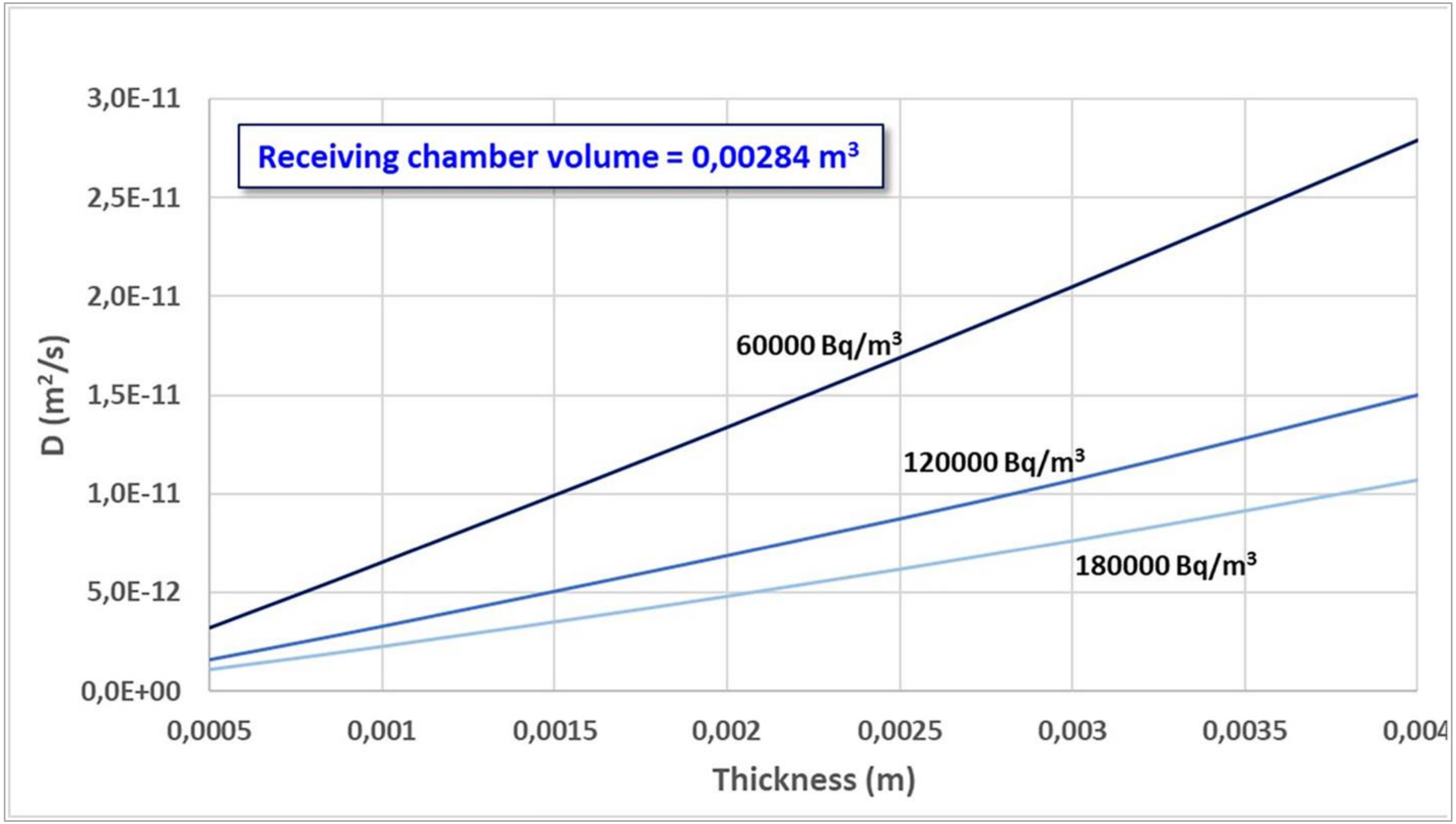
MONTE CARLO SIMULATION IS APPLIED TO EVALUATE ERRORS BASED ON A SINGLE TEST

Modified after Portaro et al (2025)

Preliminary tests to calculate:

