Fig. 4-6. Measuring system RM-3 – continual measurement of soil gas radon concentration.

(b) control and operation unit – electrometer device with a data logger;

(c) membrane pump with an electronic feedback regulation;

(d) electronic flow meter with a memory storage;

(e) sampling probe special end fitting providing a defined continuous close circuit sampling;

(f) thoron suppression unit (thoron additional signal is eliminated by its radioactive decay in a retarding piping system inserted in the close circuit).

The special sampling procedure effectively eliminates the ambient atmosphere influence on the long-term soil gas sampling (temperature and pressure fields effects) and the close circuit with defined flow characteristics ensures a minimal impact on physical properties of the sampling space (draining effects, variable geometry factor etc.).

Other important feature is the possibility of a decontamination of chamber inner surfaces from radon progeny deposition.

Particular limitation can be connected with the actual soil permeability – in low permeable soils the system need not to work properly.

5. Permeability of soils

Even low soil gas radon concentration can cause significant indoor radon concentrations, especially in case of high permeability of soil in the contact between the buildling and the soil environment. The gas permeability of soils and rocks is one of the most important factors which determine the possible radon sources of any given site and therefore one of the main parameters for final radon risk classification of building sites.

In this connection we must not forget that this measured or derived gas permeability in an undisturbed environment is just the parameter that can be used for determination of radon potential (“risk” point of view). The relation between gas permeability and soil gas radon concentration can help to explain the temporal changes of soil gas radon concentration and to confirm the reproducibility of the final assessment. But this parameter would not be the same as the permeability of the environment in the future at the contact between the building and the soil. Therefore it cannot be used without correction for the description of the transfer of radon from soils into the buildings – transfer factor etc. (“transfer” point of view).

All uniform methods that have been used for radon risk classification in Czech Republic since 1990, were based on the assessment of the soil gas radon (^{222}Rn) concentration and of the permeability of soil and rock for gases.

5.1. PERMEABILITY IN THE ORIGINAL METHOD

Due to the original method for classification (Kulajta et al. 1990) it was possible to derive the permeability very simply from the weight percentage of fine fraction (< 0.063 mm) in the chosen soil sample (Barnet 1992, Neznal, Neznal and Šmarda 1992a). Soils with the weight percentage of the fine fraction < 15 % were designated as high permeable soils, in the range 15–65 % as medium permeable and in the case of the fine fraction above 65 % as low permeable ones (Tab. 5-1). The main disadvantage was given by the fact that other factors influencing the permeability (mainly natural soil moisture, density, effective porosity etc) were not taken into consideration. Furthermore, one sample cannot describe a heterogeneous geological environment (horizontal and vertical changes, influence of human activity).

During the grain size analysis similar results can be found, although the real permeability is quite different. This relatively frequent situation can be demonstrated on two related cases:

Tab. 5-1. Permeability derived from the particle size distribution, the classification of soils respects the Czech National Standard 731001 Subsoil under shallow foundation that has been used during geological surveys – soils have been described in terms of weight percentages of each component, i.e. gravel (G, 2–60 mm), sand (S, 0.063–2.0 mm) and fine fraction (F, < 0.063 mm)

Permeability	Weight percentage of fine fraction “f” (< 0.063 mm)	Classification of soils due to CNS 731001
High	f < 15 %	G1, G2, G3, S1, S2, S3
Medium	15 % < f < 65 %	G4, G5, S4, S5, F1, F2, F3, F4
Low	f > 65 %	F5, F6, F7, F8

Loess is a typical example of soil with high amount of the fine fraction, very often higher than 70 %, which leads to the low permeable environment. But if the soil moisture is low, e.g. due to the weak precipitation, the loess layer can be medium or even high permeable. Such a situation can be illustrated with the results from detailed radon survey realized at a large area for new family houses. During the survey, the area served as a garden and field, but at one part we found old and not used green-houses (but with the soil sheltered from the precipitation). The upper soil layers with the thickness of about 4–6 meters were formed by loess. The resistance against sampling the soil gas as well as other factors in the larger part of the area corresponded to the expected low permeability. Whereas inside the green-houses we found high permeable environment because the loess had been absolutely dry. It should be mentioned that the radon potential was similar in the whole area, as the soil gas radon concentration values determined under the green-houses were substantially lower than the values from the normal conditions (due to the classification principles, the radon risk is similar, when lower values of soil gas radon concentration correspond to higher permeability and higher values to lower permeability).

