The presence of radon in indoor air

Hans Vanmarcke

Refresher course 12, European IRPA congress, The Hague, 4 June 2018

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Average exposure to ionizing radiation

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- The natural decay series
- Measurement techniques
- The fate of a radon atom in soil and building materials
- Measurement results
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  - Contribution of the soil to indoor radon
  - Radon concentrations in dwellings

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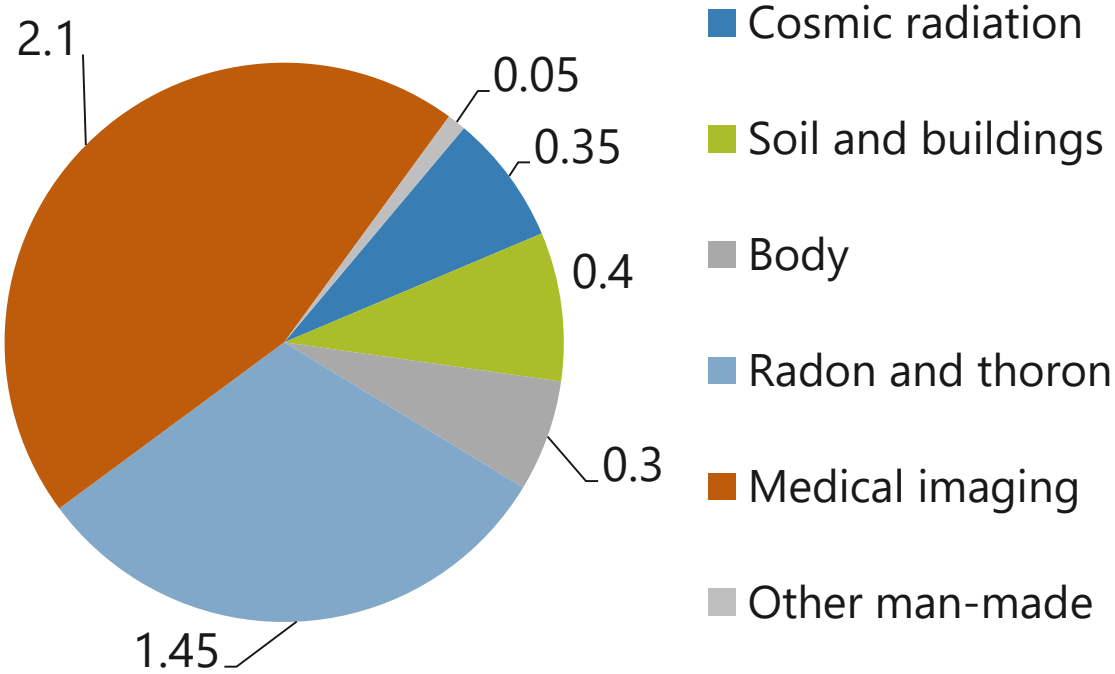
Annual average dose from natural and man-made sources

Calculated with the UNSCEAR methodology

Belgium 2006

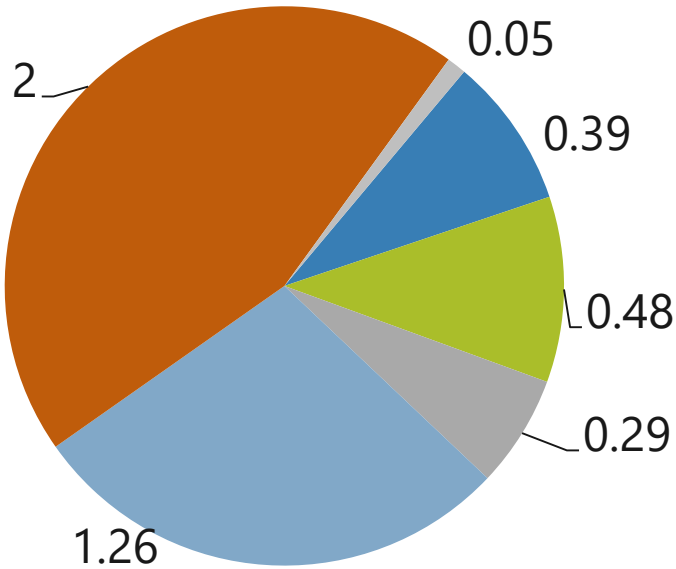
Total = 4.6 mSv/y



UNSCEAR 2008

Good health care system

Total = 4.4 mSv/y



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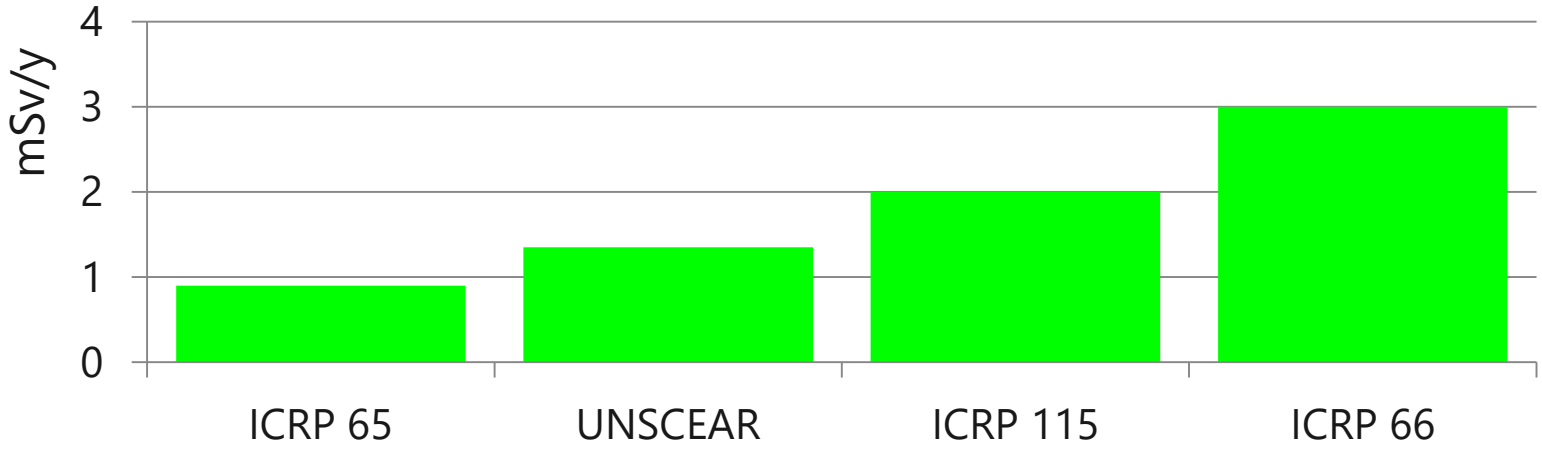
Radiation dose from radon in dwellings (50 Bq/m^3)

Only difference is the dose coefficient for radon

- *ICRP 65* (epidemiological approach): **0.9 mSv/y**
- *UNSCEAR*: **1.35 mSv/y**
- *ICRP 115* (epidemiological approach): **2 mSv/y** *(*)*
- *ICRP 66* (dosimetric approach): **3 mSv/y** *(*)*



(*) Dose coefficients from the presentation of John Harrison (IRPA Geneva, 2014)

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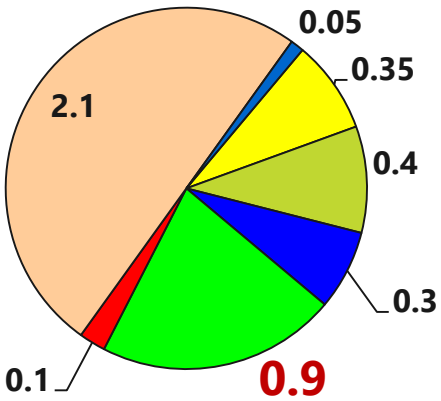
Average radiation dose in Belgium

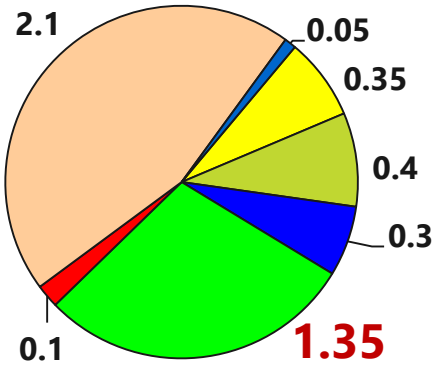
Only difference is the dose coefficient for radon

ICRP 65: 4.2 mSv/y

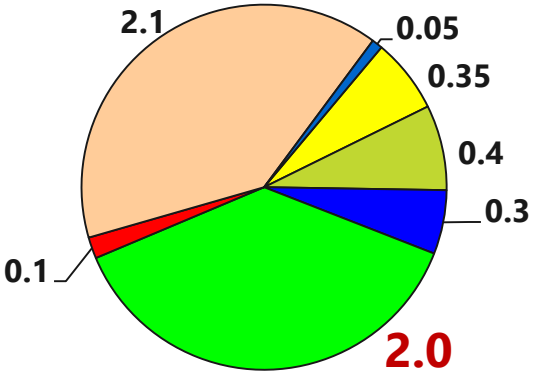


- Cosmic radiation
- Soil and buildings
- Body
- Radon
- Thoron
- Medical imaging
- Other man-made

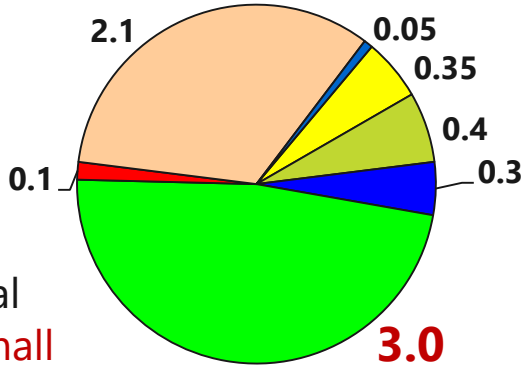
UNSCEAR: 4.6 mSv/y



ICRP 115: 5.3 mSv/y



ICRP 66: 6.3 mSv/y



All other contributions, including medical imaging, look small

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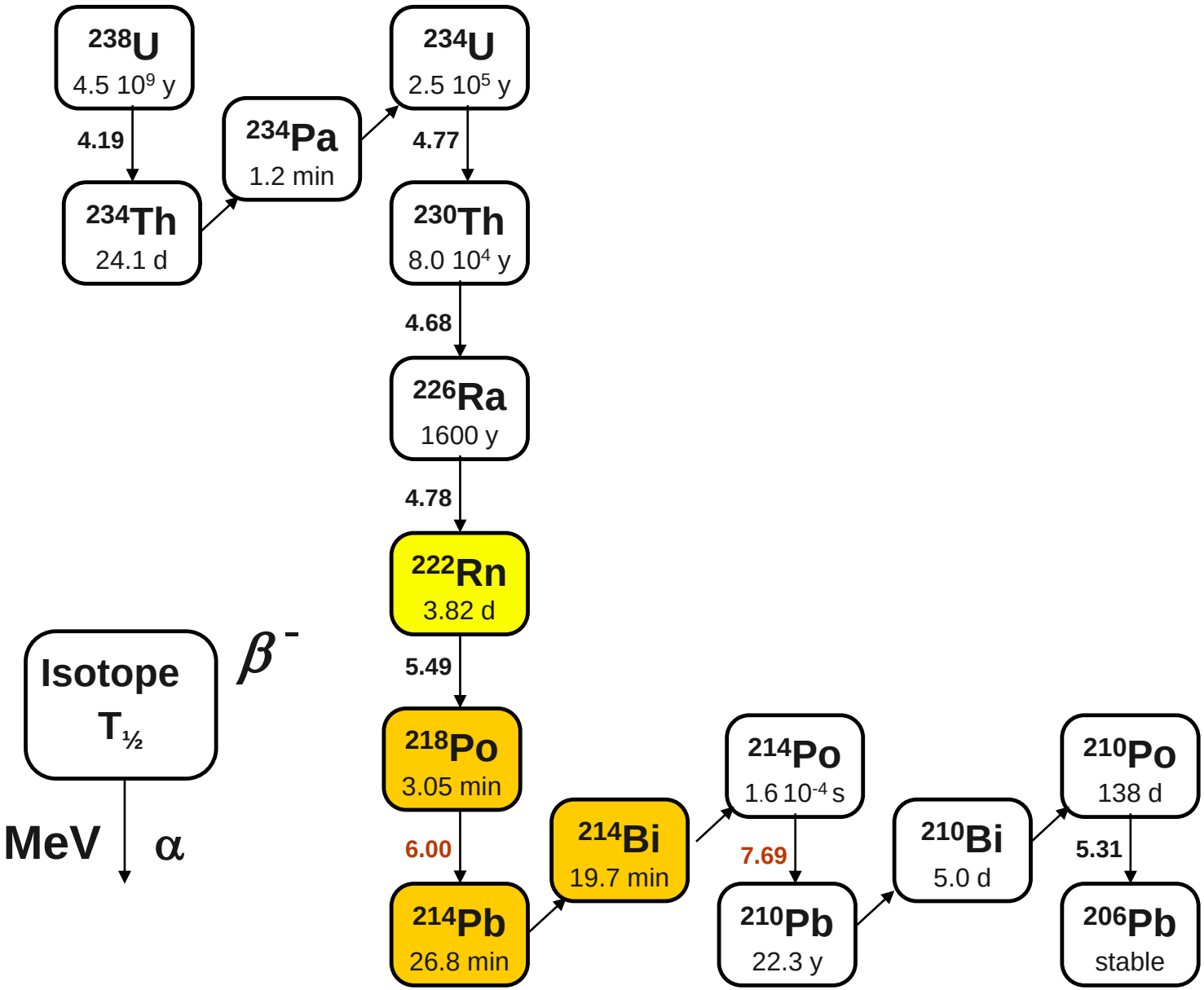