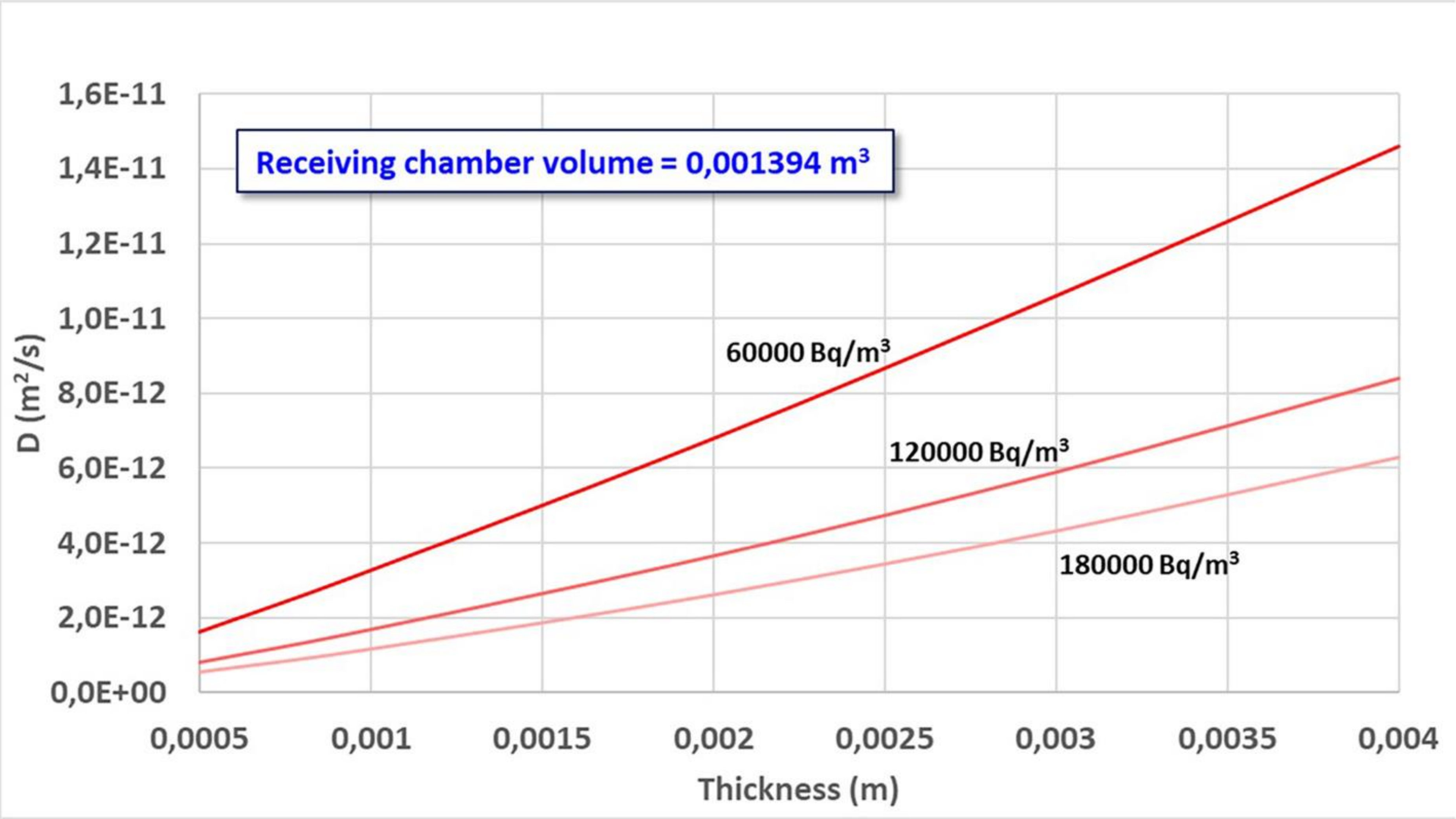
1. Leakage rate: 1.42 $\cdot 10^{-7}$ s^{-1}, only 7 % of radon decay constant
2. Environmental background: 44 Bq m^{-3}, stable during the test
3. Choice of the best sample holder to avoid radon transfer into the receiver chamber
4. Minimum radon diffusion coefficients for experimental configurations

Minimum radon diffusion coefficient measurable with co



At radon source intensities of 60,000, 120,000 and 180,000 Bq m^{-3}.

