Measuring methods for determination of gas transport parameters in soils (*)(**)

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Summary. — Measurement methods for gas transport parameters in soils have been developed to assess the geogenic radon potential. The methods are based on the determination of selected physical soil properties, *e.g.*, diffusion coefficient, gas permeability and radon emanation of undisturbed soil samples. Additionally, a probe has been developed for determination of the *in situ* gas permeability of soils. The variation of emanation coefficients shows the influence of the natural texture of the soils.

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1. – Introduction

Determination of radon availability in the subsurface is an important step for the estimation of the geogenic radon potential, which is affected by the radon concentration and a series of physical soil parameters, *e.g.* radon emanation, gas permeability, diffusivity, porosity, water content and distribution of grain size in soils (Yokel and Tanner, 1992). For the first three parameters new procedures have been developed:

– To characterize the gas transport conditions within soils the diffusion coefficient of a soil can be estimated in a diffusion device by measuring the radon flux through an undisturbed soil sample and measuring the concentration gradient between two chambers.

– The gas permeability of the soil is measured by a permeameter either *in situ* with a specially developed soil air probe, or in the laboratory on undisturbed soil samples.

– The determination of the coefficient of radon emanation is based on the measurement of the radon release in undisturbed soil samples.

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2. – Sampling

The assessment of radon availability demands different methods of sampling. For each specific condition, different sampling methods have been developed:

– sampling of soil air in 3 different depths (30 cm, 60 cm, and 90 cm) with a soil probe for measuring radon activity concentration using Lucas cells,