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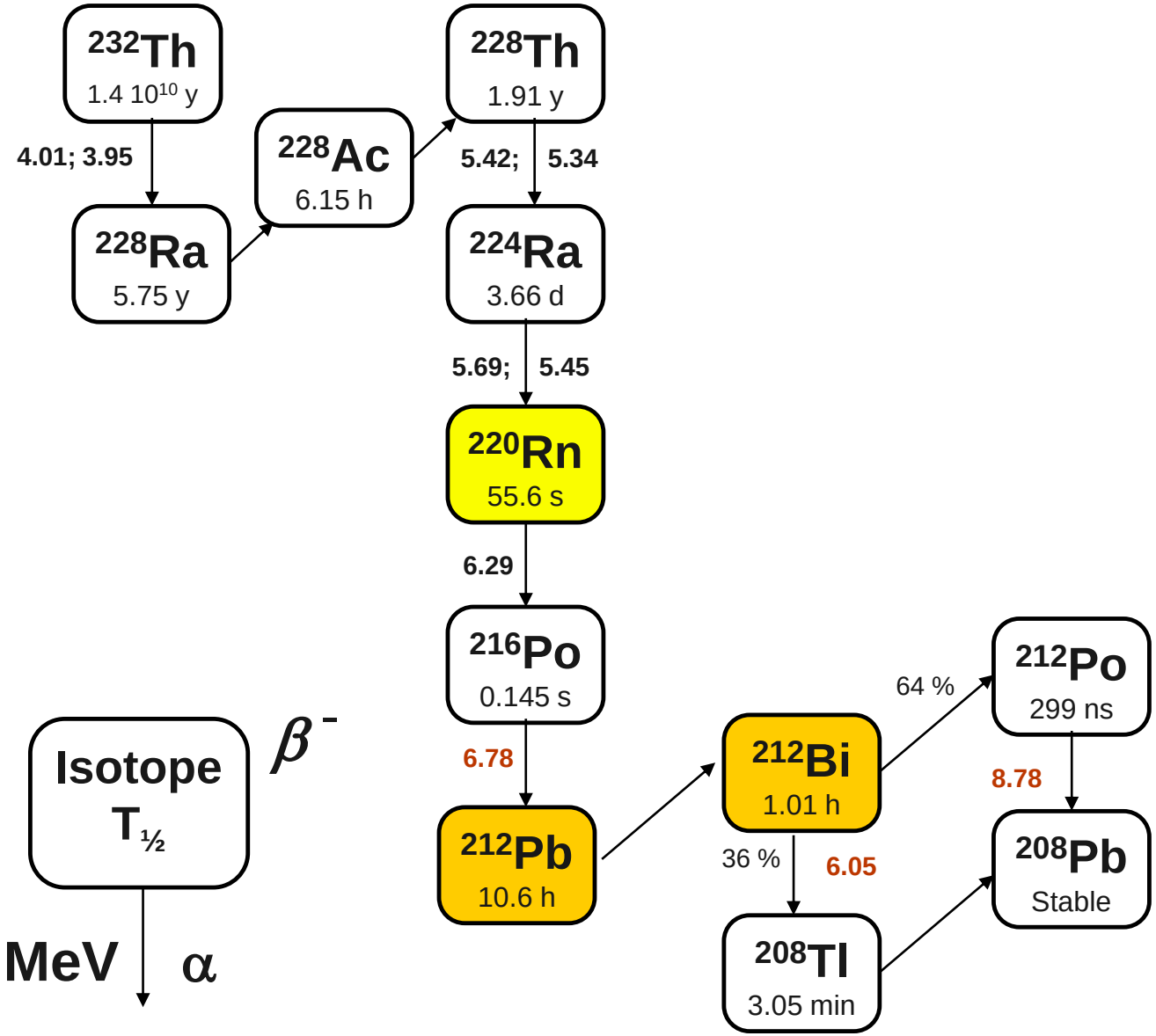

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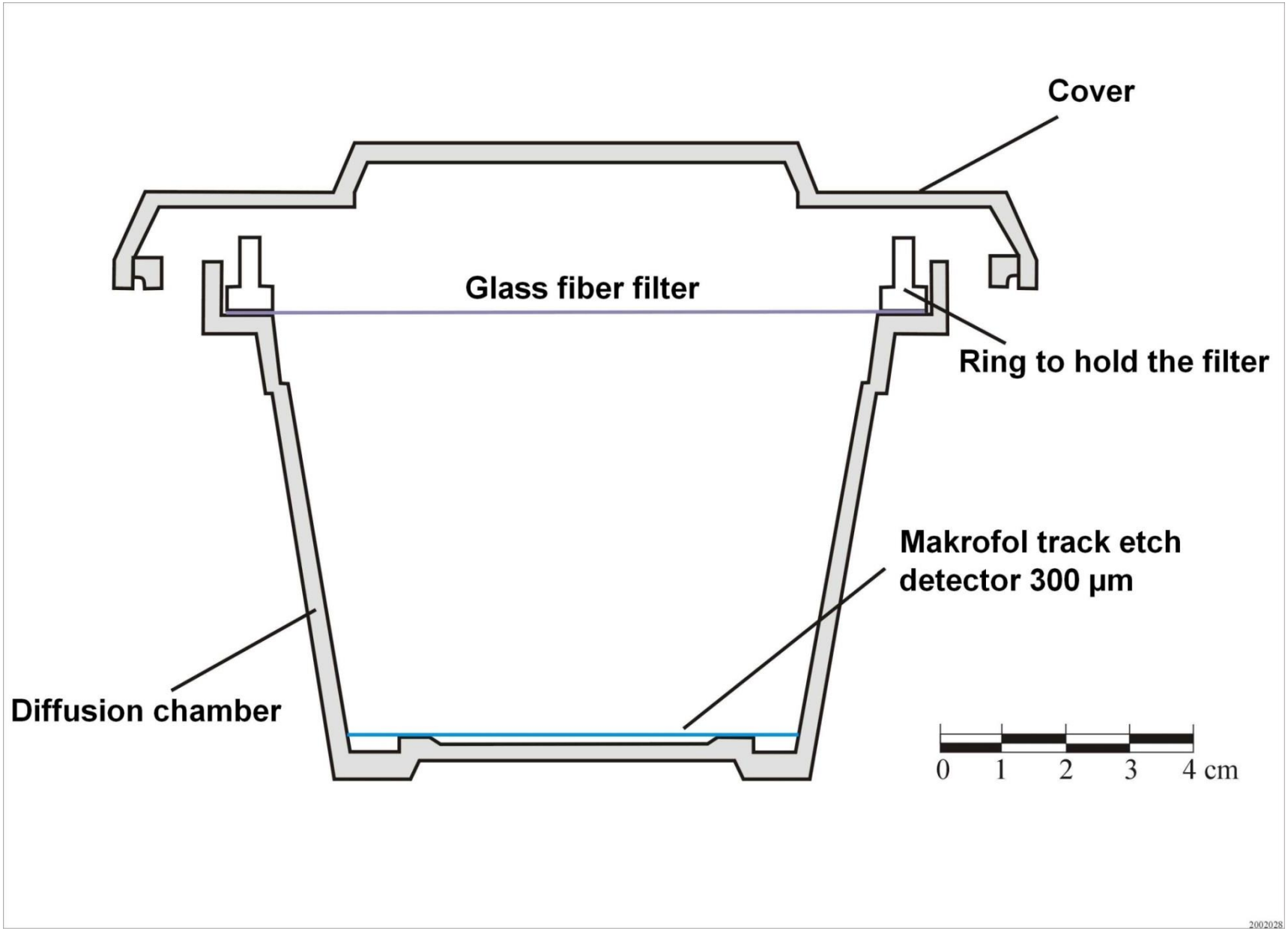

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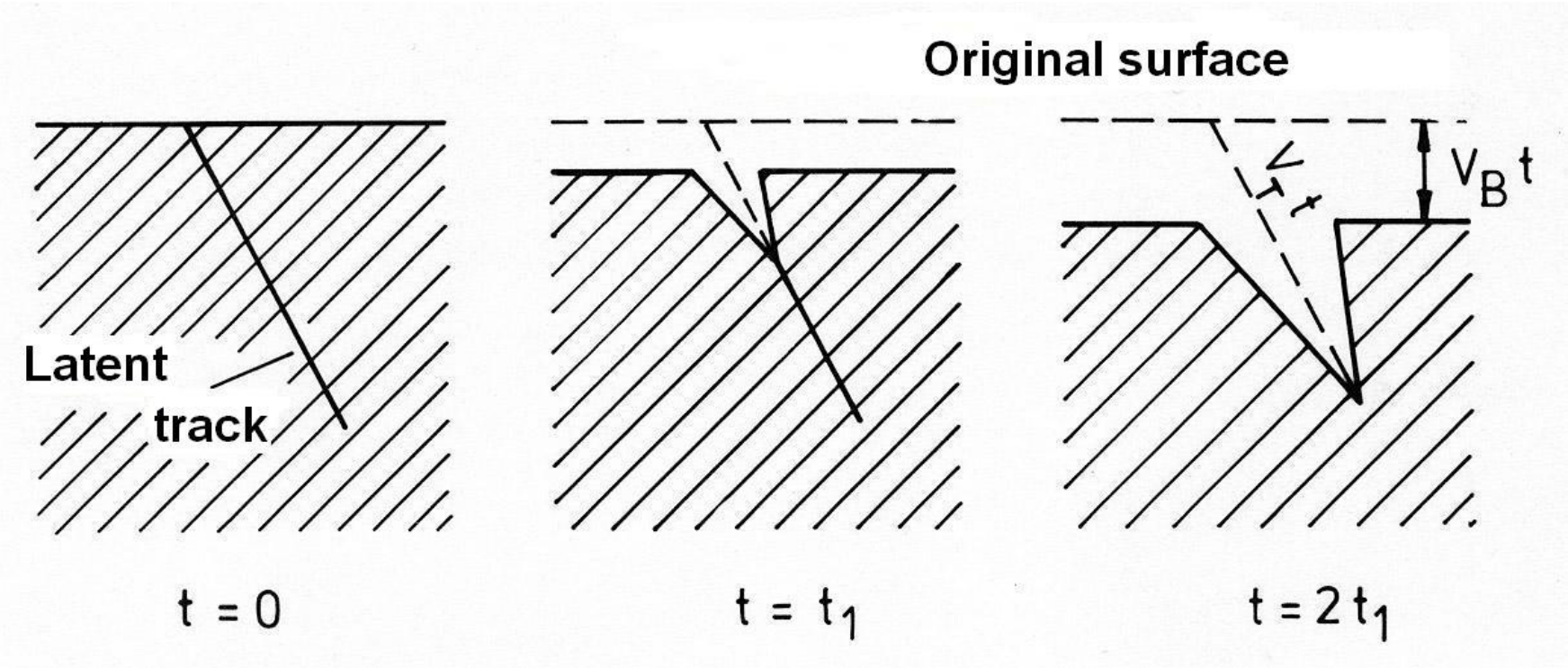

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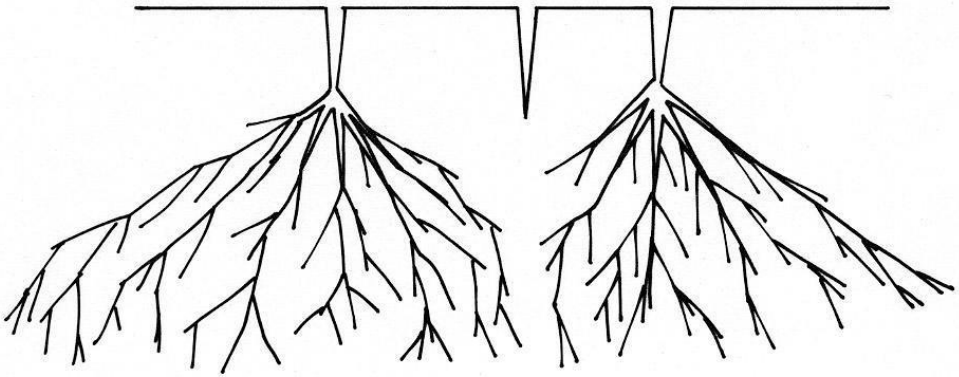
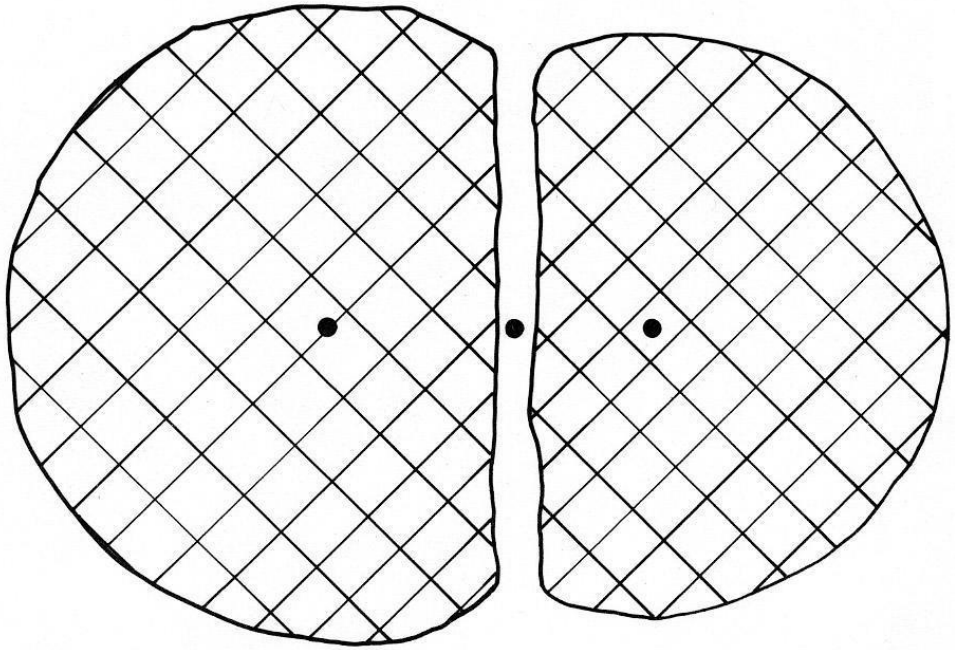