Minimum radon diffusion coefficient measurable with co



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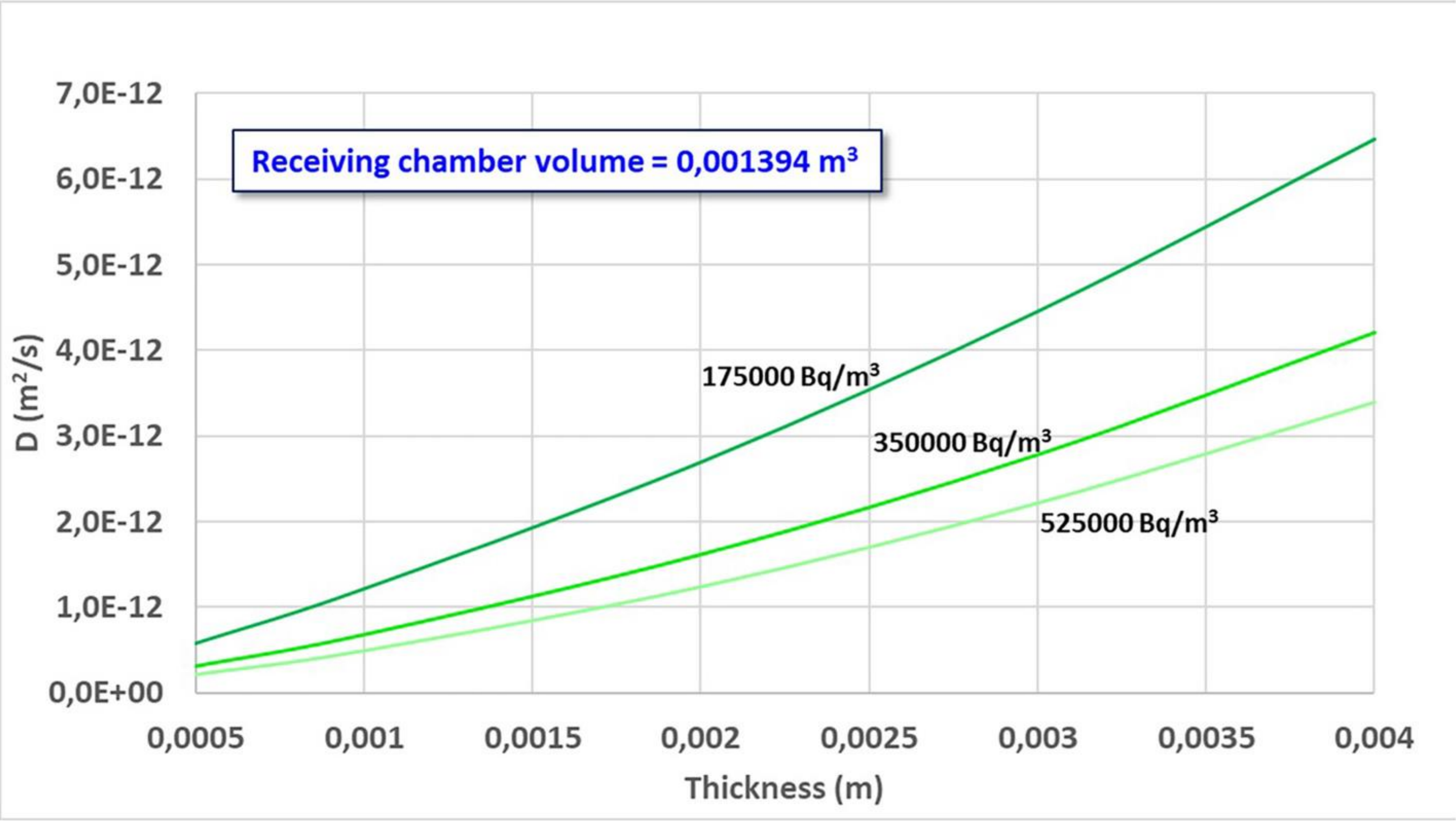