– determination of *in situ* permeability with a permeameter and soil probe,

– collecting of undisturbed soil samples with steel cylinders within a trench at

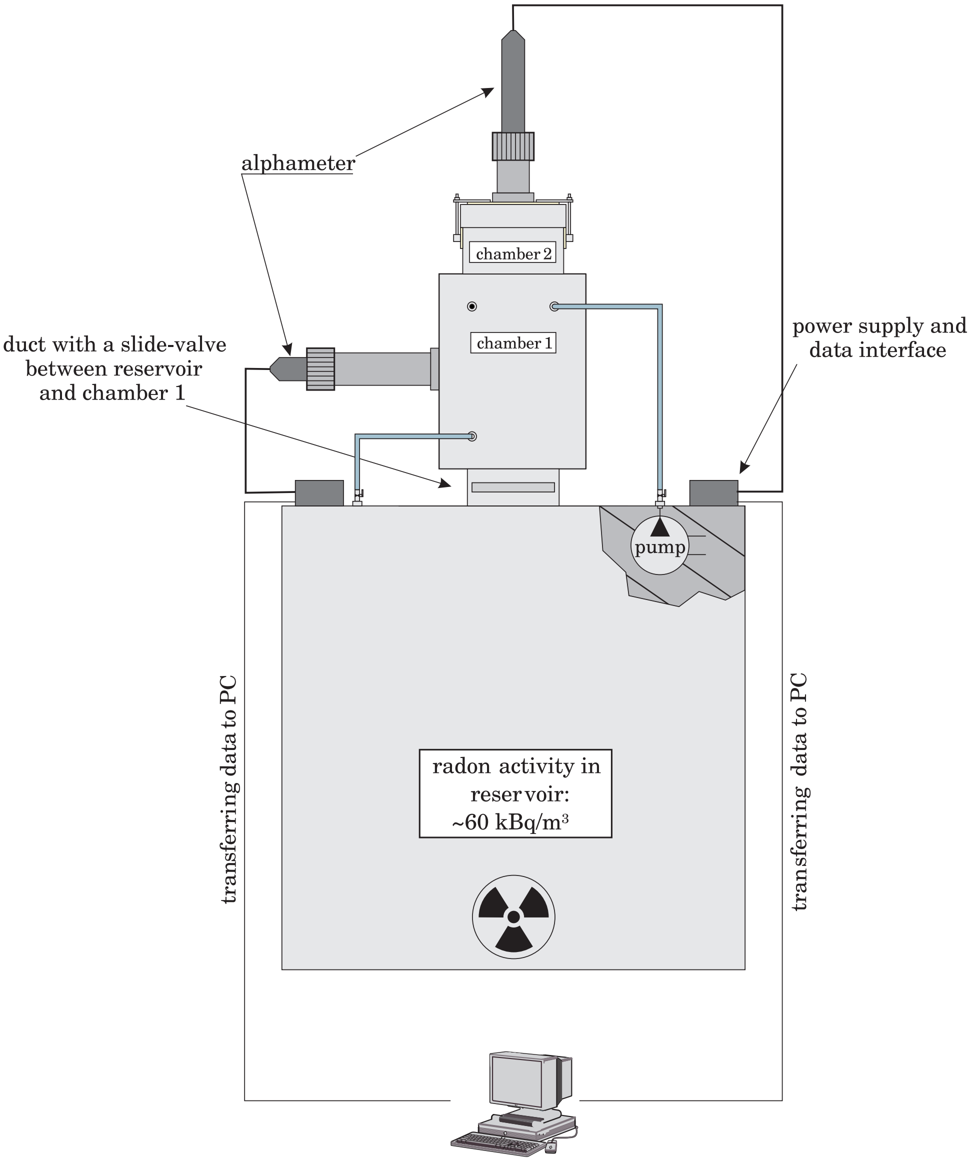

Fig. 1. – Sketch of the diffusion chamber for the determination of the radon diffusion coefficient.

different soil horizons for the determination of permeability, radon emanation, diffusion coefficient, and other physical soil properties,

– sampling of soil for measuring radium activity concentration with high-resolution gamma-ray spectrometry.

3. – Diffusion coefficient

The diffusion coefficient is determined from undisturbed soil samples. A measuring device was developed in which radon-loaded air can be transported by a pump from a reservoir into a smaller chamber (1). From there, the air enriched in radon is able to migrate through a sample into a second chamber (2) (fig. 1, 2). In both chambers, the radon concentration is permanently measured. The radon concentration in chamber 1 remains constant because of the permanent influx of radon from the reservoir. The diffusion coefficient can be calculated using the concentration gradient between the chambers 1 and 2 in radioactive equilibrium according to Fick's equation (Folkerts, Keller and Muth, 1984). The radon activity concentration in the tested soil sample can