Vertical section



Horizontal section

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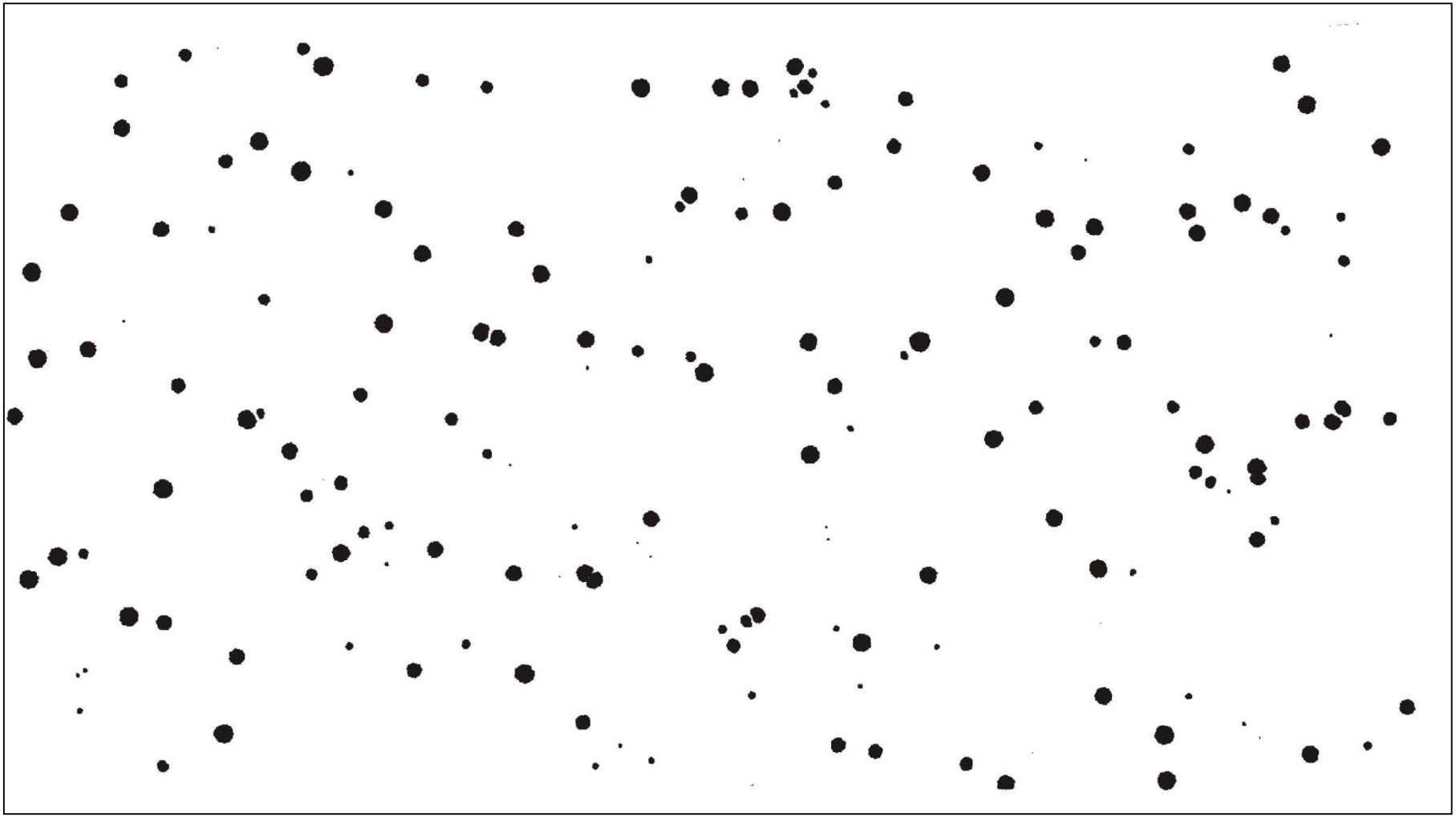

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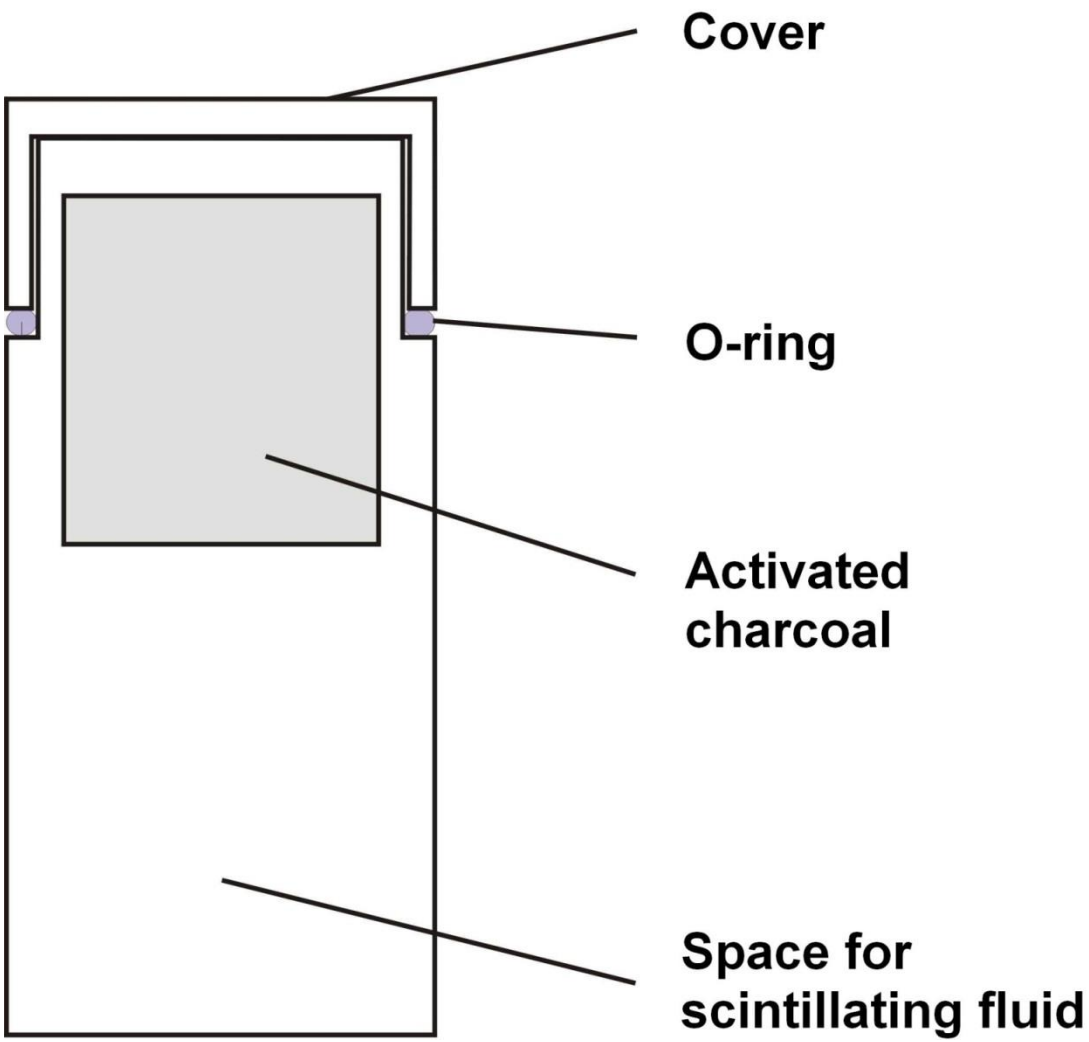

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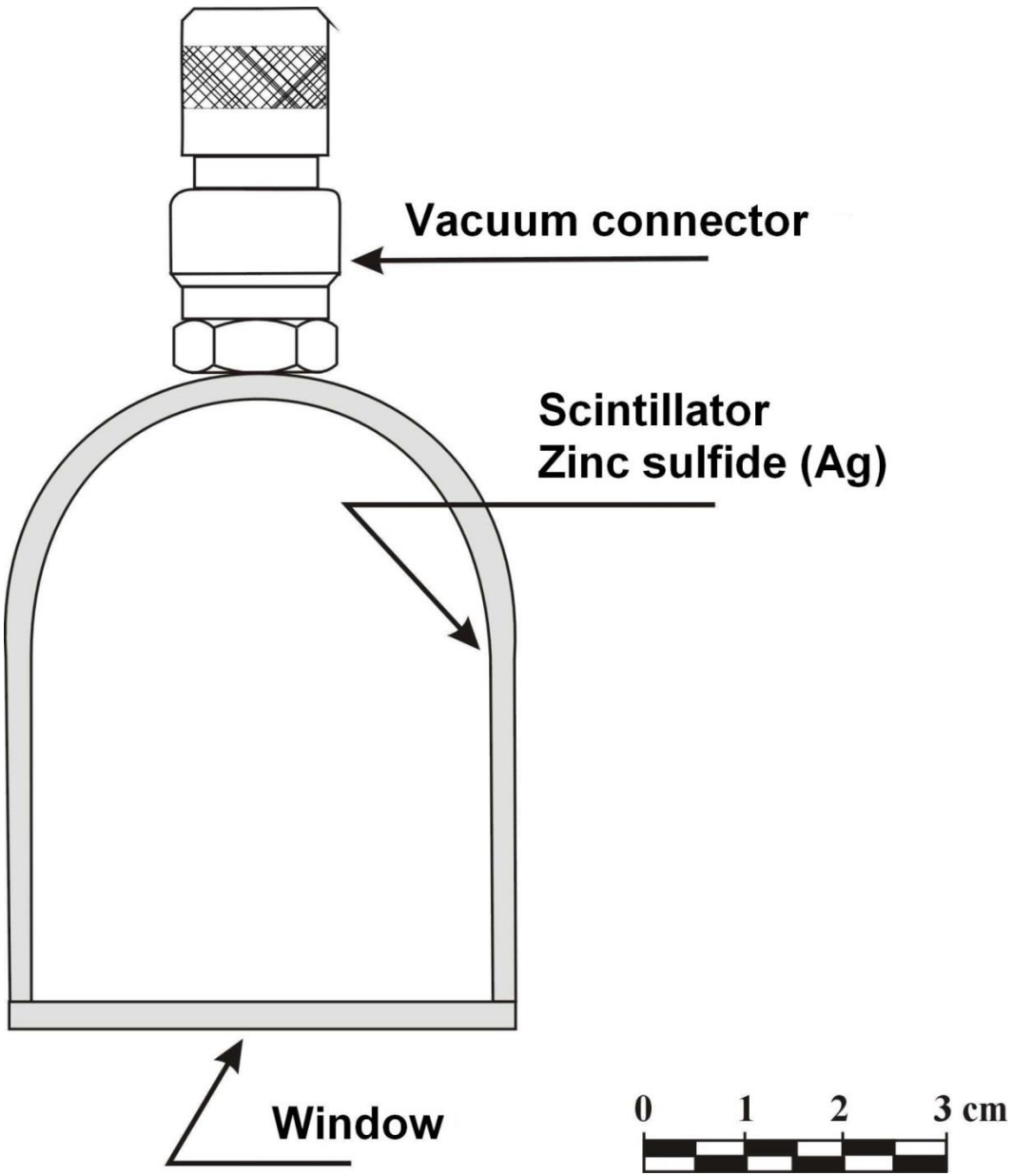

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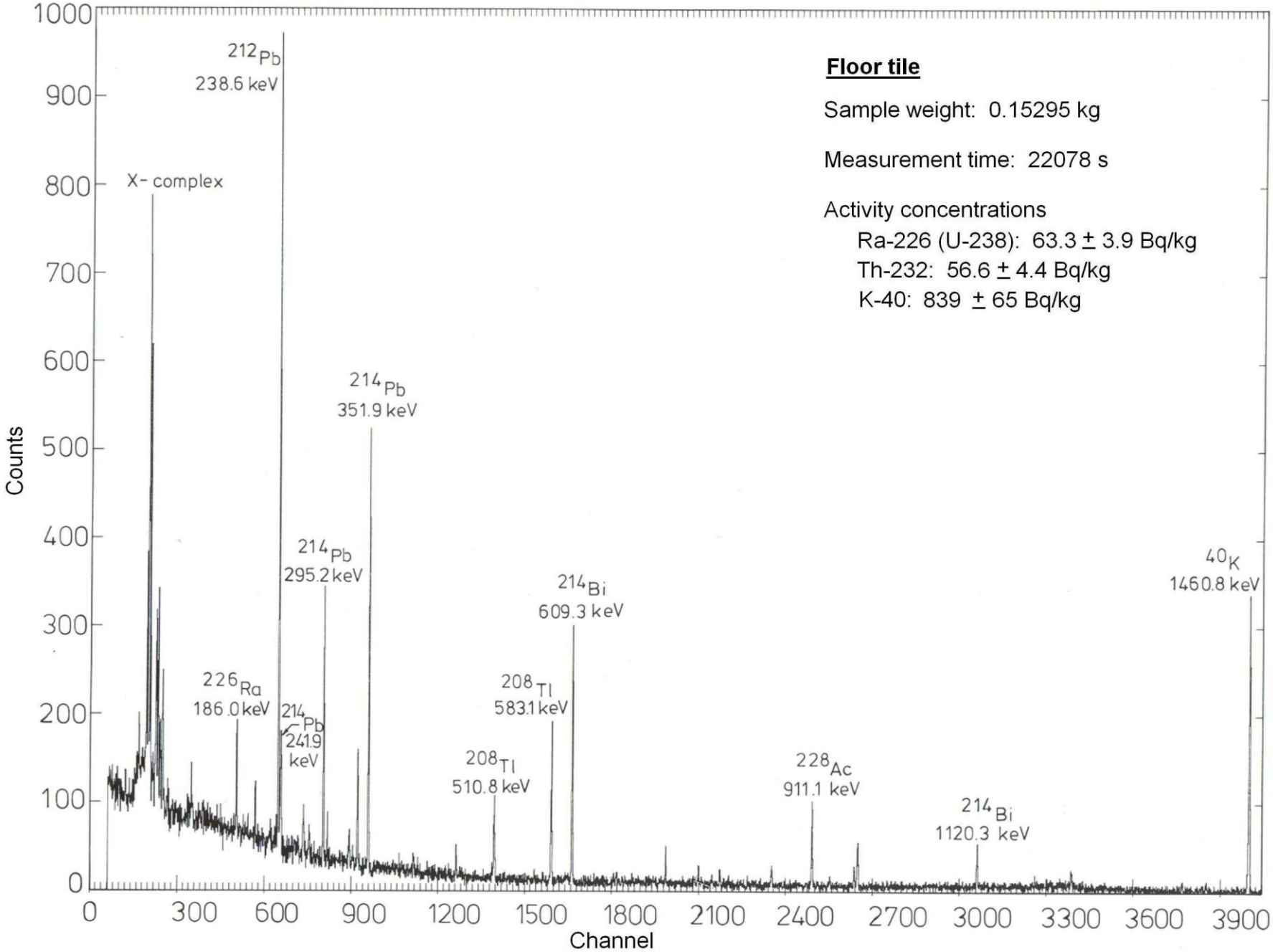