On the other hand, fluvial sands from river terraces are mainly high permeable due to their typical grain size. But if the sands have high soil moisture, i.e. almost all poruses are filled with water, the water saturation is almost 100 % and the efective porosity gets near zero, the gas permeability is instantenously or longtime really low.

5.2. CHANGES IN THE PERIOD 1994–2004

The modified uniform method for assessing the risk of radon penetrating from the underlying soil or bedrock, based on determining the radon risk of the building site (Barnet 1994a), enabled to classify one of the decisive parameters for classification of radon risk in two ways. Due to that original method for classification it was possible to use again the particle size analyses. Moreover, another method consisted in direct *in situ* measurements of permeability was opened. It was based on the soil gas withdrawal by means of low negative pressure (Barnet 1994, Kašpar, Prokop and Matolín 1993, Neznal, Neznal and Šmarda 1995). These data were completed with the description of changes in vertical profiles with respect to the expected foundation depth of the building. The main disadvantages were certainly for the case of particle size analyses the same. The second way was properly opened, but the rules contained in the modified method for this case were still too broad to enable an explicit assessment. Although the direct measurement results were strongly dependent on small scale variations of the character of the soil (results vary in several orders of magnitude), neither the precise conditions for measurements, nor the minimum number of measurements and nor any statistical evaluation were specified.

Results of detailed radon surveys as well as results obtained from research studies, carried out in the Czech Republic in the period 1994–2000, indicated that the uniform method should be improved.

At first a wide range of methods for soil gas permeability determination in radon research has been studied. Chosen methods – mainly single probe measurements (Damkjaer and Korsbech 1992), dual probe measurements (Garbesi et al. 1993) and derivation of permeability from other parameters – permeability for water (Rogers and Nielson 1991), grain size analysis (Barnet 1992, Neznal, Neznal and Šmarda 1992a) – have been considered for further investigation. After long discussions and comparison of advantages and disadvantages of different systems with respect not only to professional issues, but also to economical ones, we have focused on direct measurements of gas permeability using pressure systems. Three prototypes for direct measurements have been prepared with the main goal – to try to avoid or decrease the disadvantages of RADON-JOK equipment (single probe system that has been used in the Czech Republic since 1993, Kašpar, Prokop and Matolín 1993, Neznal, Neznal and Šmarda 1995).

Three prototypes and RADON-JOK system were tested at several test sites with different geological conditions. The tests confirmed the expected limitations of particular approaches. The range of real gas permeabilities is so large, several orders of magnitude, that it is almost impossible to find a simple way, how to measure precisely with the same equipment in low permeable environment and in high permeable one. In case of low permeability, pressure system means higher pressure differences, longer time and lower air flow. In high permeable environment it is necessay to use really low pressure differences, short time and high air flow. The determination of all parametres should be sensitive enough for both, just opposite situations. After the analysis single probe system RADON-JOK was chosen for testing of temporal and spatial variability due to the economical reasons (the determination of permeability should not increase markedly the price of radon risk classification), its simplicity and possibility of comparison with previous results.

Spatial and temporal changes in soil permeability were tested at four reference areas with respect to various geological conditions each month during a one-year period. Permeability of soils and rocks for gasses was measured at 15 points at each reference area. At two reference areas the measurements were realized at each point at two depths, 0.4 and 0.8 m, and at two reference areas at a depth of 0.8 m only. The soil gas samples for soil gas radon concentration measurements (Neznal, Neznal and Šmarda 1996) were collected at the same depths and at the same extent. Other important parameters, mainly soil moisture (Kuráž and Matoušek 1997) and/or the mass percentage of fractions, porosity and water saturation were determined with respect to Czech National Standards.