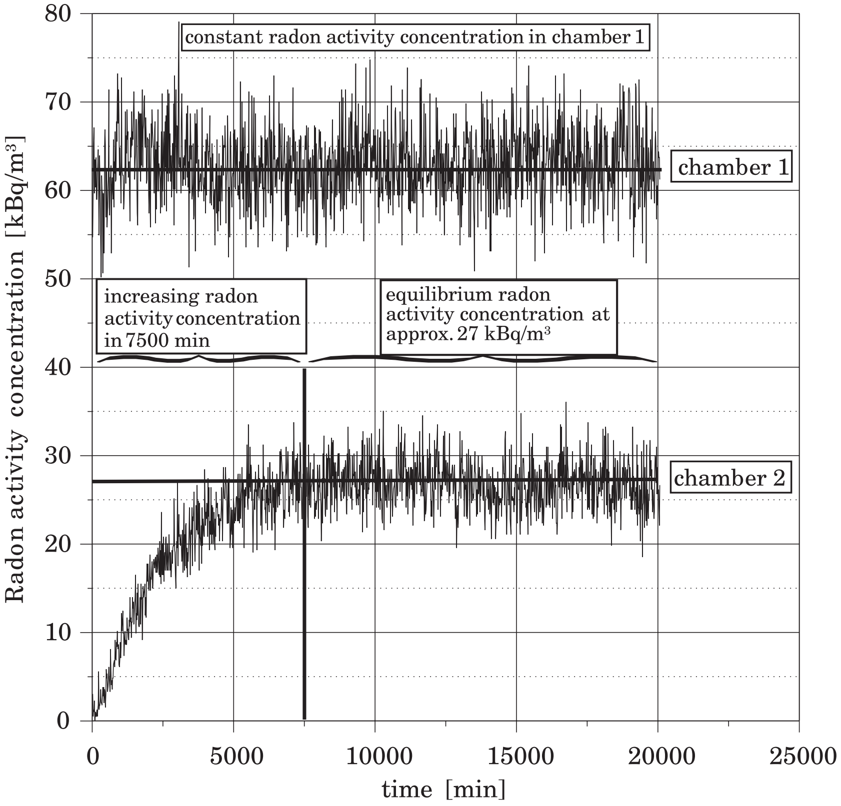

Fig. 2. – Radon activity concentrations in chamber 1 and 2. The activity is measured in a 15 min interval. The lower curve shows an increasing radon activity concentration up to an equilibrium between chamber 1 and 2.

be described for a one-dimensional case by the equation:

$$\frac{\partial a(x,\,t)}{\partial t} = D\cdot\frac{\partial a(x,\,t)}{\partial x} - \lambda\cdot a + S\,, \tag{1}$$

D = diffusion coefficient ($\mathrm{m}^2\,\mathrm{s}^{-1}$),
λ = radon decay constant (2.098E-06 s^{-1}),
a = radon activity concentration ($\mathrm{Bq\ m}^{-3}$),
S = generation rate of Rn in interstitial pore space.

4. – Permeability

The permeability of soils can be measured by two procedures (fig. 3). For measurements in the field, a portable flowmeter is connected with a soil air probe. The flowmeter reduces the pressure of the incoming air to 40 mbar. This air is injected at a constant pressure and under laminar flow conditions through the soil air probe into the drill hole which is sealed by a packer system (Damkær and Korsbech, 1991; Kemski, Klingel and Siehl, 1996; Surbeck and Piller, 1992). For measurements in the laboratory, the same flowmeter can be connected to a sample holder containing an undisturbed soil sample. The permeability of the measured soil can be calculated by

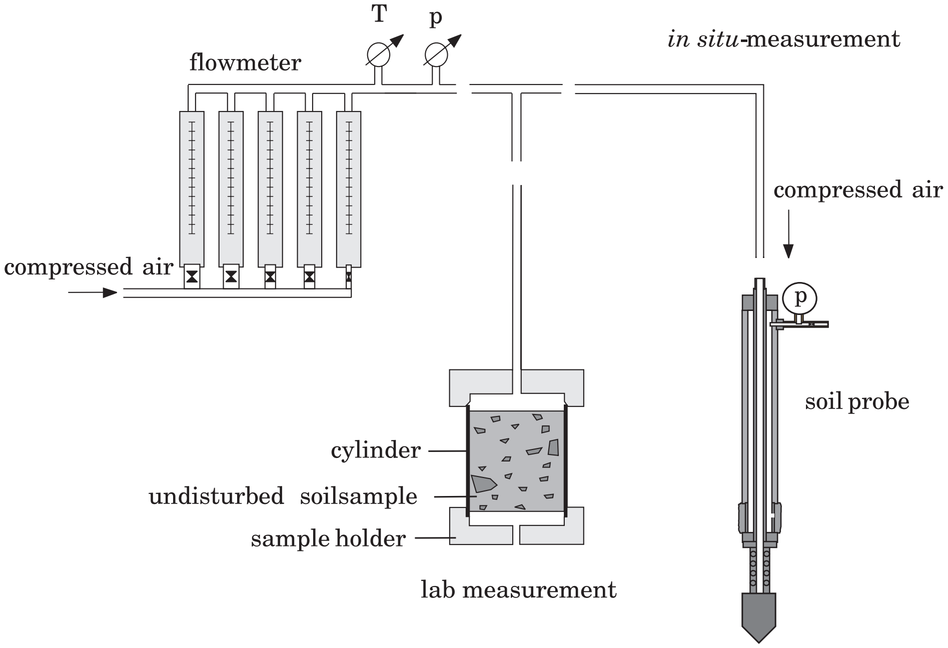

Fig. 3. – Sketch of the device for measuring gas permeability in undisturbed soil and for *in situ* measurements.

using Darcy's law:

$$V = \frac{A \cdot k \cdot P}{l \cdot \eta} \,, \tag{2}$$

V = air flux ($\mathrm{m^3\,min^{-1}}$),
P = air pressure (Pa),
A = size of sample area ($\mathrm{m^2}$),
l = sample length (m),
k = permeability ($\mathrm{m^2}$),
η = dynamic viscosity (Pa s).