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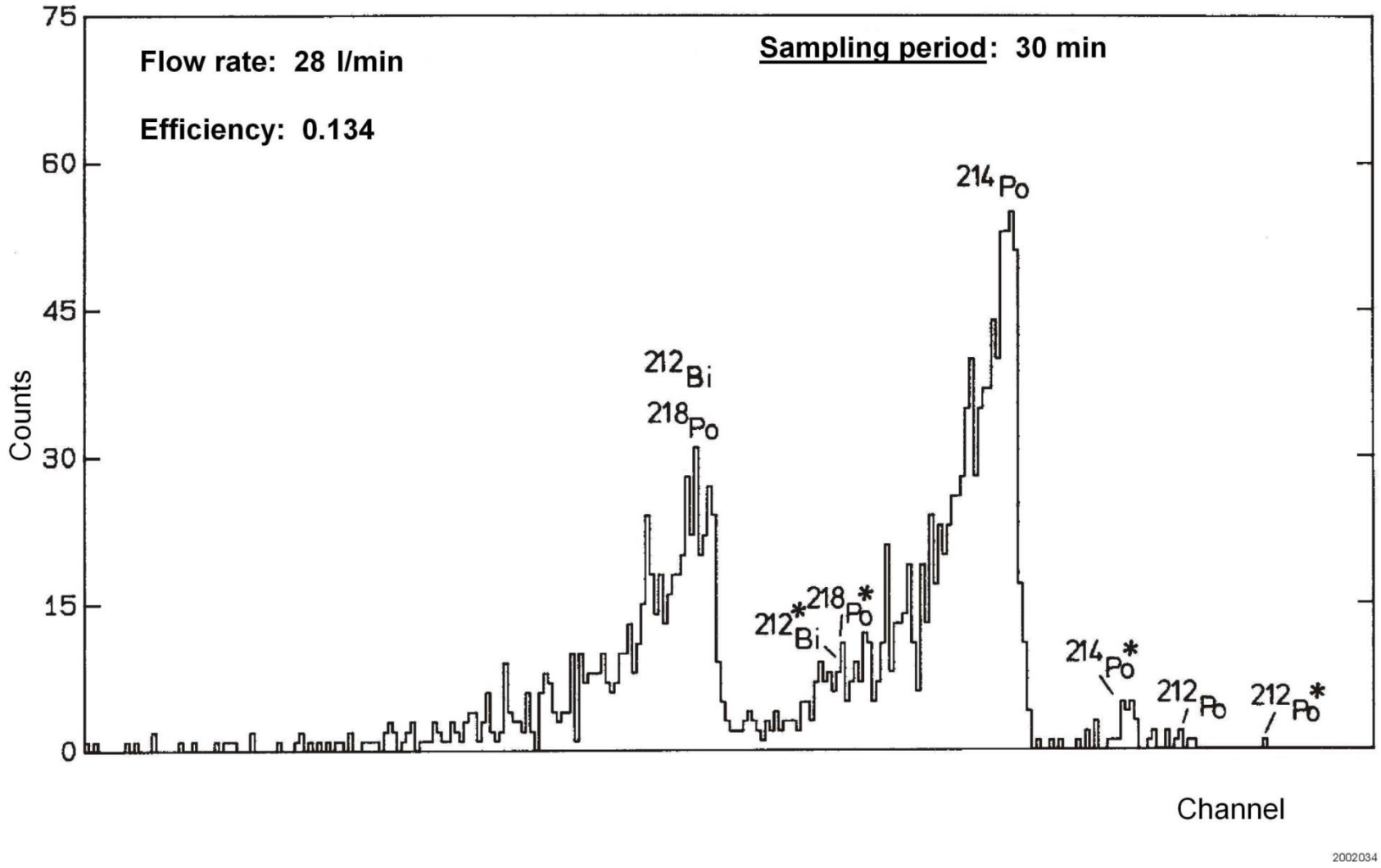

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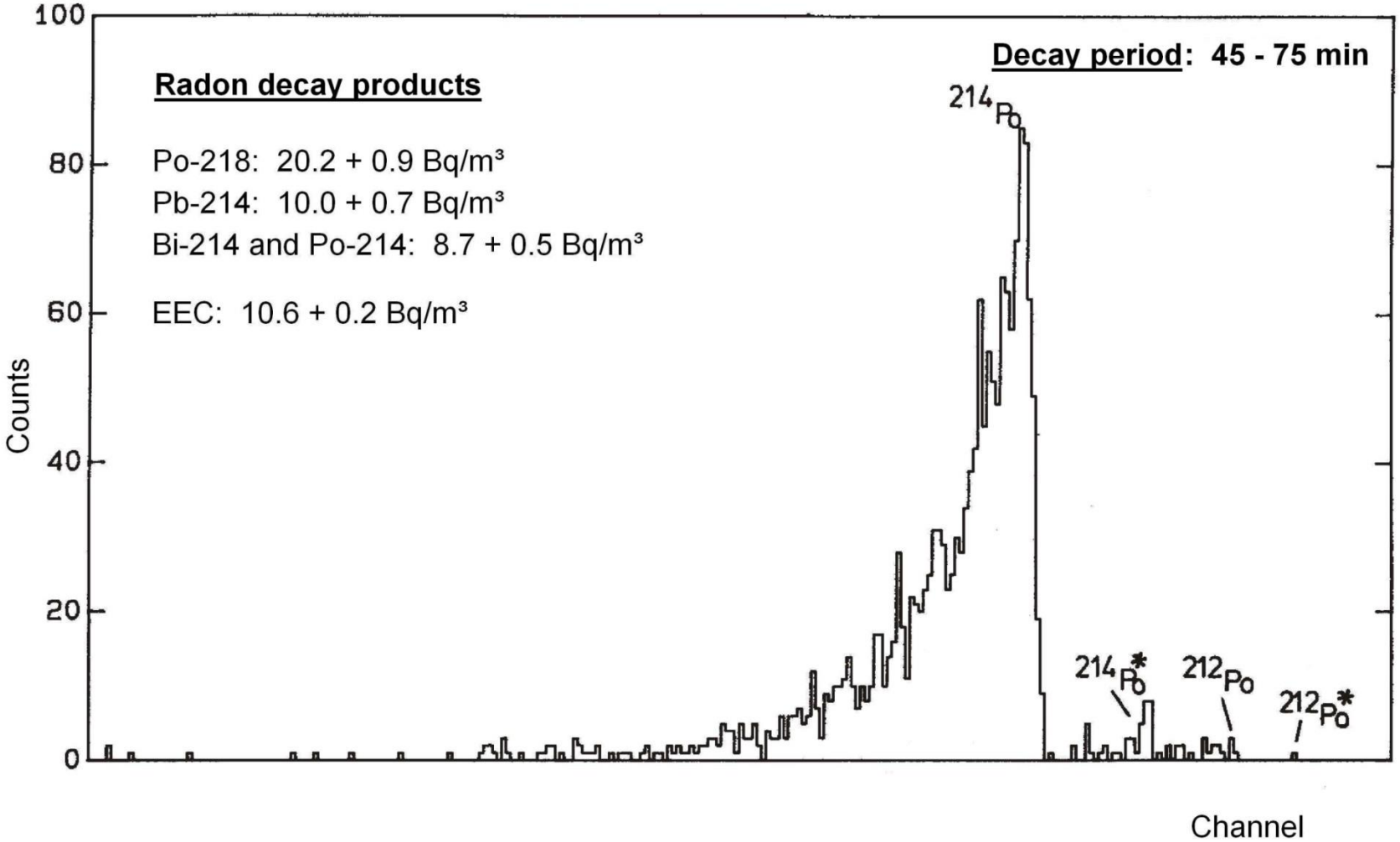

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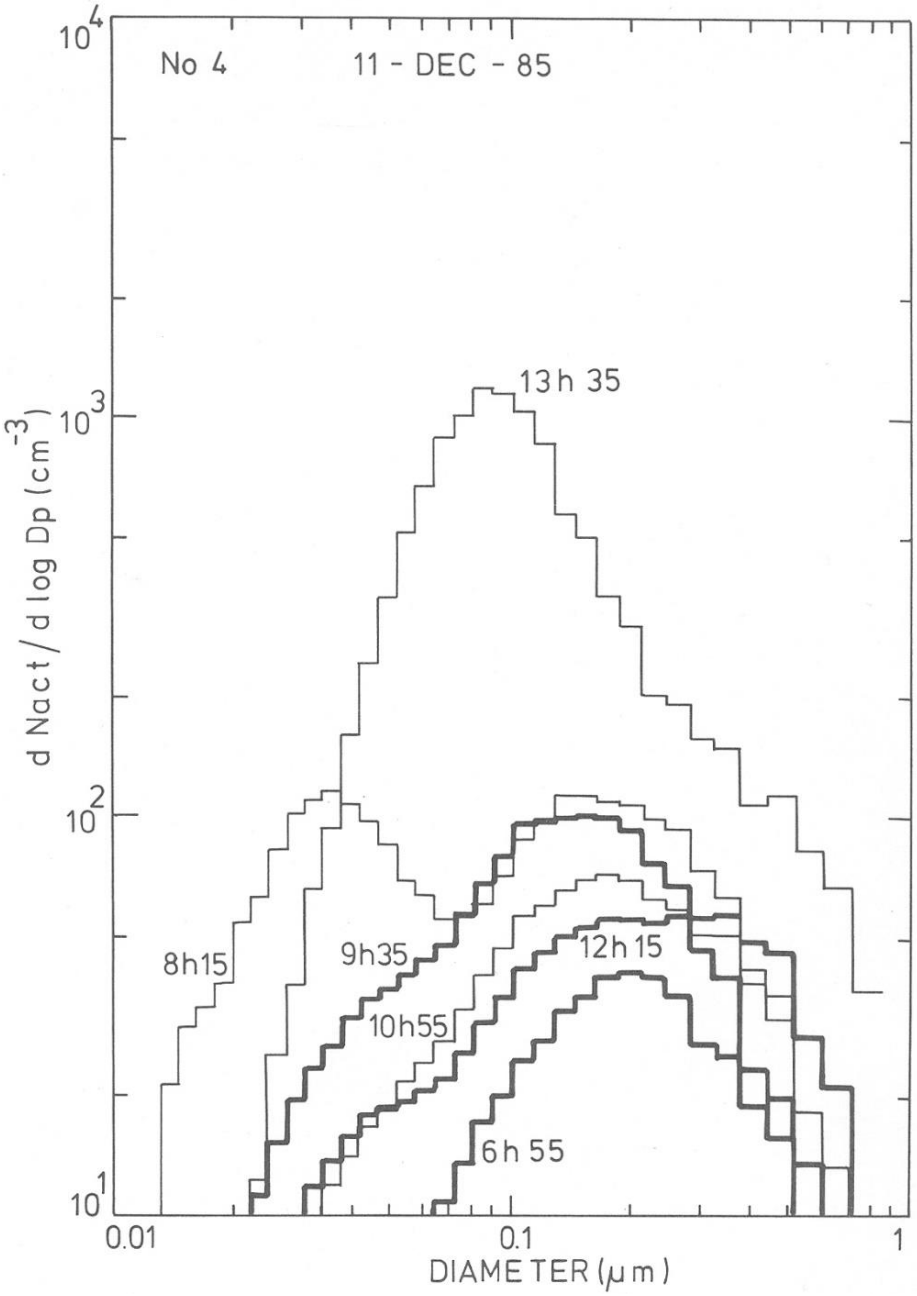

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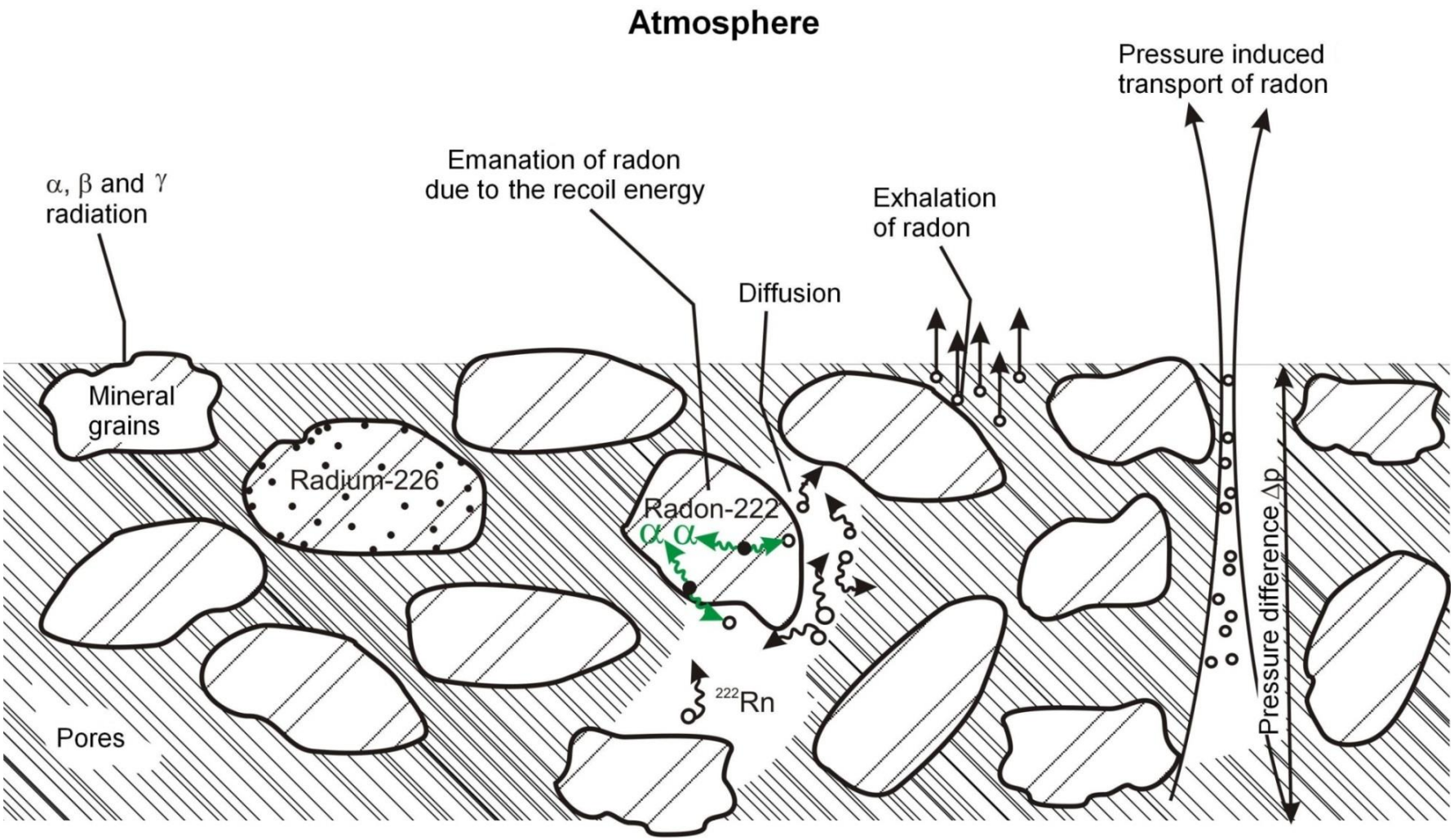