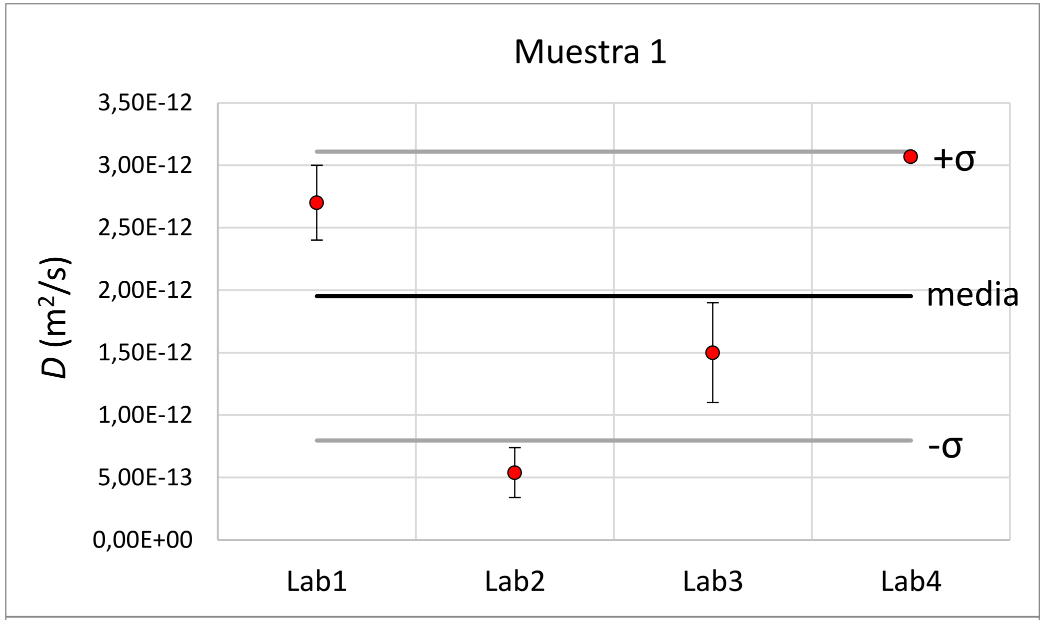
At radon source intensities of 178,000, 350,000 and 525,000 Bq m^{-3}.

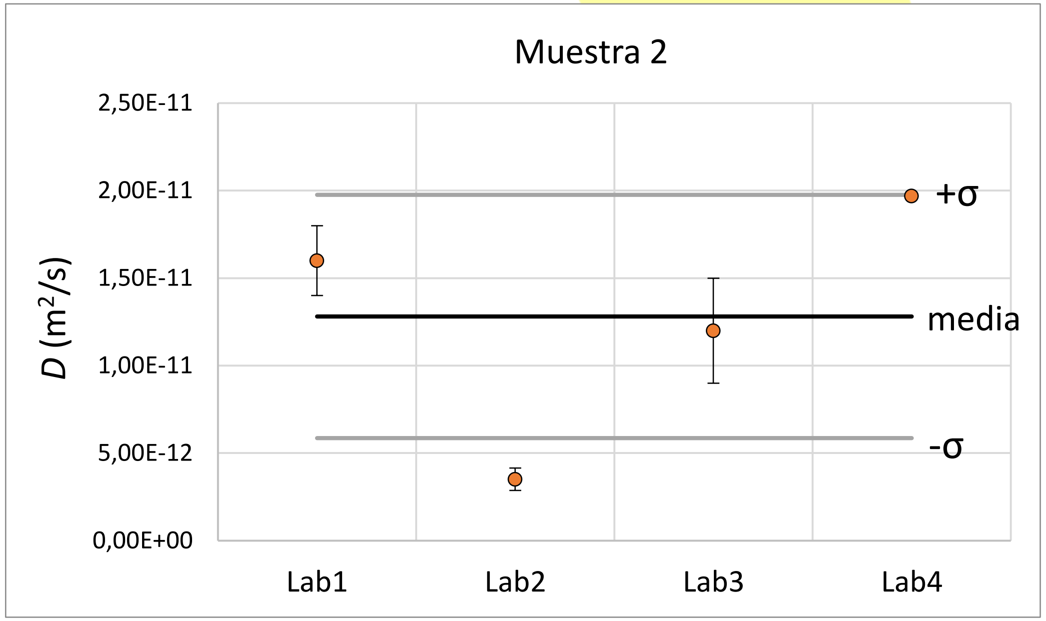
Intercomparison of radon diffusion coefficients of the three membranes