5. – Emanation

The measurement of the emanation coefficient is based on the determination of the radon activity concentration in the interstitial pore space of an undisturbed soil sample. The soil sample remains in the steel cylinder and is sealed radon-tight (fig. 4). In equilibrium between radium and radon, the soil air sample is taken by a syringe from the pore space. The radon activity concentration is measured in a Lucas cell (fig. 4). After conversion of the measured radon activity concentration values according to the pore volume, the emanation coefficient can be calculated by the following

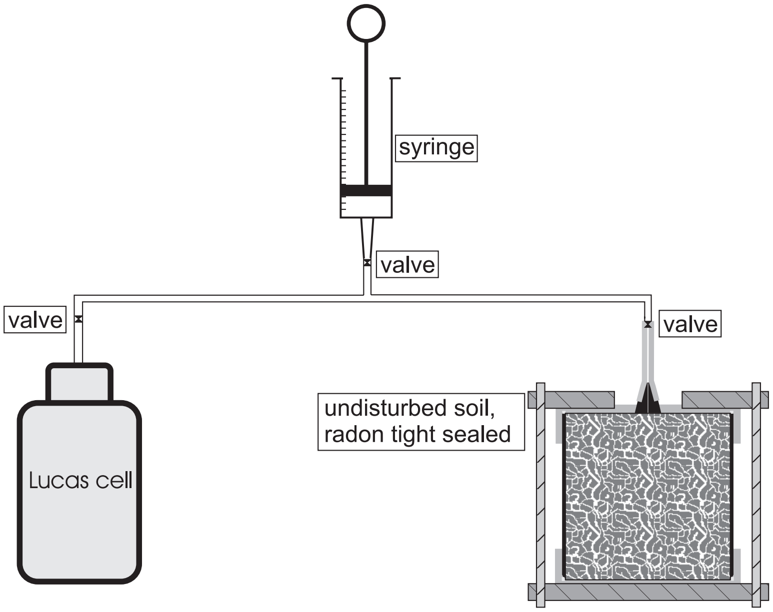

Fig. 4. – Measuring technique for radon activity concentration of interstitial pore space in a soil sample for the determination of the radon emanation.

TABLE I. – *Typical emanation coefficients of different soil types.*

	Emanation coefficient		
	median	min	max
Sandy soil (Buntsandstein)	0.12	0.08	0.15
Sandy soil (Rhyolithe)	0.28	0.21	0.43
Loamy soil (Upper Muschelkalk)	0.19	0.20	0.18
Loamy soil (Rotliegend)	0.19	0.16	0.31
Loamy soil (Carboniferous)	0.16	0.13	0.22

equation (Markanen and Arvela, 1991):

$$\varepsilon = \frac{C_c \cdot p}{\varrho_d \cdot A_{Ra}}, \tag{3}$$

ε = emanation coefficient,
C_c = corrected radon activity concentration (Bq m^{-3}),
p = porosity of soil,
ϱ_d = dry mass density (kg m^{-3}),
A_{Ra} = radium activity concentration (Bq kg^{-1}).

6. – Conclusion

The above-described methods were used for the investigation of soil profiles in south-west Germany. As a major result of the investigation we found systematically lower values of the emanation coefficients in relation to the values given in the literature (Damkær and Korsbech, 1985; Greeman, Rose and Jester, 1990). These data are based on measurements in disturbed soil samples. Our analyses demonstrate that the natural texture of the soils, which is usually not considered, is a significant parameter and explains the lower emanation coefficients (table I). A similar observation is well known in engineering geology for parameters, which were measured to describe the water permeability of soil and rock. Our studies show the importance of the application of undisturbed soil samples for the measuring methods of gas transport parameters and assessment of the geogenic radon potential.

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