Transport of radon in soil and building materials

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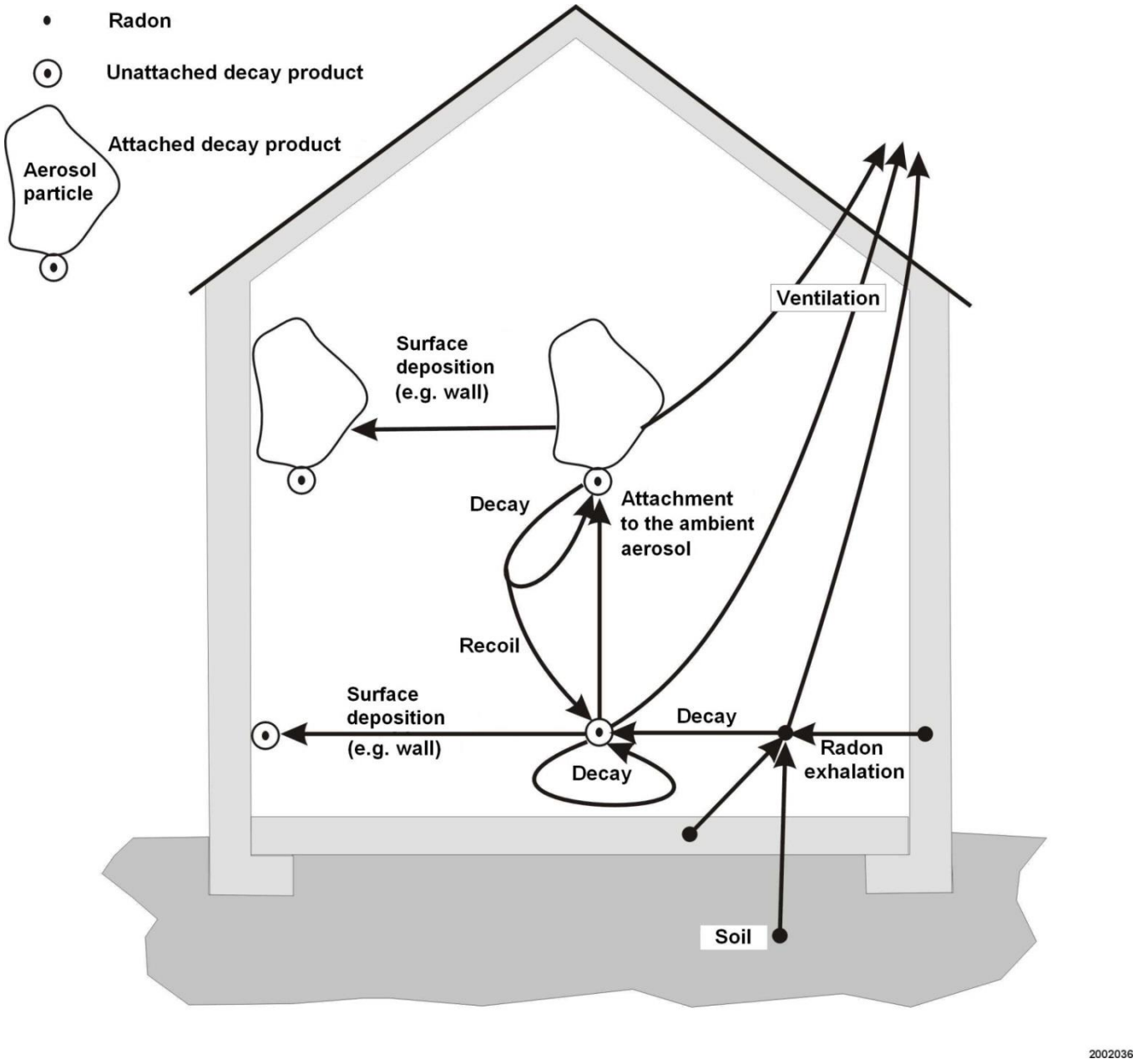

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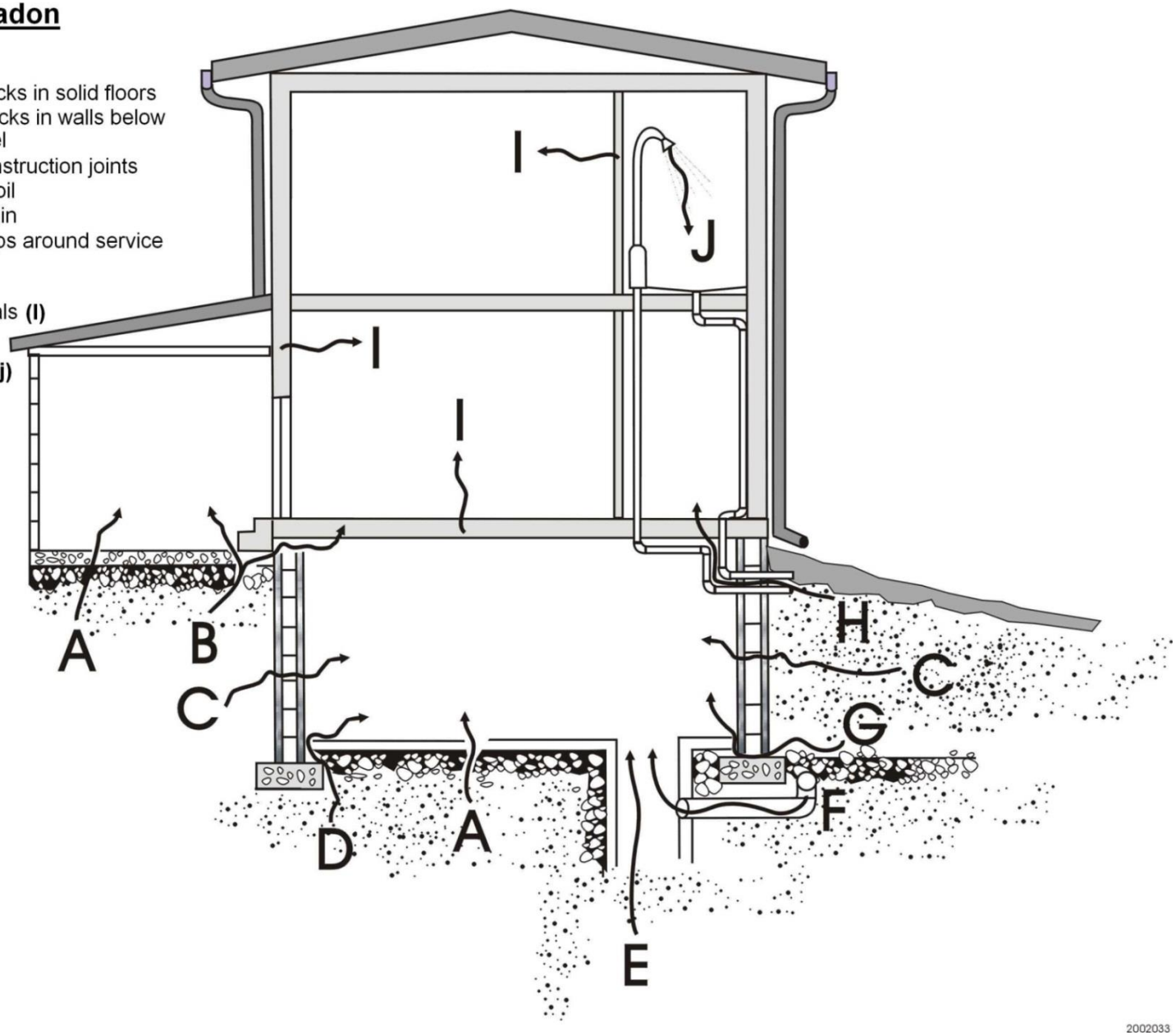
Infiltration of radon

From the soil **(A-H)**

A and B, through cracks in solid floors
C and G, through cracks in walls below ground level
D, through construction joints
E, uncoverd soil
F, through drain
H, through gaps around service pipes

From building materials **(I)**

From drinking water **(j)**



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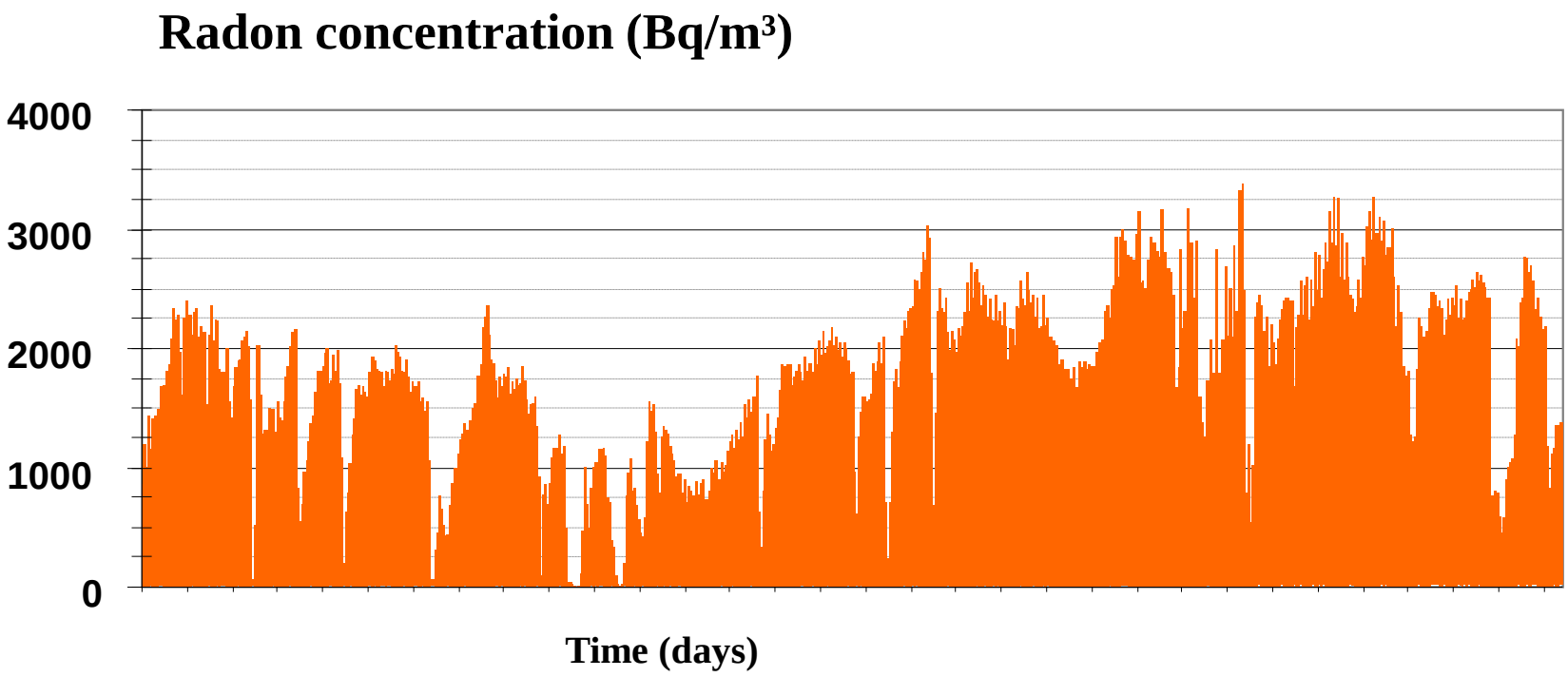
Only long-term measurements make sense

Radon concentration of a dwelling in the Ardennes measured with a continuous radon monitor



