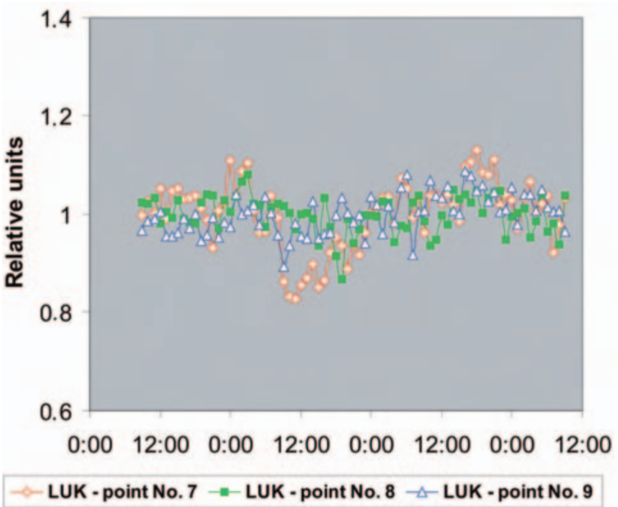

Fig. 3-4. Relative temporal variations of soil gas radon concentration – instantaneous methods; counting in the laboratory (devices LUK; measuring points No. 7–9).

a 72-hour follow-up had been generally low (see Figs 3-4, 3-5, 3-6). The ratio of maximal vs. minimal values ranged from 1.22 to 1.67 when instantaneous methods were used. Different temporal changes were observed by using distinct continuous monitors of soil gas radon concentration. The instruments' response seemed to be influenced by changes of air pressure and/or air temperature. Variable air pressure and/or air temperature might have a contradictory effect on different continuous monitors. Relations between soil gas radon concentration data obtained using different methods were weak. There are two possible explanations: (a) Short-term temporal changes of soil gas radon concentration were different in different measuring points, or (b) these changes were caused mainly by fluctuations connected with measuring methods themselves and they did not reflect real variations of the measured parameter. The latter explanation is more probable.

When temporal variations themselves are the object of investigations – for example if the soil gas radon is intended to be used for the earthquake prediction – all available tests of measuring devices should be done to avoid an occurrence of false positive signals.

4. Instrumentation

As the instantaneous methods represent prevalent measuring techniques in the Czech Republic, the presented examples of available instrumentation will be focused on the instantaneous measurements. The are two basic techniques: scintillation method using Lucas cells, and ionization chambers.

4.1. SCINTILLATION METHOD

The initial development of soil gas radon concentration measurements and of radon risk mapping in the Czech Republic is connected with the scintillation method. The family of devices called LUK first appeared in 1991. As the measured soil gas radon concentrations are relatively high ranging from 0.1 to several hundred of kBq . m^{-3}, the sufficient volume of Lucas cells is about 100 ml.

In general, two types of Lucas cells are used, nowadays: (a) Lucas cells in a form of inserts with the active volume of 145 ml in combination with the scintillometer LUK 3A (see Fig. 4-1), and (b) glass-type Lucas cells with the active volume of 125 ml in combination with the scintillometer SISIE (see Fig. 4-2).

Both systems are designed for soil gas radon concentration measurements and for detection of radon sources of higher concentration. The detector response in the equilibrium state between radon and radon progeny is about 2 pulses/s per 1 Bq of radon concentration deposited in the

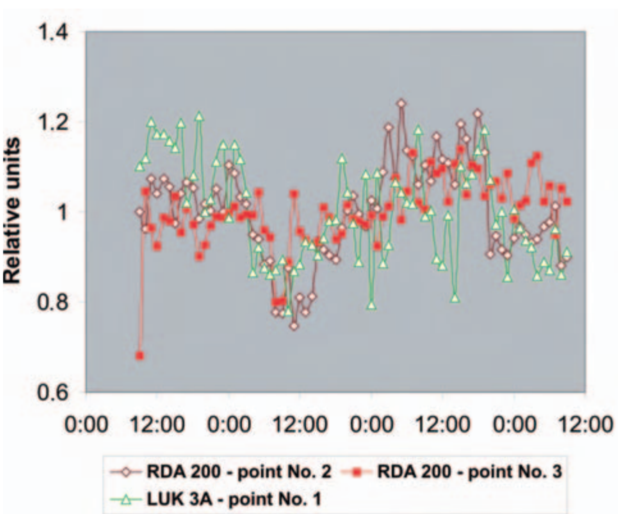

Fig. 3-5. Relative temporal variations of soil gas radon concentration – instantaneous methods; counting in the field (devices RDA 200, LUK 3A; measuring points No. 1–3).