Good correlations between the measured parameters were obtained only in the area with homogeneous and high permeable soils. These relations can be illustrated by the correlation coefficients between median values of gas permeability (k), soil gas radon concentration (c_{Rn}) and

Fig. 5-1. Permeameter RADON JOK and other equipment for in situ measurements.

soil moisture (w) at the reference area Lysá nad Labem (Tab. 5-2).

Values of the correlation coefficient indicate a positive correlation between the soil gas radon concentration at a depth of 0,8 m and the soil moisture in surface horizons and a negative correlation between the soil gas radon concentration and permeability and between the permeability and soil moisture. Positive correlation was confirmed between the soil gas radon concentration determined at two different depths. The same conclusion was valid for the permeability values measured at two different depths. As for the geological conditions, the bedrock is formed by Cretaceous sediments and the Quaternary cover by fluvial sands at the area. The upper soil layers are homogeneous, characterized by low values of soil gas radon concentration and high permeability.

Tab. 5-2. Correlation coefficients at the area Lysá nad Labem

Correlation between para meter (depth)/para meter (depth)	Correlation coefficient
cRn (0.8 m) / cRn (0.4 m)	0.92
k (0.8 m) / k (0.4 m)	0.83
cRn (0.8 m) / k (0.8 m)	–0.68
cRn (0.4 m) / k (0.4 m)	–0.60
cRn (0.8 m) / w (0.1 m)	0.70
cRn (0.8 m) / w (0.25 m)	0.88
k (0.8 m) / w (0.1 m)	–0.52
k (0.8 m) / w (0.25 m)	–0.66

On the other hand a correlation between the soil gas radon concentration and the permeability, as well as between the permeability and the soil moisture and other parameters was very weak at areas with medium or low permeable environment, and even for the high permeable environment, when relatively high water saturation of upper horizons occurred (where the changing water content caused large spatial variability of permeability results as well). Although the areas could be described as areas with homogeneous upper soil layers, observed spatial and vertical changes of permeability did not allow to confirm any relation between measured parameters. The single values of direct *in situ* measurements of permeability as well as of soil moisture were substantially affected by the small scale changes of conditions in measured soil volume, especially in case of medium and low permeable environment. The *in situ* measurements characterizing small soil elements result in a large spatial variability, although the layers seem to be homogeneous. The statistical evaluation of permeability measurements is affected by an occurrence of high permeable outsiders on one hand and of values under the minimum detection limit in case of extremely low permeability or high soil moisture on the other hand. Large variability of results obtained on small scale conditions makes any evaluation very difficult.

Tab. 5-3. Variability of soil gas radon concentration cRn and permeability k with depth

Area	depth (m)	c_{Rn} (kBq . m^{-3})	median c_{Rn} (kBq . m^{-3})	k (m^2)	median k (m^2)
Sedlcanky	0.4	11.7–38.0	21.4	$9.9 \cdot 10^{-15}$–$7.3 \cdot 10^{-13}$	$9.9 \cdot 10^{-15}$
	0.8	14.9–36.4	21.9	$7.6 \cdot 10^{-14}$–$1.1 \cdot 10^{-11}$	$6.5 \cdot 10^{-13}$
	1.1	14.0–27.6	18.8	$1.0 \cdot 10^{-13}$–$1.6 \cdot 10^{-11}$	$7.2 \cdot 10^{-12}$
Kostelec	0.4	24.7–38.7	32.7	$9.9 \cdot 10^{-15}$–$1.7 \cdot 10^{-12}$	$1.2 \cdot 10^{-13}$
	0.8	26.3–39.9	32.7	$9.9 \cdot 10^{-15}$–$1.1 \cdot 10^{-11}$	$5.8 \cdot 10^{-13}$
	1.1	29.2–43.3	32.8	$7.2 \cdot 10^{-13}$–$1.1 \cdot 10^{-11}$	$7.0 \cdot 10^{-12}$
Skochovice	0.4	39.3–100	66.1	$9.9 \cdot 10^{-15}$–$3.9 \cdot 10^{-12}$	$1.8 \cdot 10^{-13}$
	0.8	44.4–104	74.6	$9.9 \cdot 10^{-15}$–$1.1 \cdot 10^{-11}$	$8.3 \cdot 10^{-14}$
	1.1	29.8–101	74.3	$9.9 \cdot 10^{-15}$–$9.1 \cdot 10^{-12}$	$9.9 \cdot 10^{-15}$