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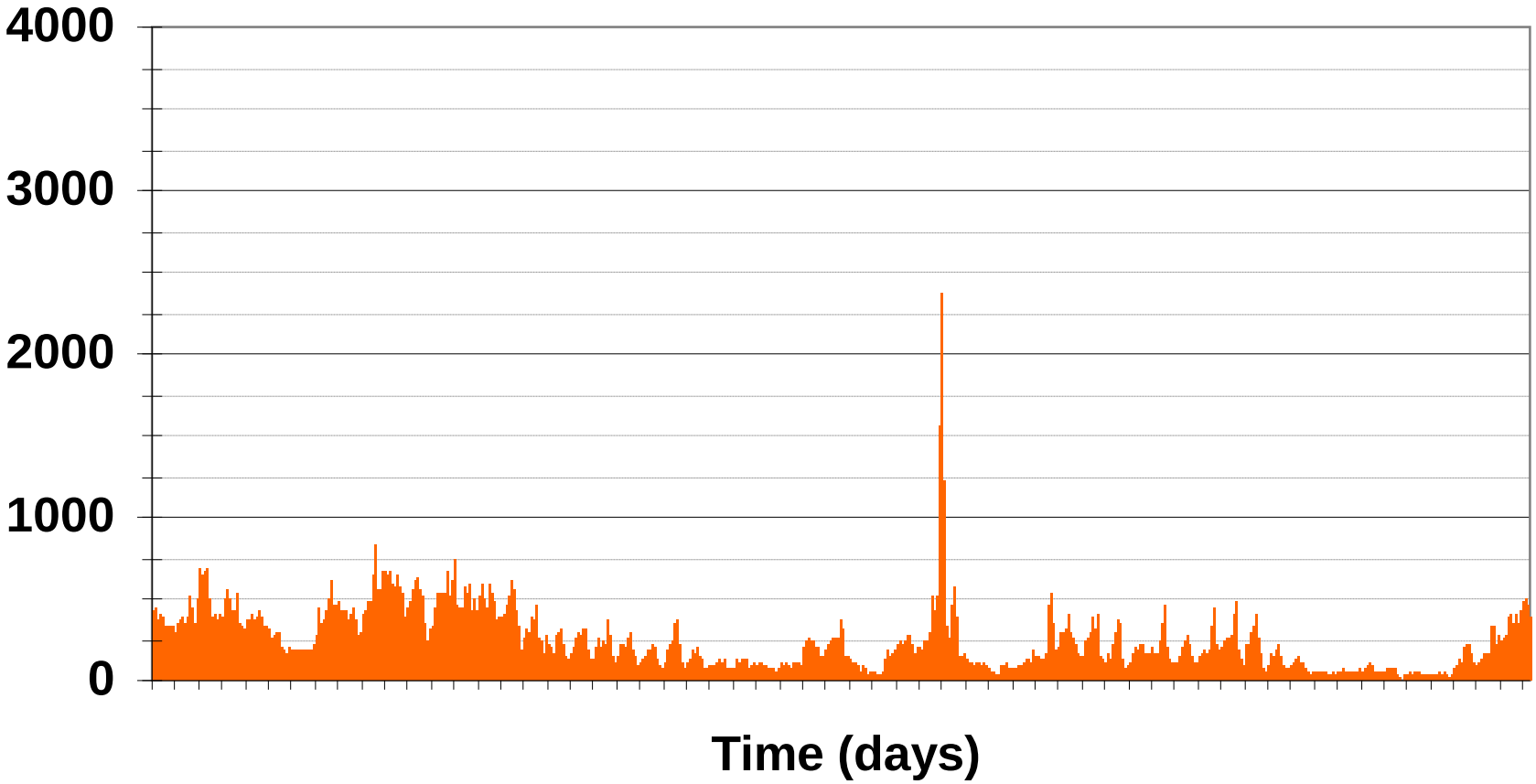
Significant reduction of the radon concentration after installing a subfloor depressurization system (Bq/m^3)



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Radium-226 concentrations measured in Belgian building materials

Building material	Number of samples	^{226}Ra (Bq/kg)	
Cement	20	47	(<11 – 161)
Sand, gravel	3	19	(13 – 24)
Clay bricks	47	34	(15 – 85)
Phosphogypsum (*)	**27**	**442**	**(333 – 847)**
Sulphogypsum	3	25	(<11 – 40)
Natural gypsum	1	9	
Slag aggregate	2	85	(79 – 91)
Concrete blocks	5	31	(<11 – 58)
Lime stones	1	21	
Schist	1	33	
Porphyry	1	27	

(*) No longer used as a building material in Belgium

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Radon exhalation from building materials

Building material	Exhalation (Bq/kg s)
Brick	~ 10^{-6}
Concrete	~ 10^{-5}
Phosphogypsum	**~ 10^{-4}**

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Typical contribution of building materials to the indoor radon concentration

Model room (concrete structure)

- Dimensions: 5 x 4 x 3 (Volume: 60 m^3; Surface: 94 m^2; S/V: 1.56 m^{-1})
- Ventilation: 0.5 h^{-1}
- Thickness of walls, floor and ceiling: 0.1 m
- Density concrete: 2400 kg/m^3
- ^{226}Ra activity concentration of the concrete: 40 Bq/kg
- Fraction of radon exhaling out of the concrete: 10 %
- Decay constant of ^{222}Rn: 0.00755 h^{-1}

If half of the radon exhales into the room the exhalation rate is:
(0.1 m / 2) x 2400 kg/m^3 x 40 Bq/kg x 0.1 x 0.00755 h^{-1} = 3.62 $Bq/(m^2\ h)$

Contribution to the radon concentration in the model room:
3.62 $Bq/(m^2\ h)$ x 1.56 m^{-1} / 0.5 h^{-1} = **11 Bq/m^3**

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Variation of the input parameters

	Thickness (m)	**^{226}Ra** (Bq/kg)	**Ventilation** (h^{-1})	**Radon** (Bq/m^3)	**Dose (*)** (mSv/y)
(ref.)	0.1	40	0.5	**11**	0.18
(low)	0.1	20	1.0	**2.8**	0.05
(high)	0.2	80	0.25	90	1.5

(*) ICRP 65, 40 % equilibrium factor, 80 % occupancy

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Typical contribution of the soil to the indoor radon concentration

Typical soil

- Density: 1600 kg/m^3
- Porosity: 40 %
- Emanating fraction: 20 %
- ^{226}Ra activity concentration of the soil: 40 Bq/kg

Radon equilibrium concentration in the pores of the soil:

1600 kg/m^3 x 40 Bq/kg x 0.2 / 0.4 = 32 000 Bq/m^3

Dwelling assuming

- A radon concentration under the dwelling of 10 000 Bq/m^3
- A fraction of the infiltrating air coming from the soil of 0.3 %

Contribution to the indoor radon concentration: 10000 x 0.003 = **30 Bq/m^3**

➡ **Can result in very high indoor radon concentrations**

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Typical contribution of the different sources of radon in Belgian homes (Bq/m^3)

Source	**Range**	**Typical contribution**
Soil	**5-1000**	23
Building materials	5-100	15
Outdoor air	5-20	10
Water supply	0-10	0
Total (rounded)	**15-1000**	**48 Bq/m^3**

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Radon survey in dwellings in the province of Limburg (Belgium)

- XIOS Hogeschool Limburg: distribution of the radon detectors
- LISEC: geological properties
- SCK: radon measurements and statistical analysis

Funding by the provincial government of Limburg

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Full results were obtained in 97.4 % of the cases

500 track-etch detectors of which

- 350: according to population density
- 150: according to geological characteristics
  - Southern part of Limburg
  - Transition area from the Kempen plateau to the river Maas

Exposure period: 1 year

Questionnaire filled in by the occupants

Full results obtained for 487 dwellings (97.4 %)

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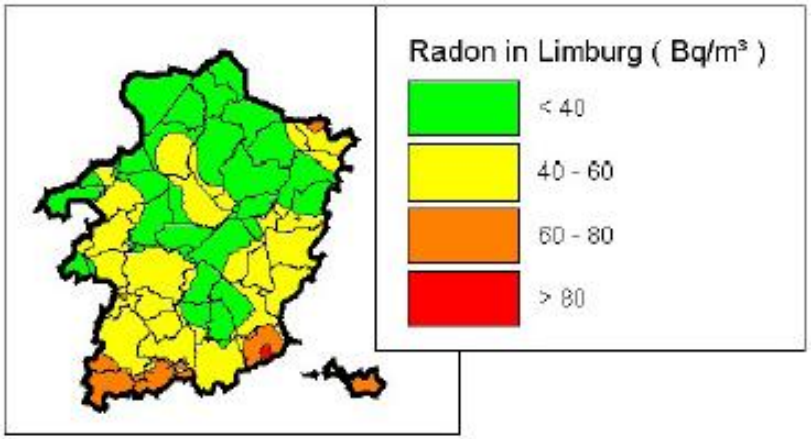

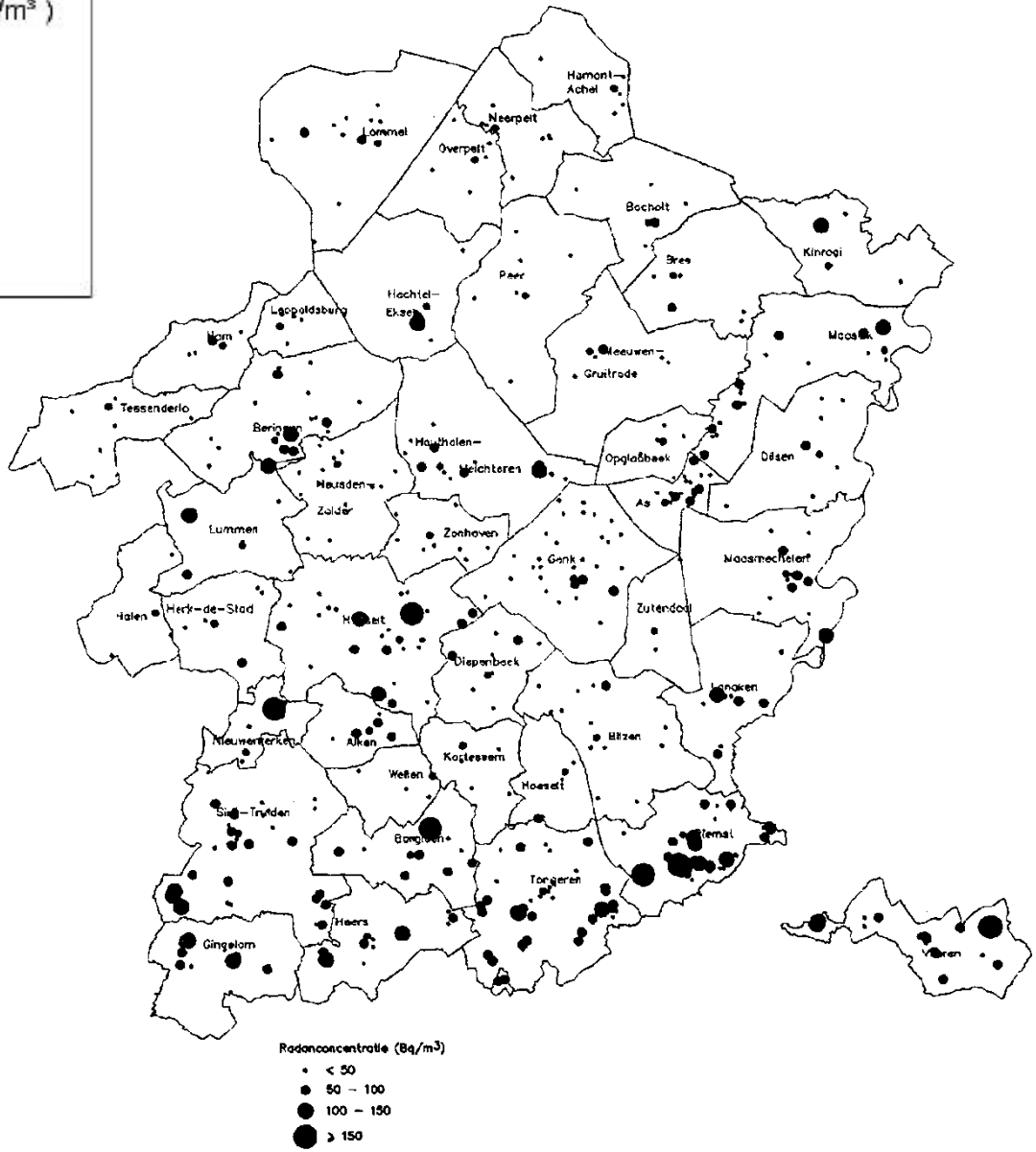

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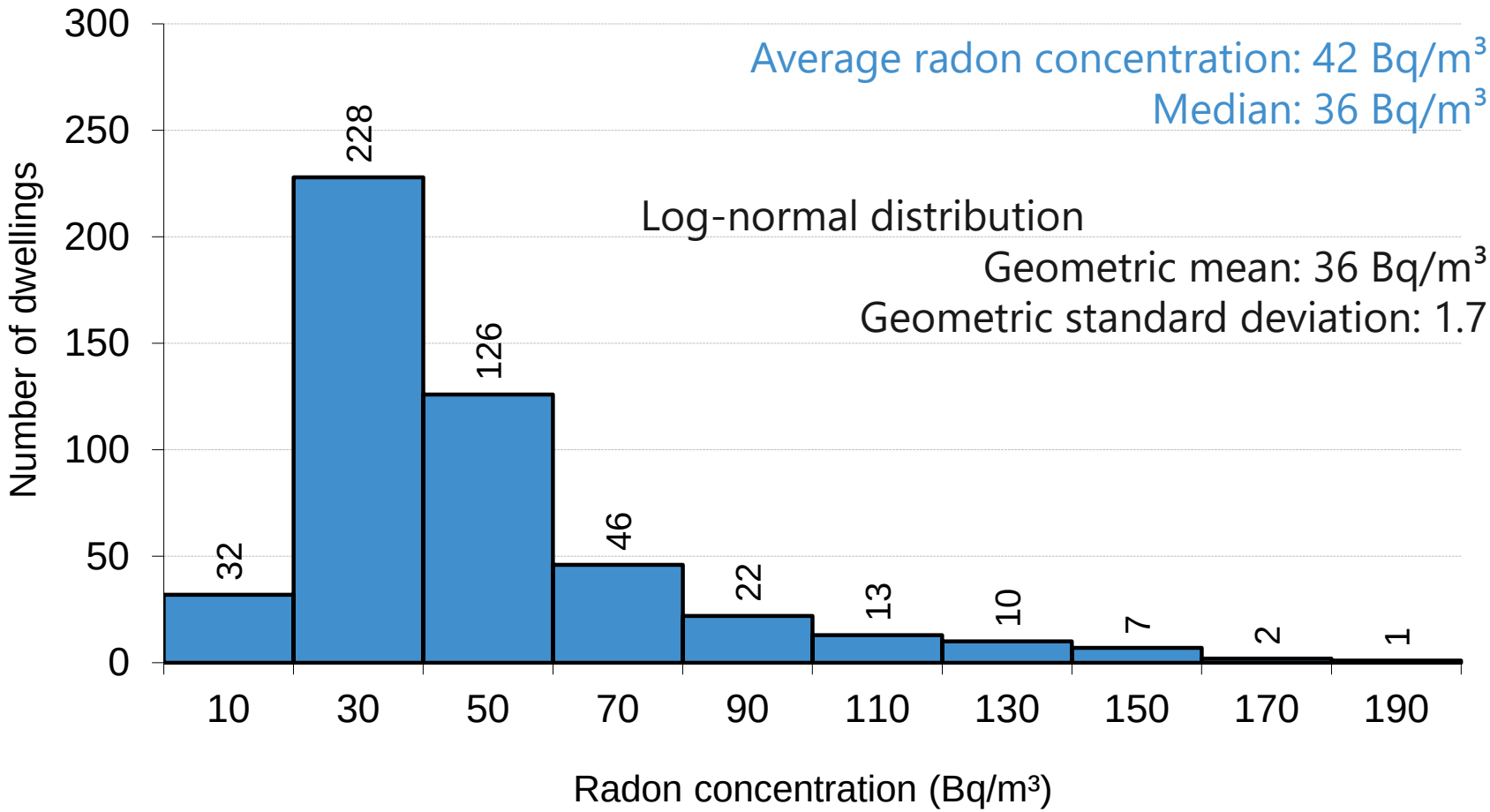
Radon concentrations in the province of Limburg