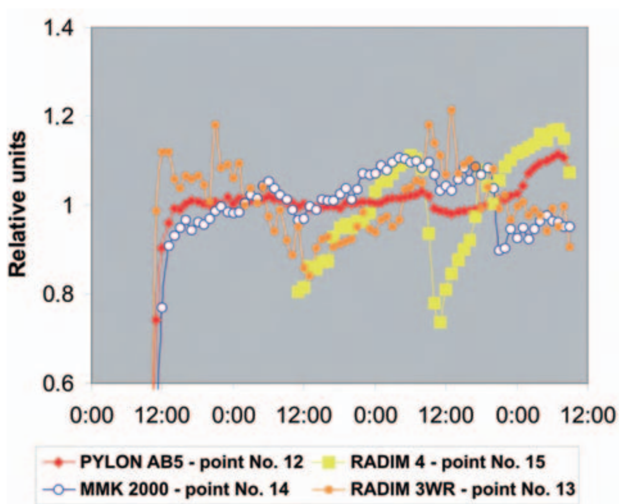

Fig. 3-6. Relative temporal variations of soil gas radon concentration – continual monitors (devices PYLON AB5, RADIM 4, MMK 2000, RADIM 3WR; measuring points No. 12–15).

Fig. 4-1. Scintillometer LUK 3A; Lucas cells in a form of inserts.

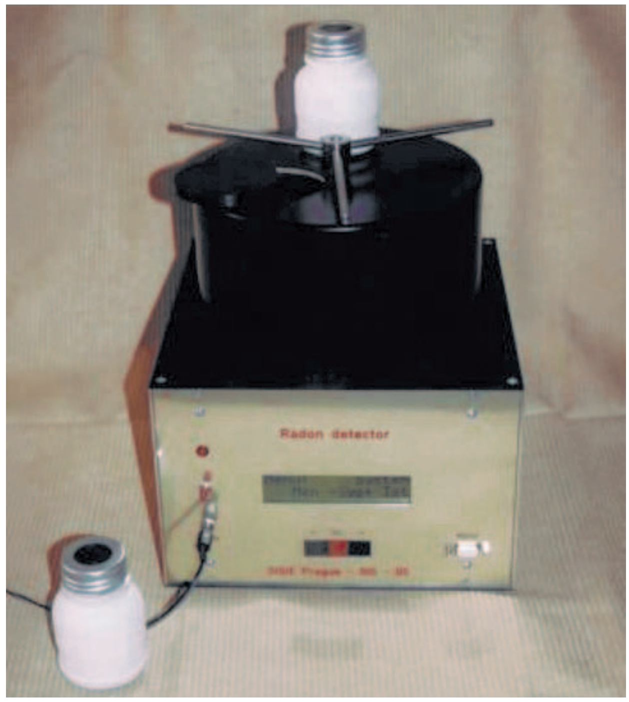

Fig. 4-2. Scintillometer SISIE; glass-type Lucas cells.

cell. Both systems provide a simple operation by means of three buttons. The electronics of both scintillometers is based on the low power CMOS.

The program offers different modes of automatic measurement of soil gas radon concentration in Lucas cells (results are given in kBq . m^{-3}), as well as a simple counting mode (results are given in pulses, or counts), which is directed by the operator.

For example, the LUK 3A device offers following three modes of automatic measurements:

(i) service **Radon fast**: Automatic measurement of radon concentration with a preset statistic error of 5%, automatic correction for radon progeny growth. The result is presented in Bq . m^{-3} with the corresponding statistical error. They can be stored in the memory.

(ii) service **Radon Th-:** The service is used when the expected thoron concentration is low. Automatic measurement of the background, filling of the Lucas cell controlled by the processor, delay between filling of the cell and radon measurement adjusted to two minutes, automatic measurement of radon in 20 s intervals till the 5 % statistic error is obtained. The countings are corrected for radon progeny growth. The result is presented in Bq . m^{-3} with the corresponding statistical error. They can be stored in the memory. The thoron concentration is estimated.