To be able to describe the influence of permeability changes on radon concentration with depth and to classify possible errors connected with the application of the uniform depth for permeability measurements, measurements of permeability and of soil gas radon concentration were performed in various vertical profiles with substantial changes in permeability.

Various types of areas were chosen for these measurements, mainly with markedly increasing permeability in the vertical profile with depth, but with the low permeability along the whole vertical profile as well. Soil gas radon concentration measurements and direct in situ permeability measurements were performed at 15 points and at three depths (0.4 m, 0.8 m and 1.1 m) in each area.

Almost no changes of soil gas radon concentration with depth were observed – Tab. 5-3.

The presumed increase of radon concentration with depth, especially at areas with substantial changes in permeability, was not confirmed. Any dramatic changes as well as local anomalies of radon concentration caused by a sealing effect of upper layers with lower permeability did not appear. The influence of permeability changes on changes of radon concentration with depth seems to be low (Neznal, Neznal and Šmarda 1996).

As we have kept at disposal the assessment of permeability based on various methods from various areas, we could compare those results as well. For 80 areas we could compare the classification of permeability determined through weight percentage of the fine fraction (particle size analysis), direct permeability measurements (only one measurement at area) and expert assessment of permeability based on the description of the vertical profile of soil. The results are summarized in Tab. 5-4.

Moreover at 21 areas we could compare the above mentioned methods completed with the statistical set of direct measurements of permeability and the expert assessment has been enlarged using the resistnance against sampling the soil gas – Tab. 5-5.

It was observed that one sample or one result cannot often describe a heterogeneous geological environment (horizontal and vertical changes, influence of human activity, small scale variations of the character of the soil).

Tab. 5-4. Comparison of permeability determined at 80 areas through various methods: (1) – derived from the particle size analysis, (2) – one direct measurements, (3) – expert assessment of permeability based on the description of the vertical profile of soil

Agreement	Number of areas
(1) + (2) + (3)	29
“only” (1) + (2)	6
“only” (1) + (3)	22
“only” (2) + (3)	23

Tab. 5-5. Comparison of permeability determined at 21 areas through various methods: (1) – derived from the particle size analysis, (2) – statistical evaluation of 15 direct measurements, third quartile as a decisive value, (3) – expert assessment of permeability based on the description of the vertical profile of soil and the resistance against sampling the soil gas

Agreement	Number of areas
(1) + (2) + (3)	14
“only” (1) + (3)	1
“only” (2) + (3)	6

Therefore it was recommended to increase substantially the number of measurements (and the costs of classification), althoug the large spatial variability of results could make any statistical evaluation rather complicated (changes in soil moisture, significant occurrence macro- and micro-fissures etc.).

The expert who is responsible for the classification should focus not only on those results of laboratory or in situ tests, but also on factors influencing the permeability and their changes in vertical profile from surface down to the level of assumed building foundations or to the level of assumed contact building – soil: grain size distribution, soil moisture, water saturation, effective porosity, porosity, density, bulk density, compactness, thickness of Quaternary cover, weathering character of the bedrock, modification of soil layers by various antropogeneous activities.

The expert evaluation of permeability based on the subjective expert assessment of the description of changes of those parameters in vertical profile, with the supporting character of results of laboratory or in situ tests, should improve the classification.

5.3. PERMEABILITY IN NOWADAYS PRACTICE

The new uniform method for assessing the risk of radon penetrating from the underlying soil or bedrock, based on determining the radon index of the building site (Neznal et al. 2004), has become obligatory in 2004 for all radon specialists in private companies and other entities that deal with assessing the radon risk of building sites in the Czech Republic. The method enables to classify one of the decisive parameters for classification of radon risk in two ways. The permeability of soils and rocks for gases can be determined by direct in situ permeability measurements or by an expert evaluation of permeability.