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Statistical significant correlations

Soil type ($p < 0.00001$)

- loam (56 Bq/m^3) > sand (39 Bq/m^3)

Groundwater level ($p \sim 0.0005$)

- > 5 m (50 Bq/m^3) > < 5 m (41 Bq/m^3)

Use of gypsum ($p \sim 0.004$)

- yes (48 Bq/m^3) > no (35 Bq/m^3)

Basement under the whole house ($p \sim 0.014$)

- no (47 Bq/m^3) > yes (43 Bq/m^3)

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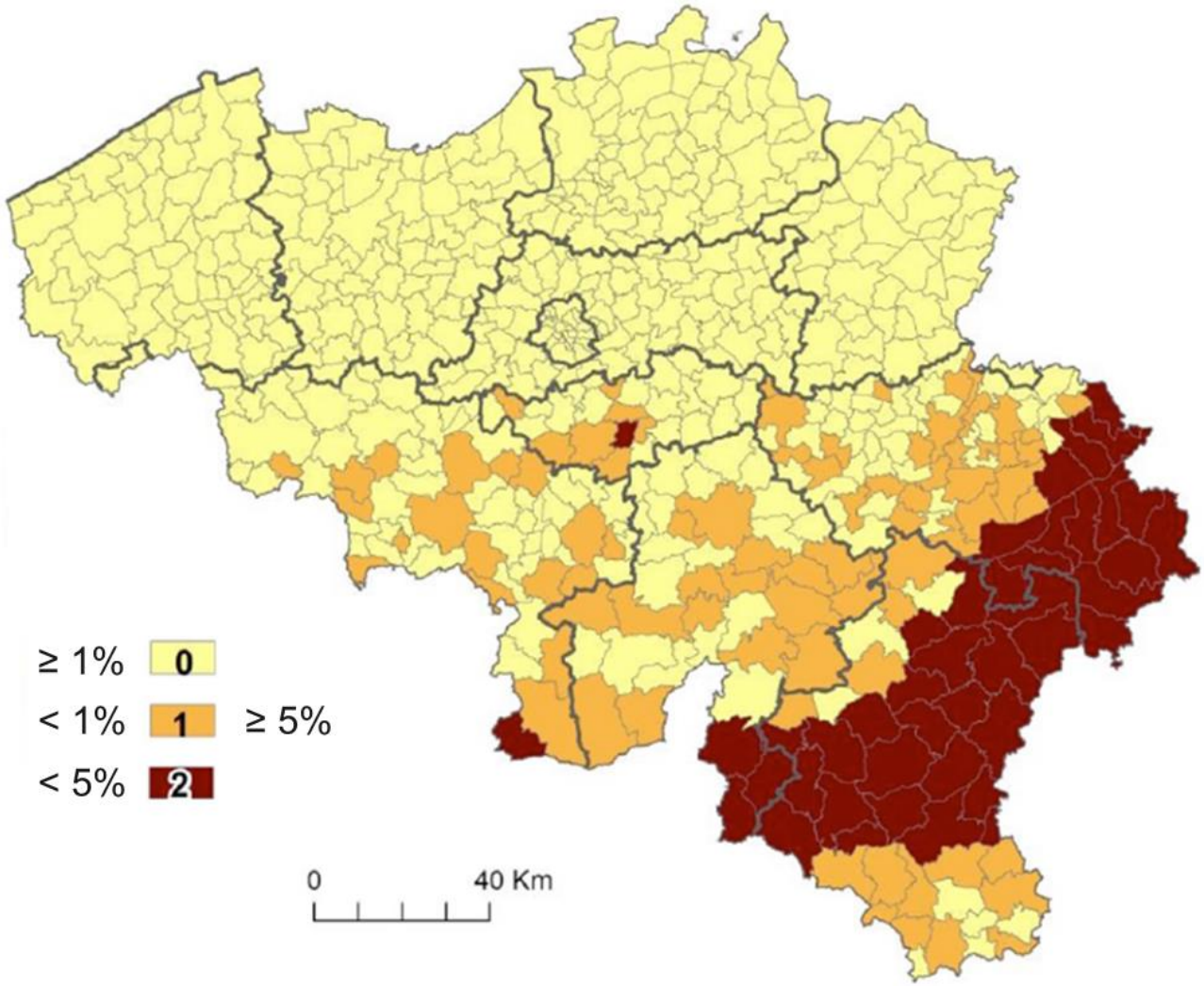
Percentage of dwellings in Belgium above the current action level of 400 Bq/m³



FANC decree 2015

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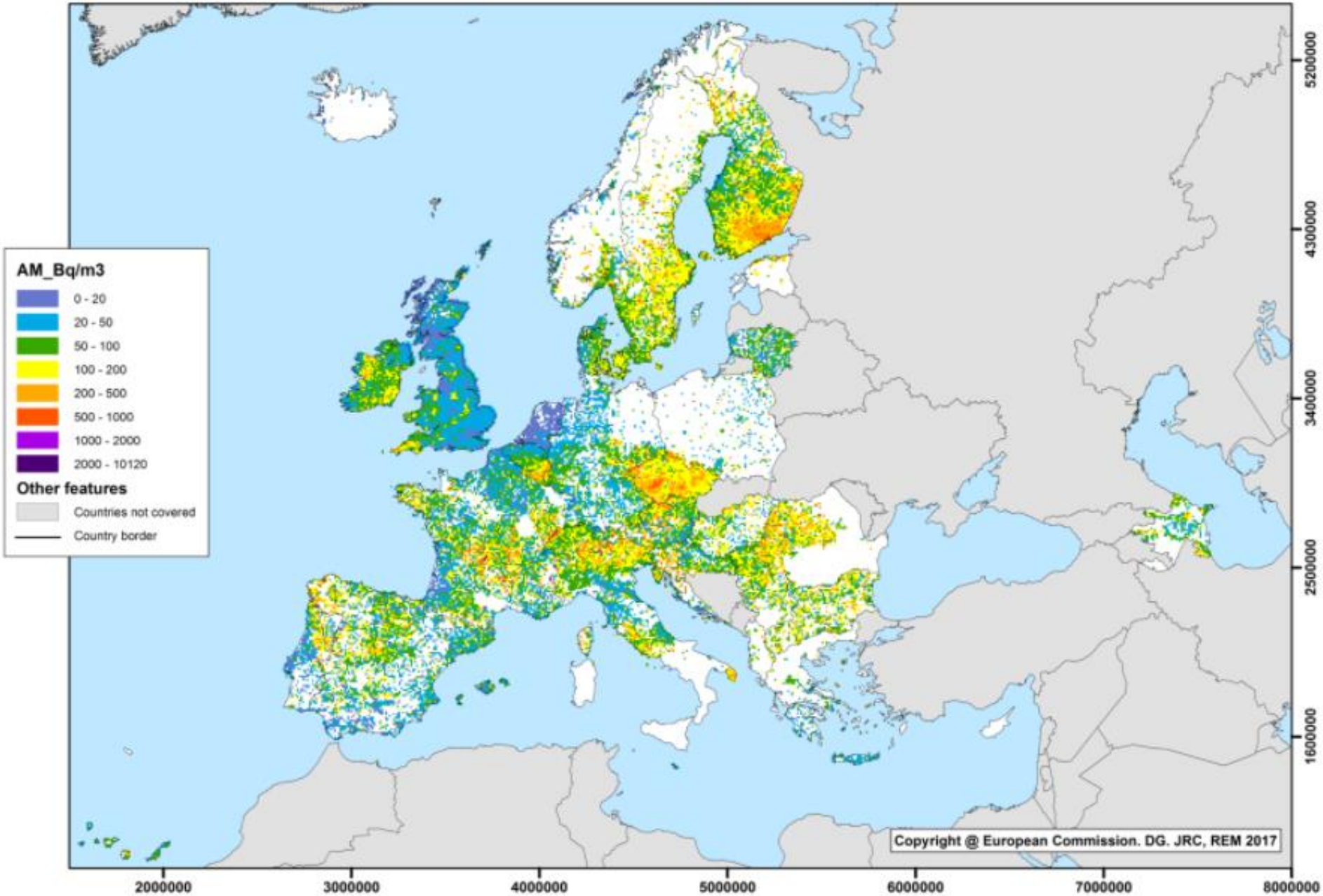
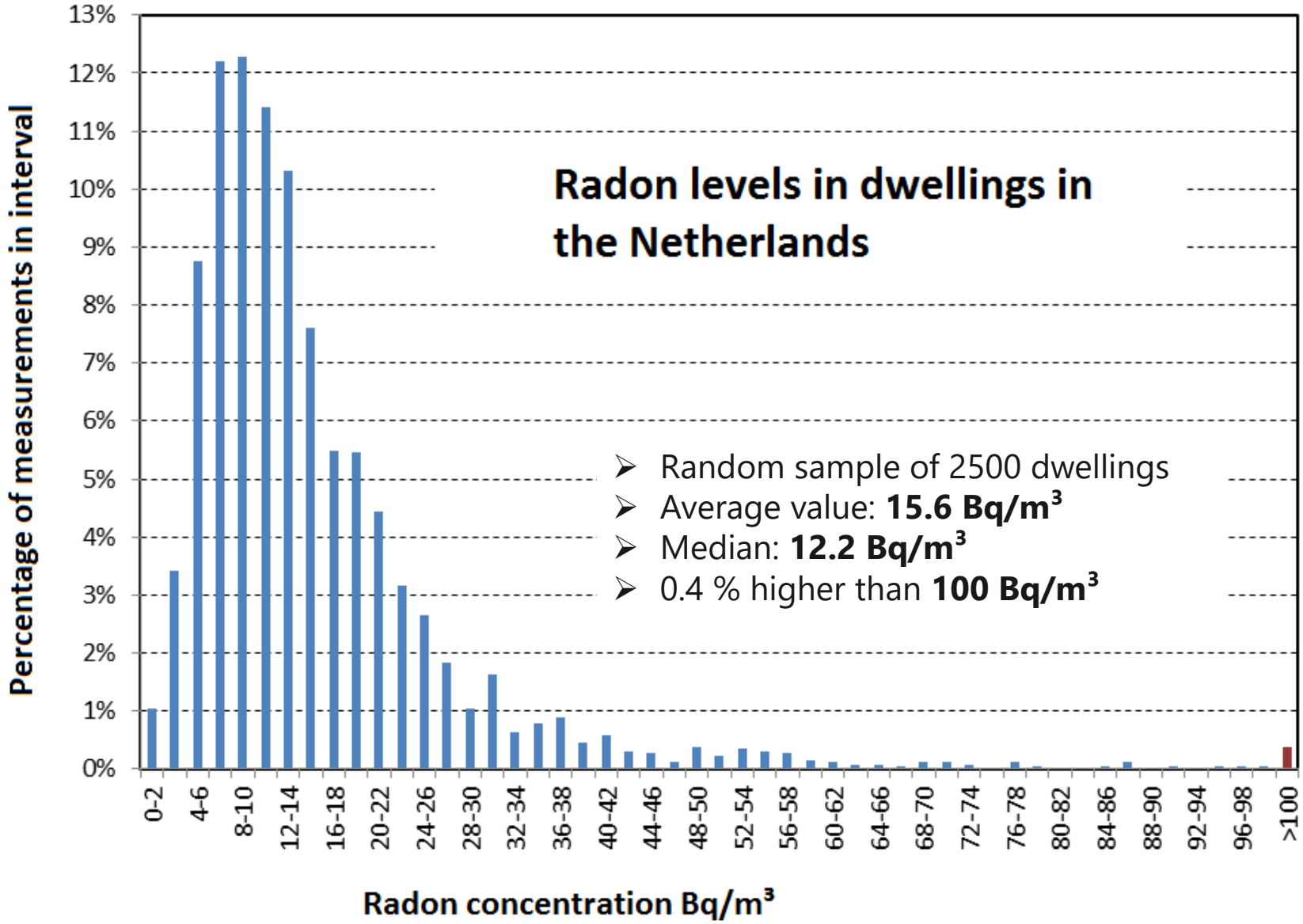
European Indoor Radon Map, August 2017