(iii) service **Radon Th+:** The service is used when the expected thoron concentration is high. Automatic measurement of the background, filling of the Lucas cell controlled by the processor, delay between filling of the cell and radon measurement adjusted to six minutes, automatic measurement of radon in 20 s intervals till the 5% statistic error is obtained. The countings are corrected for radon progeny growth. The result is presented in Bq . m^{-3} with the corresponding statistical error. They can be stored in the memory. The thoron concentration is estimated.

The scintillometer LUK 3A is powered by the NiCd battery with a capacity of 1500 mAh. An automatic battery voltage measurement and processor-control of the battery charging are available. The operation time without charging is approx. 60 hours.

The scintillometer SISIE is a more simple and robust instrument. Similarly as in case of LUK 3A, the photomultiplier is placed inside the device, but there is an external sample changer, located above the measuring unit. The sample changer has three positions: one for inserting the Lucas cell (inserting position, covered by a removable cap), a “waiting” position (Lucas cell should be kept in the darkness for at least 2 minutes before measurement) and a measuring position. During measurement, the Lucas cell is located above the photomultiplier. Two basic measurement modes are available: a counter mode (results are given in pulses), and an automatic “Rdn” mode (results are given in Bq . m^{-3} with the statistical error). An electric power supply is required for the operation of SISIE – no batteries available. The detector response for the equilibrium state between radon and its short-lived progeny is approx. 2 pulses/s per 1 Bq of radon deposited in the Lucas cell.

4.2. IONIZATION CHAMBERS

A relatively new device based on ionization chambers and designed for the in situ soil gas radon concentration measurement was developed several years ago (www.radon.eu – link to Equipment).

Fig. 4-3. Measuring system RM-2 with the ionization chamber.

Fig. 4-4. Measuring system RM-2. Detail of the ionization chamber.

The detection principle of the measuring system called RM-2 is based on an ionization chamber operating in a current mode (see Figs 4-3, 4-4, 4-5). The substantial characteristic features of the system are: very easy operating and control modes; applicability of the device under demanding weather conditions; simple decontamination of chamber inner surfaces from radon progeny deposition.

The measuring system consists of a set of cylindrical ionization chambers IK-250 with a detection volume of 250 ml and an electrometer ERM-3 (voltage reader device). A chamber case is a steel pressed piece with sheet metal thickness of 0.8 mm. The axial collecting electrode, made from brass, is fastened in the upper part of the chamber. The collecting electrode passes through a teflon insulator impressed in a metal tube, operating as a protective electrode. The described set is fastened in an insulating bushing, placed in a center of the upper part of the detector. A direct operating voltage of the detector is 40 V. In the upper part of the chamber, there is located a silicon hose with a three-way inlet valve, providing input of the soil gas sample into the inner detection volume. The input hose can be equipped with a filter providing a radon decay products suppression. The detection system operates in two measuring modes, (i) measurement starting 15 minutes after the transfer of the sample into the chamber and (ii) standard equilibrium measurement. Time period needed for the measurement of one sample is 120 s. The soil gas is used as an operating detection gas inside the ionization chamber. The detector operates in a non-saturated mode of a volt-ampere characteristic. The operating voltage between electrodes of the chamber is 40 V. The electric current sensitivity of the detector using the working voltage 40 V is 85 % of the saturated current. The ionization current is amplified and then electronically and statistically processed. Processed results are subsequently displayed and stored in the memory. Basic measuring functions are set-up from the control panel. The measuring device communicates with PC by a standard serial communication interface RS232, used for data transfer and for entering the calibration constant and other operating instructions. The electrometer enables a current signal recording each 2 s that is useful for specific measurements of radon and thoron mixture and for investigations of radon behavior inside the ionization chambers. The measuring range for the 250-ml ionization chambers is 3–1200 kBq . m^{-3}.

4.3. CONTINUAL MEASUREMENT OF SOIL GAS RADON CONCENTRATION

The third example of the available instrumentation concerns the system RM-3 that enables to perform in-situ continual measurements of soil gas radon concentration and to study temporal variations of the measured parameter (see Fig. 4-6). It can be used for the follow-up of long-term and/or short-term variations of radon concentration in the subsoil of buildings, i.e. as one of the fundamental radon diagnosis method. It enables the investigation and analysis of radon entry parameters and characteristics relating to variable weather conditions and residential habits.

The detection principle is based on an airflow ionization chamber operating in the current mode. The main system components can be summarized as follows:

(a) detector – airflow ionization chamber (sensitive detection volume 2.2 l);

Fig. 4-5. Measuring system RM-2. Tranfer of the soil gas sample into a previously evacuated ionization chamber.

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