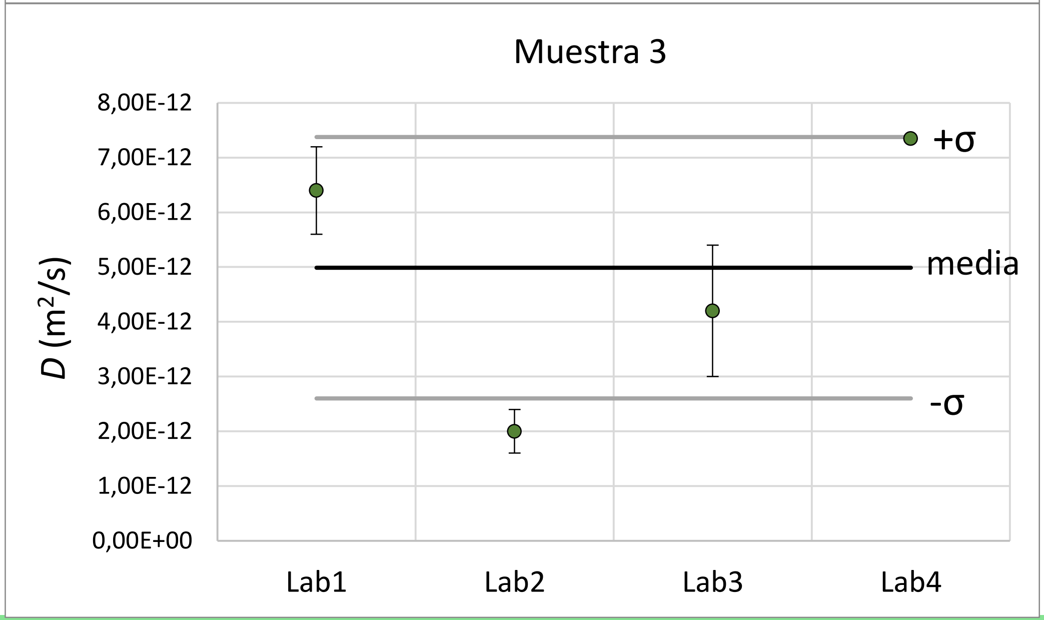
- **Sample 1:** a synthetic high-density polyethylene (HDPE) sheet with an adhesive side covered with a pressure-sensitive protective coating
- **Sample 2:** a polyolefin (FPO) membrane, laminated with non-woven polypropylene fabric
- **Sample 3:** a sheet of HDPE tightly coupled to a layer of non-woven fabric

Rabago et al., 2024

Rabago et al., 2024	CHECK REPUBLIC	POLAND	SPAIN	ITALY
Volume of the source chamber (m3)	0,005 - 0,015	0,011	0,0244	0,00292
Volume of the receiver chamber (m3)	0,0027	0,006	0,0244	0,00281
Surface of the material to test (m2)	0,029	0,048	0,048	0,003
Surface / Volume (m^{-1})	10,9	8,1	2,0	1,0
Material the chambers are made	stainless steel	steel	Inox Steel	PVC
Equilibrium/highest *activity* in the source chamber (MBq/m^3)	3 - 4.3	1,4 - 1,5	1	0,1
Equilibrium/highest activity in the receiver		1,6 -		







- General good agreement within results
- Discrepancies could be due to:
  - Calculation methods
  - Experimental set-ups

Rabago et al., 2024

Final remarks

- A new methodology to determine radon diffusion coefficient (D) of anti-radon membrane, based on ISO/TS 11665-13 (2017) technical specification was developed.

- The PolyVinyl Chloride (PVC), the material the TESTMAT is made of, proved to guarantee a good gas tightness (about 7 % of the radon decay constant).

- We demonstrated that a weak, not-stationary radon source (with radon activity concentration in the order of 50–500 kBq m^{-3}) can be successfully used

Final remarks

- Through the use of the ENDORSE software, we also showed the Explicit Finite Difference Method (EFDM) can be applied to solve the diffusion equation describing the flow of radon through regularly shaped materials.

- The Montecarlo method, also implemented in ENDORSE, confirmed to be the best resource to calculate the uncertainty of D (considering all the sources of uncertainties, such as radon concentration in the two chambers, the membrane thickness and the leakage rate of the TESTMAT) based on a single test.


THANK
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