Direct permeability measurements are performed at a depth of 0.8 m beneath the ground surface. The method consists of measuring the airflow during suction from the soil or when pumped into the soil under constant pressure. The procedures used in CR for permeability measurements are similar to those of soil gas sampling (small-diameter hollow steel probes with a free, sharpened lower end – a lost tip). The internal surface area of the cavity formed by pounding out the free tip must be exactly defined for each measurement system. Various devices designed for in situ gas permeability measurements can be used. As for the lack of the gas permeability standardization and various other complications (determining the shape factor of the probe, which depends on its geometry and internal dimensions, individual corrections for the free flow of air in specific instruments), the results obtained from various devices should be standardized against the RADON-JOK permeameter, widely used in the Czech Republic.

For direct in situ permeability measurements, the requirements for the number of measurements are the same as for the soil gas radon concentration measurements, i.e. at least 15 measurements for a single building, or the taking of measurements in a 10 × 10 m grid for building sites >800 m^2. The same statistical parameter, i.e. the third quartile of the data set, is used as a decisive value for the assessment, because it diminishes the influence of outliers and local permeability anomalies. However the authorized person responsible for the final classification must consider any local permeability anomalies and variations and the spread of data. The permeability classification for larger areas, where permeability measurements must be made in a 10 × 10 m grid, depends on the homogeneity of the site and the data set (geologically homogeneous site, division into several homogeneous subsites, a zone with distinct permeability, local permeability anomalies).

The permeability is designated by the symbol **k**. When direct in situ measurements are performed, the gas permeability is given in **m²** (rounded to one decimal position, e.g. $1.7 \cdot 10^{-12}$ m^2).

An expert evaluation of soil permeability is necessary when in situ permeability measurements are not performed at all sampling points of soil gas radon concentration measurements. This expert evaluation of permeability leads to assigning the low – medium – high categories of permeability and is based on the description of the vertical soil profile. The evaluation must involve following methods:

- The macroscopic description of the fractions in samples from a depth of 0.8 m, with the classification of its permeability (low – medium – high). Estimating the proportion of the fine fraction (particle size < 0.063 mm) is the base in this classification, the final corrections are performed with respect to the factors that could influence the actual permeability.
- Evaluating the resistance encountered when drawing the soil gas samples for the radon concentration measurements at all sampling points, and estimating the prevailing permeability category (low – medium – high).

For the better evaluation of vertical and horizontal changes in permeability, the number of performed hand drill tests is imposed with respect to the extent of the measured area. The expert responsible for the evaluation should consider during the process of assessment the influence of various factors on actual permeability (soil moisture, degree of water saturation, effective porosity, porosity, density or compactness, loose texture, occurrence of macro- and micro-fissures, degree of inhomogeneity of the fine fraction, content of the coarse fraction – fragments, cobbles, stony debris, character of the weathering surfaces of rocks, presence of faults, anthropogenic effects on the ground surface or in the upper soil layers – such as deep ploughing or the presence of paths, deep compactness of upper soil layers, presence of concrete or asphalt coverings, vertical and horizontal variability of soil layers with different permeability). Especially in case of larger areas the results of detailed geological or hydrogeological survey at the same areas are very often used for the expert evaluation of soil permeability.

The resulting permeability is classified as low, medium, or high, i.e. only a single evaluation at homogenous sites and the highest category of the separate subsites for a building covering several soil permeability subsites.

As the main aim of permeability classification during the radon risk assessment is the final categorization of radon index, the possible differences between the results obtained from expert assessment of permeability and direct measurements and their impact on final categorization are most important. The tests performed during last years are promising (Neznal and Neznal 2006). Almost all results of radon index based on direct measurements of permeability and the radon potential model agree with the results based on expert assessment of permeability and the classification table. That conclusion is valid in "border" cases, too, i.e. when the observed values are closed to the border between categories of radon index. As for the permeability classification, if we use the "unwritten" border values between categories of permeability for RADON-JOK equipment, i.e $k = 4.0 \cdot 10^{-12}$ m^2 between high and medium permeability and $k = 4.0 \cdot 10^{-13}$ m^2 between medium and low permeability, we can find rarely some differences, when the category of permeability from expert evaluation does not correspond to the category derived from direct measurements. But those minor differences do not take effect on differences in the radon index classification.