Adapted from RIVM 2015-0087 report

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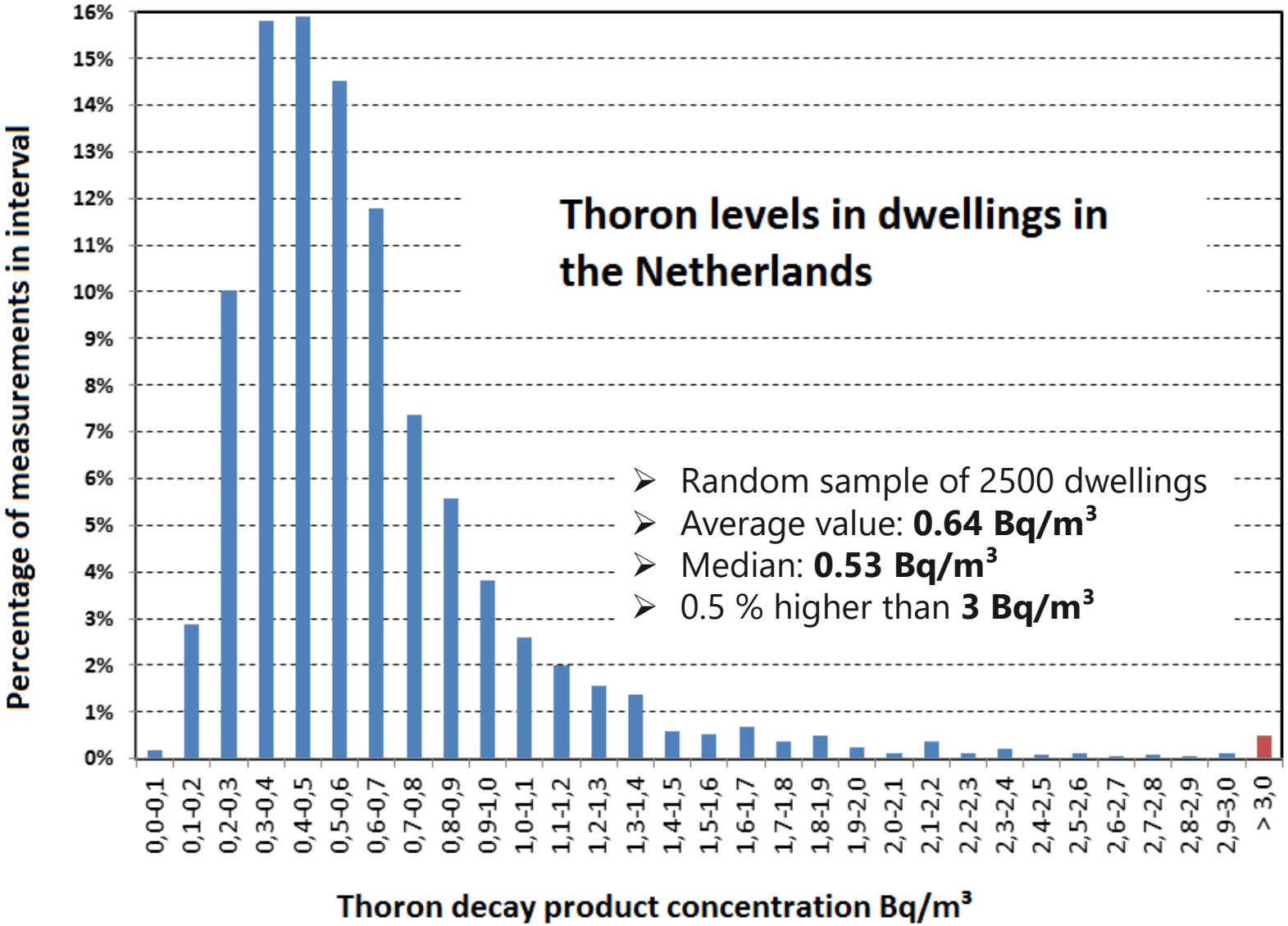

Adapted from RIVM 2015-0087 report

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Thoron decay product concentrations in the Netherlands (*)

First study ever on this scale, made possible by the low radon concentrations in the Netherlands

- Detectors covered with a foil
  that only lets through high energy alpha particles of ^{212}Po (8.78 Mev)
- Deposited activity measured
  and not the thoron decay product concentrations in the air
  - Deposition depends on many factors
    such as: location of the detector in the room, aerosol concentrations and rate at which the attached and unattached thoron decay products deposit
  - Conversion of deposited activity to air concentrations determined in Japan
    for a situation that is quite different from that in the Netherlands

➡ Risk of systematic errors

(*) Thoron quickly decays ($t_{1/2}$ = 55.6 s), so that the thoron concentration at the wall is much higher than in the middle of the room

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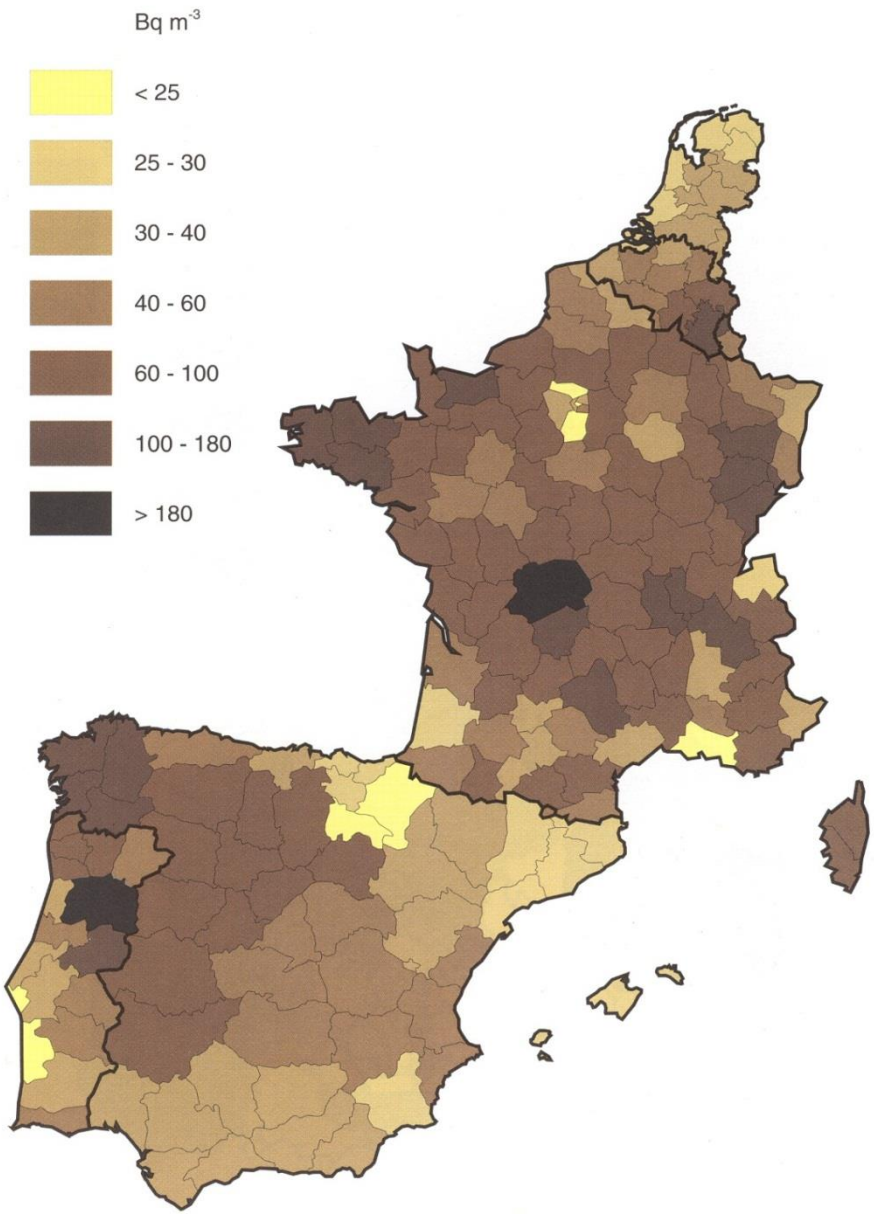

European Commission 1993

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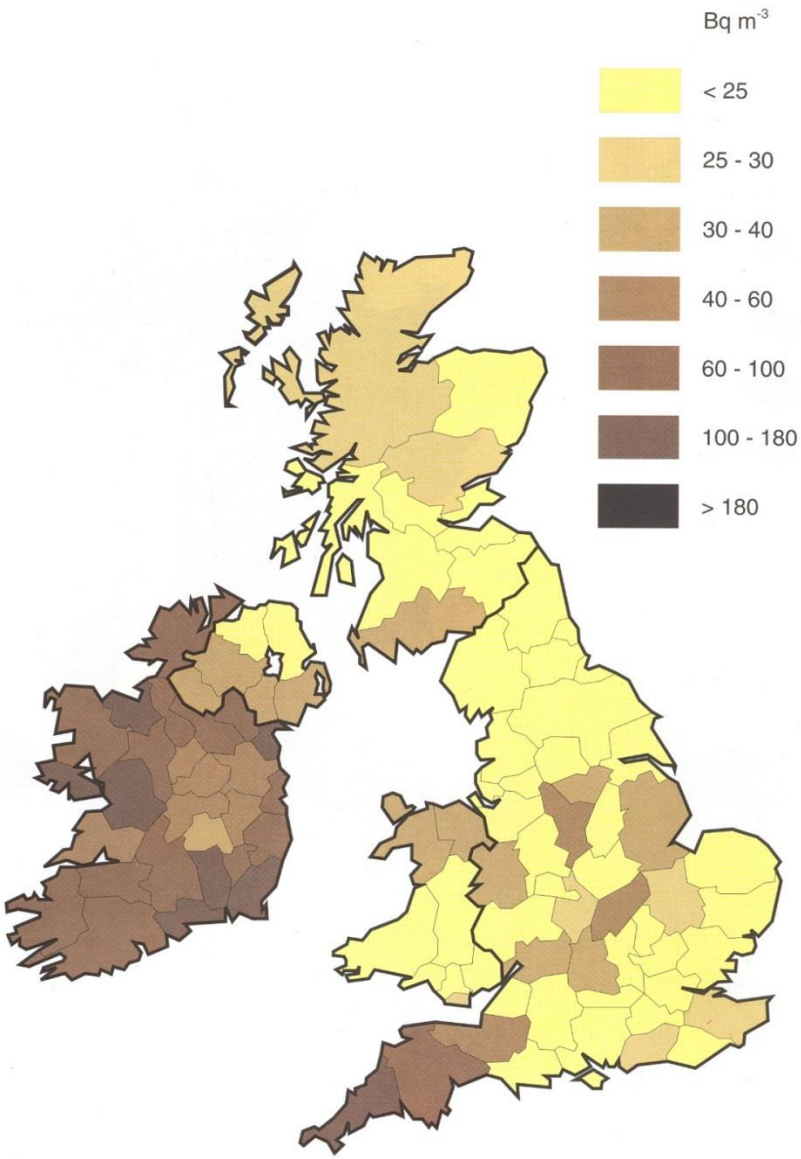

European Commission 1993

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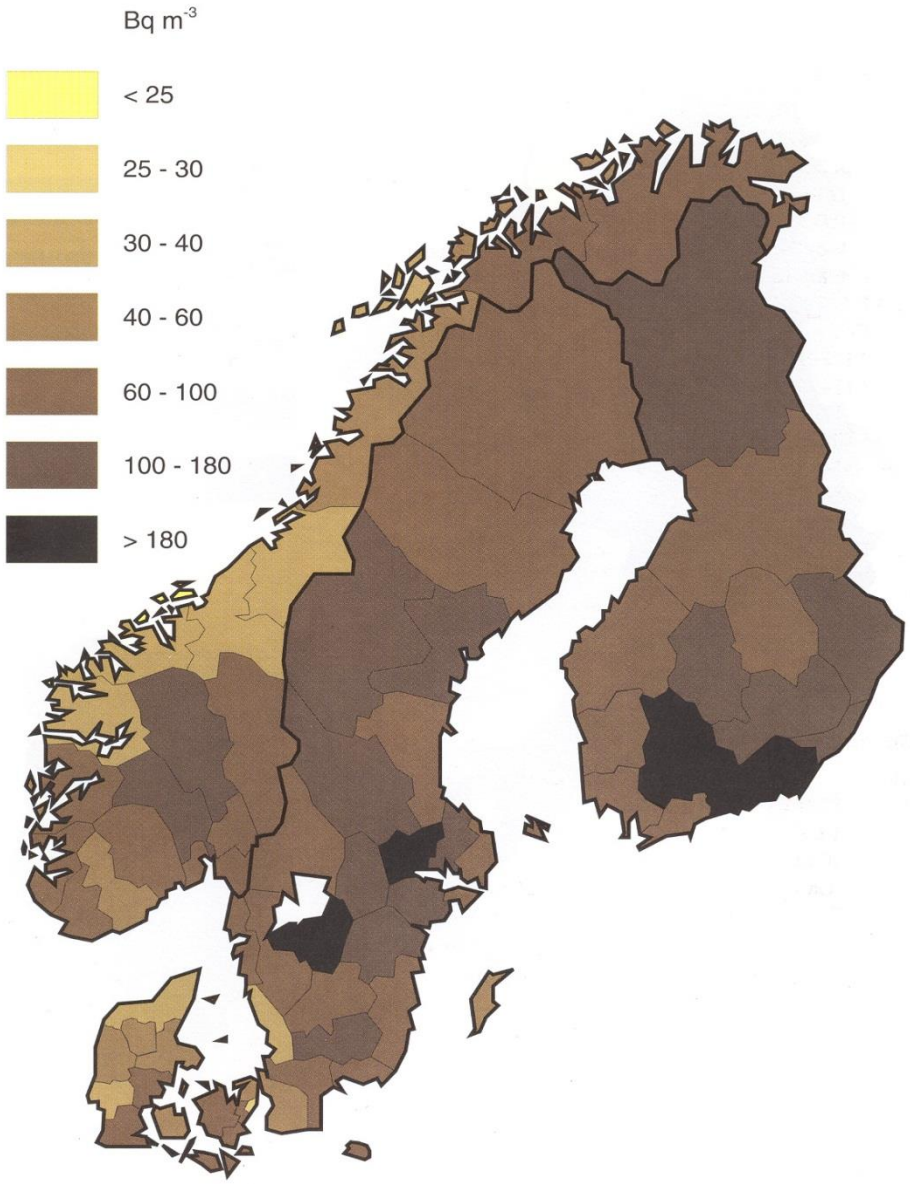

European Commission 1993

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Country	Average radon concentration Bq/m³	Geometric mean Bq/m³	Maximum value Bq/m³
Belgium	***48***	***38***	***12 000***
Worldwide average	***40***	***30***	
Japan	16	13	310
United Kingdom	20	14	17 000
Netherlands	23	18	380
Canada	34	14	1 720
United States	46	25	
Germany	50	40	> 10 000
Denmark	59	39	1 200
France	62	41	4 690
Norway	73	40	50 000
Switzerland	75	41	10 000
Sweden	108	56	84 000
Finland	120	84	20 000

UNSCEAR 2006

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Radon causes more than half of the natural exposure in most countries

- Effective dose in Belgium: 1.35 mSv/y
  (calculated with the UNSCEAR dose conversion factor)
  - Average indoor radon concentration: 48 Bq/m^3
  - Average outdoor radon concentration: 10 Bq/m^3

- Estimation of the number of dwellings in Belgium above
  - 150 Bq/m^3: 150 000: 4 mSv/y
  - 400 Bq/m^3: 20 000: 10 mSv/y
  - 4000 Bq/m^3: 1 000: 100 mSv/y
    Ardennes, Condroz, between Sambre and Meuse river, …

- Reference level for radon-reducing measures (EU BSS)
  - Dwellings: not higher than **300 Bq/m^3**
  - Workplaces: not higher than **300 Bq/m^3**

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