5.4. RADON-JOK

The permeameter RADON-JOK is a portable equipment, which has been developed directly for in situ measurements of gas permeability of soils. Its robustness and its simplicity is very practical for easy, quick and at the same time sufficiently exact in situ investigation. The principle of the RADON-JOK equipment consists of air withdrawal by means of negative pressure. Air is pumped out from the soil under constant pressure through a specially designed probe with a constant surface of contact between the probe head and the soil. The constant active area is created in the head of the probe (driven into the soil to a measured depth) by the extrusion of the tip by means of the punch wire inside the probe by an exact distance. The special rubber sack, with one or two weights, pumps the air from the soil and allows to perform measurements at very low pressures. The gas permeability is calculated from the equation (see below) using the known air flow through the probe. The air flow is defined by the known air volume (= 2000 ccm) in the rubber sack (depression of the bottom of the sack between two notches) and by the pumping time measured. The great advantage of RADON-JOK is the possibility to perform measurements independently of any source of energy (electricity, compressed air…).

Fig. 5-2. RADON-JOK – detail.

Theoretical framework for the gas permeability measurement is based on Darcy's equation (Koorevaar, Menelik and Dirksen 1983). The soil is assumed to be homogeneous and isotropic and a standard state is considered. Further more the air is assumed to be incompressible (pressure differences are very much smaller than the atmospheric pressure). The air flow can be expressed by the following equation:

$$Q = F \,.\, (k/\mu) \,.\, \Delta p$$

where

Q	$[m^3 . s^{-1}]$	is the air flow through the probe,
F	[m]	is the shape factor of the probe (depending on its geometry),
k	$[m^2]$	is the gas permeability of the soil,
μ	[Pa . s]	is the dynamic viscosity of air (at 10 °C $\mu = 1{,}75 \,.\, 10^{-5}$ Pa . s),
Δp	[Pa]	is the pressure difference between surface and the active area of the probe.

Critical point of use of this equation is the determination of the shape factor F. A solution can be found in Damkjaer and Korsbech (1992). Resultant formula is as follows:

$$F = 2 \,.\, \pi \,.\, L/\ln \{2.\, L \,.\, [(4D - L)/(4D + L)]^{1/2}/d\}$$

where

L	[m]	is the length of the active area of the probe head,
d	[m]	is the diameter of the active area,
D	[m]	is the depth below the surface

and the approximation L > d has been used.

Using the RADON-JOK system, with the shape factor F = 0.149 m (L = 50 mm, d = 12 mm and D = 825 mm), the feasible range of measured gas permeability (k) is approx. from $k = 10^{-11}$ m^2 to $k = 10^{-14}$ m^2. The maximum detection limit (measured time of 8 s corresponds to $k = 1.4 \,.\, 10^{-11}$ m^2) is determined by the resistance of the equipment, the minimum detection limit depends on the time spent in any given measurement. As this time can be too long, especially in case of low soil permeability and/or high groundwater saturation, it is recommended to choose a minimum detection limit (f.e. measured time of 3600 s corresponds to $k = 1.7 \,.\, 10^{-14}$ m^2) and express the result in a way k is lower than the chosen detection limit. It is possible to extend the range to higher values using a probe with reduced shape factor.

As for the assessment of measured gas permeability values (k) in the framework of radon risk classification, it is possible to use measured values themselves, as well as to derive the category of gas permeability using specified boundaries (in the Czech Republic it is recommended to use following ones: $k = 4.0 \cdot 10^{-12}$ m^2 between high and medium permeability and $k = 4.0 \cdot 10^{-13}$ m^2 between medium and low permeability) and/or to use measured values for calculation of a so called "radon potential" derived from any of available radon potential models.

In case the same probe is used for soil gas radon concentration measurement as well as for permeability measurement (the special type of "lost" sharp tip for gas permeability measurement must be used), it is necessary to start with the gas permeability measurement (higher underpressure during soil gas sampling could cause a destruction of an internal surface of the cavity and affect the permeability measurement).

Note. Direct measurements of gas permeability can be certainly utilized during the diagnostic measurements and assessment of the contact layers between the building and the soil (description of the transfer of radon from soils into the buildings – "transfer" point of view).

5.5. PERMEABILITY UNITS

Permeability of rocks (soils) is defined for the flow of liquid medium (water) through the rock and the subject is described in hydrological literature. Derived application for other media (as gas, namely hydrocarbons in petroleum industry) is also mentioned. This relates to radon.

The flow of water through a rock medium is described by Darcy's law (1856):

$$Q/S = K\,(h_1 - h_2)/\Delta L$$

where Q – volume of water penetrating per unit time through the area S [m^3 . s^{-1}]
S – area [m^2]
K – hydraulic conductivity (also coefficient of filtration) [m/s]
$(h_1 - h_2)/\Delta L$ – applied hydraulic pressure (eg. difference of height of the water levels/ difference of horizontal/vertical length L of flow)

For other media than water, the density of the media ρ, the gravitational force F = mg (mass × gravity acceleration), and viscosity μ of the media must be taken into consideration:

m – mass [kg]
g – gravity acceleration [m/s^2]
μ – dynamic viscosity [Pa . s = kg/m . s], Pa (pascal) = N(newton)/m^2 = kg . m/(s^2 . m^2)
ρ – density of the liquid (other media) [kg . m^{-3}]

For the flow of liquid (and other media, specified by ρ and μ) in percolate rock environment, the permeability k [m^2] (also coefficient of permeability) is introduced by relation

$$K = k \cdot \rho \cdot g/\mu$$

Note: k [m^2] – is the characteristics of permeability of the solid phase of the rock ("intrinsic" permeability)
K [m/s] – is dependent on characteristics (permeability) of the solid phase of the rock and on the liquid (other) medium of flow specified by its and μ.

The dimension of permeability k [m^2] is given from the above equation. The older "industrial" unit of permeability was Darcy (D), $1\ D = 9.87 \cdot 10^{-12}$ m^2. Dynamic viscosity of air at 10 °C is $\mu = 1.75 \cdot 10^{-5}$ Pa . s.

6. Building site assessment method

In the Czech Republic, detailed radon risk assessment is used to design preventive protective measures in new buildings. This approach is obligatory, i.e. the detailed assessment and classification of radon risk (since 2004 called radon index) of the building site is an integral part of building permission. For the purposes of new buildings, since 1990 the soil characteristics are measured in-situ and protective measures are designed with respect to the measured properties of the soil and to the dwelling design. The main advantage of the method is the fact, that it is a site specific, individual approach that enables to propose an optimal preventive strategy corresponding to local conditions.

At the same time, the methods for radon risk assessment are used for mapping purposes as well. In this case, the results serve as a base for the description of radon potential of specific geological units.

6.1. ORIGINAL METHOD 1990

Already the first uniform method, that had been used for radon risk classification in the Czech Republic since 1990 (Kulajta et al. 1990), was based on the assessment of two main parameters: the soil gas radon (^{222}Rn) concentration and the permeability of soil and rock for gasses. The higher the soil gas radon concentration and the permeability of soil layers, the higher the probability of radon penetrating into the building. As can be seen in Tab. 6-1, the original method utilized the same categories of radon risk (radon index) and the same boundaries, that are used in the Czech republic for the classification up to now.

The main disadvantage was given by the fact that the method was too rough and uncertain. The main problems were connected with the permeability classification (See Chap. 5). It was based on the pedological description and permeability classification derived from the grain size analysis, the other factors influencing the permeability were not taken into consideration. Furthermore, the permeability were not classified with respect to changes in vertical profiles from surface to the level of expected foundation depth of the building.